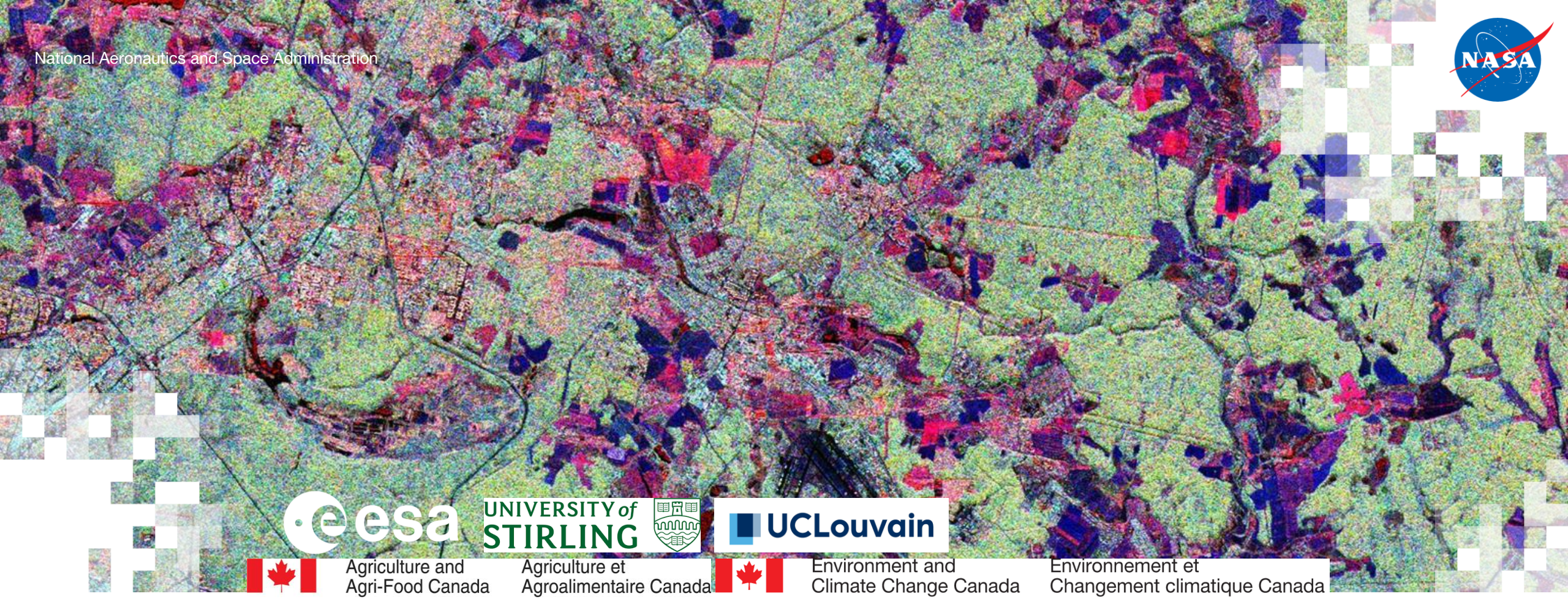


Mapping Crops and their Biophysical Characteristics with Polarimetric Synthetic Aperture Radar and Optical Remote Sensing

Part 4: Crop-Specific Time Series Analysis for Growth Monitoring

Pr. Pierre Defourny (UCLouvain) and Fabrizio Ramoino (ESA)

3 May, 2022

Training Outline

April 12, 2022

SAR Polarimetry for Agriculture

April 19, 2022

Polarimetry Practical Part 2: SAR Polarimetry with Sentinel-1, RCM, & SAOCOM Imagery for Agriculture

April 26, 2022

Sen4Stat Open-Source Toolbox

May 3, 2022

Crop-Specific Time Series Analysis for Growth Monitoring

Training Objectives

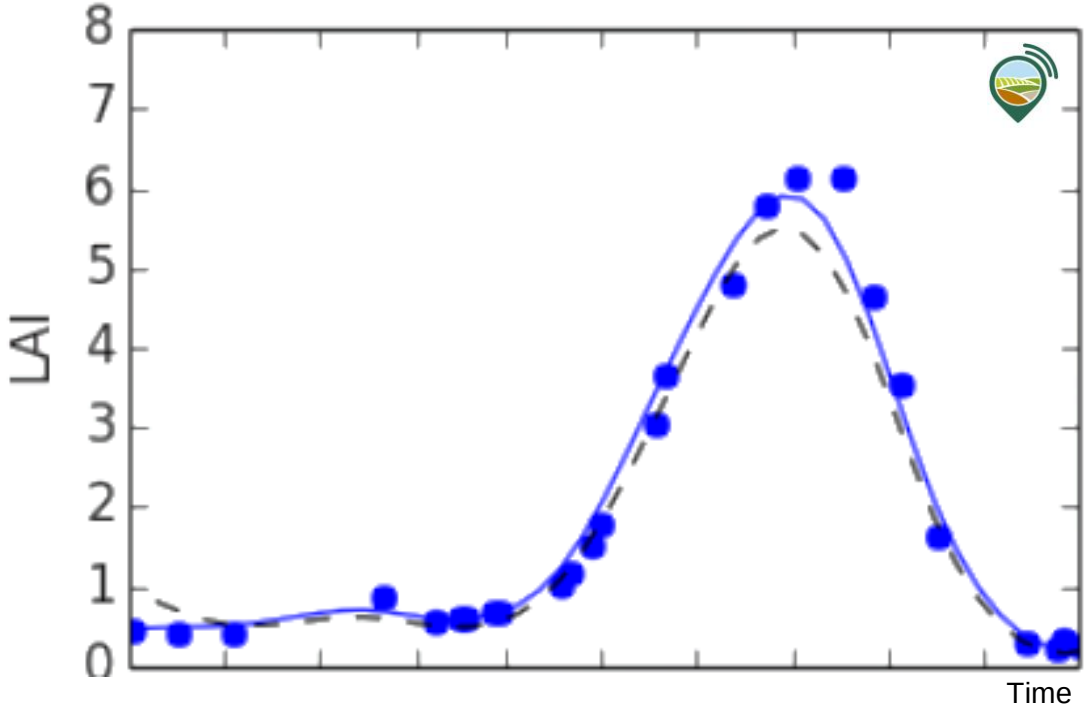
By the end of this training attendees will learn:

- What is a time series of satellite multispectral reflectance
- How to prepare a reflectance time series using SNAP toolbox
- How to retrieve the Leaf Area Index (LAI) from an optical time series
- How to control the quality of a LAI time series
- How to exploit crop-specific LAI time series at regional level
- How to assess the inter- and intra-parcel heterogeneity for all corn fields

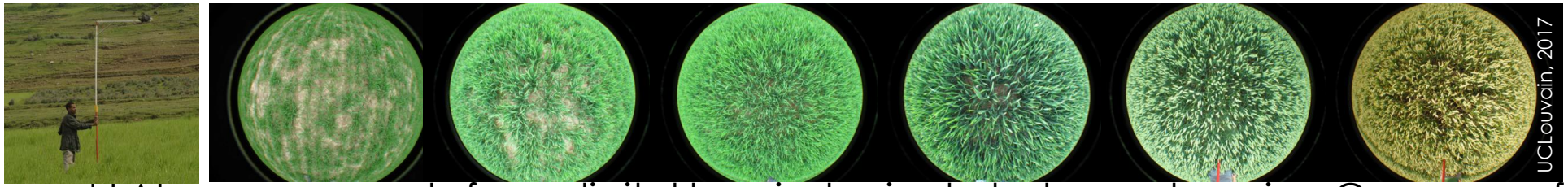
Table of Content

Time series analysis for crop growth monitoring

Leaf Area Index (LAI) as a key indicator of the vegetation development



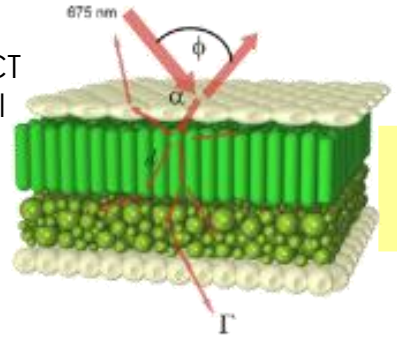
LAI time series retrieved from Sentinel-2 images acquired along the growing season



