SAR & Optical Remote Sensing for Agriculture

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Trans-Atlantic Training 2022 (TAT-9): A Changing Eastern Europe: New Challenges for Science and Capacity Building in Land Remote Sensing, annual workshops and training courses in Earth Observation (EO) organized by NASA and ESA

5 to 9 September 2022, Charles University, Prague, Czechia

Outline

- Optical remote sensing
- Interaction with the atmosphere and surface, spectral response
- Removing the atmosphere
- SAR basics
- SAR processing
- What do we measure in remote sensing
- Analysis Ready Data
- Time series
- Vegetation development
- SAR/Optical/SAR+Optical
- Cloud or local processing

Before starting

✓ • GitHub TAT 2022
  • https://github.com/EarthObservation/tat2022

✓ • SNAP
  • https://step.esa.int/main/download/snap-download/

• Anaconda ✓

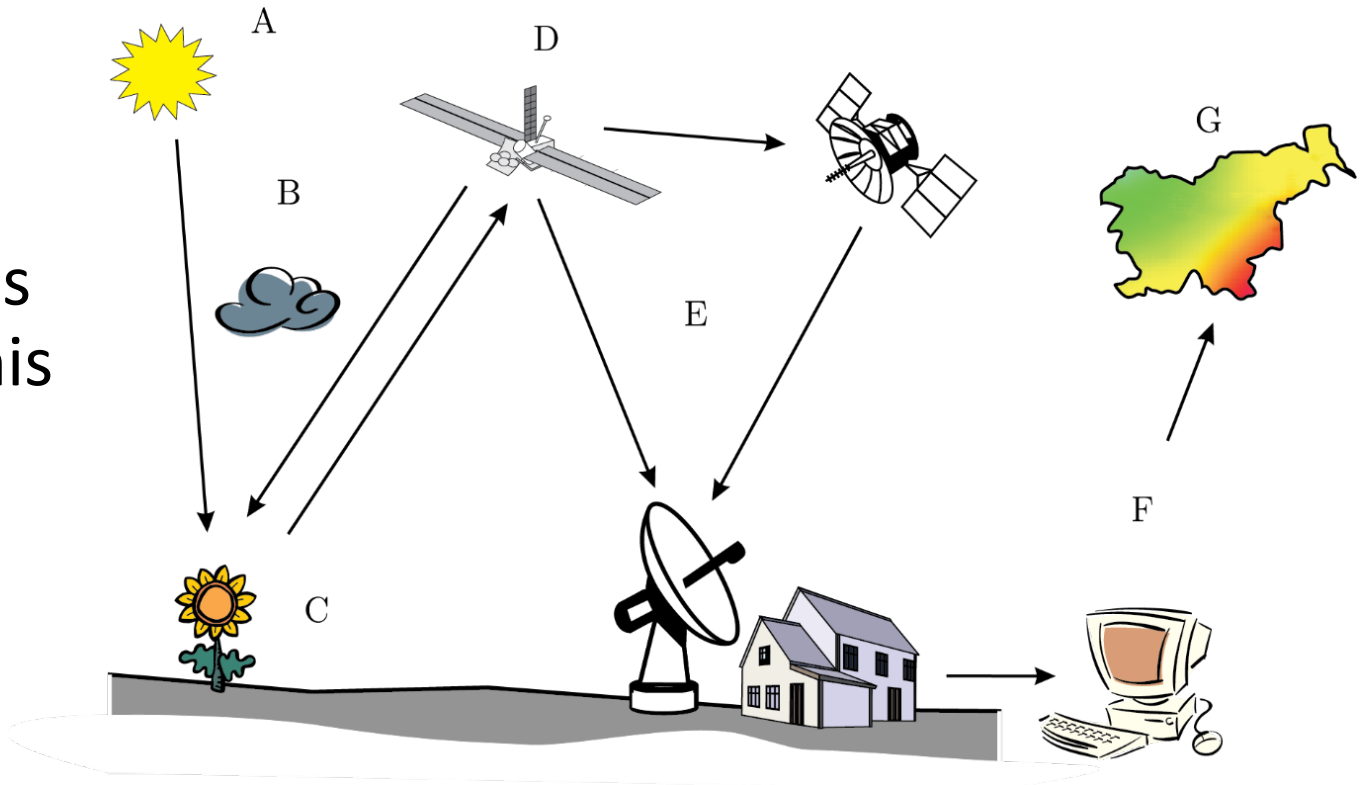
• New environment from environment.yml
  • conda env create --name optical-workshop --file environment.yml ✓
  • conda activate optical-workshop

If not, ask for help.

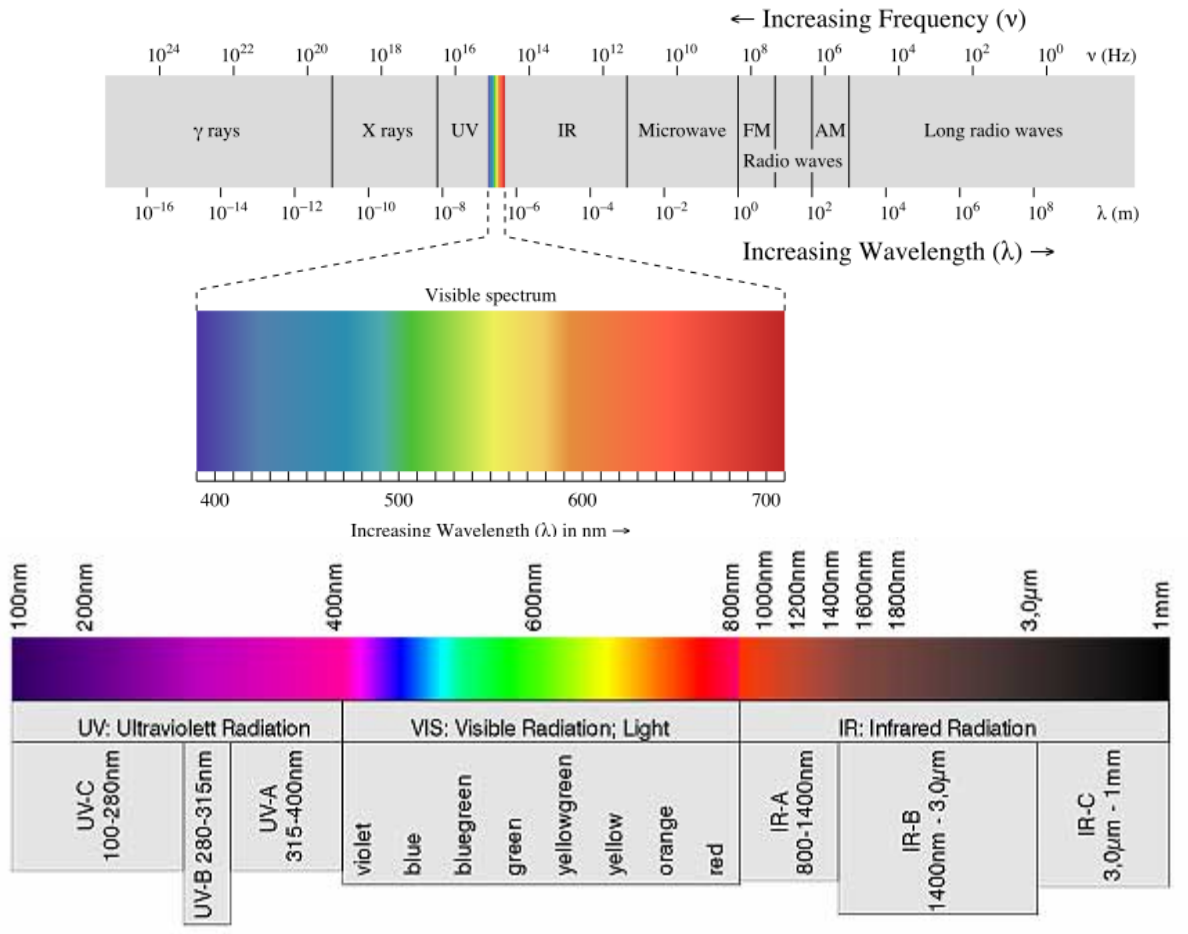
What is remote sensing?

- Remote sensing is the science of obtaining information on Earth's surface without coming into direct contact with it. In doing so, we detect and record a reflected or radiated electromagnetic waves, process them, analyse them and use this information in different applications.

Energy or Illumination Source (A)
Radiation and the Atmosphere (B)
Interaction with the Target (C)
Recording by the Sensor (D)
Transmission, Reception, and Processing (E)
Interpretation and Analysis (F)
Application (G)



Spectrum EMR



- Visible (VIS) 400 nm – 800 nm – perceived by the human eye
- Near infrared (IR) 1,55–1,75 µm and 2,05–2,4 µm
- Thermal 8,0–9,2 µm and 10,2–12,4 µm
- Microwave (SAR) 7,5–11,5 mm and 20 mm–

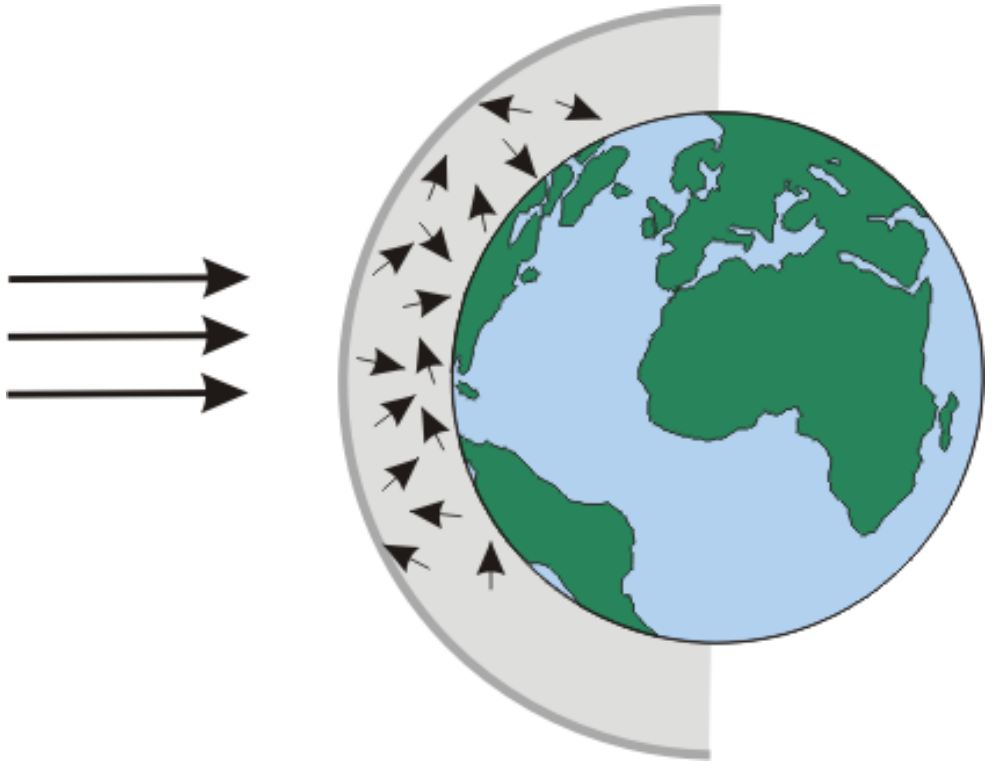
[The Wavelength Range Of Optical Radiation (light-measurement.com)]

Interaction with the atmosphere

- Before radiation used for remote sensing reaches the surface it has to travel through some distance of the atmosphere.
- Particles and gases in the atmosphere can affect the incoming light and radiation.
- Three types of interaction:
  - Scattering
  - Absorption
  - Refraction

Interaction with the atmosphere

- Scattering occurs when particles or large gas molecules present in the atmosphere interact with and cause the electromagnetic radiation to be redirected.
- Rayleigh
- Mie



Interaction with the atmosphere

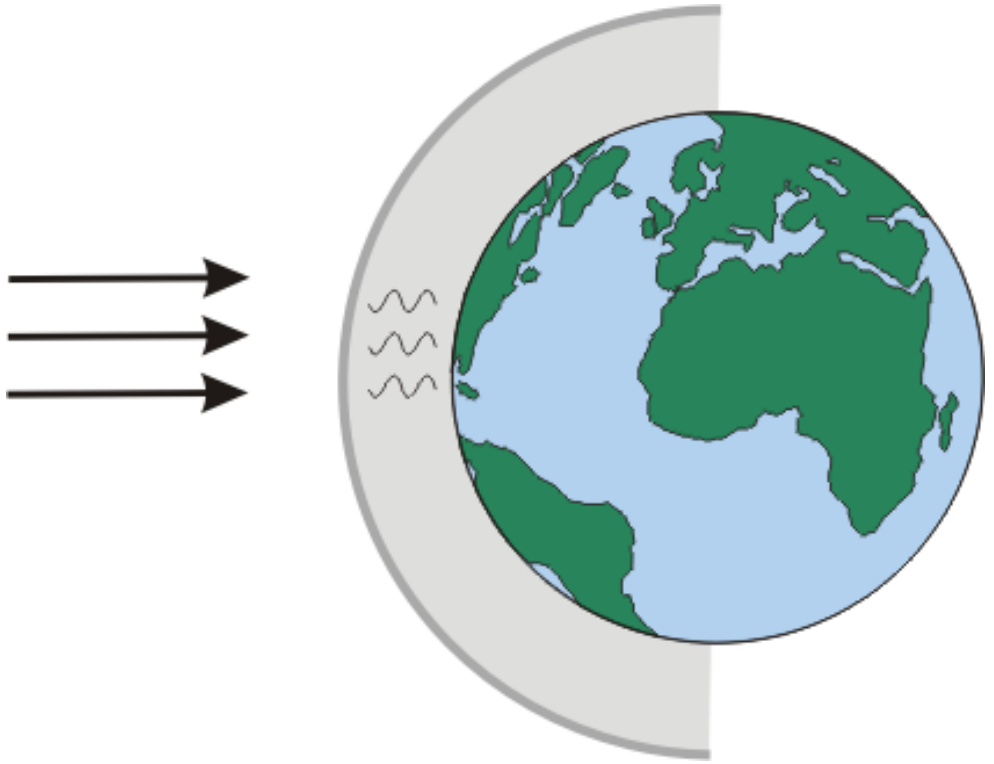
- Rayleigh
- Small-size particles in the atmosphere compared to the wavelength
- Intensity is proportional to the $1/\lambda^4$
- At the wavelength 400 nm is almost 10 x stronger than in 700 nm
- Blue sky

Interaction with the atmosphere

- Mie
- Particles about the same size as the wavelength
- Dust, pollen, smoke and water vapour
- More strongly affects longer wavelengths

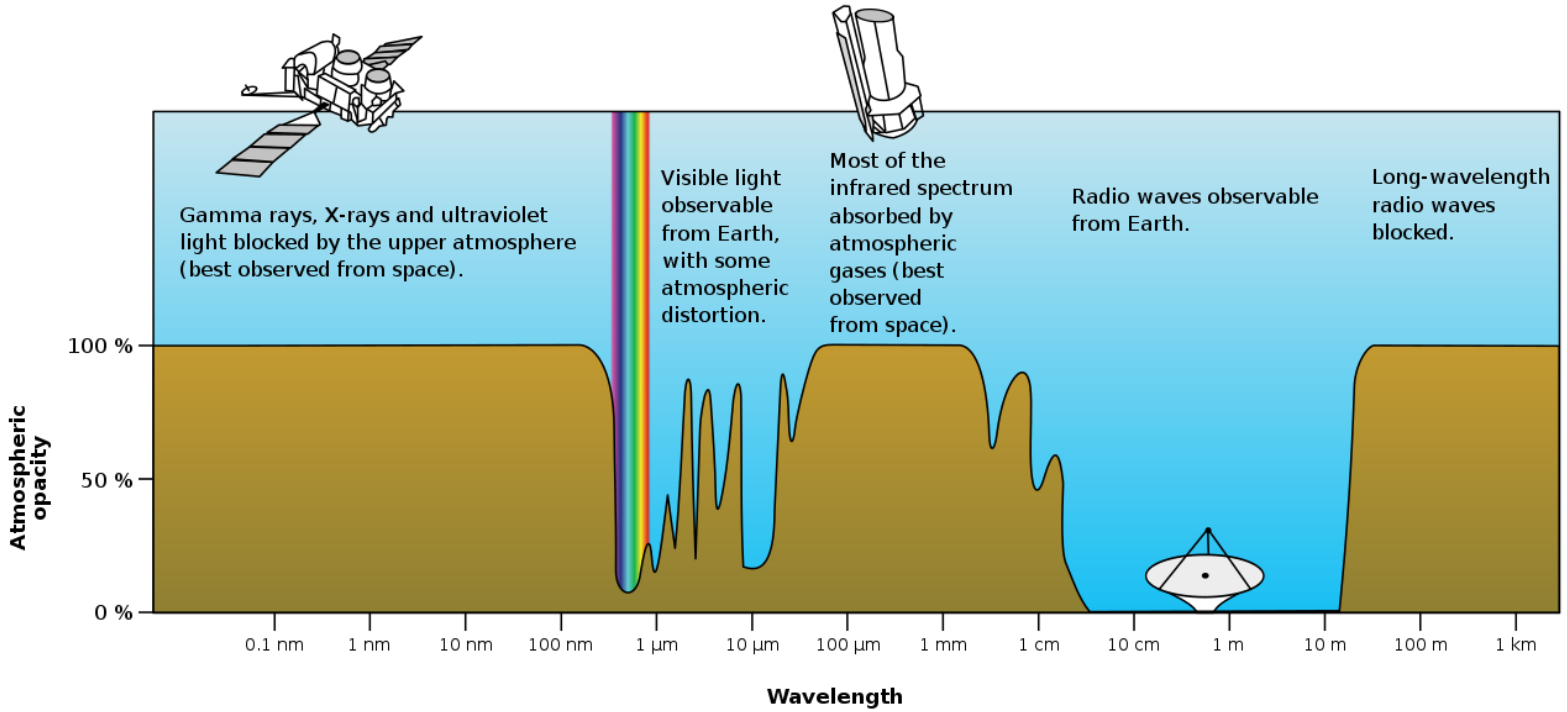
Interaction with the atmosphere

- Absorption causes molecules in the atmosphere to absorb energy at various wavelengths.
- Ozon, UV
- Carbon dioxide, Thermal IR
- Water vapor, long wave IR, microwaves

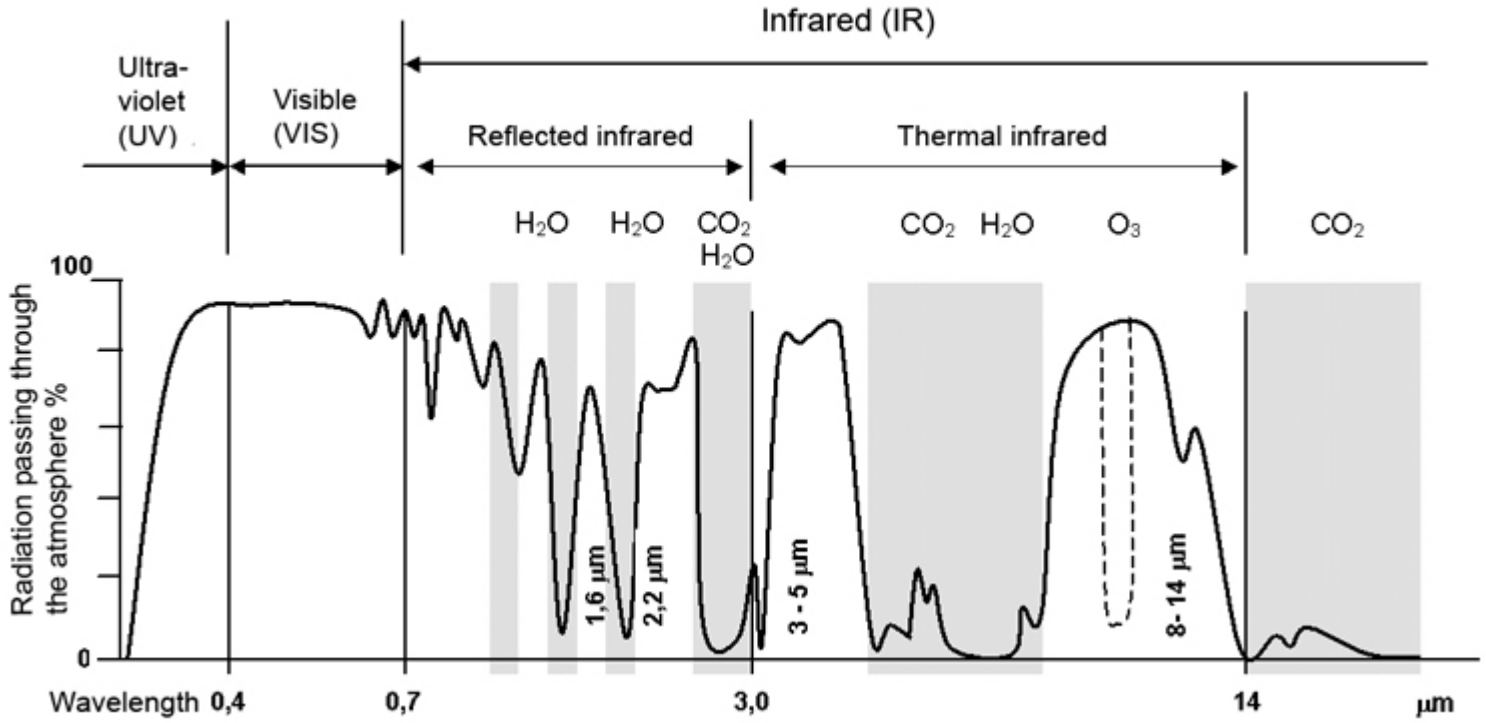


Earth's atmosphere opacity

- Some wavelengths are more effected by the atmosphere than others
- Those with little effect on signal are ‘windows’ for remote sensing.