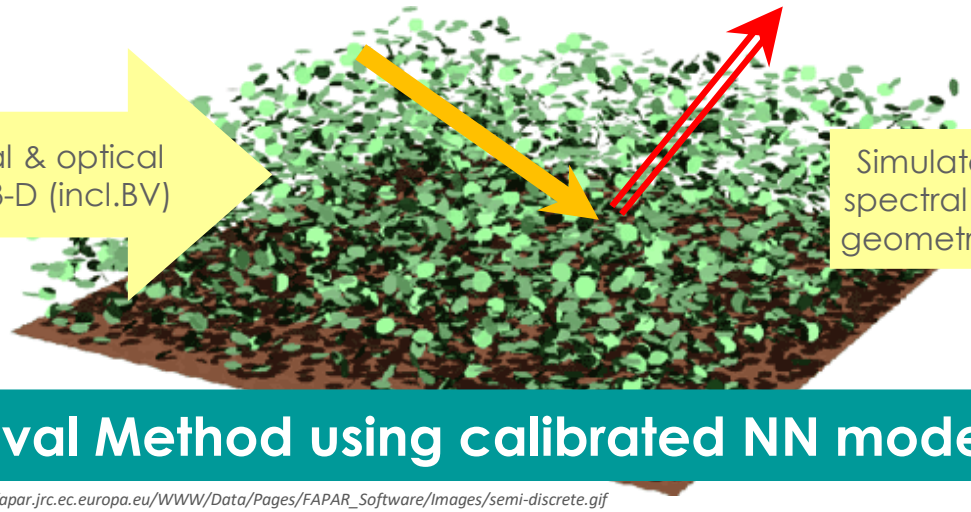
Ground LAI measurements from digital hemispherical photography using Can-eye software

LAI retrieval by Radiative Transfer model inversion using Neural Network

PROSPECT RT model at leaf level

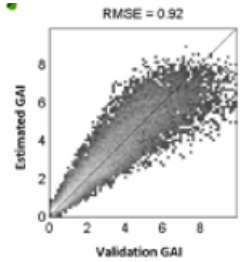


Crop structural & optical properties in 3-D (incl.BV)



Simulated reflectances for all spectral bands and observation geometries (sun and satellite angles)

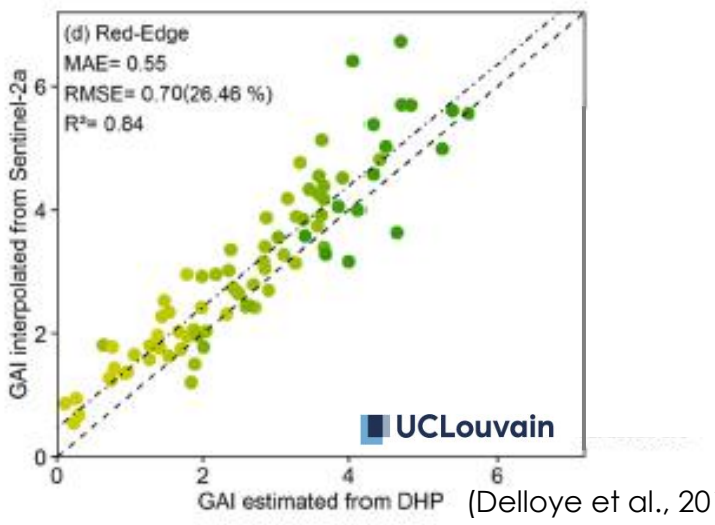
Simulated performances (model values only)



Retrieval Method using calibrated NN model

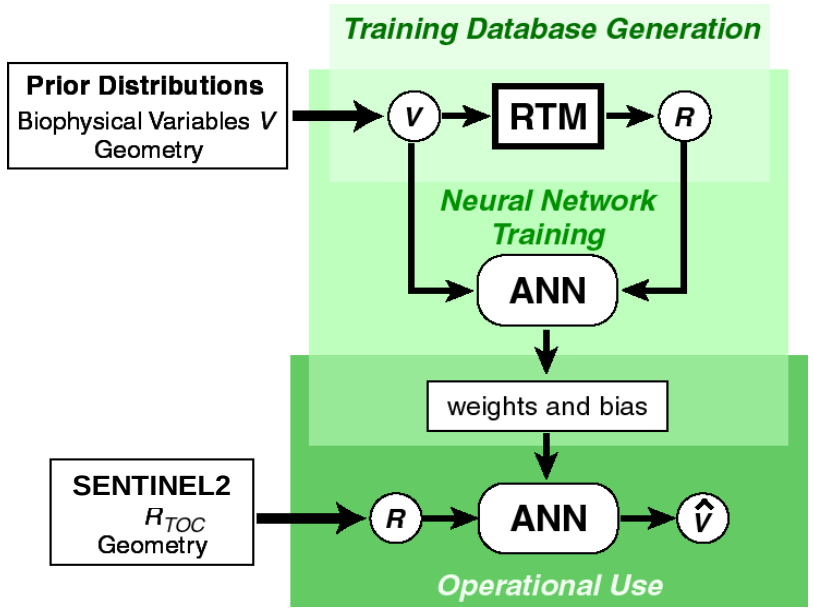
Source: http://fapar.jrc.ec.europa.eu/WWW/Data/Pages/FAPAR_Software/Images/semi-discrete.gif

Actual validation of retrieval performance (validation from ground measurements)



(Delloye et al., 2018)

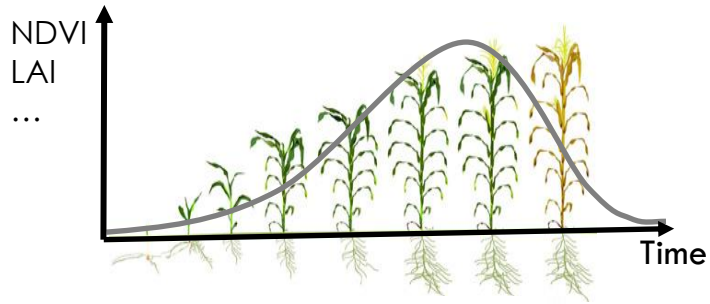
BV-net in SNAP toolbox



(Weiss et al., 2019)

UCLouvain

LAI time series to estimate the vegetation productivity



Vegetation productivity and phenology variables :