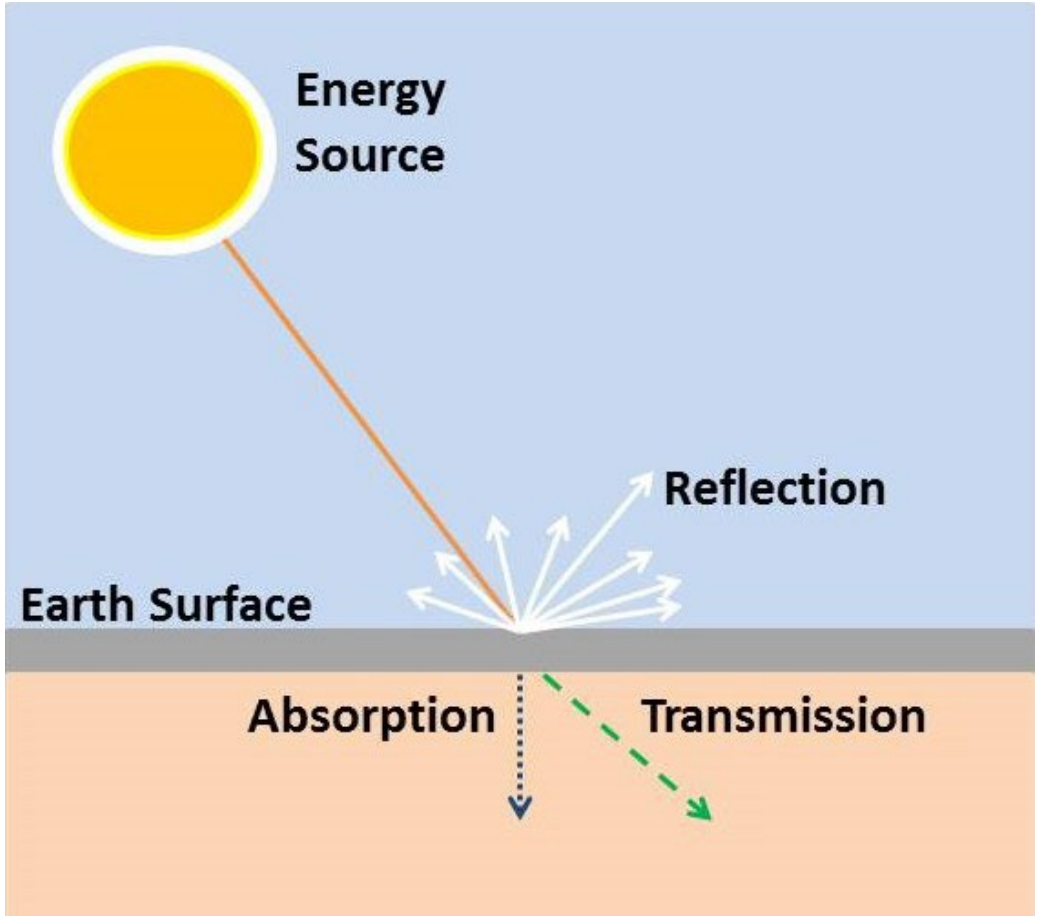
Optical Atmospheric Windows



Wavelength (λ)	Band
0.30 – 0.75 µm 0.77 – 0.91 µm	Visible light
1.55 – 1.75 µm 2.05 – 2.40 µm	Near infrared
8.0 – 9.2 µm 10.2 – 12.4 µm	Thermal infrared
7,5–11,5 mm 20 mm–	Microwave (SAR)

Interaction with the surface

- The interaction of electro-magnetic radiation with the surface is driven by three physical processes: reflection, absorption, and transmission of radiation.
- Reflection involves the returning or throwback of the radiation incident on an object on the surface.

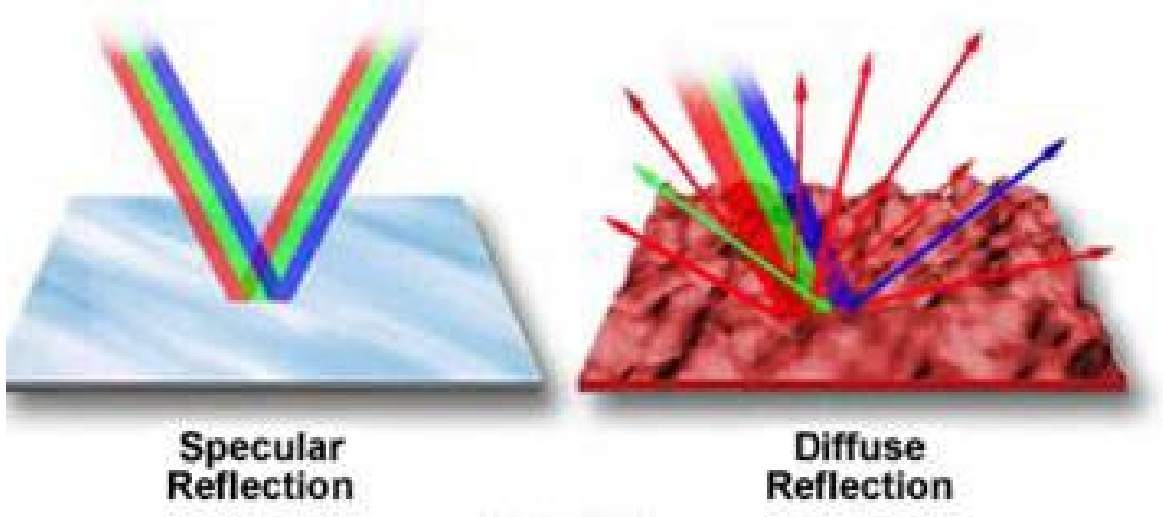


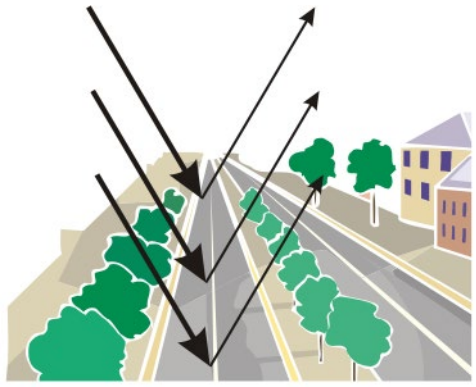
Electro-Magnetic Radiation (EMR) Interaction with Earth Surface Features (gisoutlook.com)

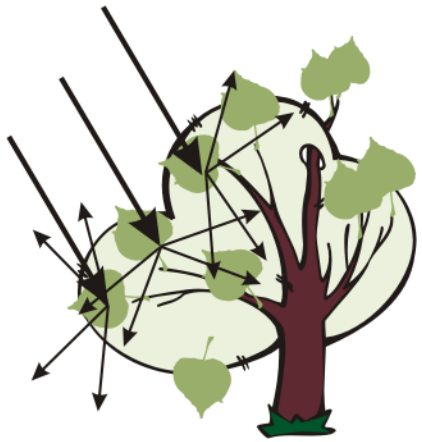
Interaction with the surface

- Spectral reflectance refers to the amount of reflectance in a specified wavelength range.
- It depends on:
  - the type of material
  - the nature of the surface, particularly whether it is a rough surface or a smooth surface, diffuse and specular
  - the wavelength of the incident radiation
  - other factors, such as the slope of the surface, its condition …

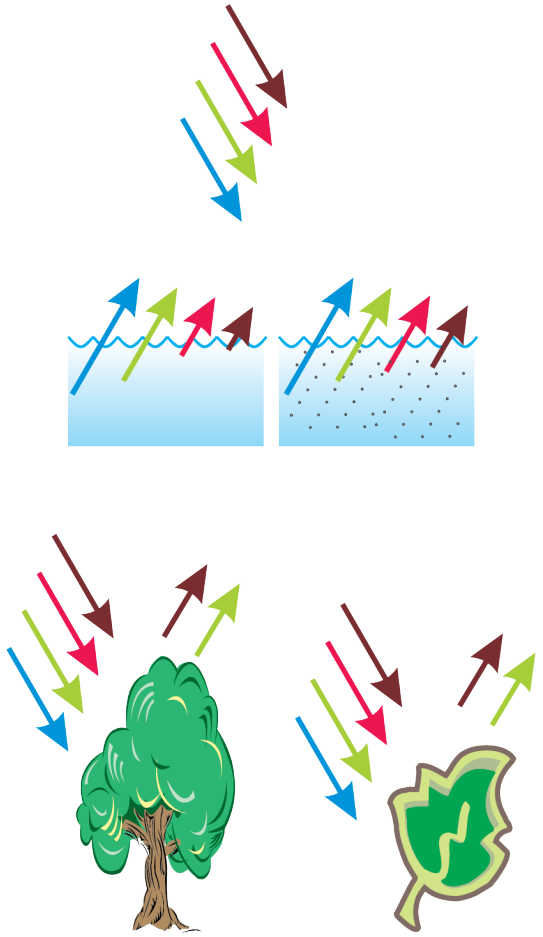
Specular and diffuse reflection

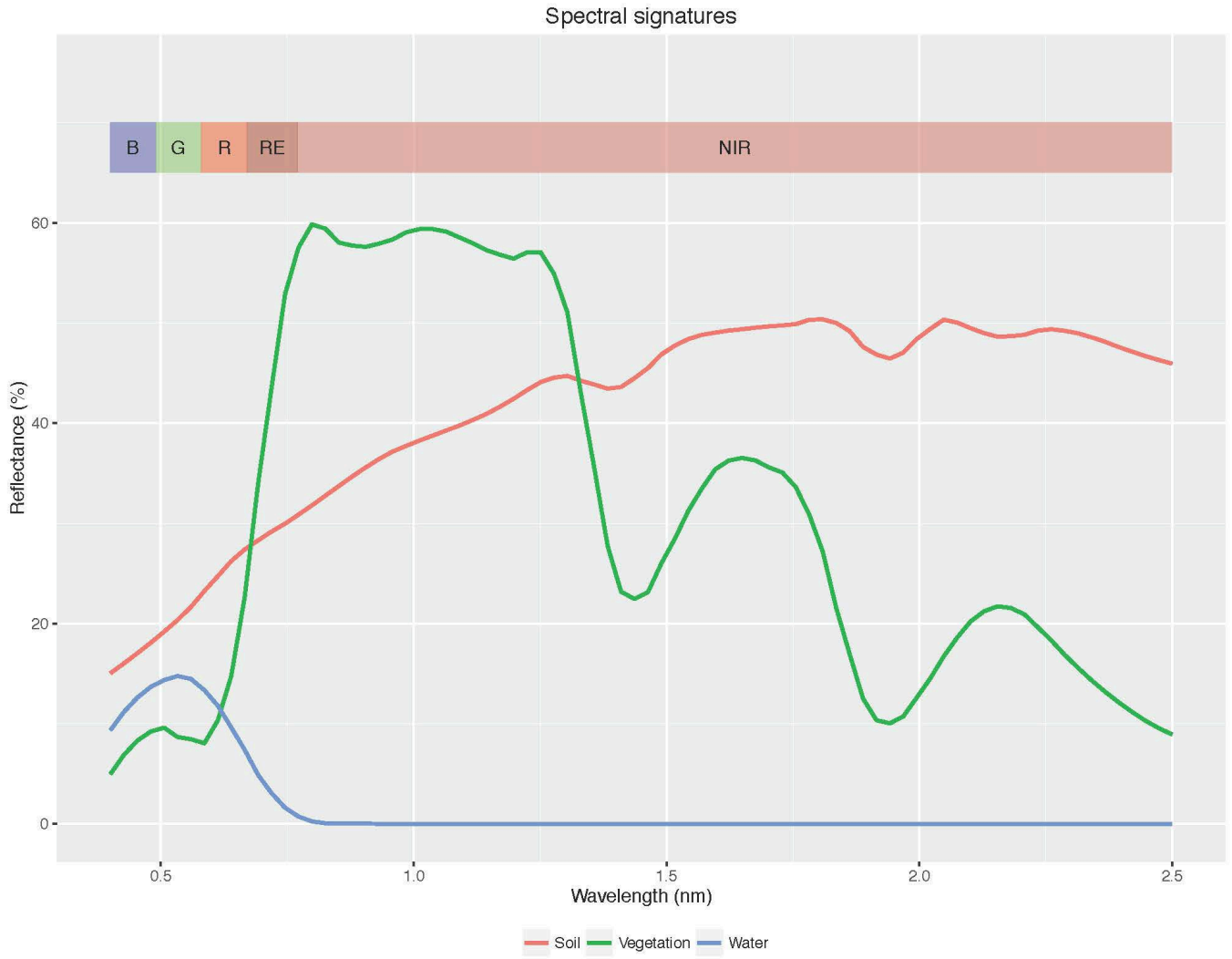




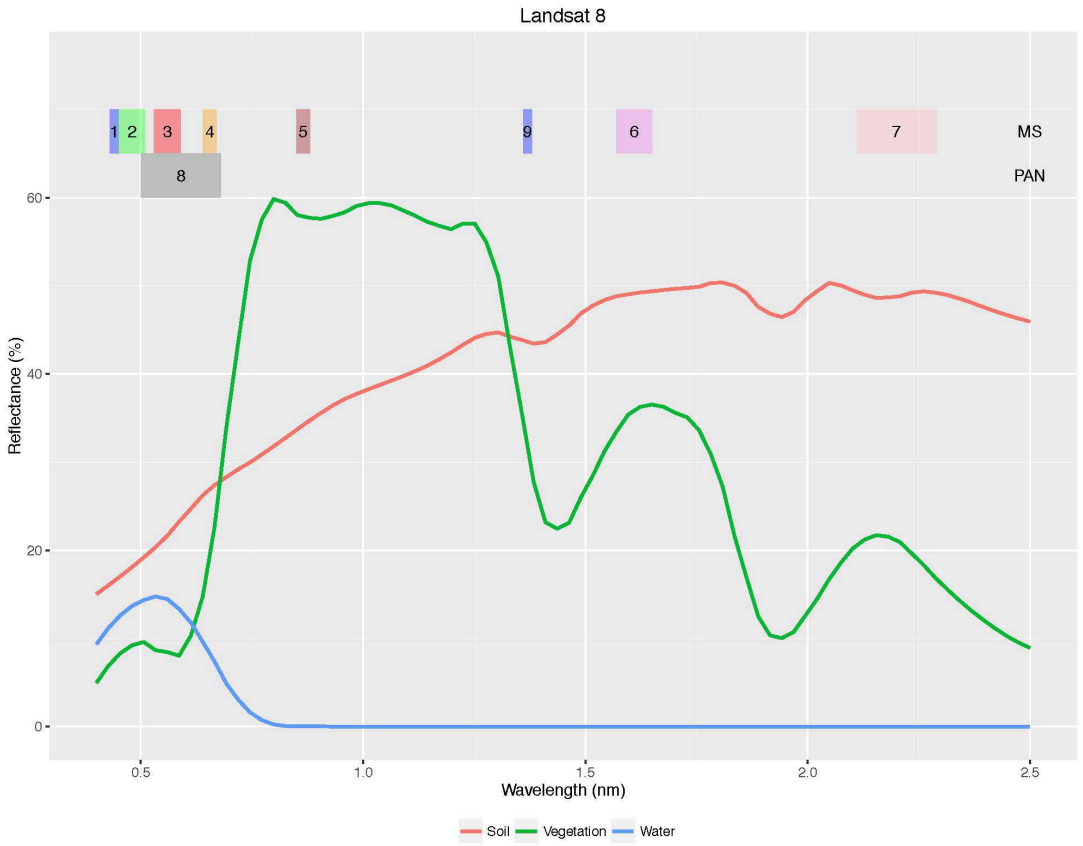


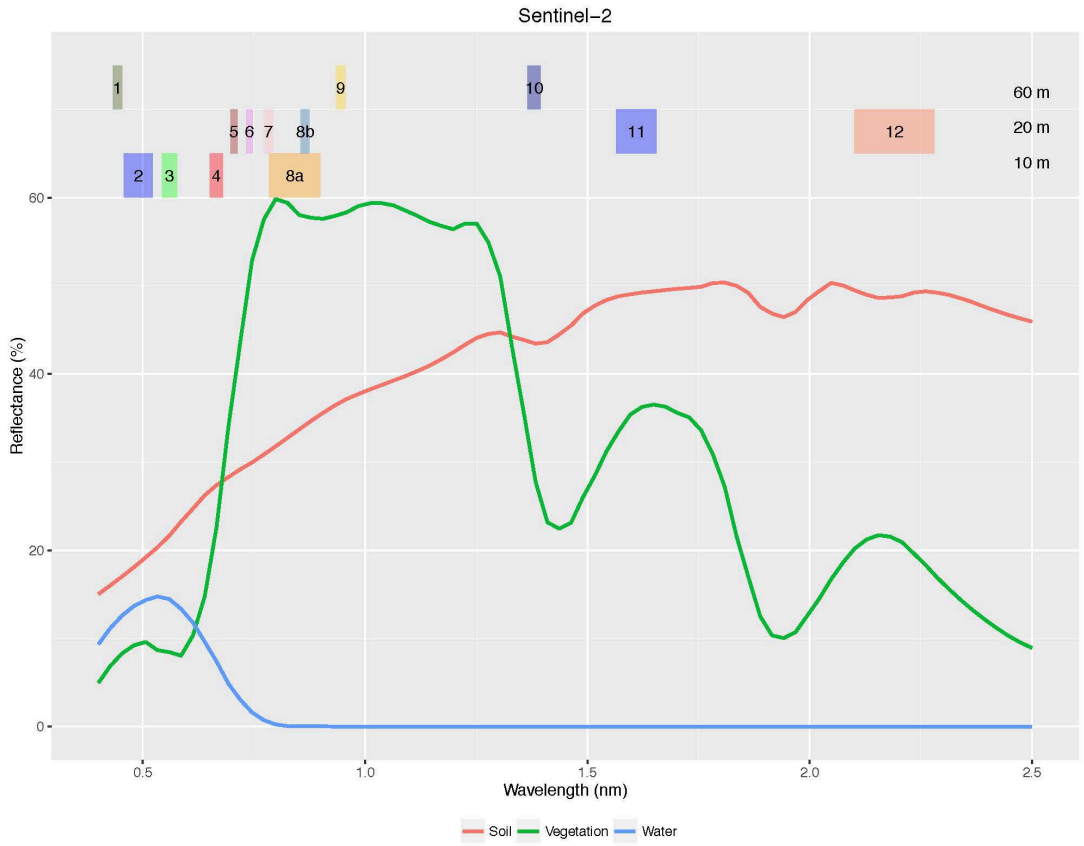
Interaction with vegetation and water





Landsat 8 and Sentinel-2 bands



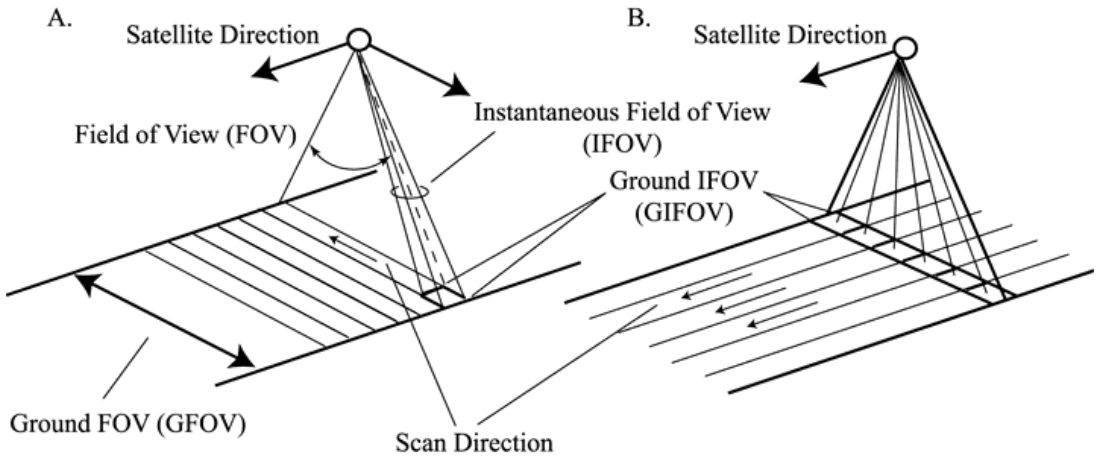


Optical satellites

- Optical satellites are passive
- They use devices that are simples – lens and detectors
- They observe the surface of the Earth across a varied spectrum of wavelengths
- The number of spectral channels/bands and bandwidth is different
- Optical imagery is more accessible and easier to interpret

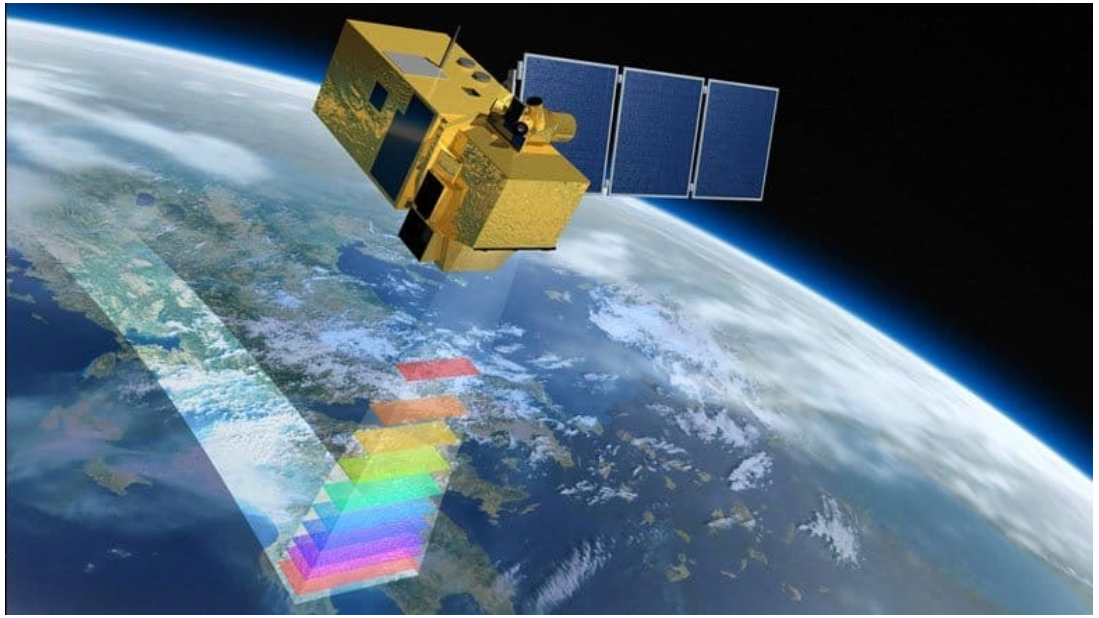
Optical scanners

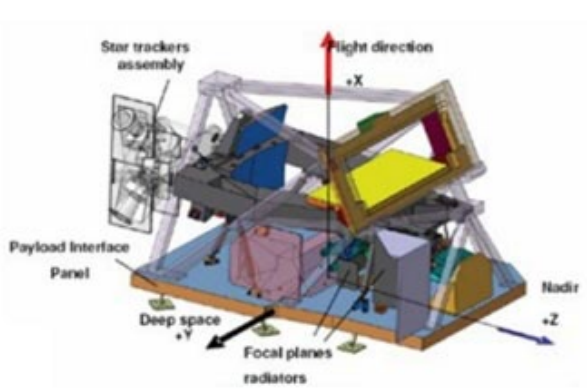
- Across track
  - Landsat – up to 7
- Along track
  - All HR and VHR
  - Sentinel-2
  - Landsat 8