(a) start of season

(b) end of season

(c) length of season

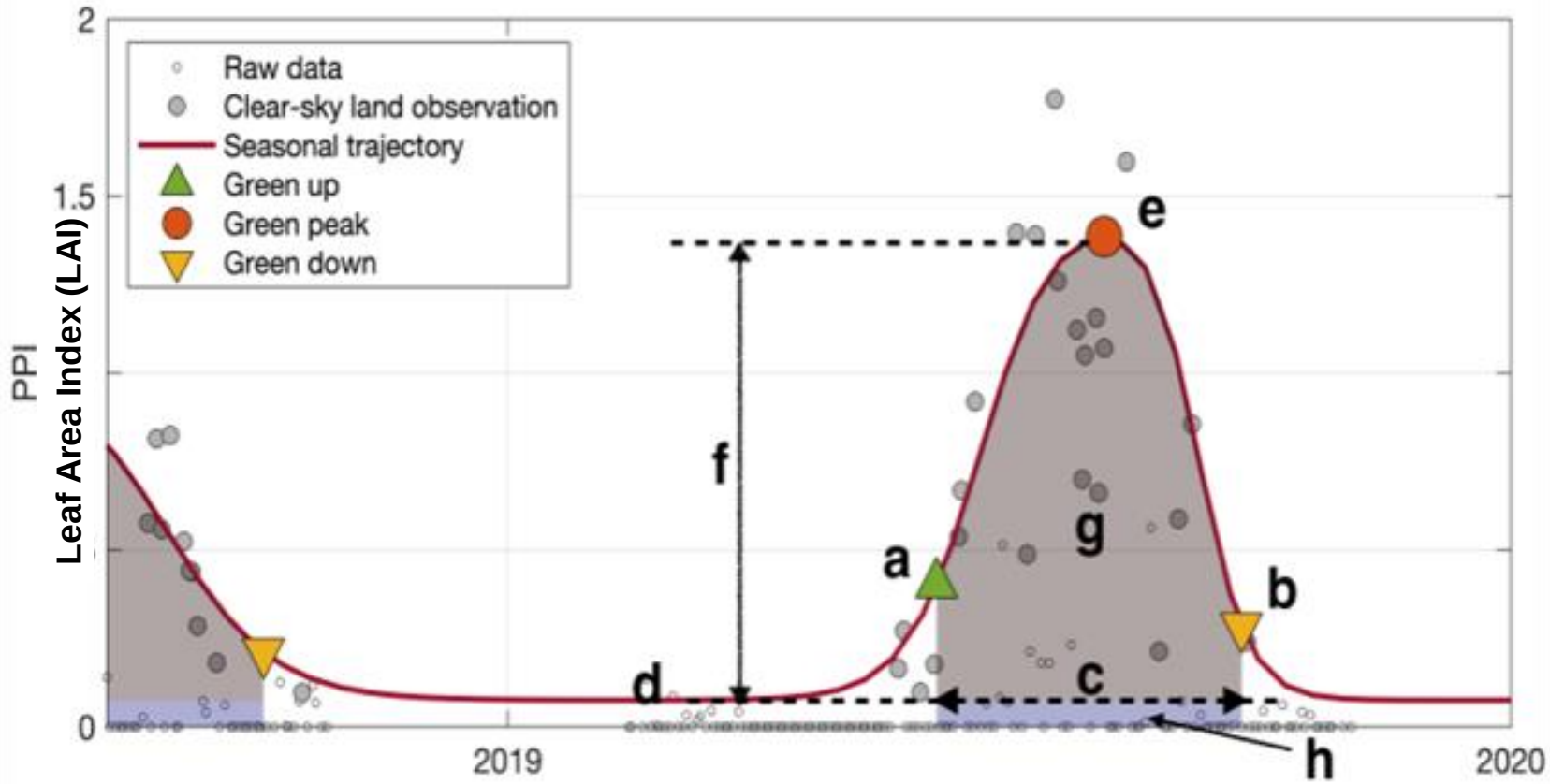
(d) minimum of season

(e) peak of the season

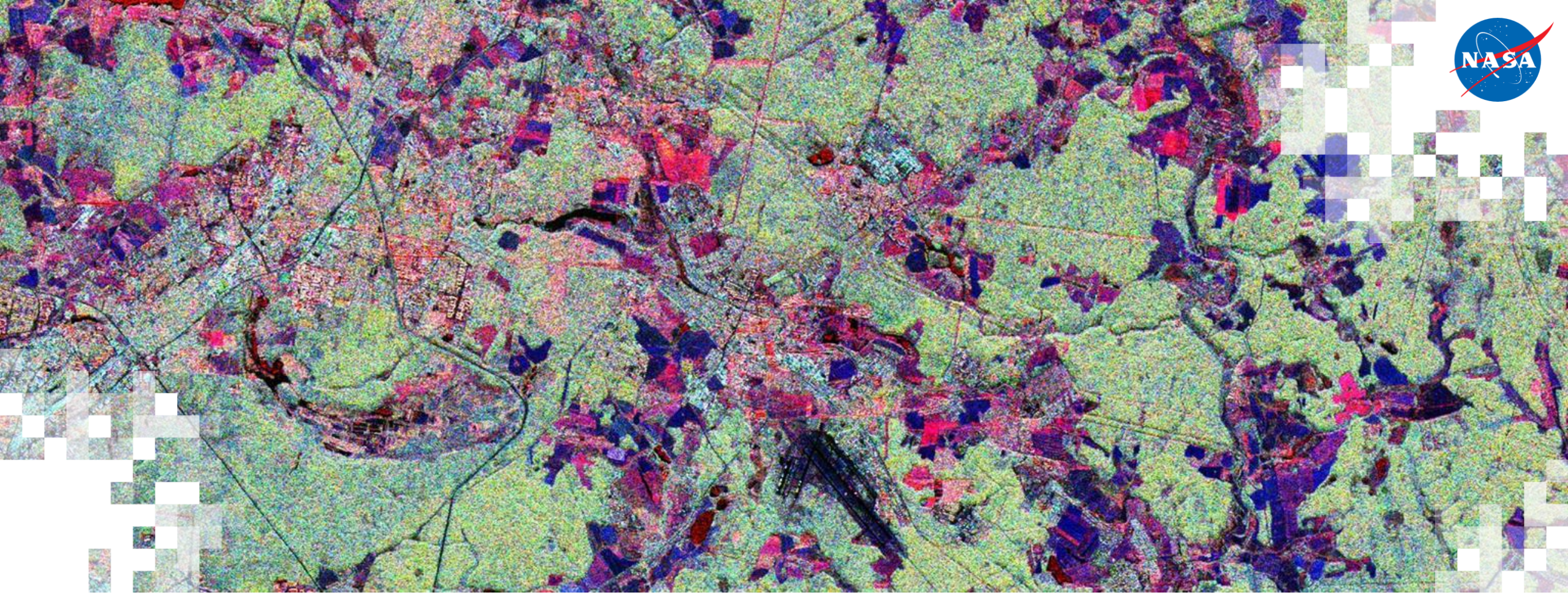
(f) amplitude

(g) small integrated value

(g+h) large integrated value



Source: Copernicus Land Monitoring Service



Section 1: Pre-processing of optical time series

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

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 Coordinate Reference System (CRS) the reprojection to a common CRS is needed.

Resampling

Data coming from different sources could have different spatial resolutions, therefore in this case, before analysing 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: Extremes are balanced; image loses sharpness compared to Nearest Neighbour
- Cons: Less contrast compared to Nearest Neighbour (NN); new values are calculated which are not present in the input product

Cubic convolution:

- Pros: Extremes 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 needed especially if you work with VHR and HR data.

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

Why use time series

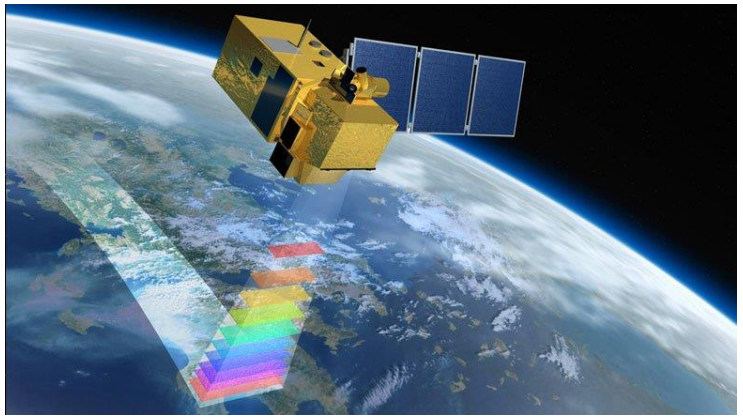
- A time series is defined as a set of satellite images taken over the same area of interest at different times
- It makes use of different satellite sources to obtain a larger data series with short time interval between two images
- Time Series of Satellite observations offer opportunities:
    - for understanding how Earth is changing
    - for determining the causes of these changes
    - 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.

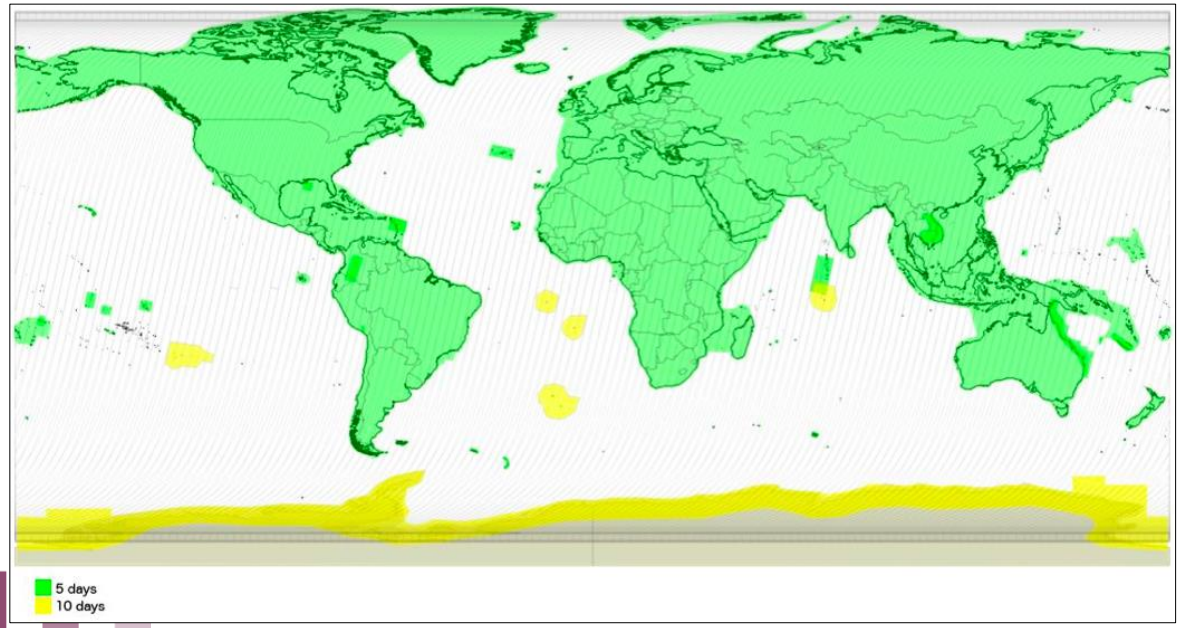
Sentinel-2 characteristics

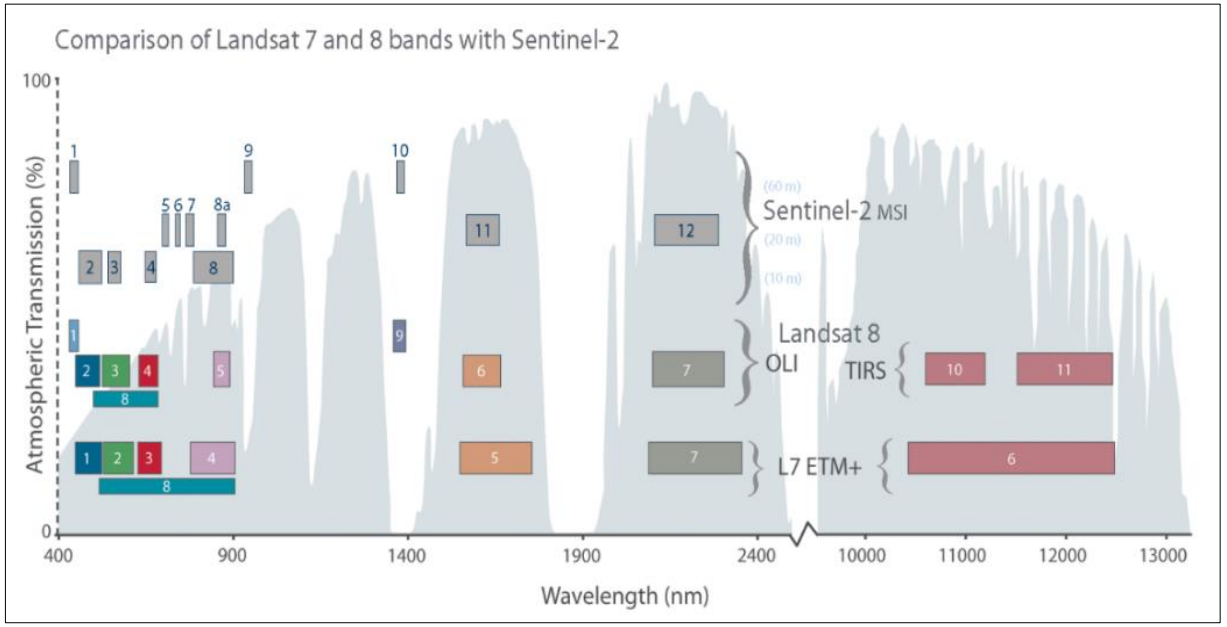
Optical mission for the monitoring of land and coastal regions



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



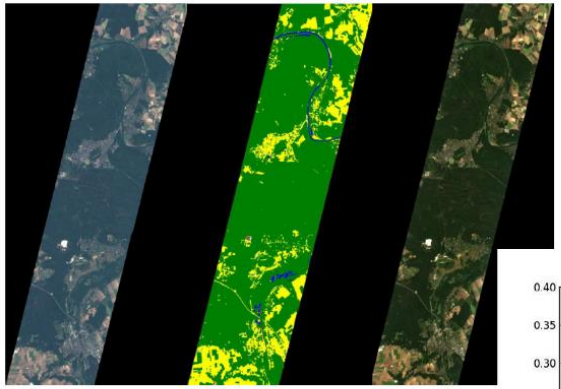


Sentinel-2 products

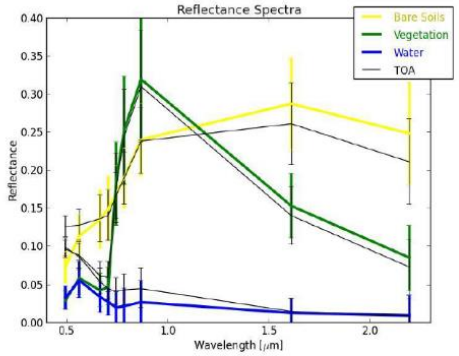
SENTINEL-2 products available for users (either generated by the ground segment or by the SNAP) are:

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

Level-2A
- Bottom-Of-Atmosphere reflectance 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) reflectance 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

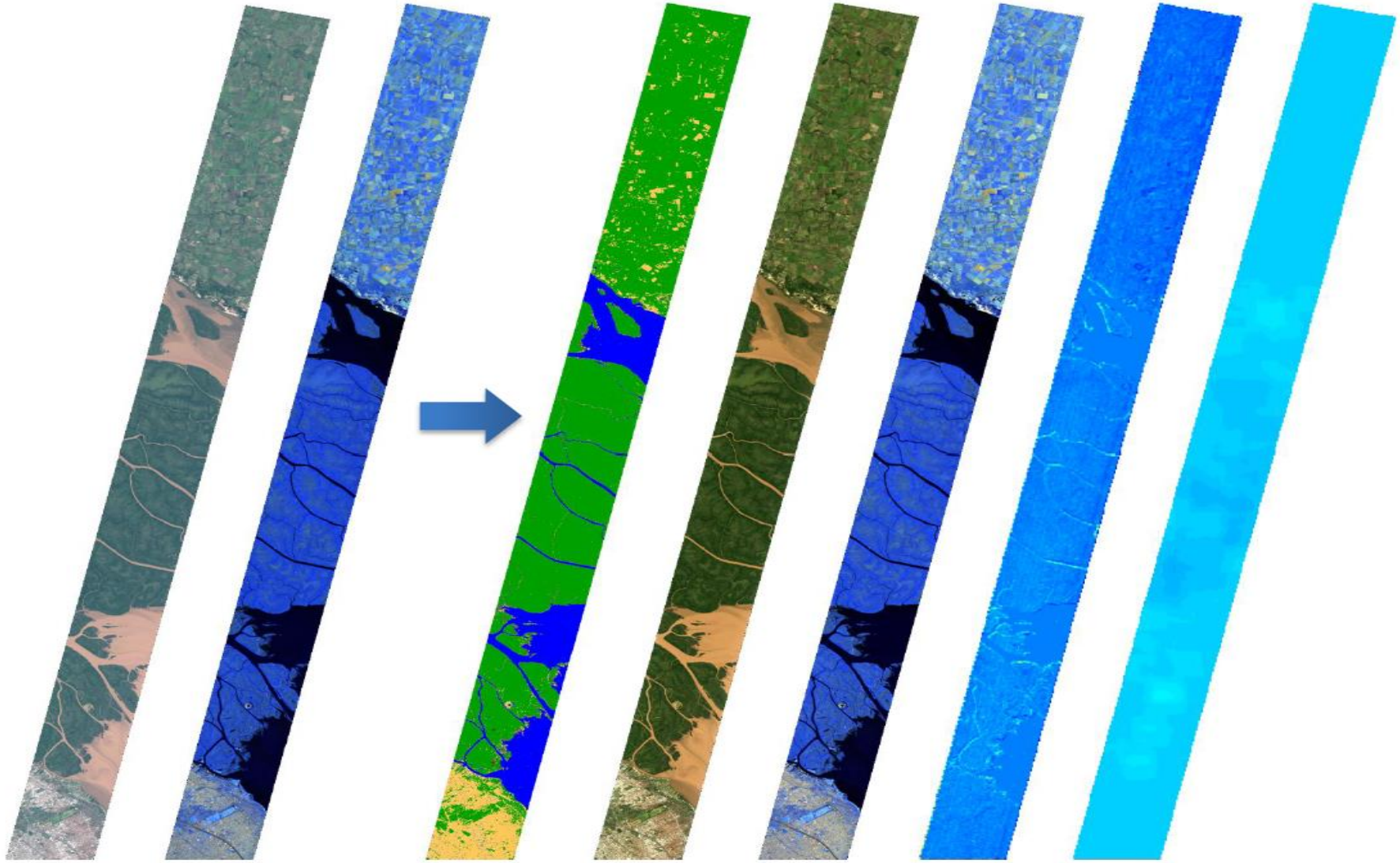
From left to right:

Level-1C [TOA]

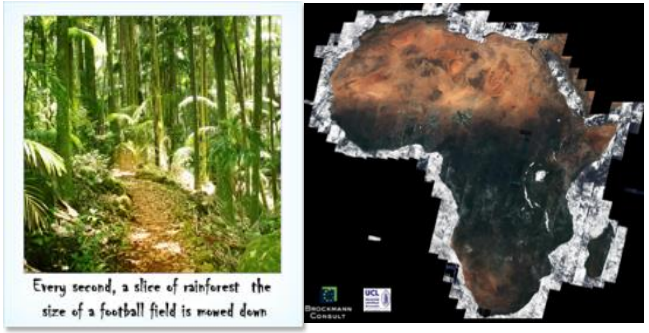
- *[RGB] B4-B3-B2*
- *[RGB] B12-B11-B8a*

Level-2A [BOA]

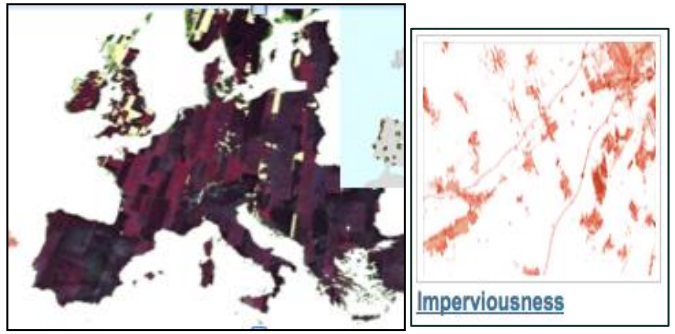
- *Scene Classification*
- *[RGB] B4-B3-B2*
- *[RGB] B12-B11-B8a*
- *Water Vapour*
- *Aerosols Optical Thickness*



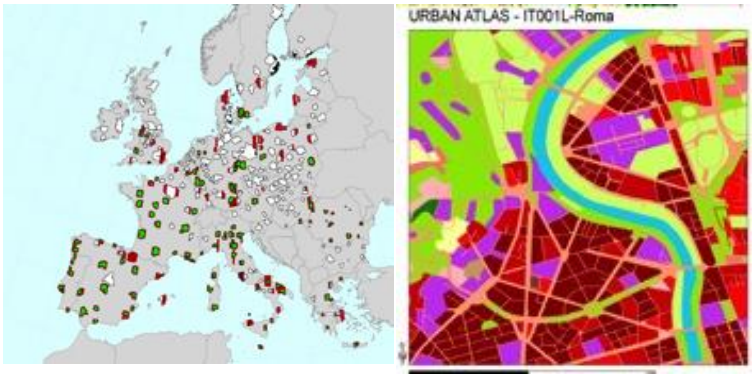
Sentinel-2 applications



Agriculture, Forests & Carbon, Vegetation monitoring

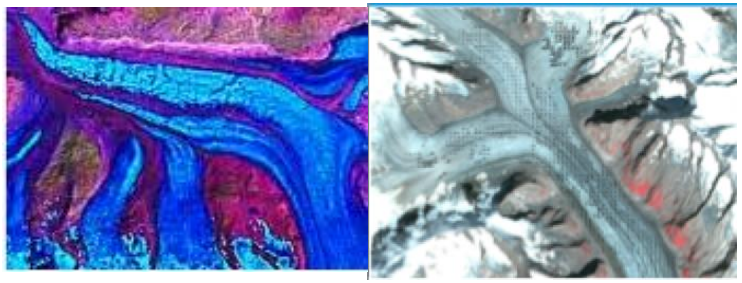


Land cover classification, high resolution layers & change.