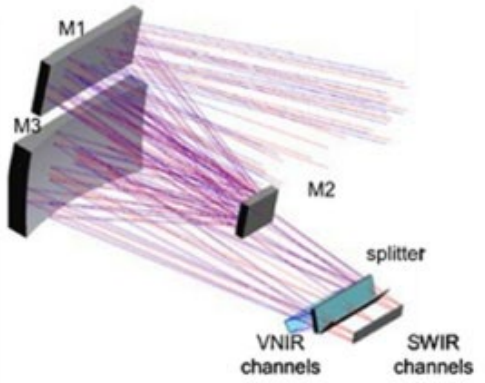


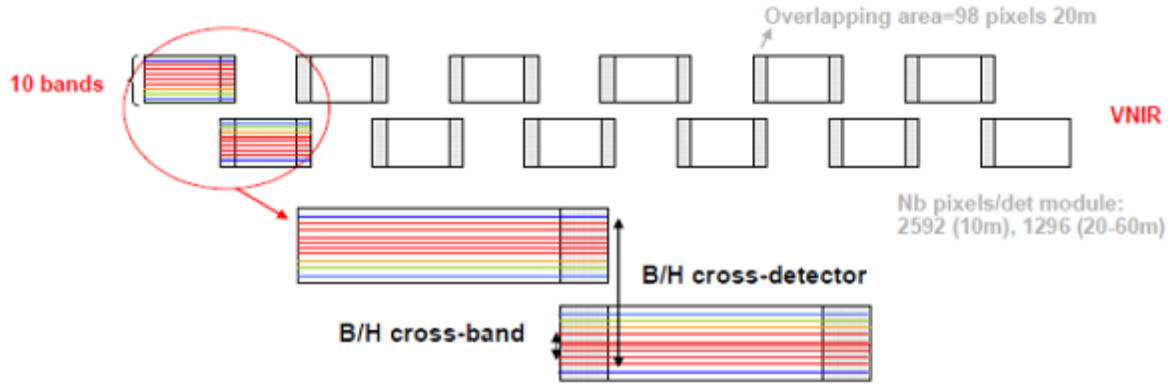
(18) (PDF) An introduction to satellite sensors, observations and techniques (researchgate.net)

Sentinel-2 imaging







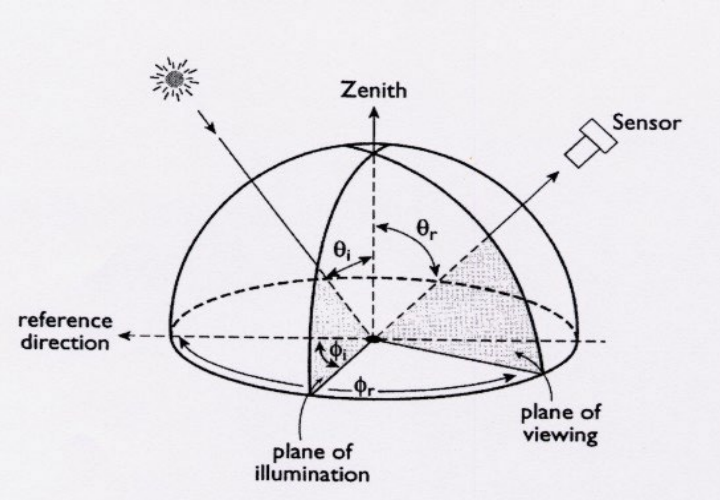


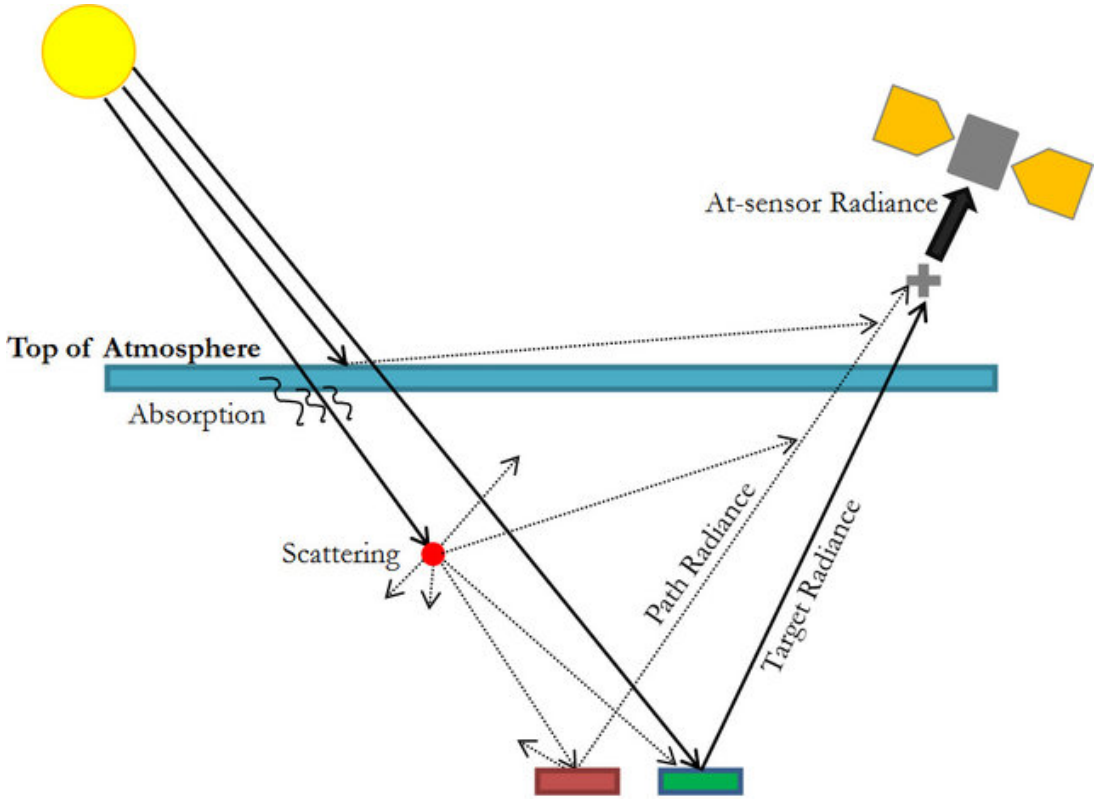
[MSI Instrument – Sentinel-2 MSI Technical Guide – Sentinel Online - Sentinel Online (copernicus.eu)]

Sentinel-2 imaging

What is being measured?

- The quantity of radiation passing through or emitted from a surface and falls within a given solid angle in a specified direction.



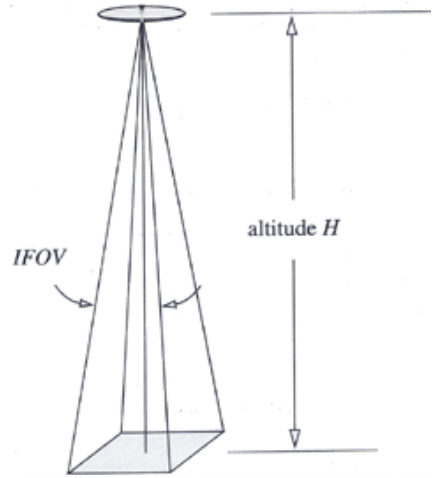


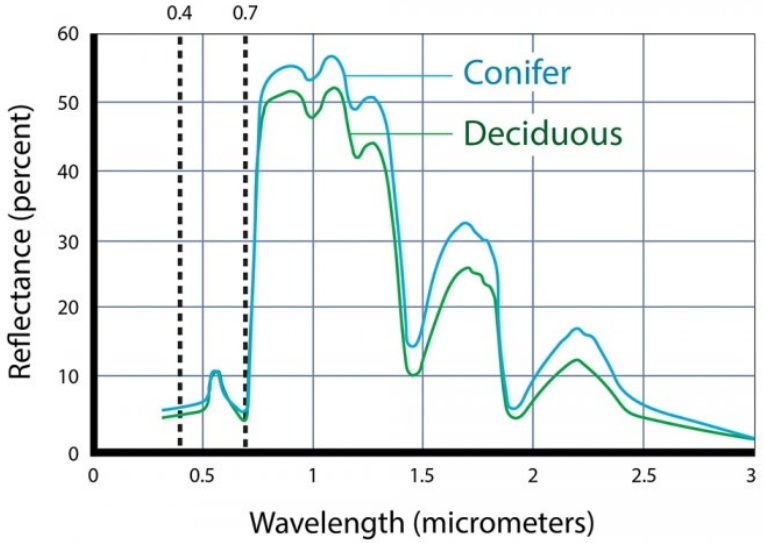
PowerPoint Presentation (ucdavis.edu)

(18) (PDF) Estimation of PM10 Distribution Using Landsat5 and Landsat8 Remote Sensing (researchgate.net)

Resolution

- Spatial resolution
- Spectral resolution
- Radiometric resolution
- Temporal resolution





Sentinel-2

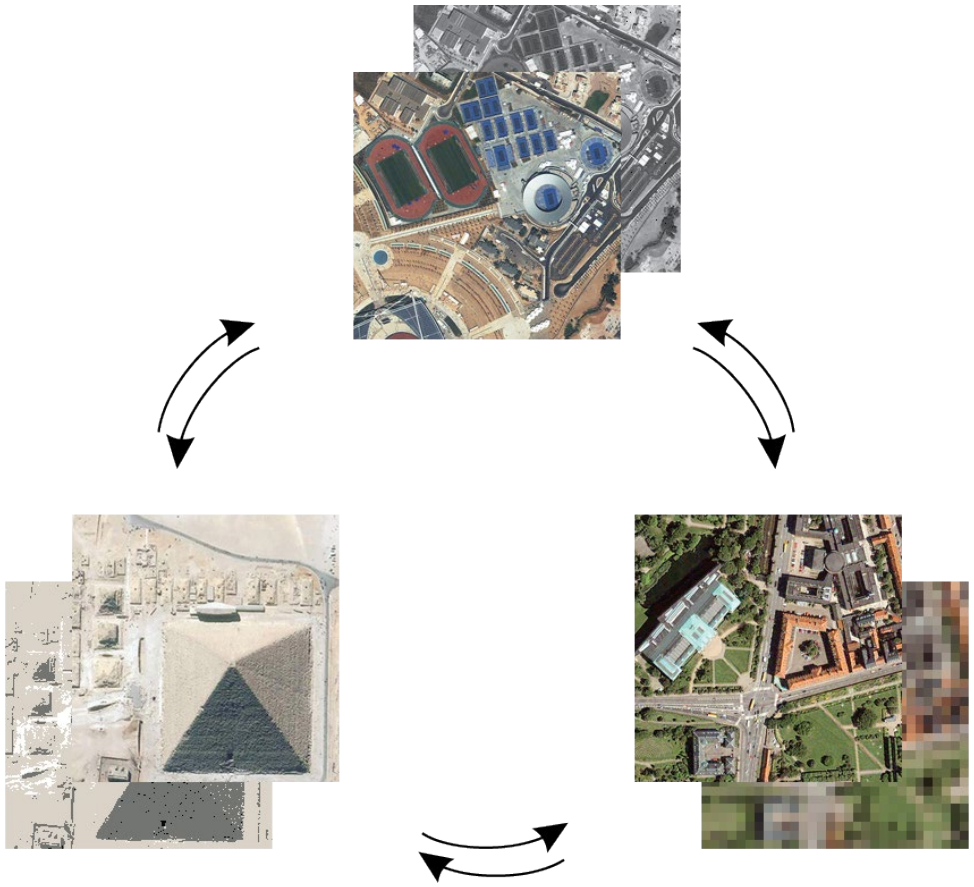
10, 20, 60 m

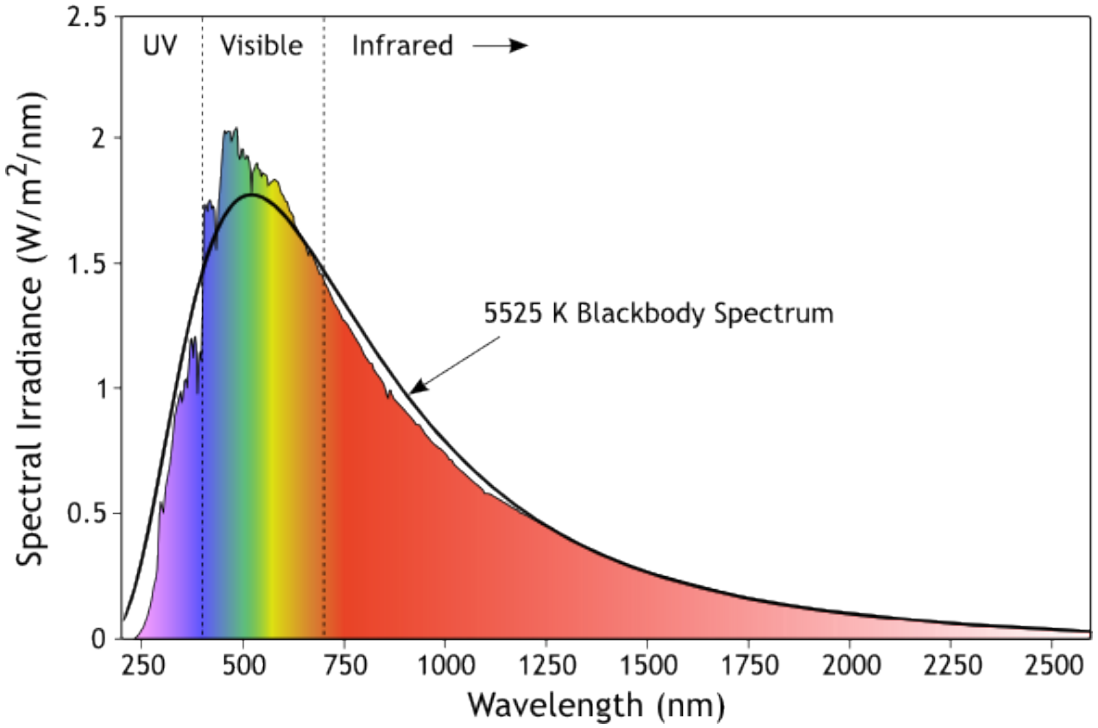
13 bands

12-bit

5 days

Selecting optimum resolution

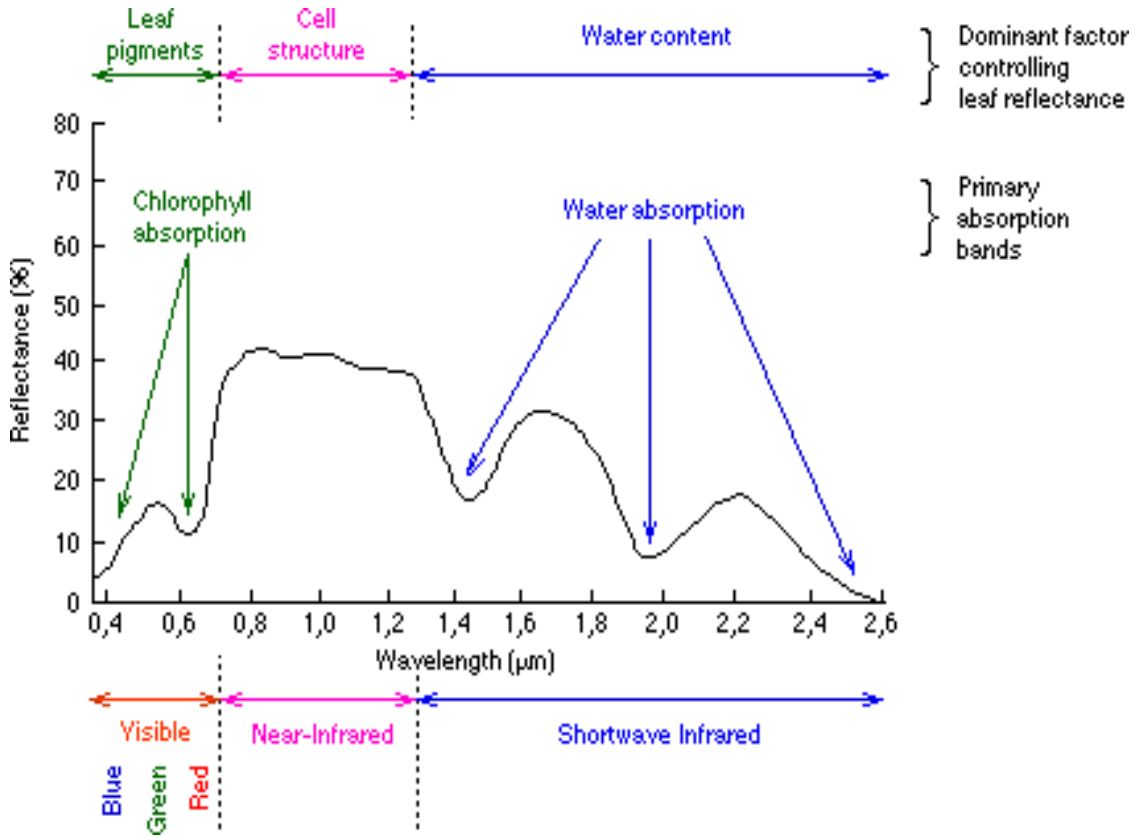




Vegetation Spectra

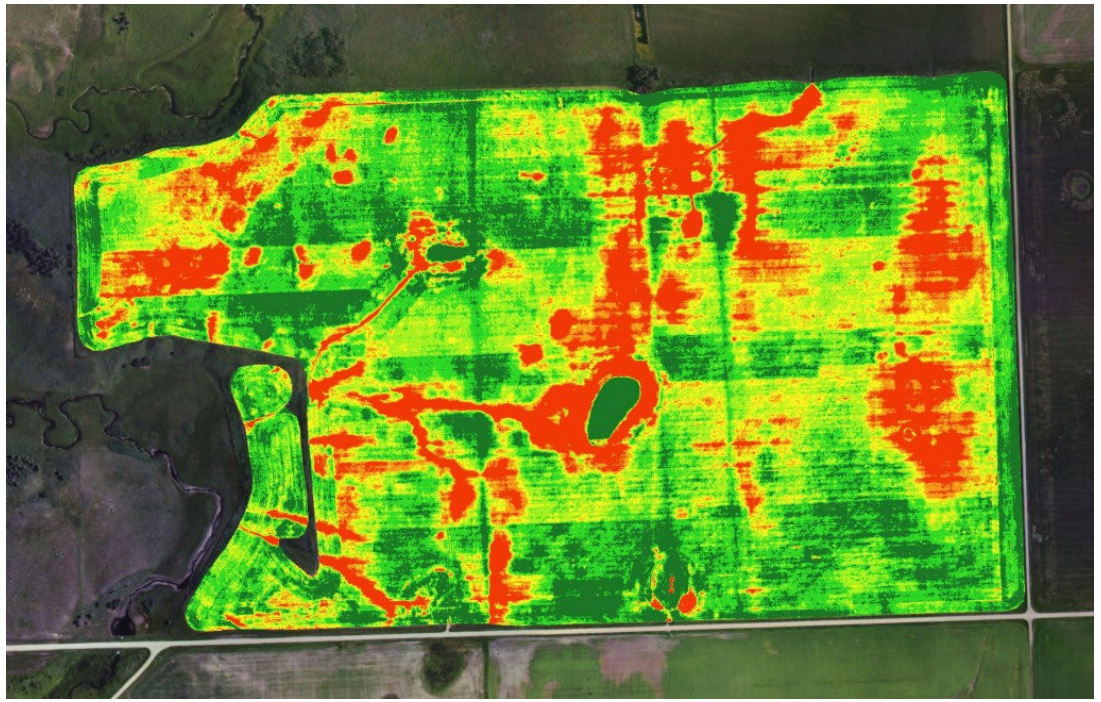
- Particular wavelengths are sensitive to particular chemicals and compounds.
- Result in absorption features.
- Make measurements related to those compounds.

- Indices take advantage of these wavelength features.



Vegetation Indices

- VI - Vegetation Index
- NDVI - Normalized Difference Vegetation Index
- EVI - Enhanced Vegetation Index
- SAVI - Soil Adjusted NDVI
- AVI - Advanced Vegetation Index
- NDMI - Normalized Difference Moisture Index ...