Regional to Urban Applications

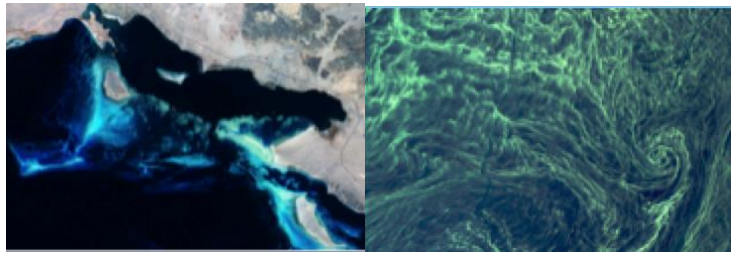
Emergency management



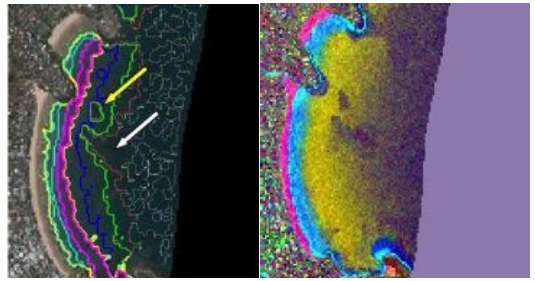
Glaciers & Ice

Global Land use & change

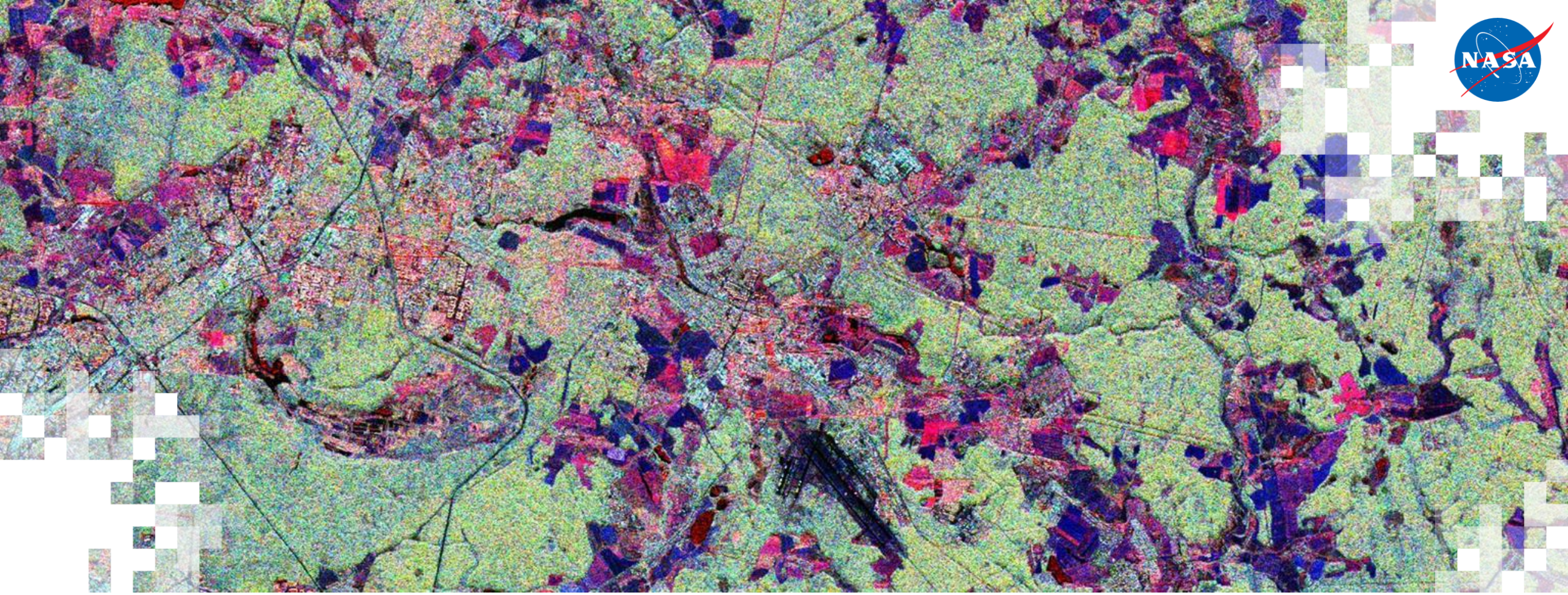
Geology



Water quality



Coastal zones/bathymetry



Section 2: Retrieval of crop specific LAI time series from Sentinel-2 using SNAP toolbox

Radiometric Indices

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

Vegetation indices

- DVI, RVI, PVI
- NDVI, WDVI, TNDVI, GNDVI
- SAVI, TSAVI, MSAVI, MSAVI2
- GEMI
- ARVI
- NDI45
- MTCI, MCARI, PSSRa
- S2REP, REIP, IRECI

Soil indices

- BI
- BI2
- RI
- GEMI

Water indices

- NDWI
- NDWI2
- MNDWI
- NDPI
- NDTI

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.

Biophysical Variables

- **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

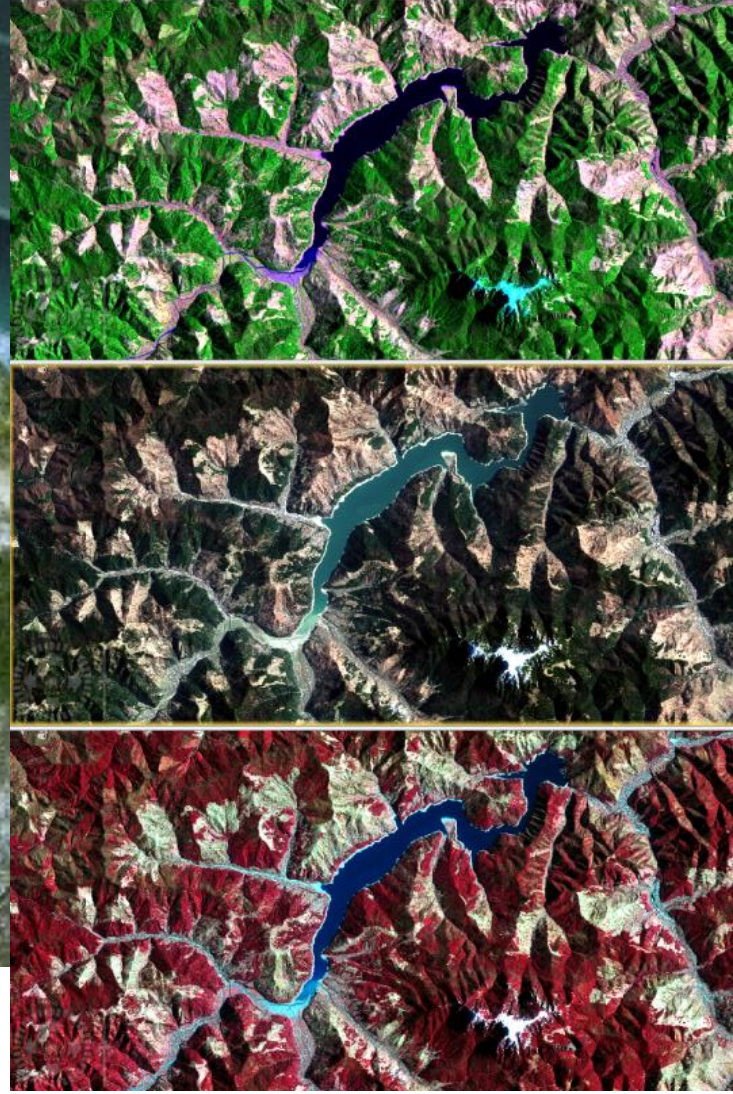
  The chlorophyll content is a very good indicator of stresses including nitrogen deficiencies. It is strongly related to leaf nitrogen content (Houlès et al. 2001). This quantity can be calculated both at the leaf level and at the canopy level by multiplication of the leaf level chlorophyll content by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