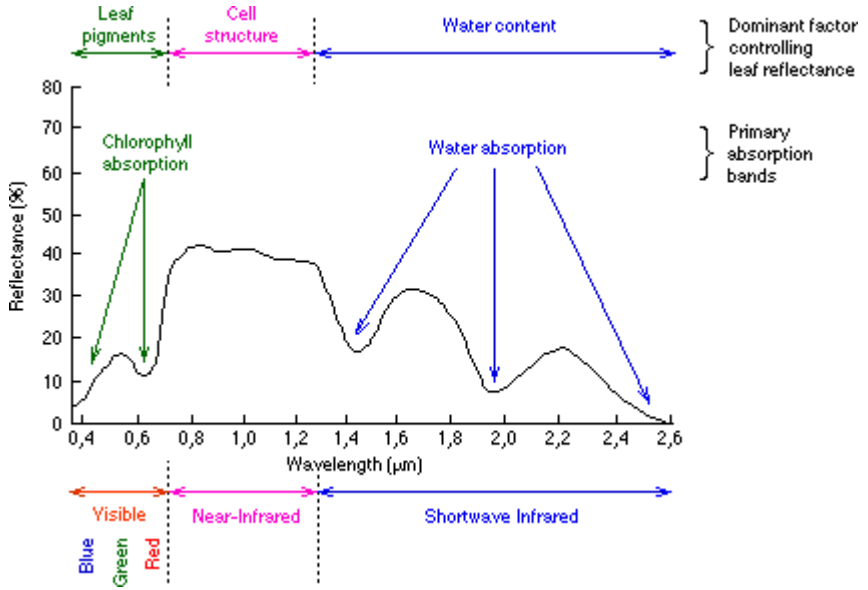
IDB - Index DataBase

Normalised Difference Vegetation Index (NDVI)

- Vegetation has high NIR and low Red reflectance.
- Other land cover have NIR and Red which are much close together

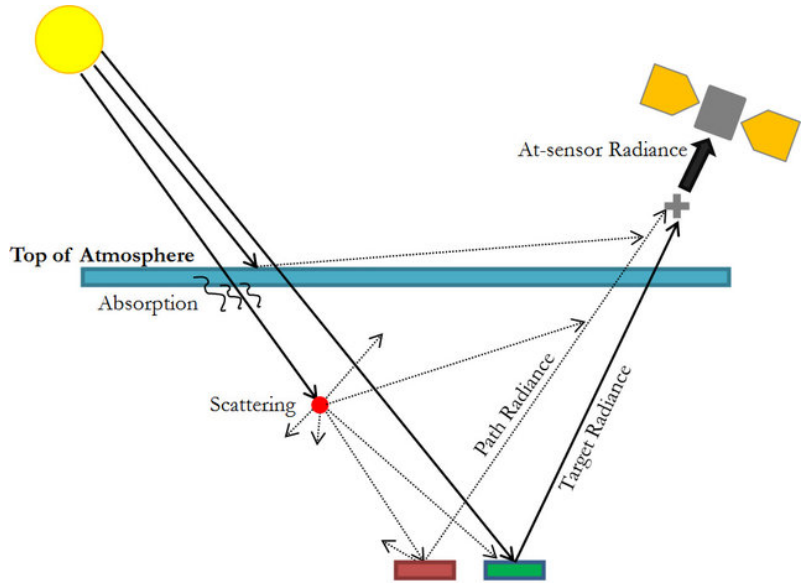
$$NDVI = \frac{IR - R}{IR + R}$$

- -1.0 to +1.0
- vegetation from 0.3 to 0.8, depending on health/intensity
- water (sea, lakes, rivers) low positive or even negative
- bare soil low positive values from 0,1 to 0,2



Retrieval of Surface Reflectance

- We want to use a surface reflectance
- Allows comparison between images
- Allows repeatable measurements
- Represents a physical unit
- To retrieve surface reflectance we need to ‘add back’ the component ‘lost’ in the atmosphere.
- At Sensor Refl = Surface Refl + Atmospheric Refl

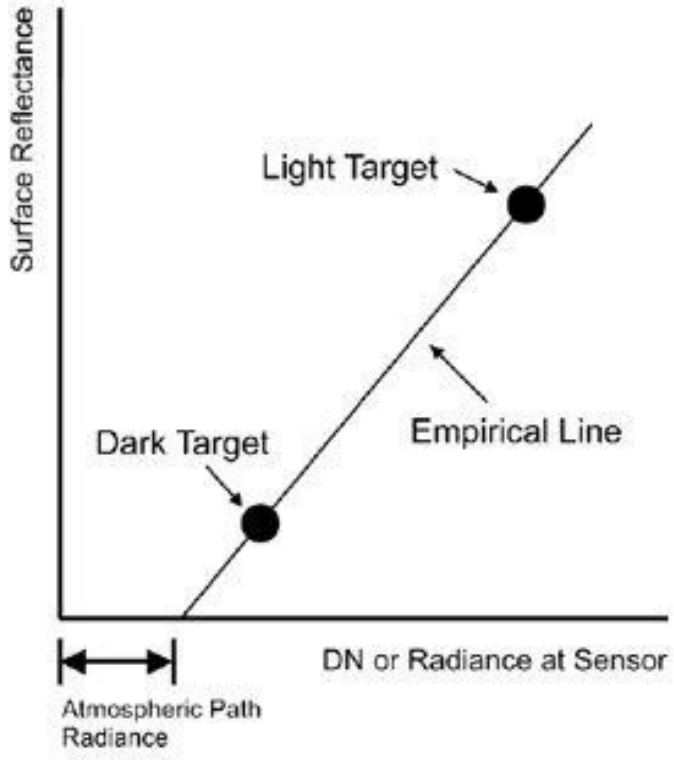


What is in the atmosphere?

- 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

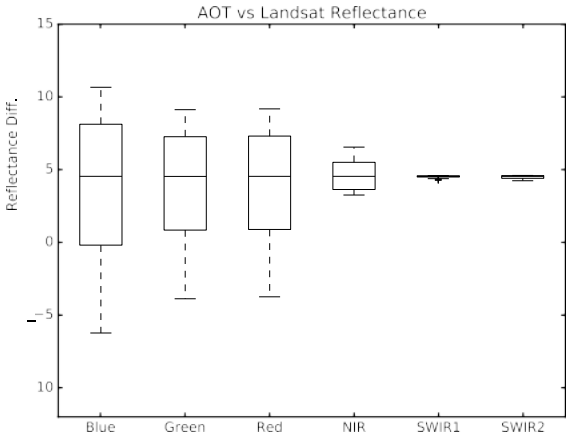
Options for Atmospheric Correction

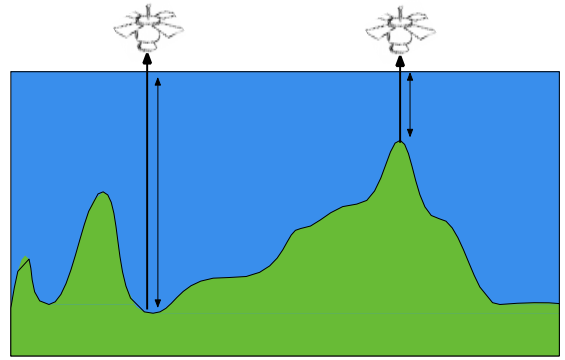
- Empirical Line Calibration
- Dark Object Subtraction
- Modelled Atmosphere

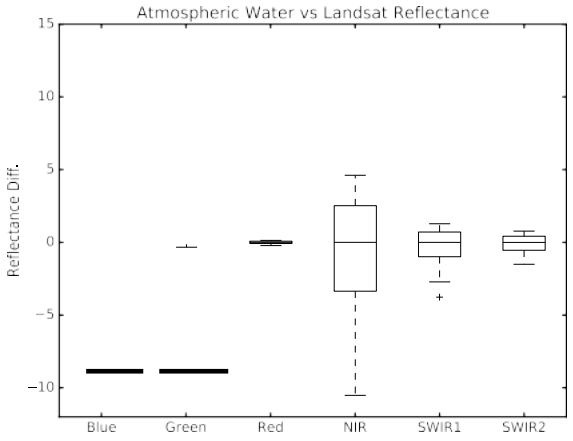


Modelled Atmosphere

- Aerosol Optical Depth
  - Amount and proportion of aerosols within the atmosphere Varies over small spatial distances and temporal baselines.
- Water Vapour
  - Amount within the vertical column
- Surface Elevation
  - Thickness of the atmosphere







Relative contributions:

AOT = 80 %

Water Vapour = 15 %

Altitude = 4 %

Modelled Atmosphere

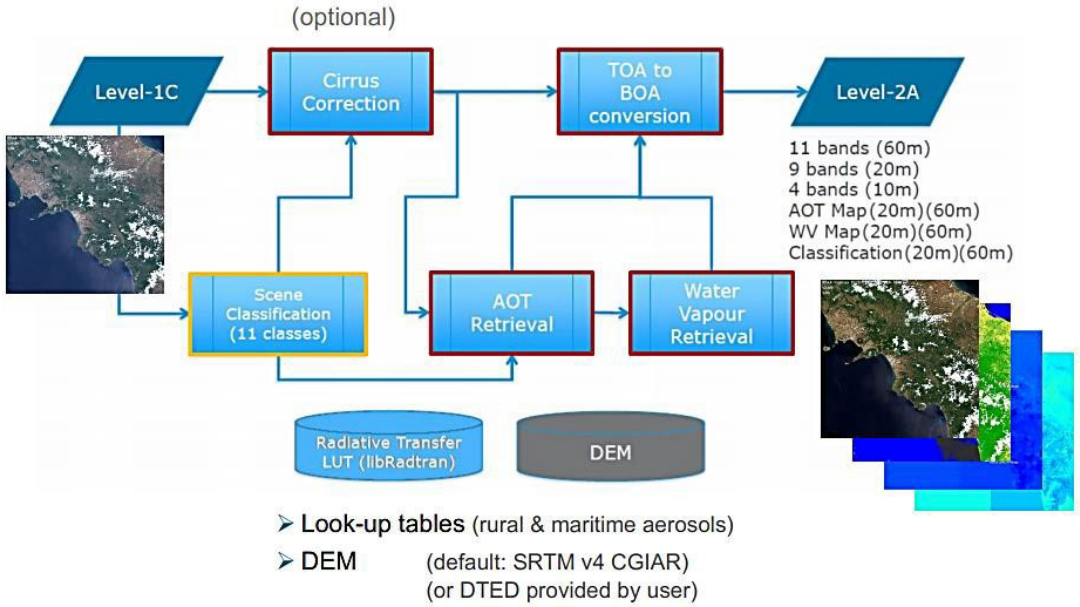
- Use an atmospheric radiative transfer model to calculate the amount of atmospheric reflectance to be removed from the TOA to get surface reflectance.
- Number of models are available but the main two are:
  - MODTRAN (Commercial)
    - http://modtran.spectral.com/
  - 6S (Open Source)
    - https://salsa.umd.edu/6spage.html

Available Software Tools

Software	RT Model	Sensors	License	URL
ATCOR-4 (Airborne)	MODTRAN	Many – see website	Commercial	https://www.rese-apps.com/software/atcor-4-airborne
ATCOR-3 (Satellite)	MODTRAN	Many – see website	Commercial	https://www.rese-apps.com/software/atcor-3-satellites
FLAASH	MODTRAN	Many – see website	Commercial	http://www.harrisgeospatial.com/docs/FLAASH.html
LEDAPS	6S	Landsat (TM, ETM+)	Partly Open Source	http://ledaps.nascom.nasa.gov
Sen2Cor	MODTRAN	Sentinel-2	Partly Open Source	http://step.esa.int/main/third-party- plugins-2/sen2cor/
ARCSI	6S	Landsat (MSS, TM, ETM+,OLI), Rapideye, SPOT5, SPOT6, SPOT7, WorldView-2, Sentinel-2	Open Source	https://github.com/remotesensinginfo/arcsi

Sen2Cor

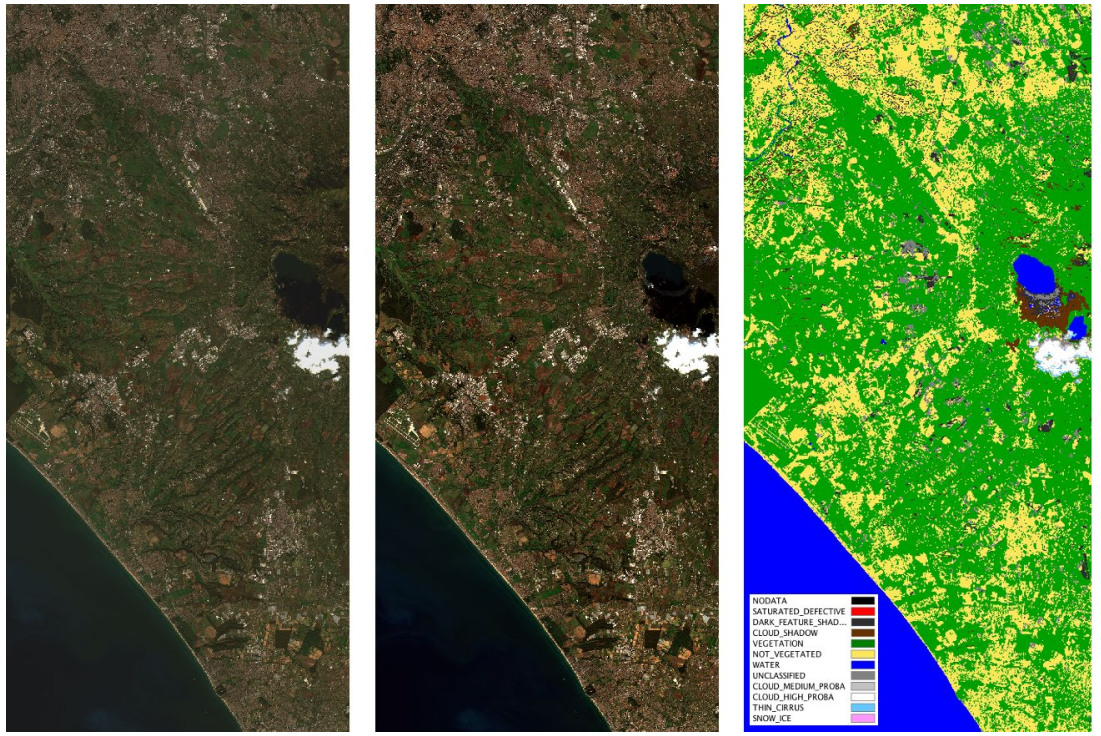
- Single image processing algorithm with orthorectified L1C granule in input
- Cloud Screening and Classification
- Atmospheric Correction over land surface (from ATCOR DLR)
- Radiative Transfer code: LibRadtran (Look-Up-Tables)
- Python application, as command line tool, plug-in of S2 toolbox, and integrated in S2 Ground Segment



Sentine-2 Level 2 Data

- Level-2A main output is an orthoimage Bottom-Of-Atmosphere (BOA) corrected reflectance product.
- Aerosol Optical Thickness (AOT) Water Vapour (WV)
- Scene Classification Map (SCM)

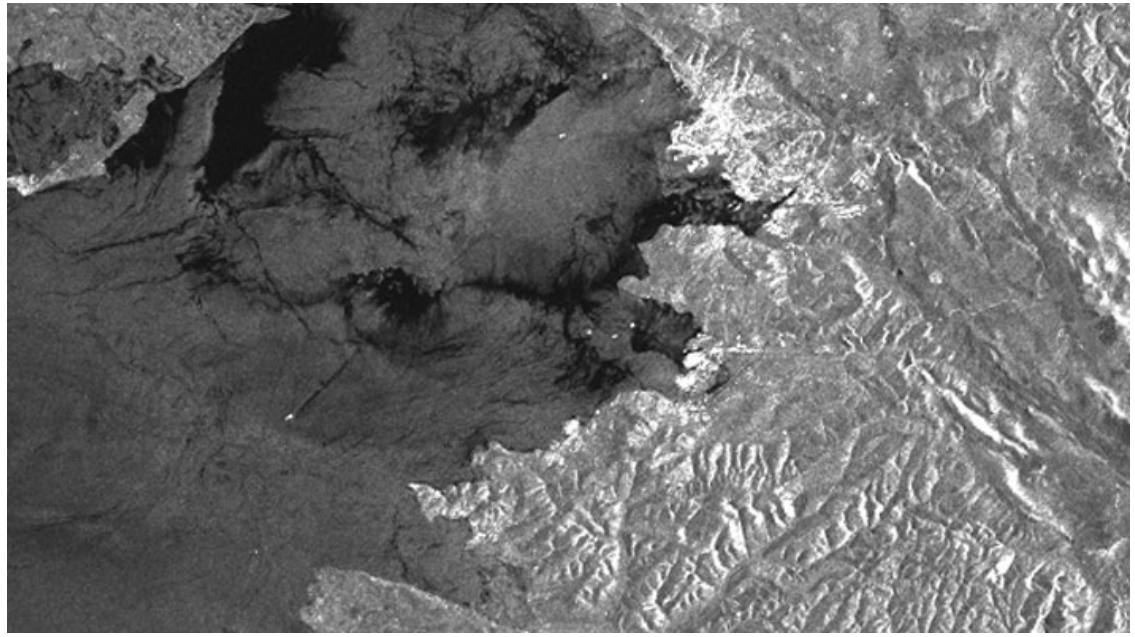
L1C L2A SCM



Radar

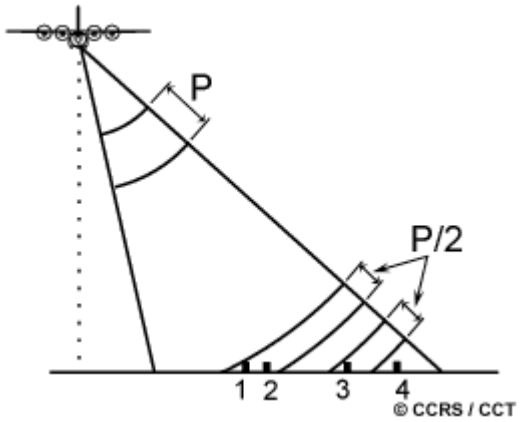
- Radar (radio detection and ranging)
- It measures the strength of the microwave signal, which is emitted by the antenna and reflecting off the remote surfaces or objects on them.
- The radar system determines the position of the observed surface based on the time of the microwave travel to the Earth and back (or the slant range distance).

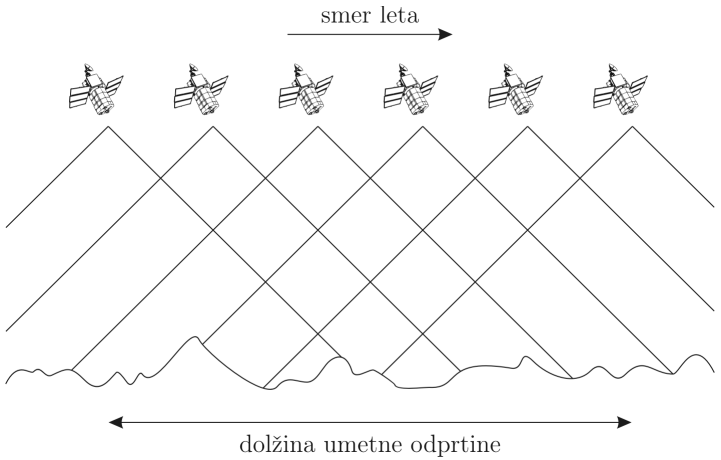
Radar imaging

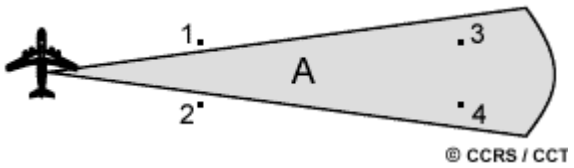


Radar system resolution

- Depends on the direction
- In the direction of looking -the length of the pulse
- In the direction of flight -antenna length
- In space the antenna can not be very long → SAR





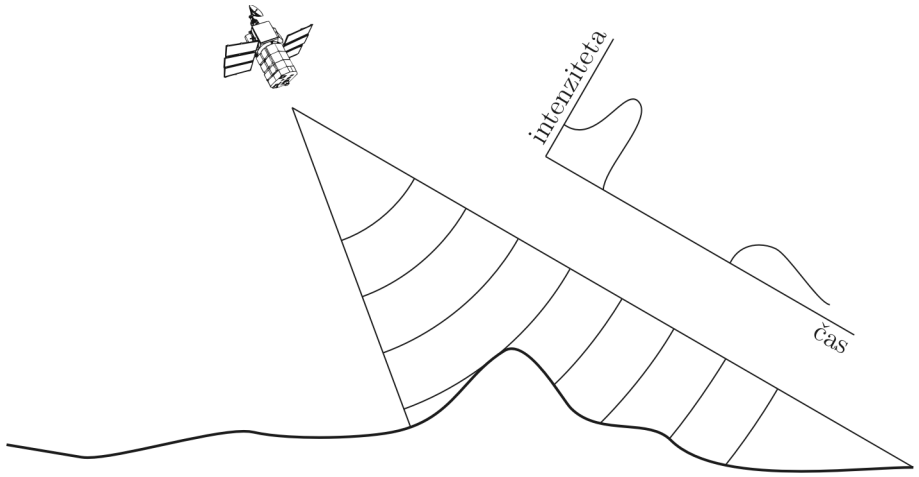


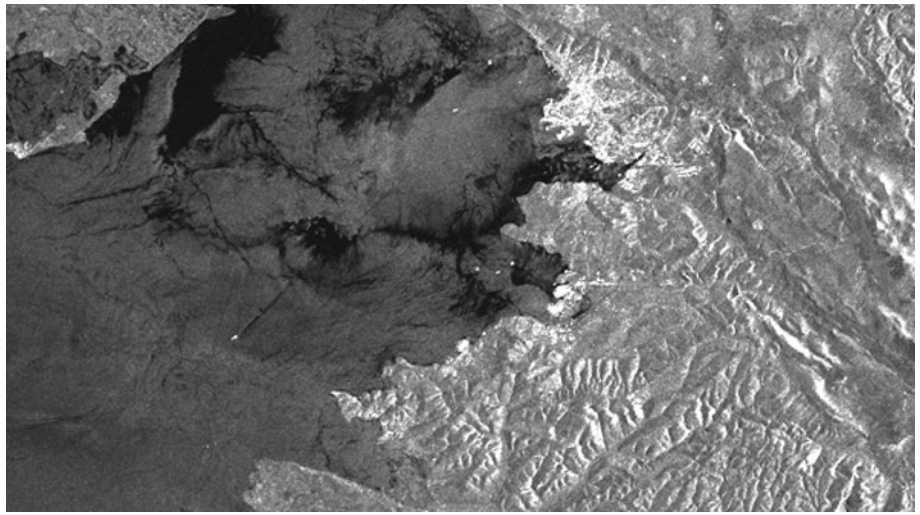
Interaction with the surface

- Incidence angle
- Terrain roughness
- Conductivity and dielectricity of the surface

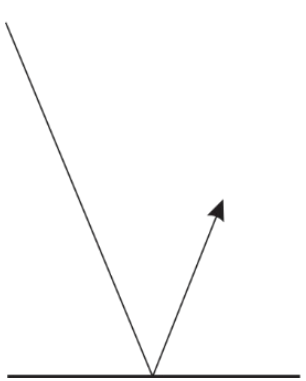
Incidence angle

- The local incidence angle is one of the most important factors that determine the intensity of the reflected wave and thus the brightness of the radar image.