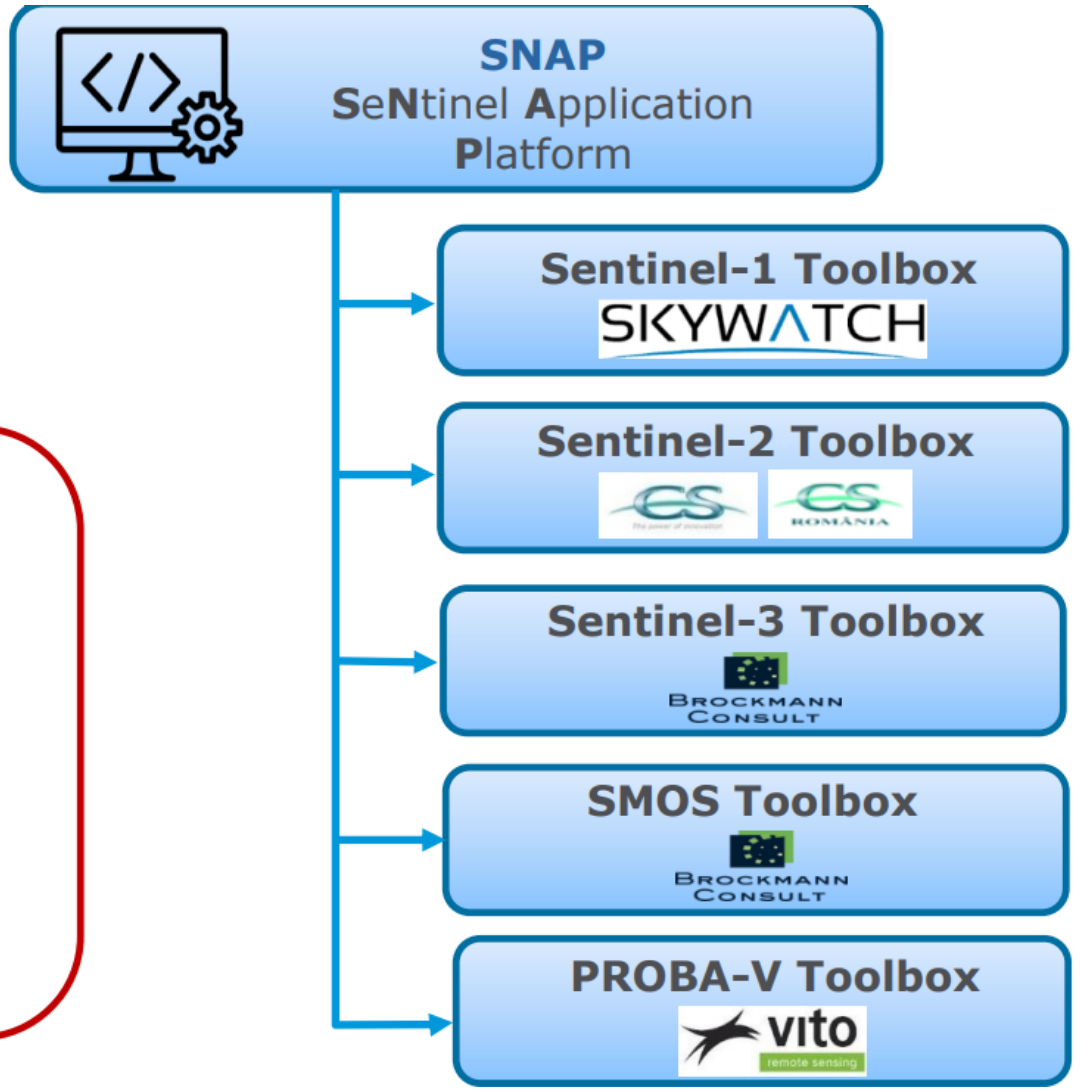


Introduction to data processing with SNAP

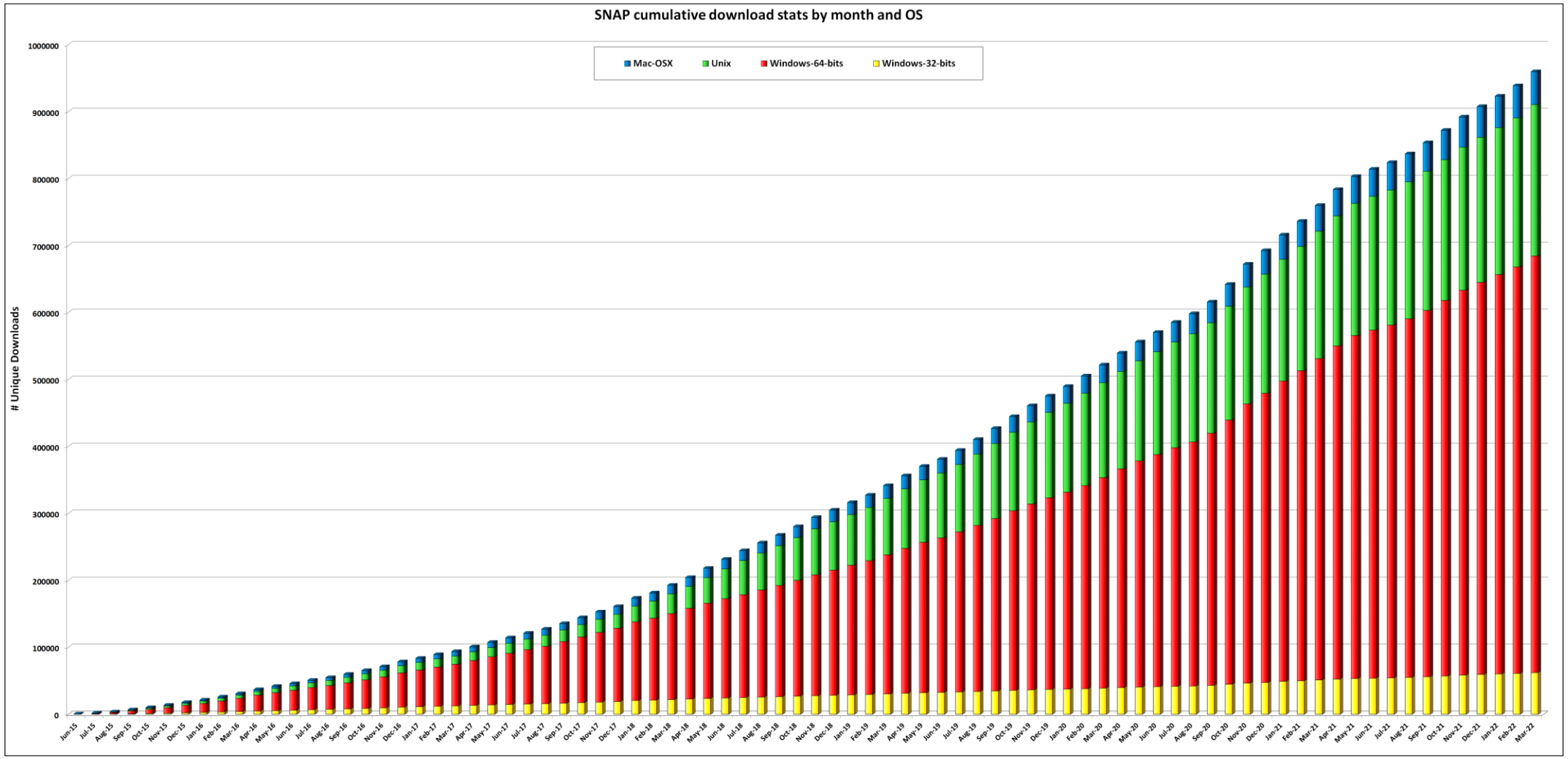
SNAP – SentiNel Application Platform

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



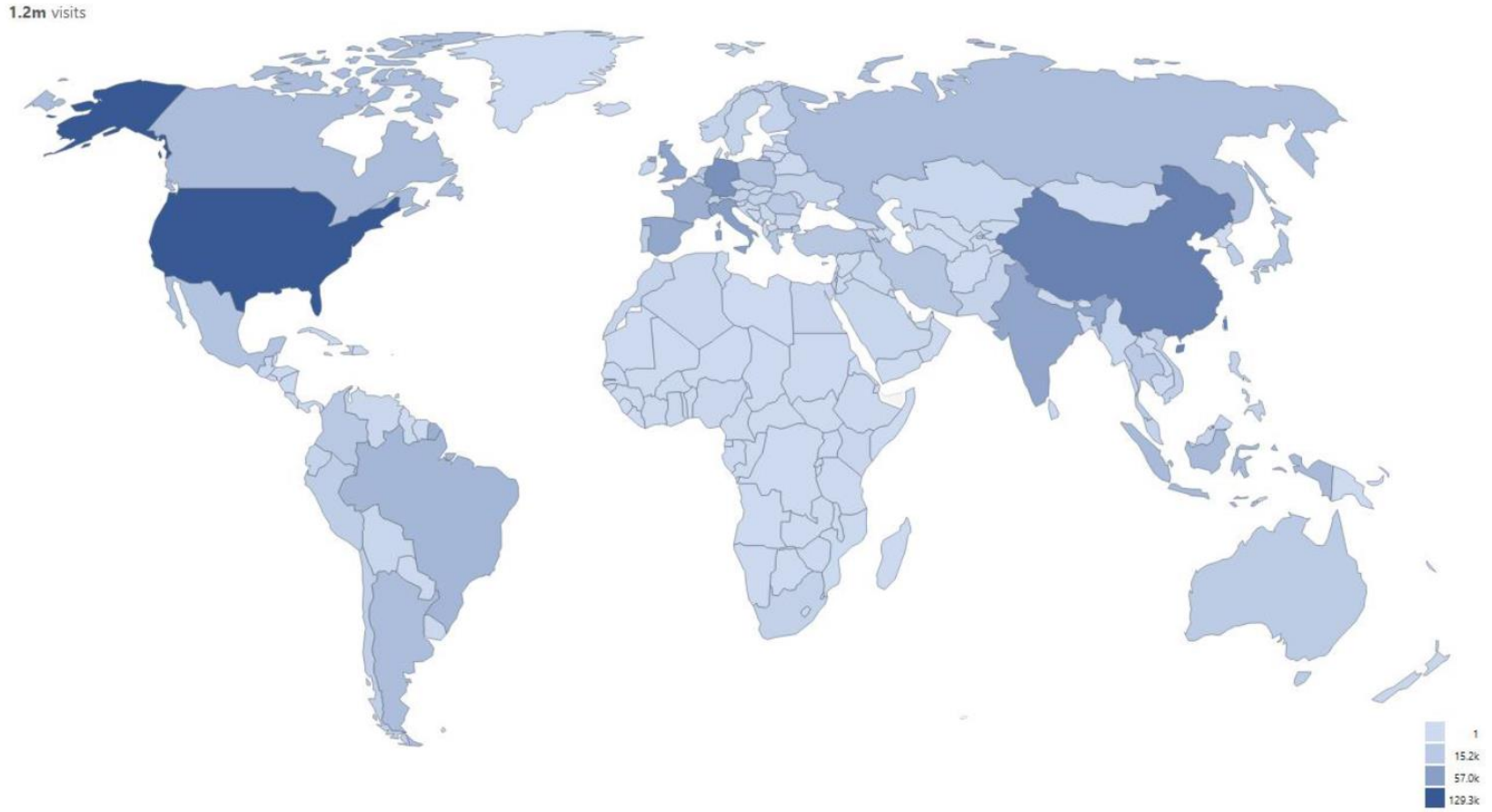
SNAP – SentiNel Application Platform



SNAP download reached almost 960˙000 from June 2015 until today

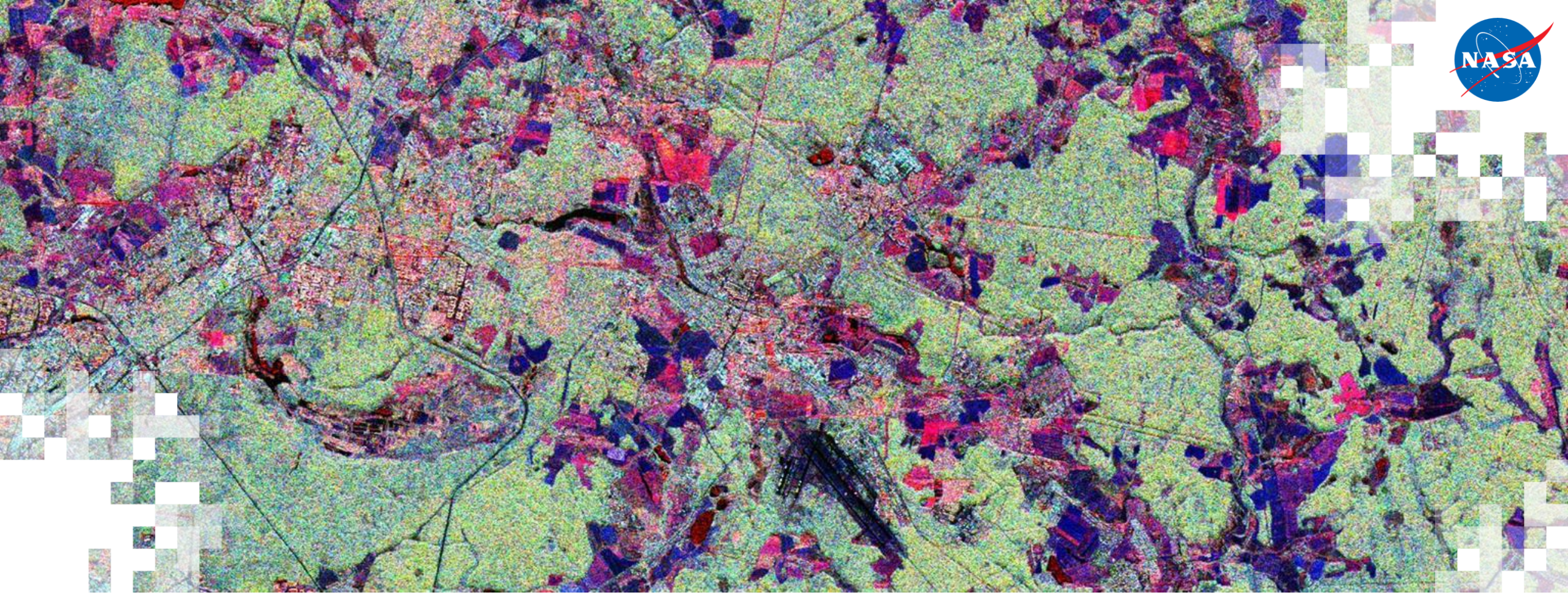
STEP – Scientific Toolbox Exploitation Platform

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



STEP Forum

- ✓ Since June 2015, the STEP website has reached almost **1˙530˙000** visit sessions
- ✓ **11˙432** discussion topics have been created, with a total of **78˙794** posts since June 15, 2015



Section 3: Crop-specific LAI time series analysis for growth monitoring (Jupyter Notebook)

- Quality control of the LAI time series
- Crop-specific LAI time series analysis at regional level
- Inter-field and intra-field heterogeneity assessment for many maize fields