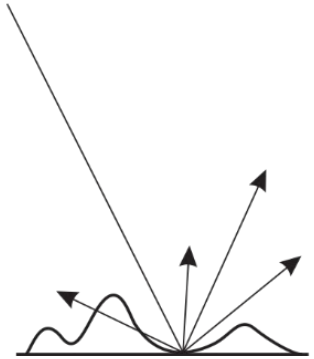




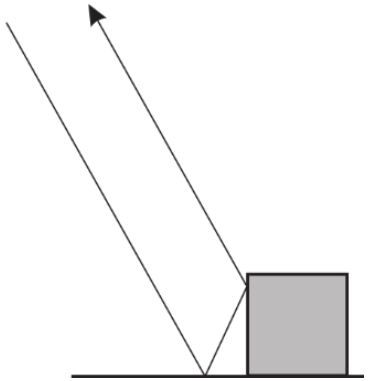
Terrain roughness



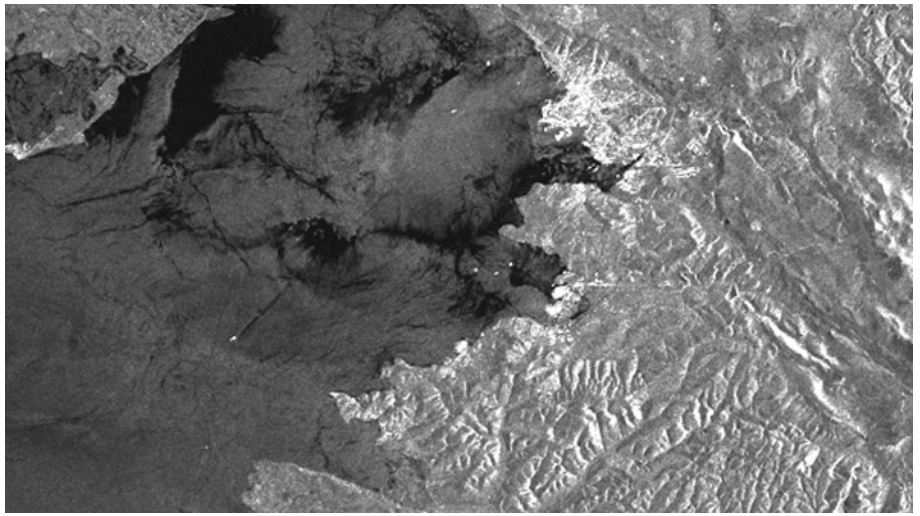
mirrored



diffuse reflection



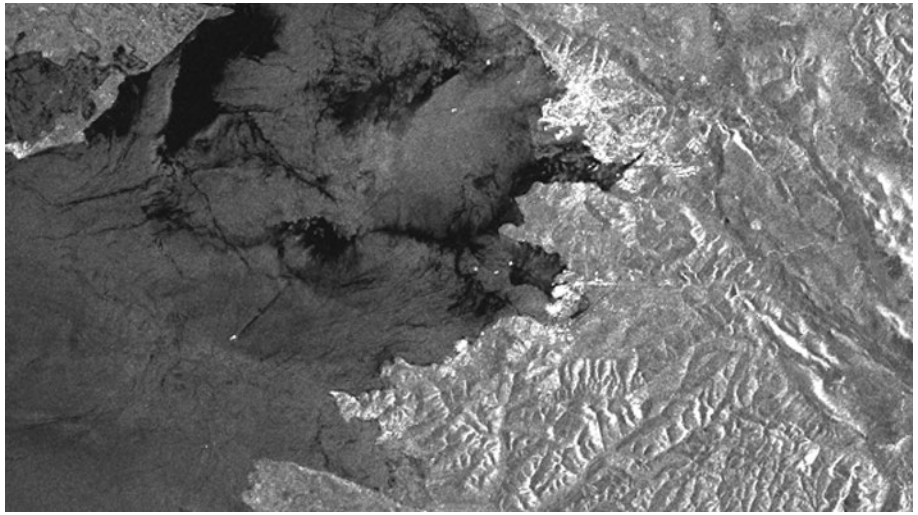
rectangular



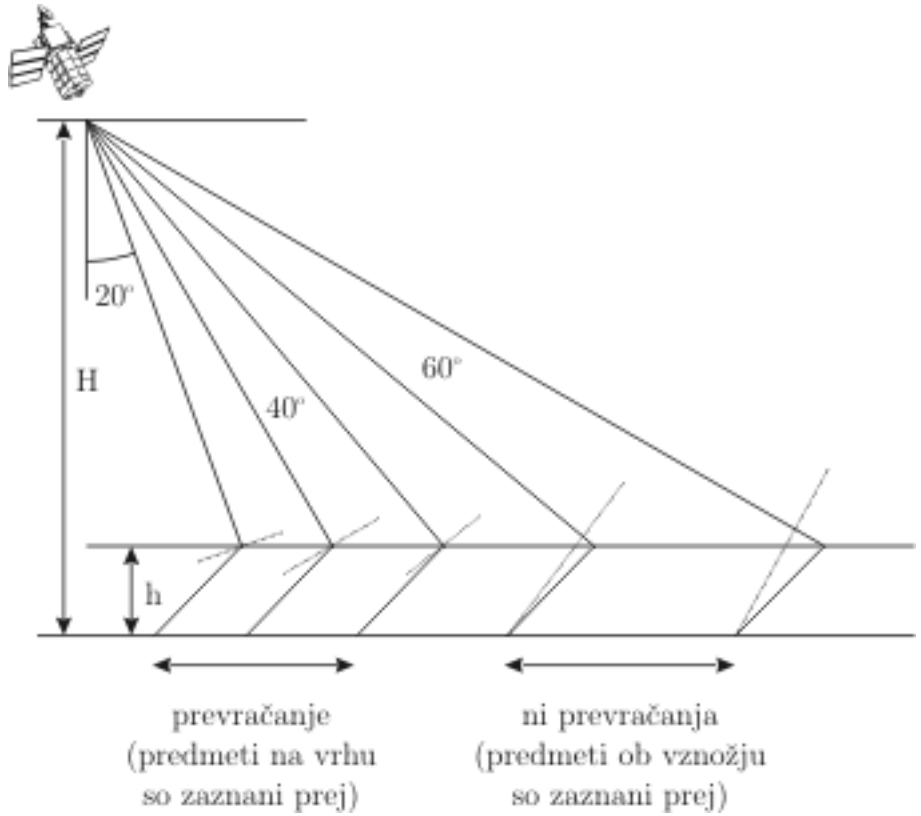
Rectangular reflector

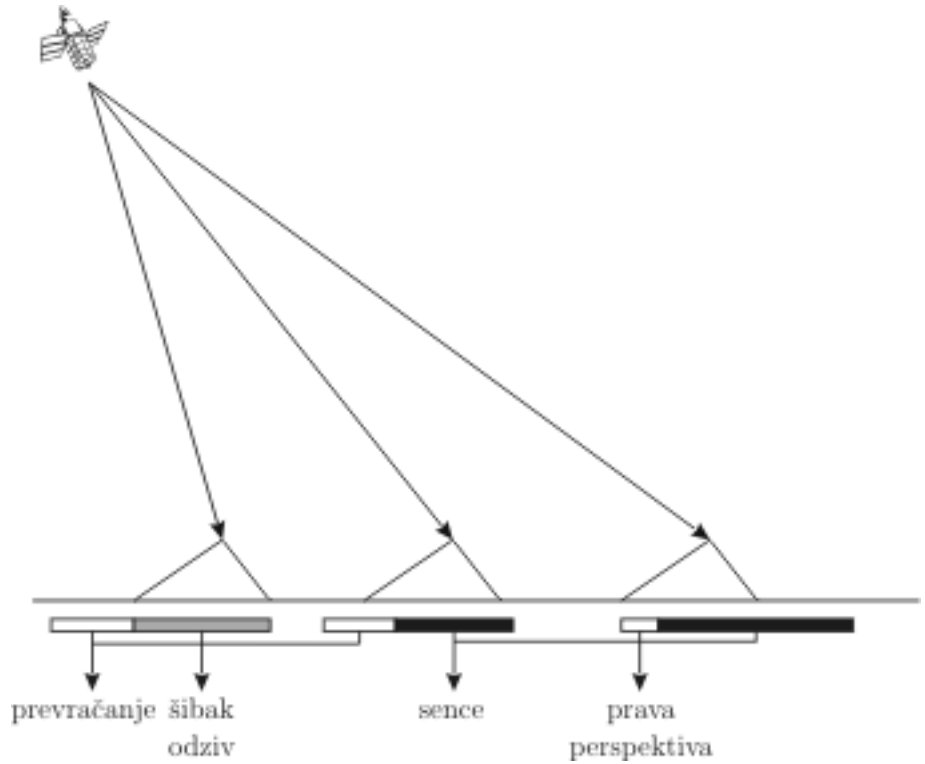
Conductivity and dielectricity of the surface

- Conductivity
  - Metal objects, such as, for example, ships, tin roofs or rail rails, have great electrical conductivity and are therefore heavily reflecting radar waves.
- Complex dielectric constant
  - Water has one of the largest dielectric constants among all natural substances, so the reflectivity of the soil and plant depends heavily on the water content.

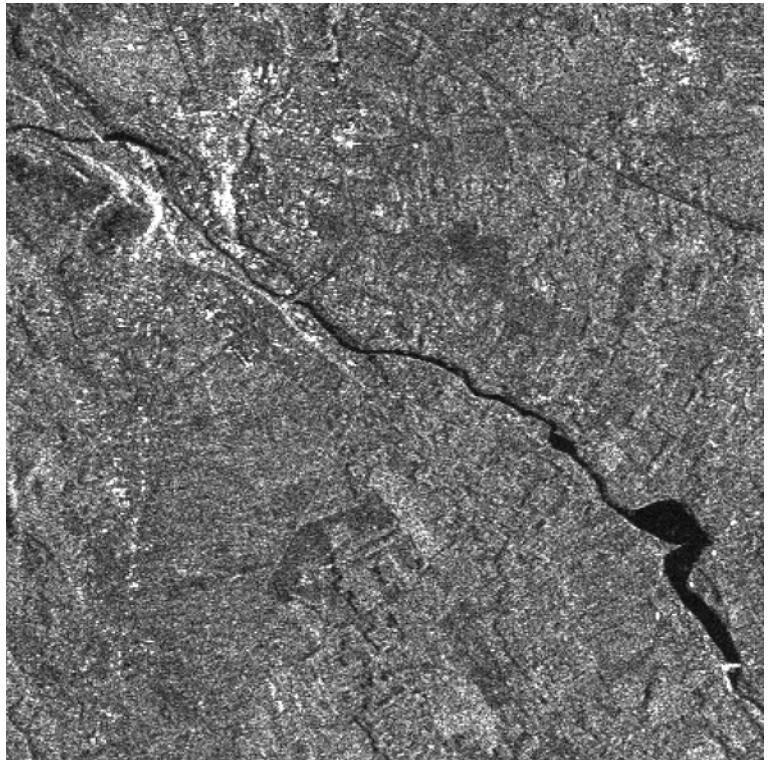


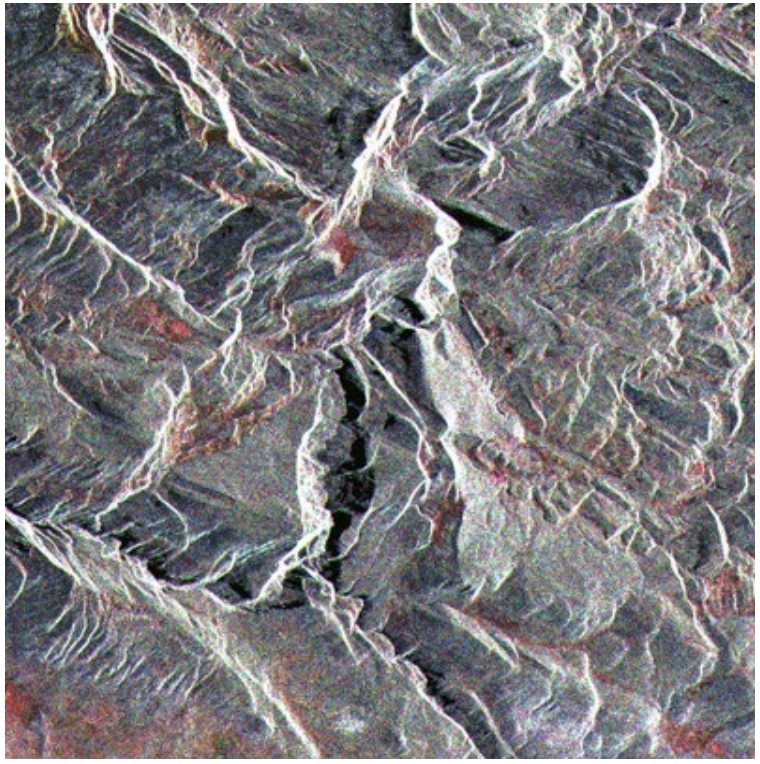
Layover and shadows



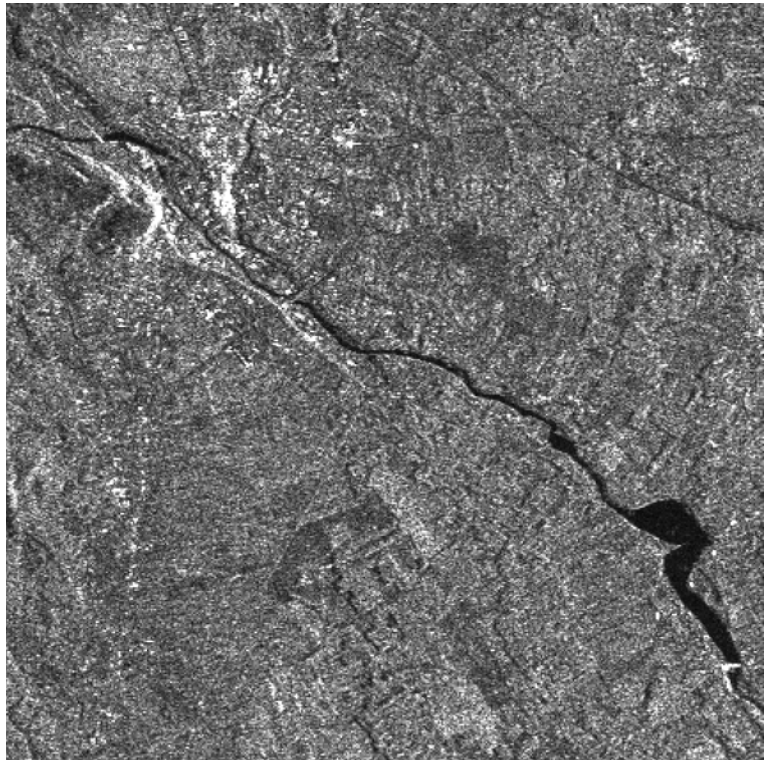


Layover and shadows





Speckle



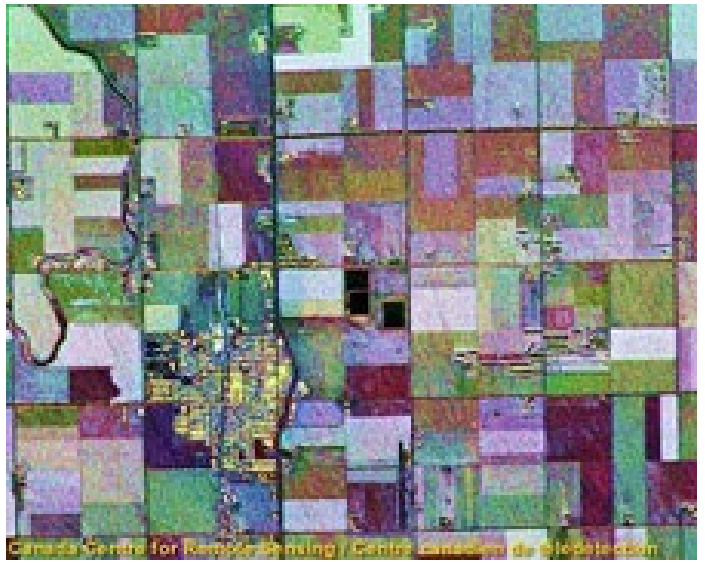
- Typical radar image noise
- Adding reflections on different objects

Polarisation

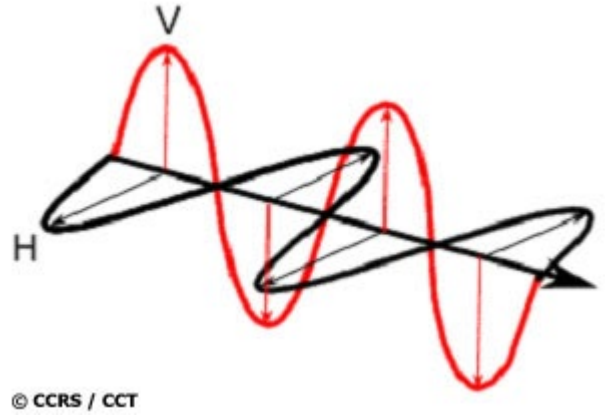
HH

VV

HV

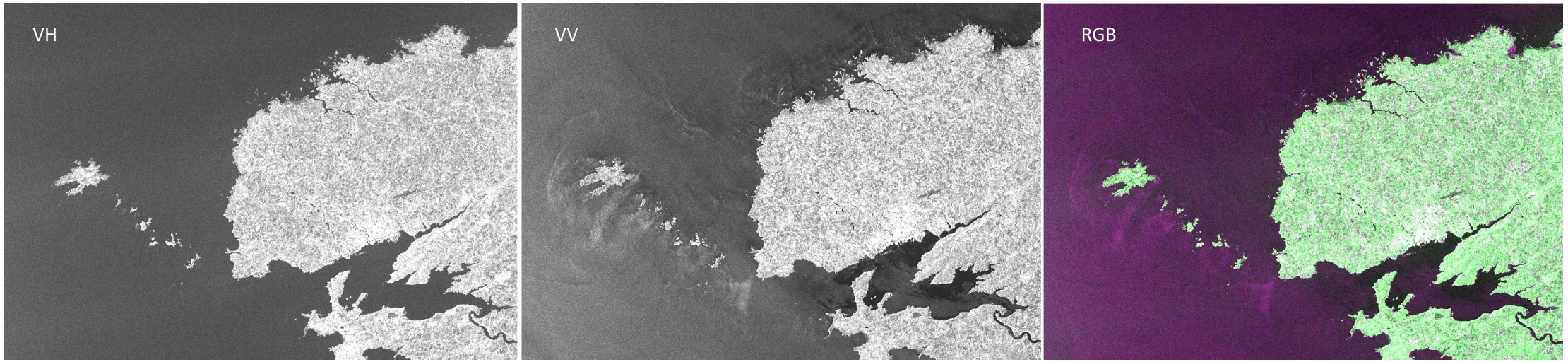


colour composite



[Radar Polarimetry (nrcan.gc.ca)]

Sentinel-1 polarimetry

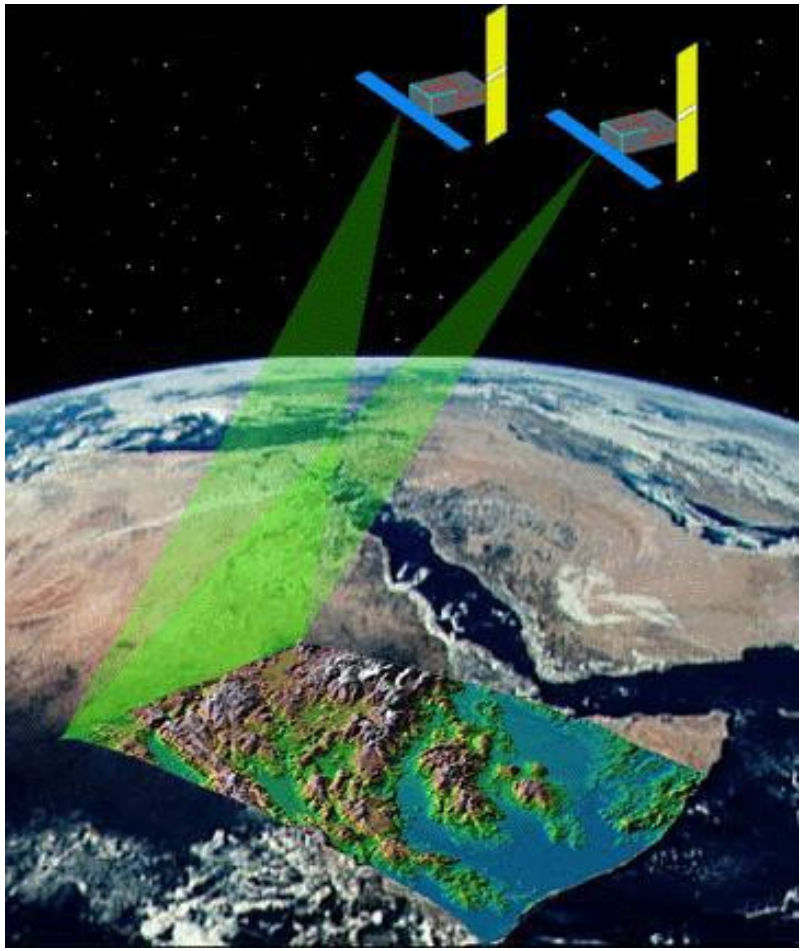


VV intensity image, VH intensity image, and RGB color composite

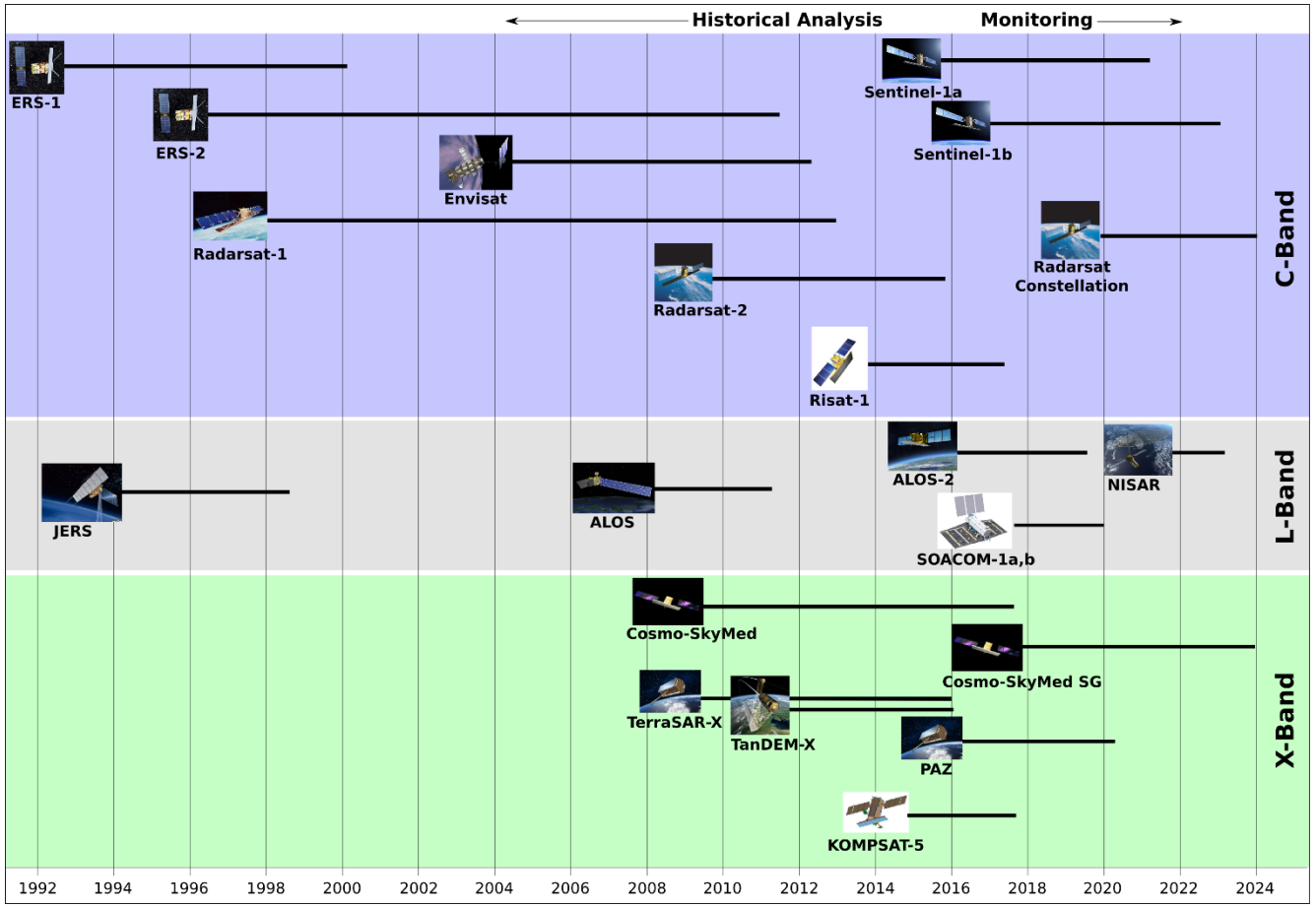
User Guides - Sentinel-1 SAR - Polarimetry - Sentinel Online - Sentinel Online (copernicus.eu)

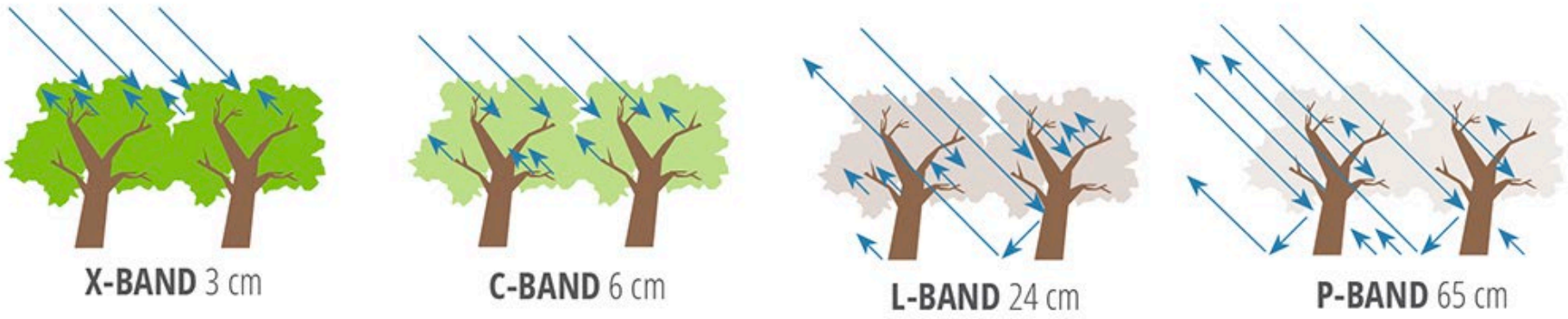
Radar interferometry

- Two images from slightly displaced orbits
- Relief model
- Displacements
- Land cover classification
- Techniques
  - InSAR
  - DInSAR
  - PS InSAR
  - SBAS InSAR
  - SqueeSAR

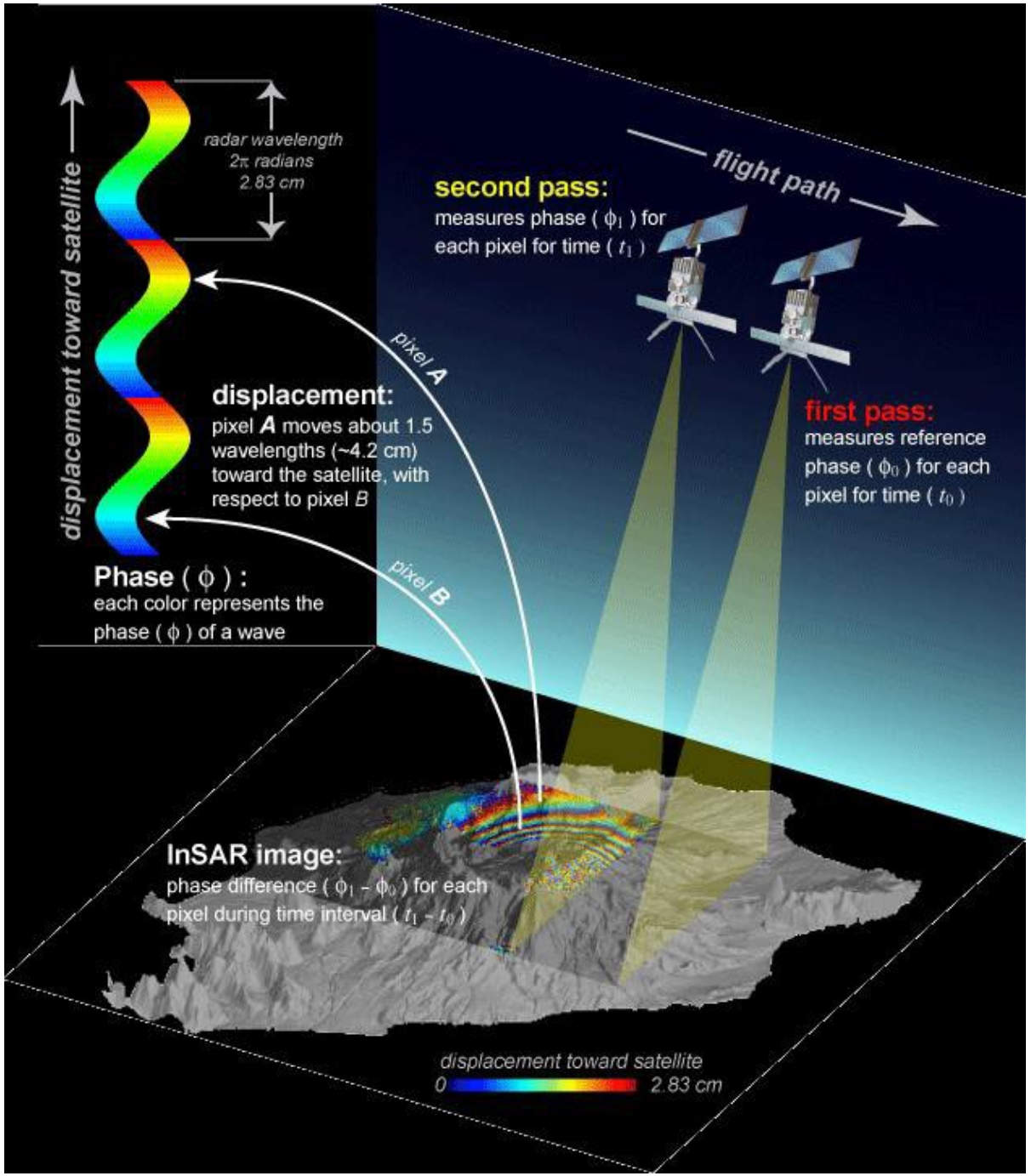


Satellites and bands





[What is Synthetic Aperture Radar? | Earthdata (nasa.gov)]

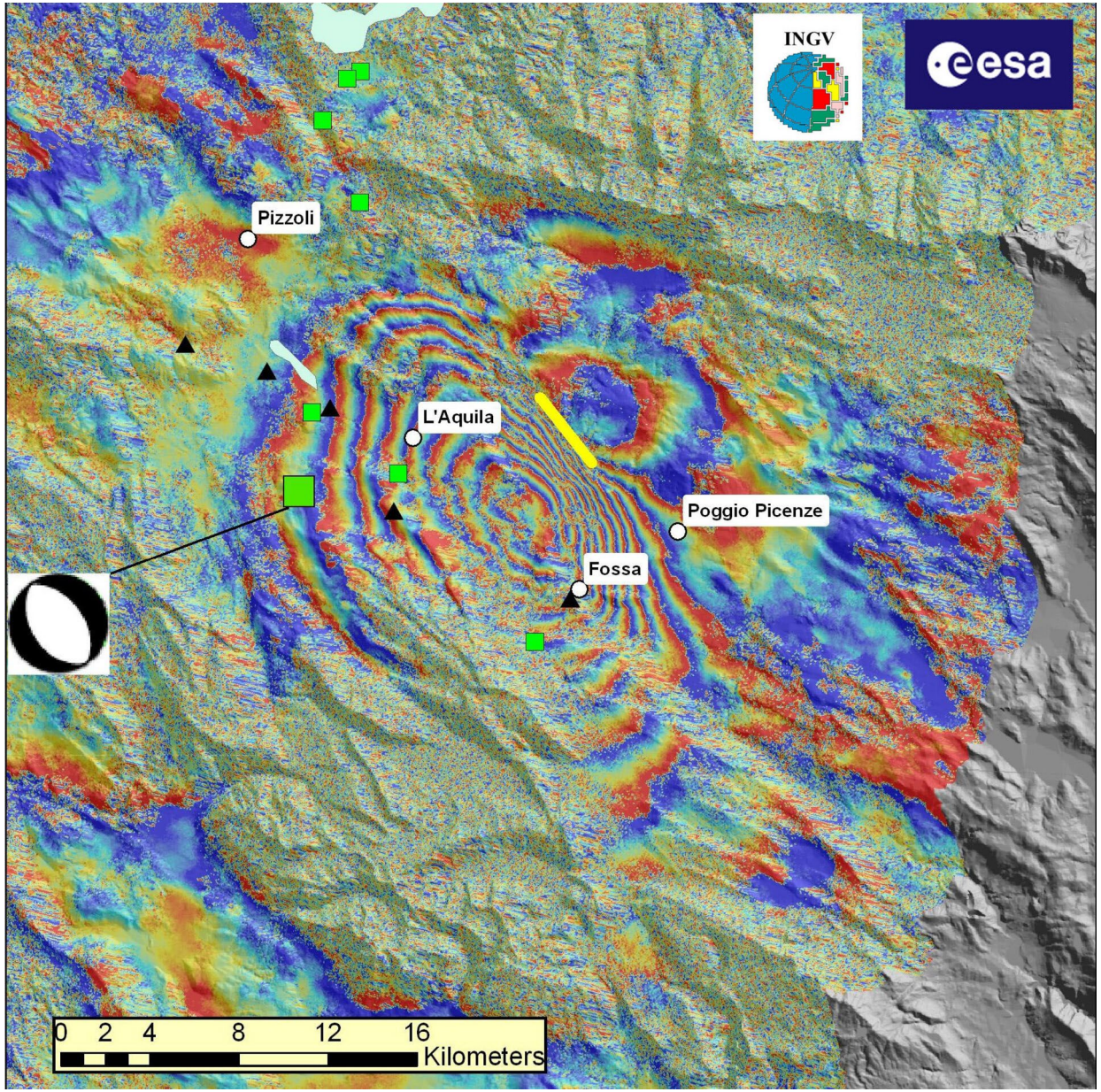


Phase differences due to

Parallax
Elevation differences
Relief Surface movements
Atmospheric phenomena

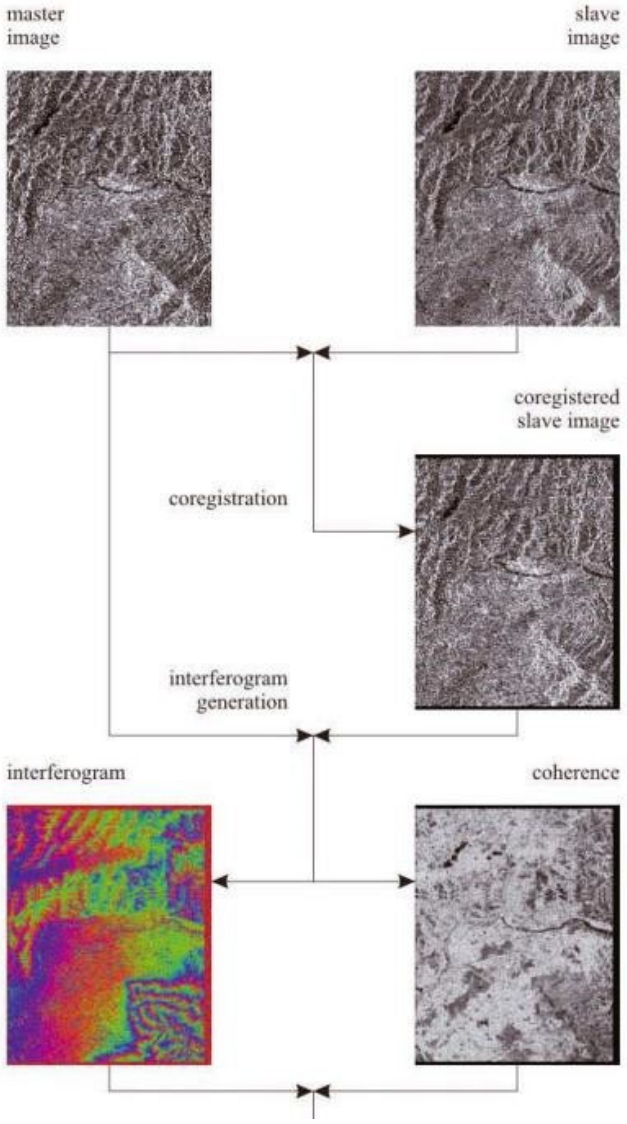
Elevations in m
Displacements in mm

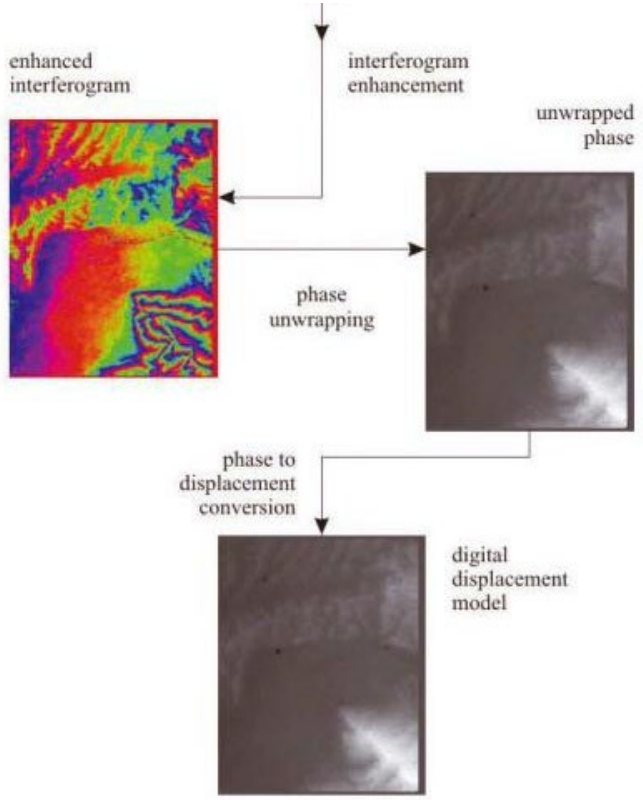
Interferogram



[ESA - L'Aquila earthquake: Envisat interferogram]

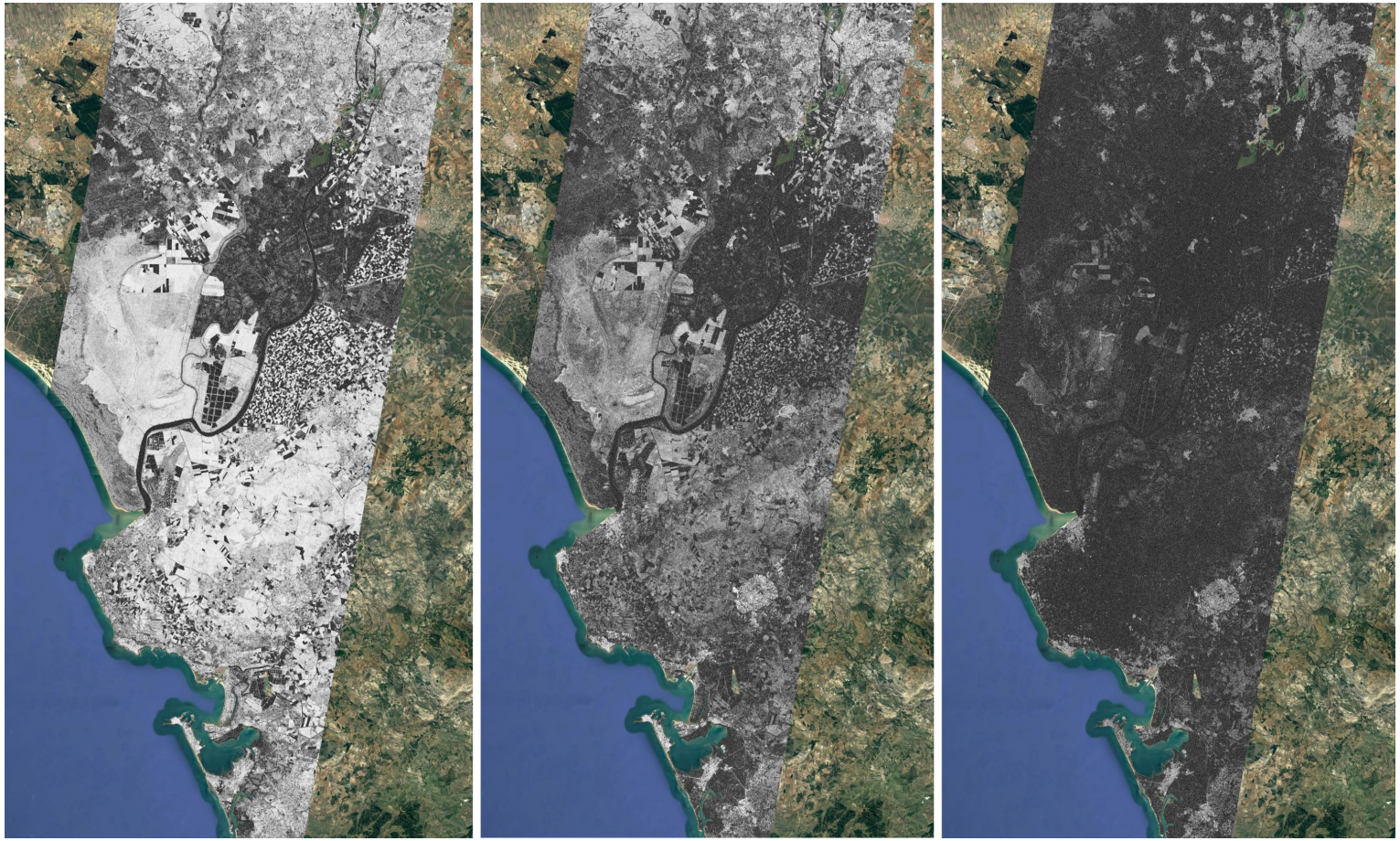
InSAR processing





Coherence for vegetation mapping

6 12 18 days



Interferometric coherence evolution considering consecutive interferometric pairs

[Home | SInCohMap]