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/
- **NASA ARSET** Agricultural Crop Classification with Synthetic Aperture Radar and Optical Remote Sensing **Part 5: Biophysical Variable Retrieval using Optical Imagery to Support Agricultural Monitoring Practices**
  https://appliedsciences.nasa.gov/join-mission/training/english/arset-agricultural-crop-classification-synthetic-aperture-radar-and
- **ESA '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/

Contacts

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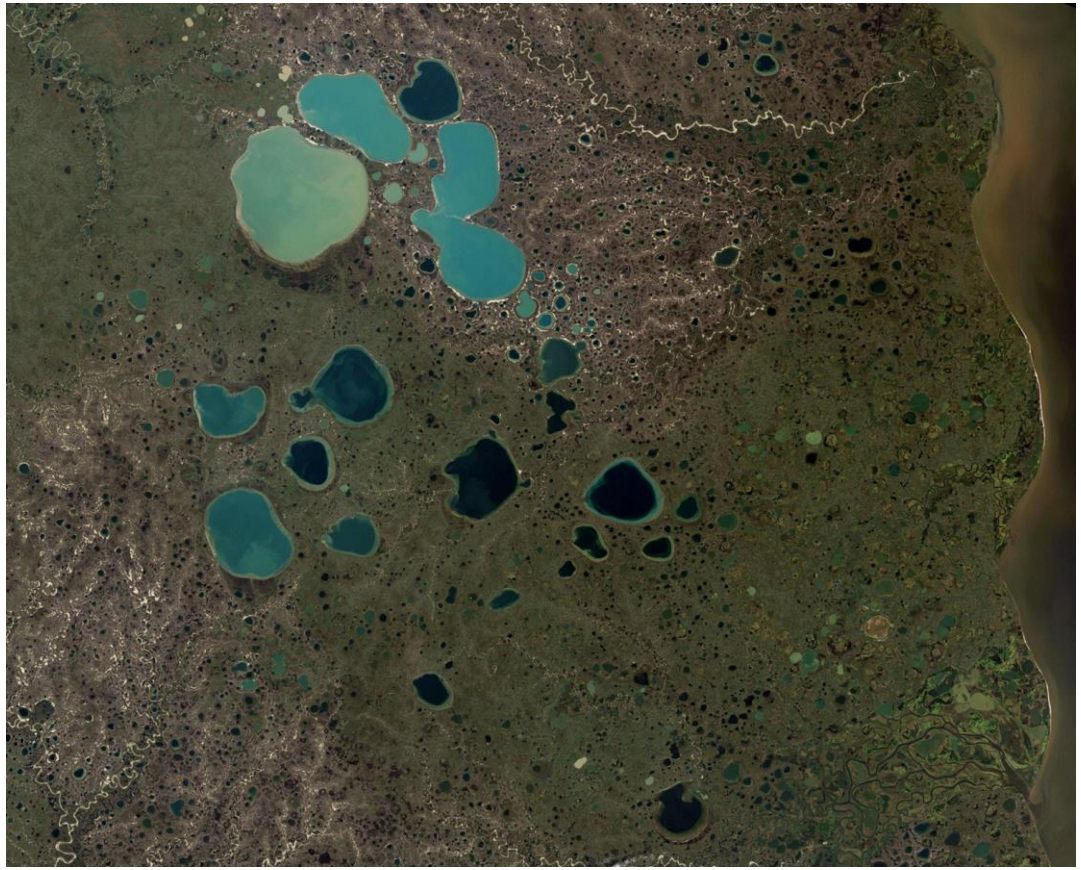
  - Fabrizio Ramoino fabrizio.ramoino@esa.int
  - Pr. Pierre Defourny pierre.defourny@uclouvain.be
- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-agricultural-crop-classification-synthetic-aperture-radar-and
- ESA's EO4Society Website:
  - https://eo4society.esa.int/training-education/
- Twitter: @EOOpenScience

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


APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

Thank You!