Copernicus and Sentinel satellites


S1A/B: Radar observations


S2A/B: High-resolution optical observation


S3A/B: resolution imaging and altimetry


S4A/B: Observation of the atmosphere from the geostationary orbit

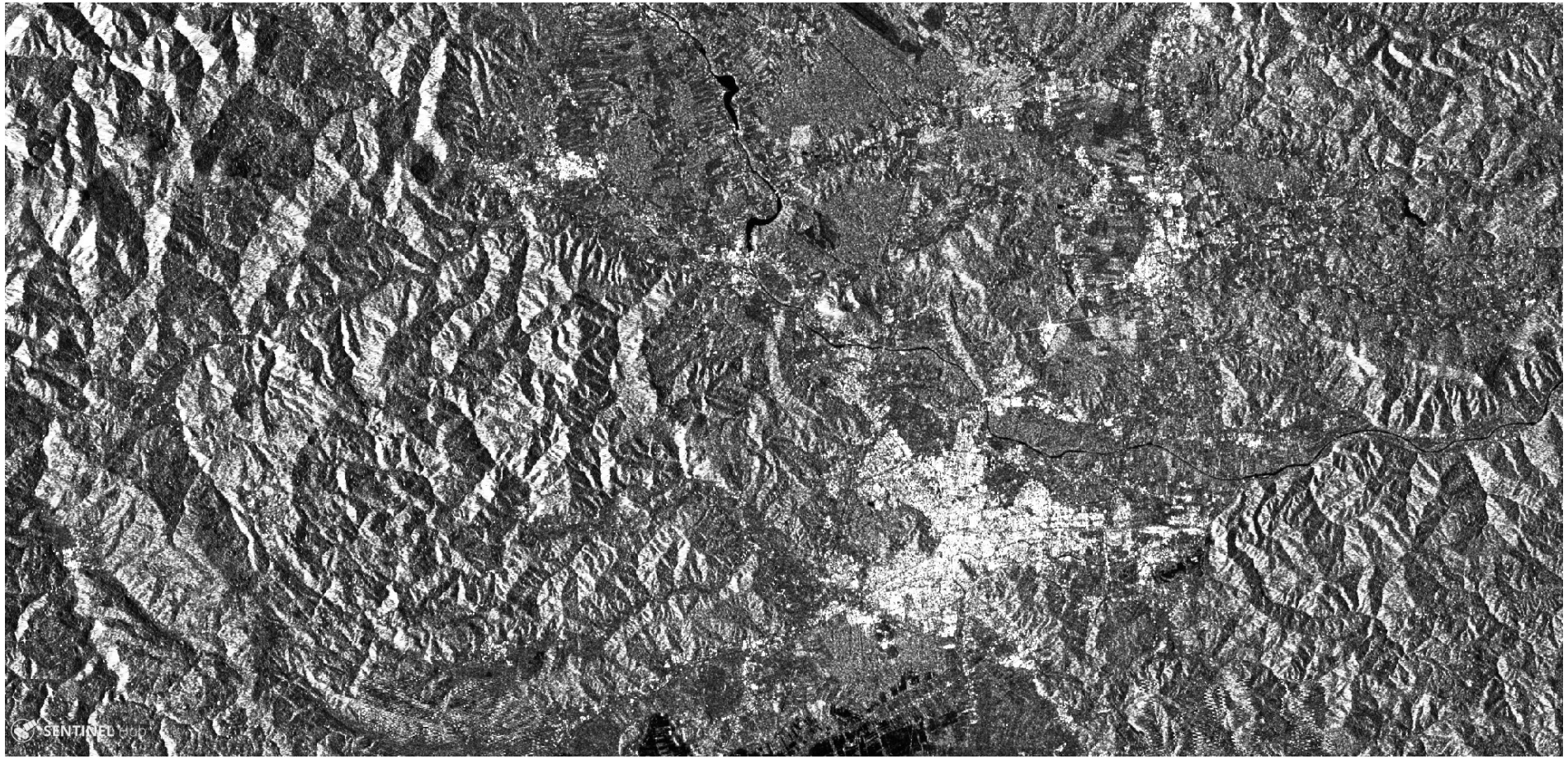

S5P: Observation of the atmosphere from low orbit - predecessor


S5A/B/C: Observation of the atmosphere from low orbit

Sentinel-1

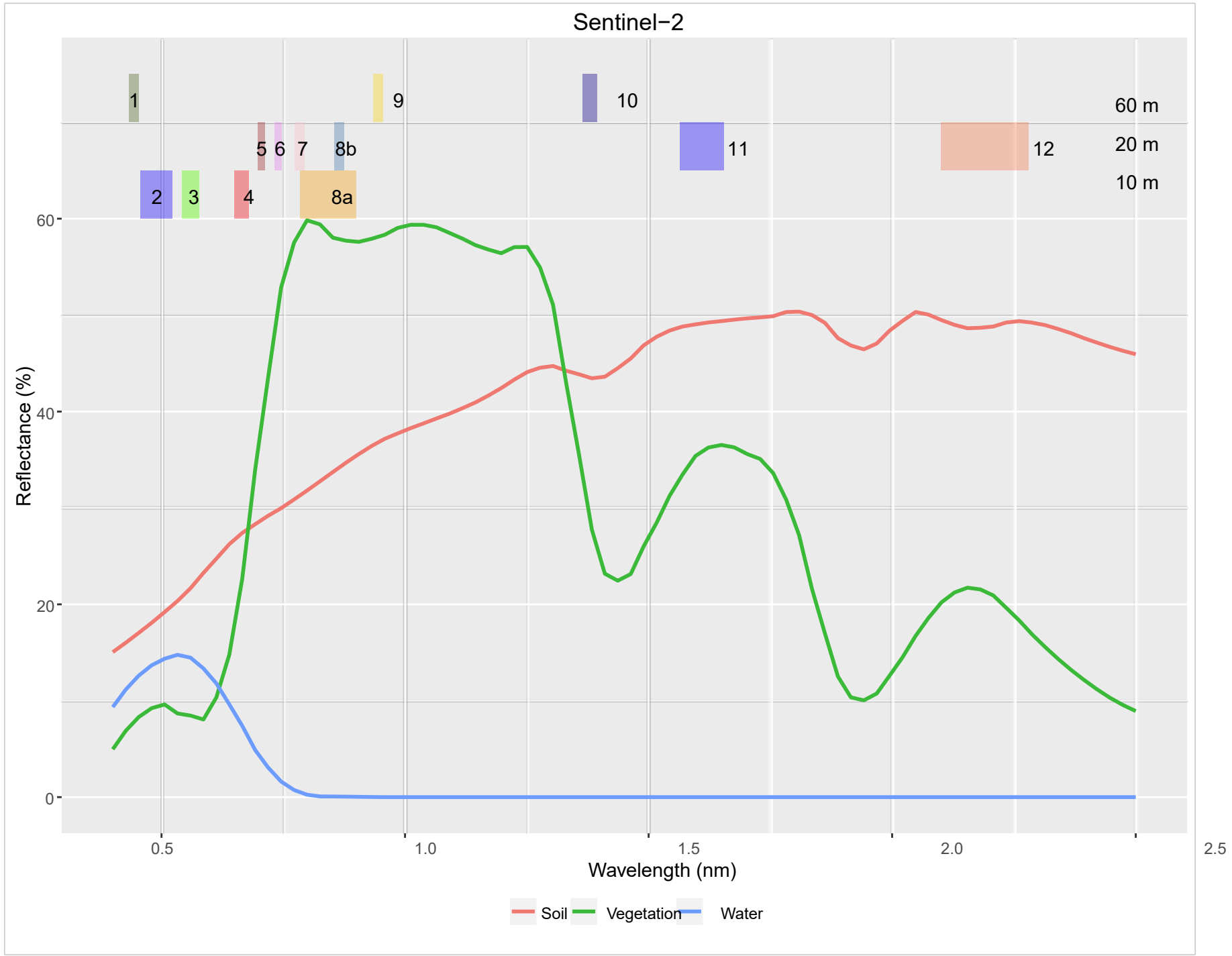
- Sentinel-1A – 2014
- Sentinel-1B – 2016 – not working since 23.12.2021
- Observation of land, forests, water, soil and agriculture
- Rapid mapping in case of natural disasters
- Shipping traffic
- Watching ice at sea
- C-SAR (C-band Synthetic Aperture Radar)
- Resolution:
  - 80 km – 5 x 5 m
  - 250 km – 5 x 20 m
  - 400 km – 25 x 100 m

Sentinel-1



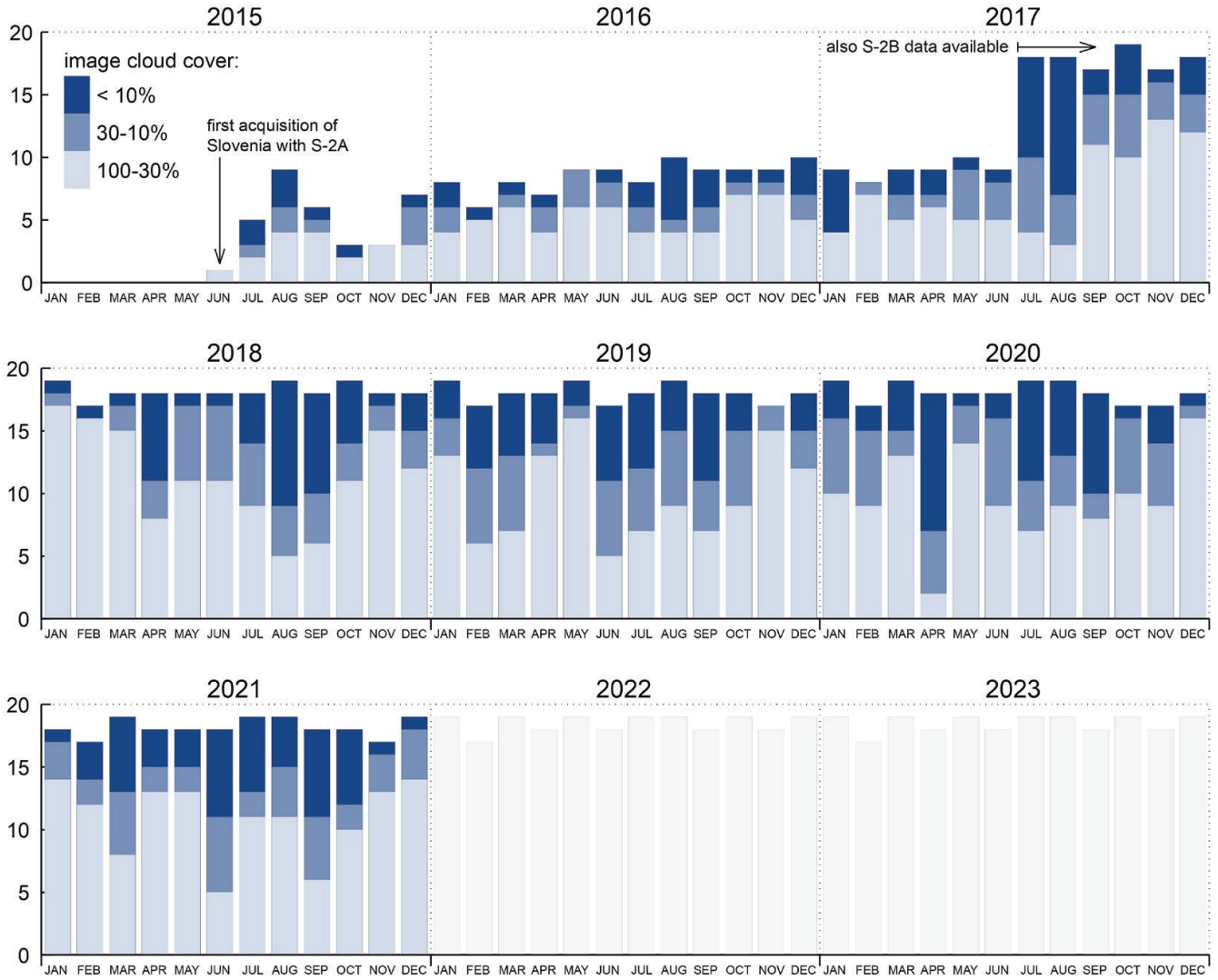
Sentinel-2

- Sentinel-2A – 2015
- Sentinel-2B – 2017
- Observation of land, vegetation, soil, water surfaces, coastal bands
- Land cover detection and changes
- Rapid mapping in case of natural disasters
- Climate change observation
- Orbit repeatability 10 days, 5 days with two satellites
- MSI (Multispectral Imager)
- Resolution
  - 290 km - 10 m, 20 m in 60 m


Sentinel−2
1
9
10
5 6 7 8b
11
12
60 m
20 m
10 m
2 3 4 8a
60
40
20
0
Reflectance (%)
0.5
1.0
1.5
2.0
2.5
Wavelength (nm)
Soil
Vegetation
Water

Sentinel-2

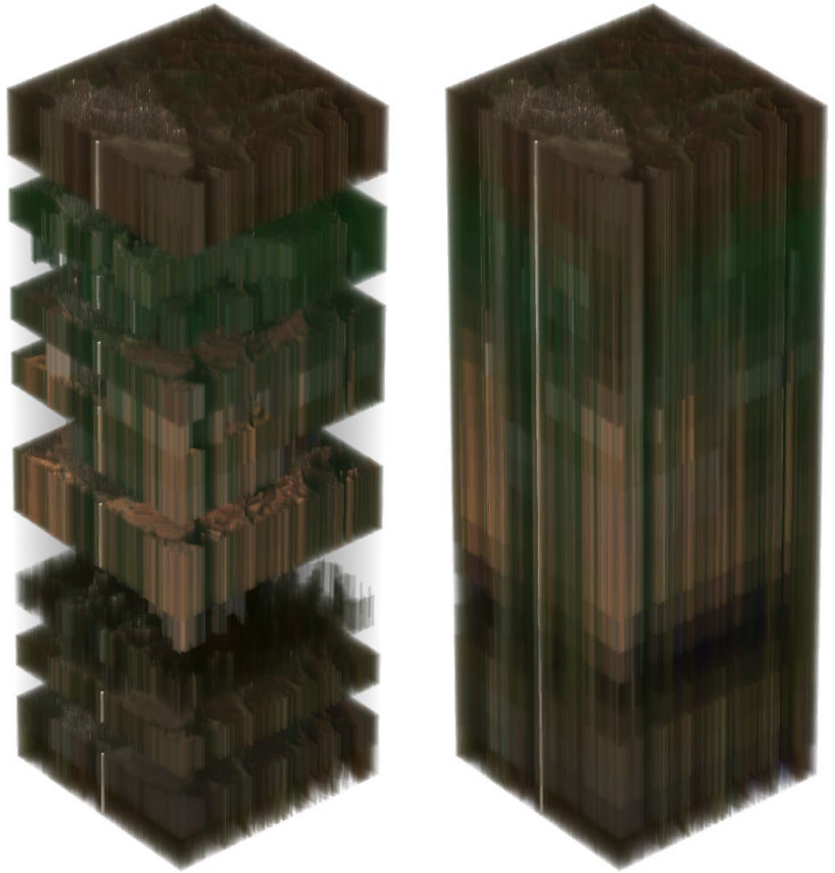
Sentinel-2 archive Slovenia



[Paper: Six years of Sentinel-2 archive of Slovenia | Geodetski vestnik (geodetski-vestnik.com)]

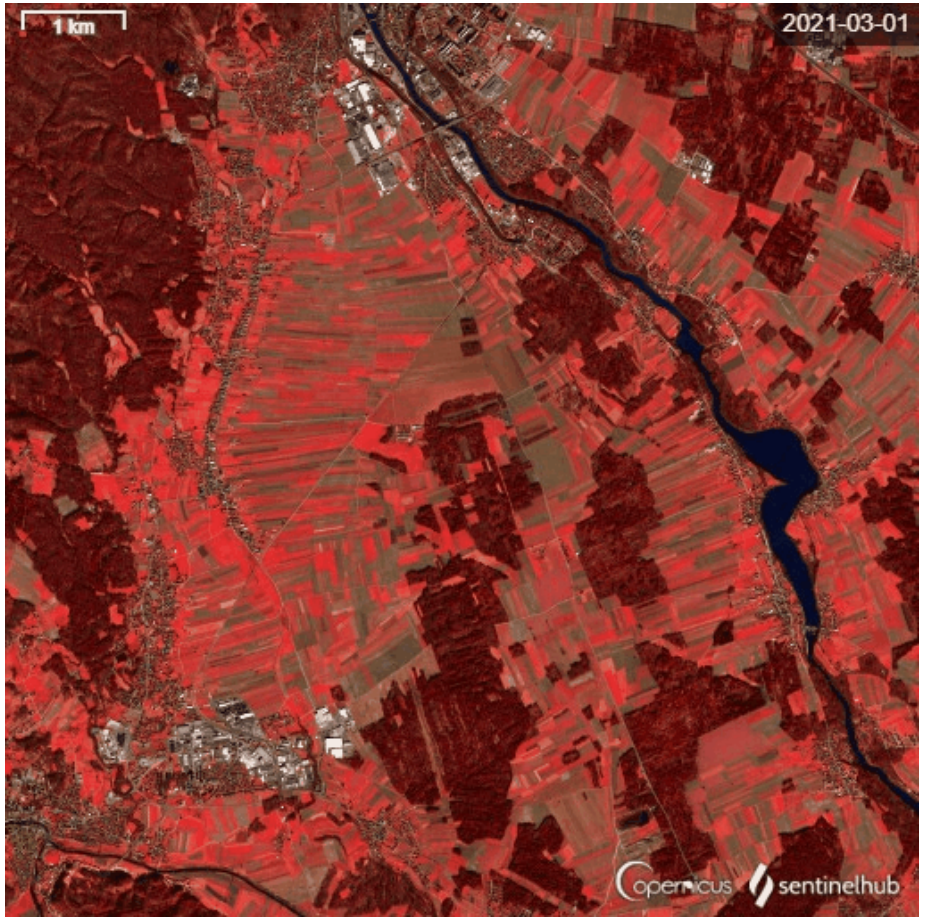
Time series

- Set of satellite images taken over the same area of interest at different times
- Same or multiple sensors
- Time Series:
  - understanding how Earth is changing
  - determining the causes of these changes
  - predicting future changes
  - discriminating features



Land Cover Classification with eo-learn: Part 2 | by Matic Lubej | Sentinel Hub Blog | Medium

Time series – Sentinel-2

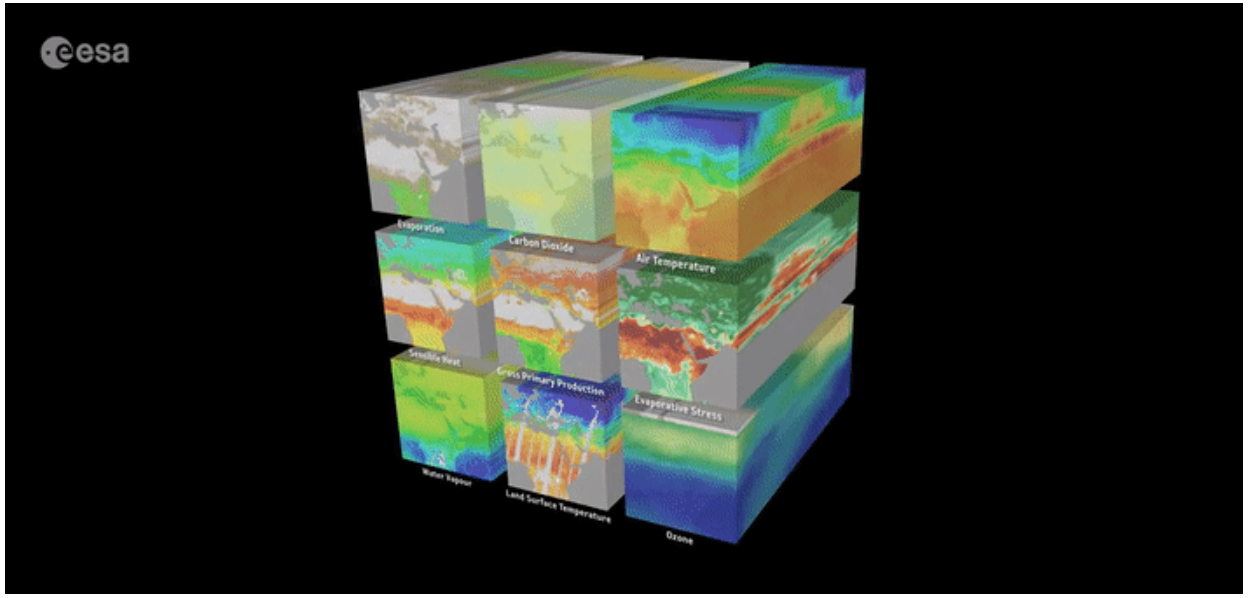


8, 4, 3

NDVI

Analysis Ready Data (ARD)

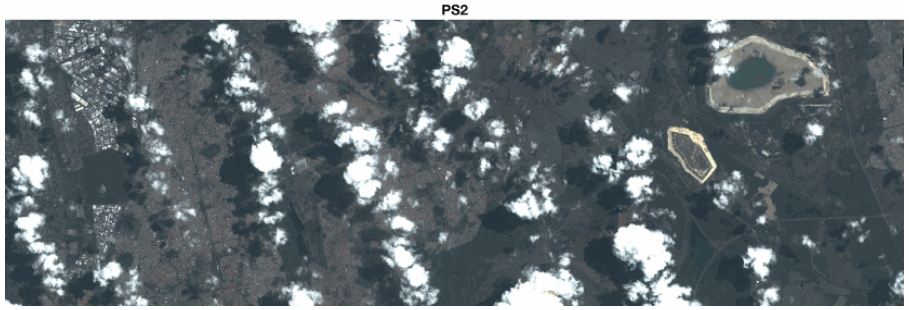
- CEOS – Committee on Earth Observation Satellites:
  - Analysis Ready Data are satellite data that have been processed to a minimum set of requirements and organized into a form that allows immediate analysis with a minimum of additional user effort and interoperability both through time and with other datasets.
- Data which is ready to use.

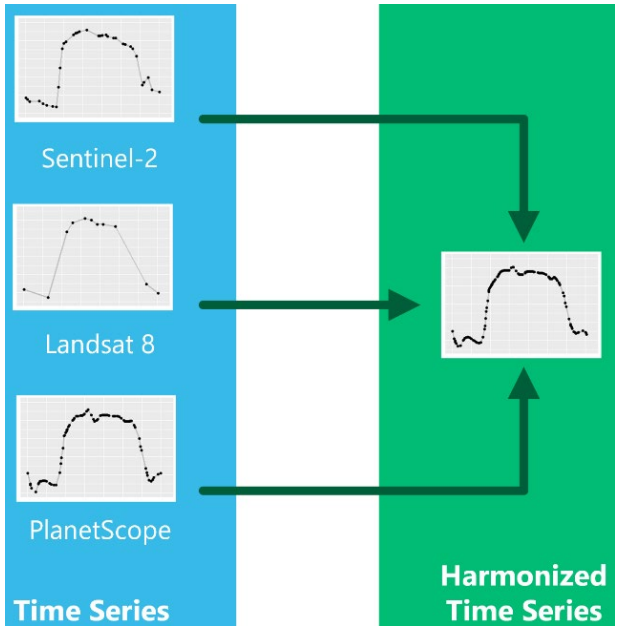


CEOS Analysis Ready Data
Analysis Ready Data Defined. Cloud Native Geoprocessing Part 2 | by Chris Holmes | Planet Stories | Medium
Harness the power of Sentinel Hub, xcube, EOxHub, GeoDB and more in Euro Data Cube | by Dorothy Rono | Euro Data Cube | Medium

Analysis Ready Data (ARD)

- ARD processing may differ between applications
- Image clipping
- Masking – Usable/Unusable Data Masks
- Atmospheric Correction
- Pixel Alignment
- Sensor Alignment

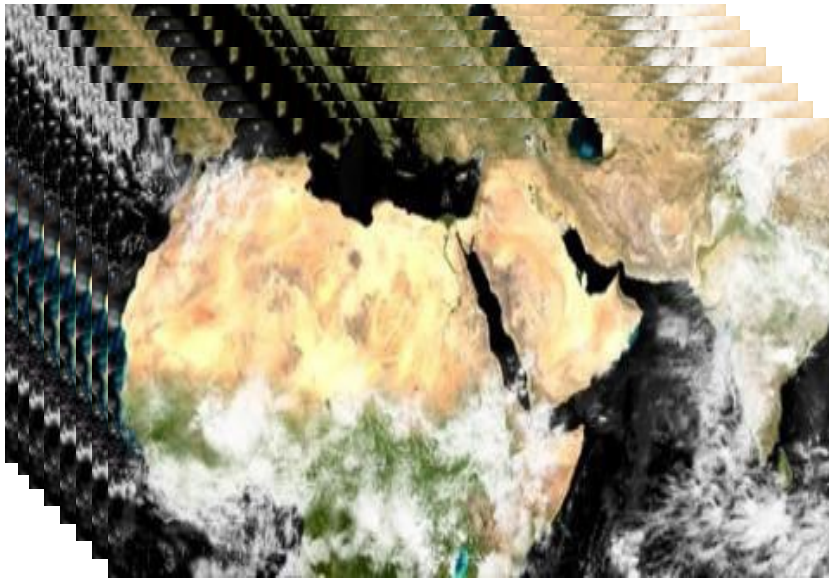




[Analysis Ready Data Defined. Cloud Native Geoprocessing Part 2 | by Chris Holmes | Planet Stories | Medium]

Compositing

- An image where the holes associated with cloud and other invalid pixels are filled with data from another images.
- Weekly, Monthly, Yearly …
- Compositing produces images with added value, but can mask important information.

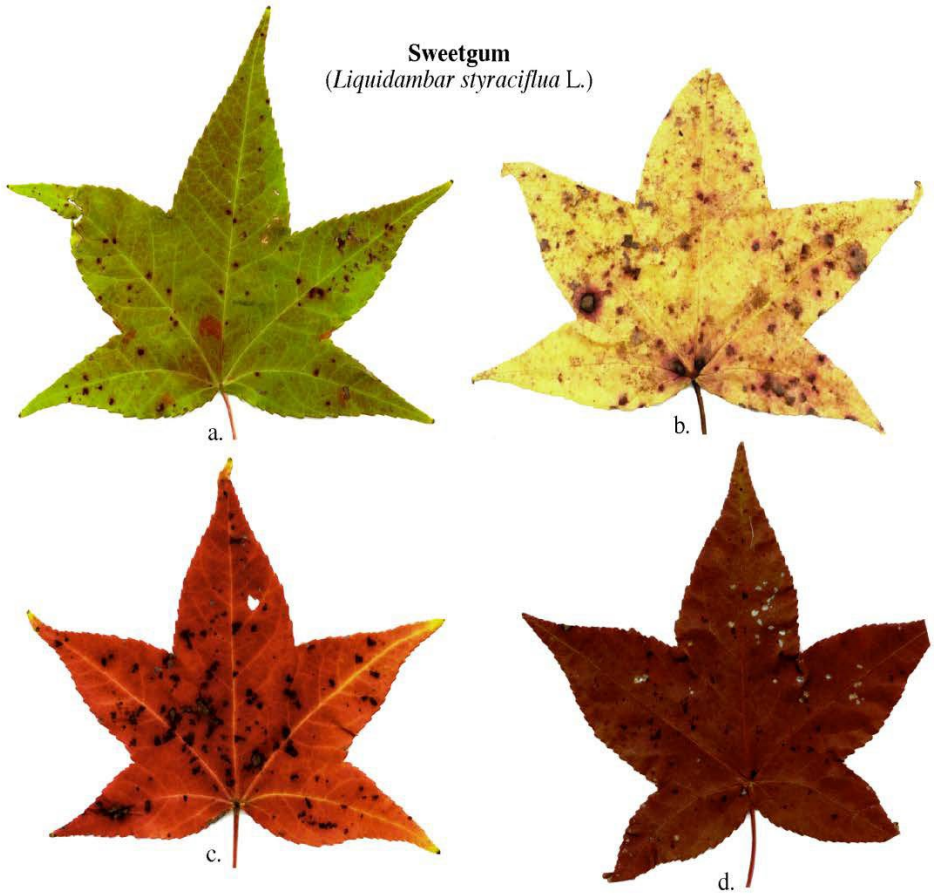


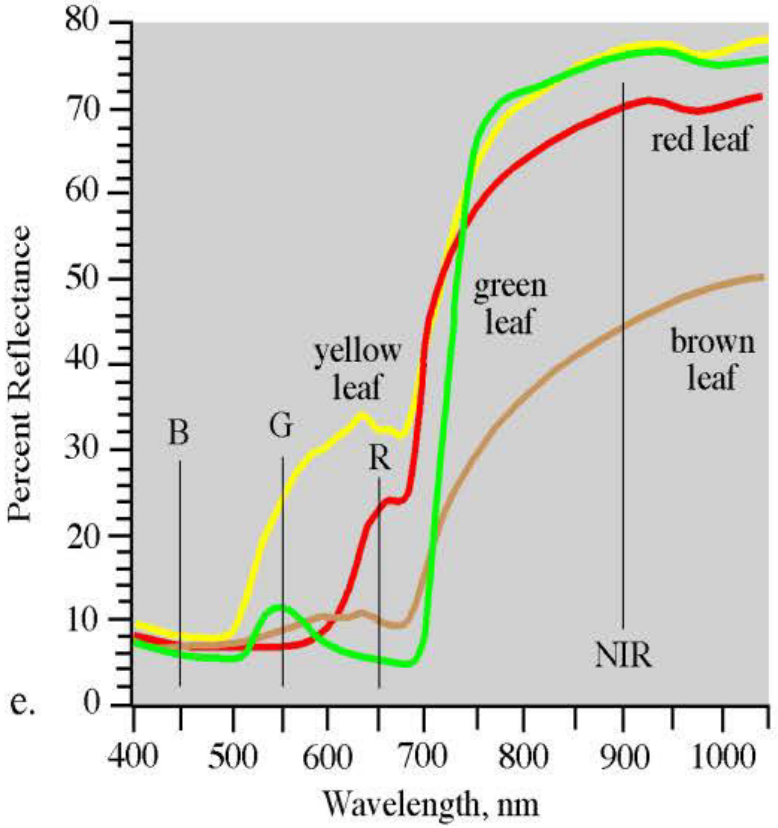
Temporal development of vegetation

- a - beginning of season
- b - end of season
- c - length of season
- d - base value
- e - middle of season
- f - maximum value
- g - amplitude

[Welcome to the TIMESAT pages! (lu.se)]

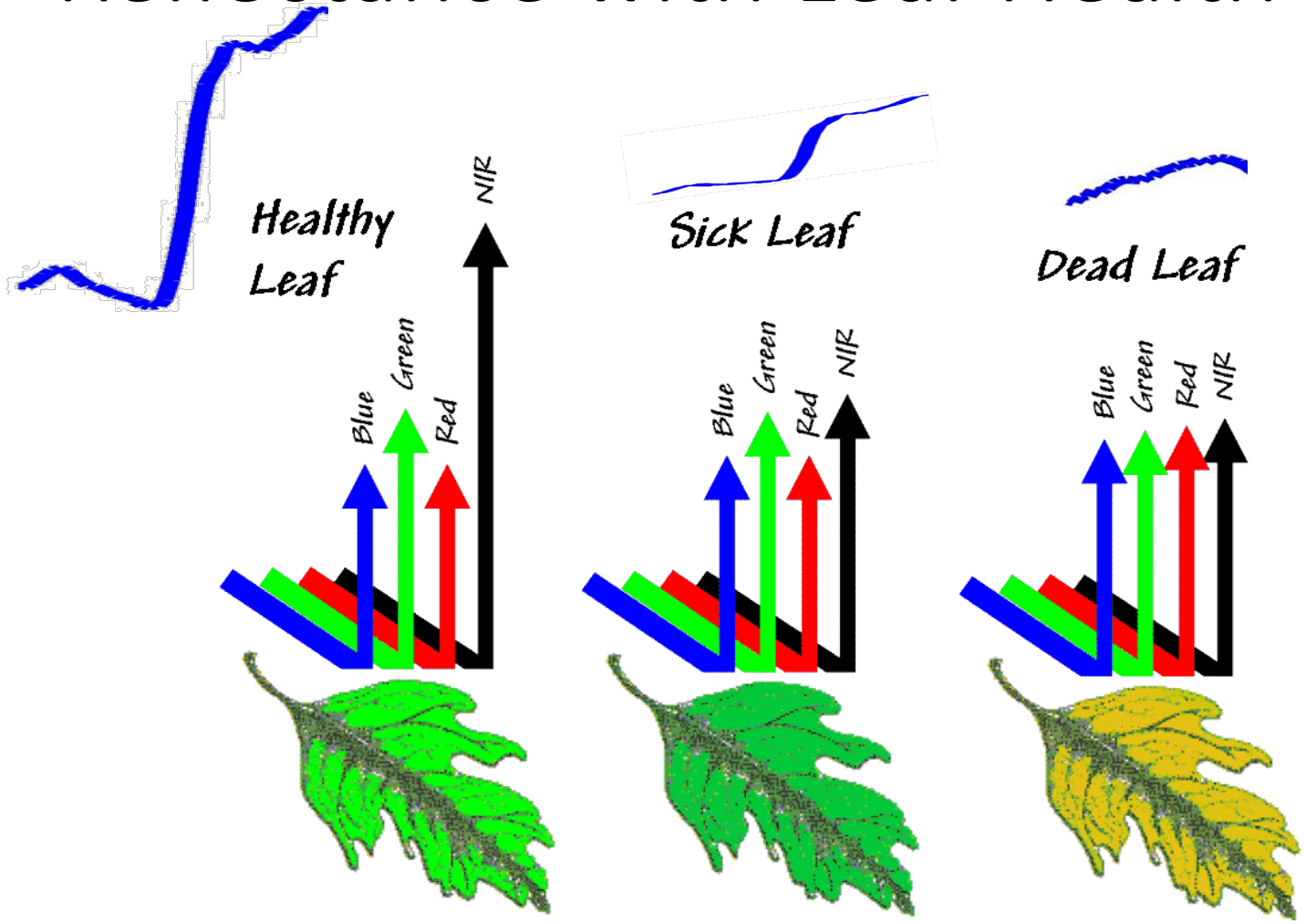
Sweetgum Leaves (Liquidambar styraciflua L.)



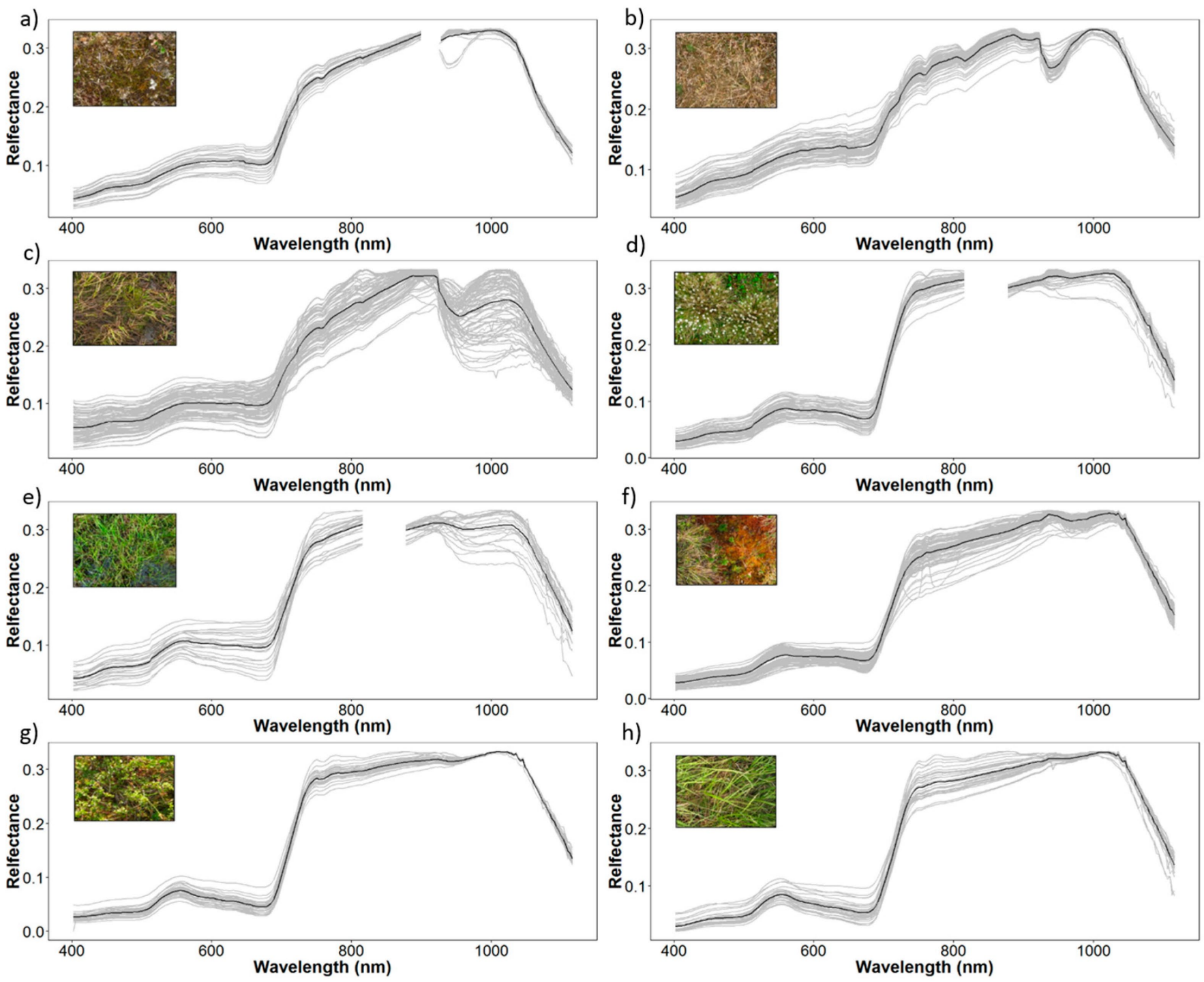


[PowerPoint Presentation (ucdavis.edu)]

Reflectance with Leaf Health

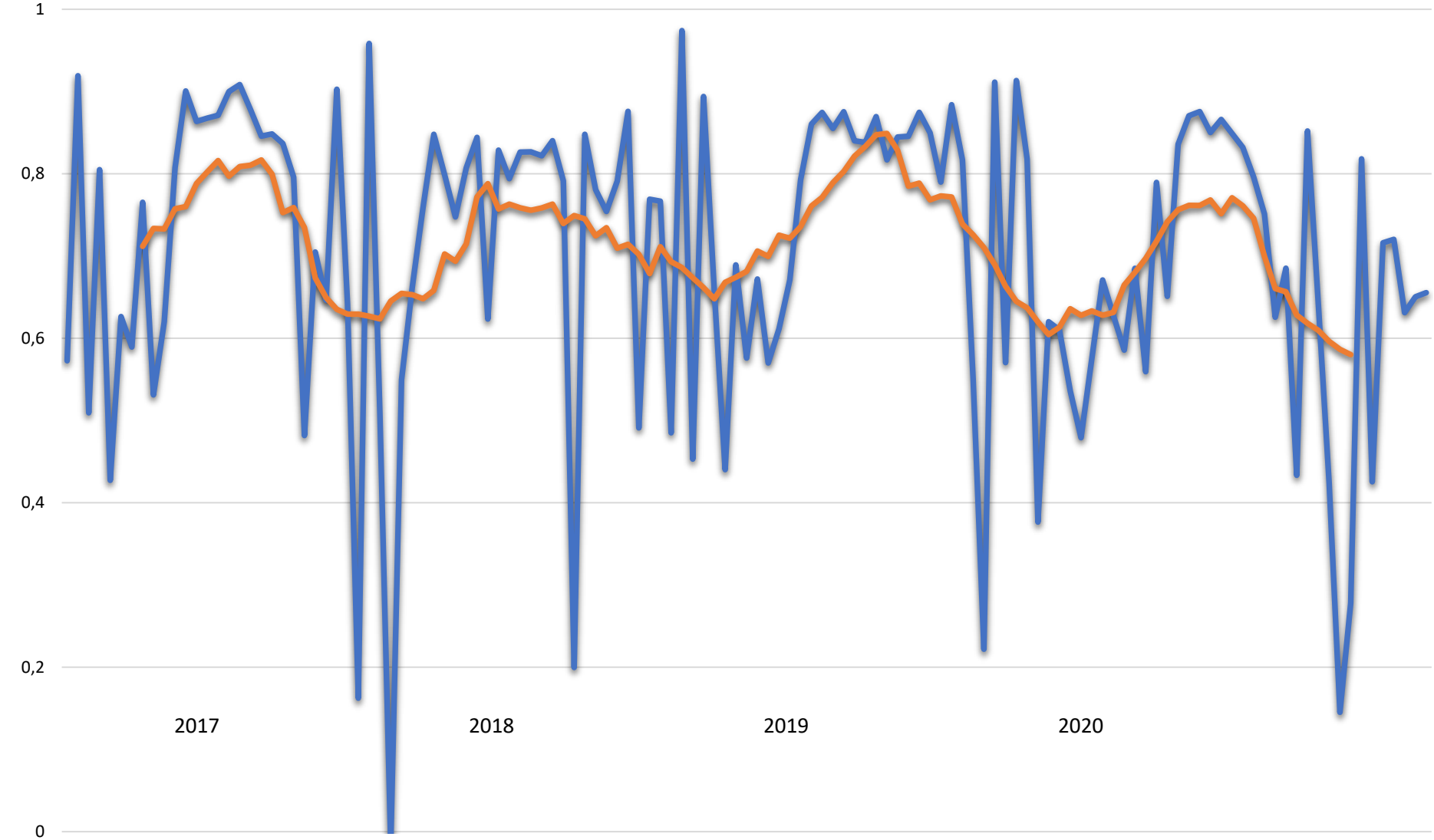


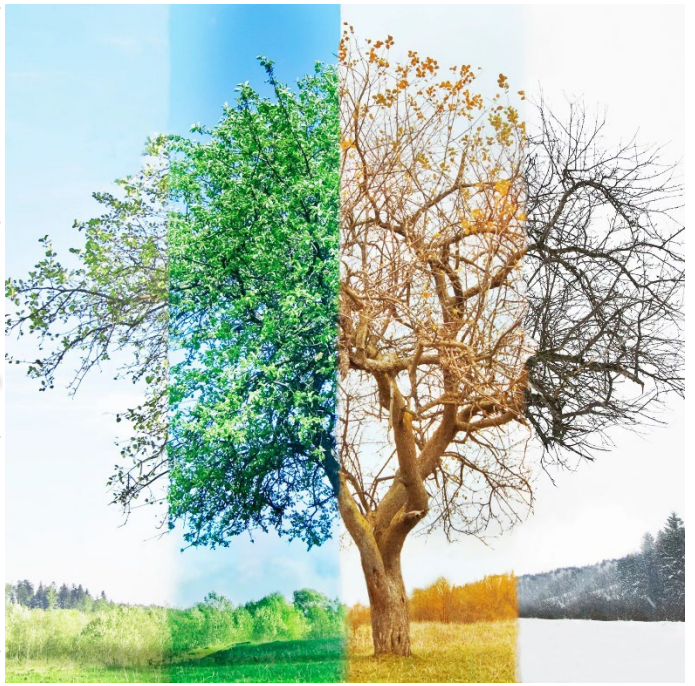
[PowerPoint Presentation (ucdavis.edu)]



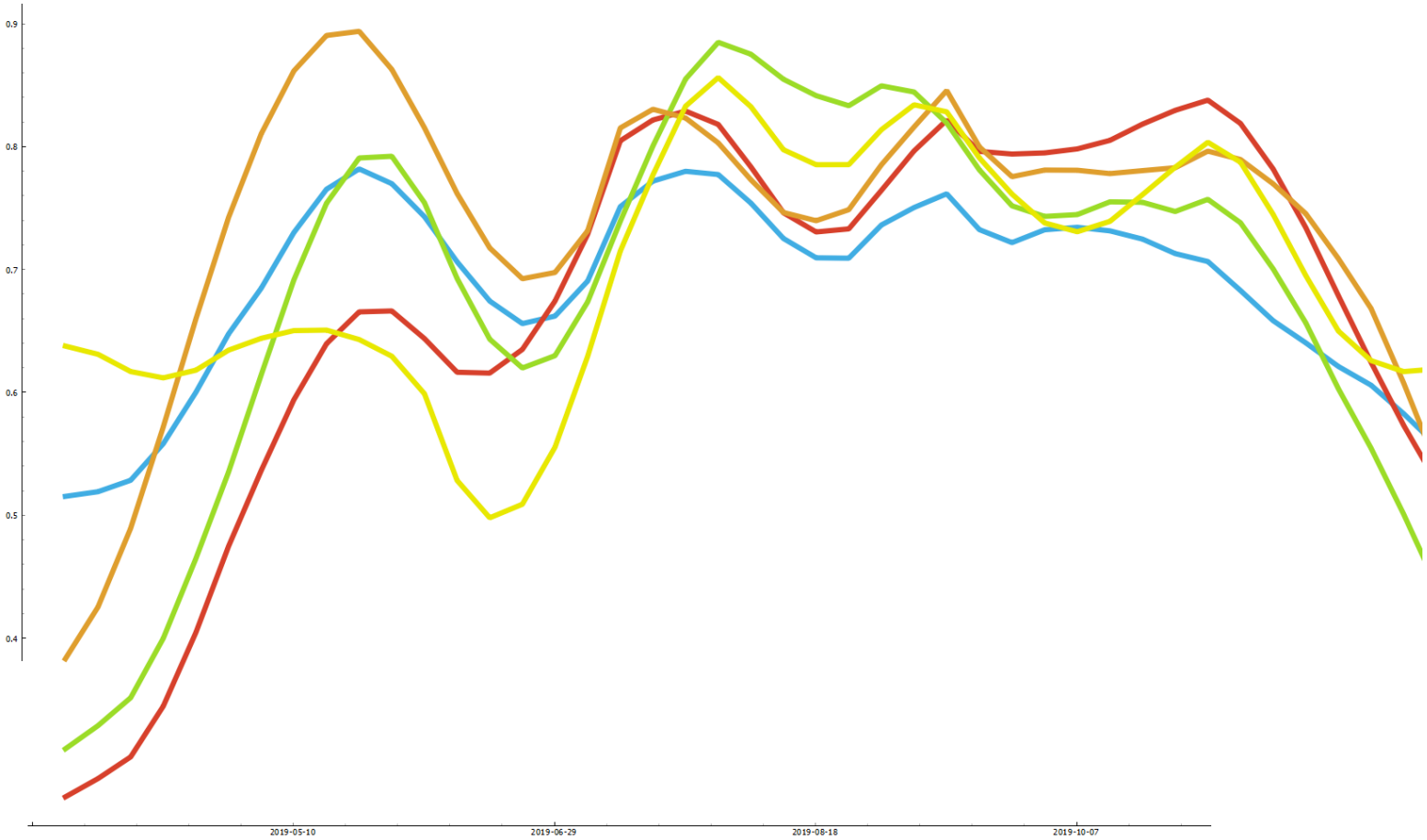
[Remote Sensing | Free Full-Text | Mapping Arctic Tundra Vegetation Communities Using Field Spectroscopy and Multispectral Satellite Data in North Alaska, USA | HTML (mdpi.com)]

Beech – Multiyear development





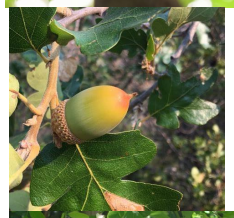
Different tree types



pine

beech

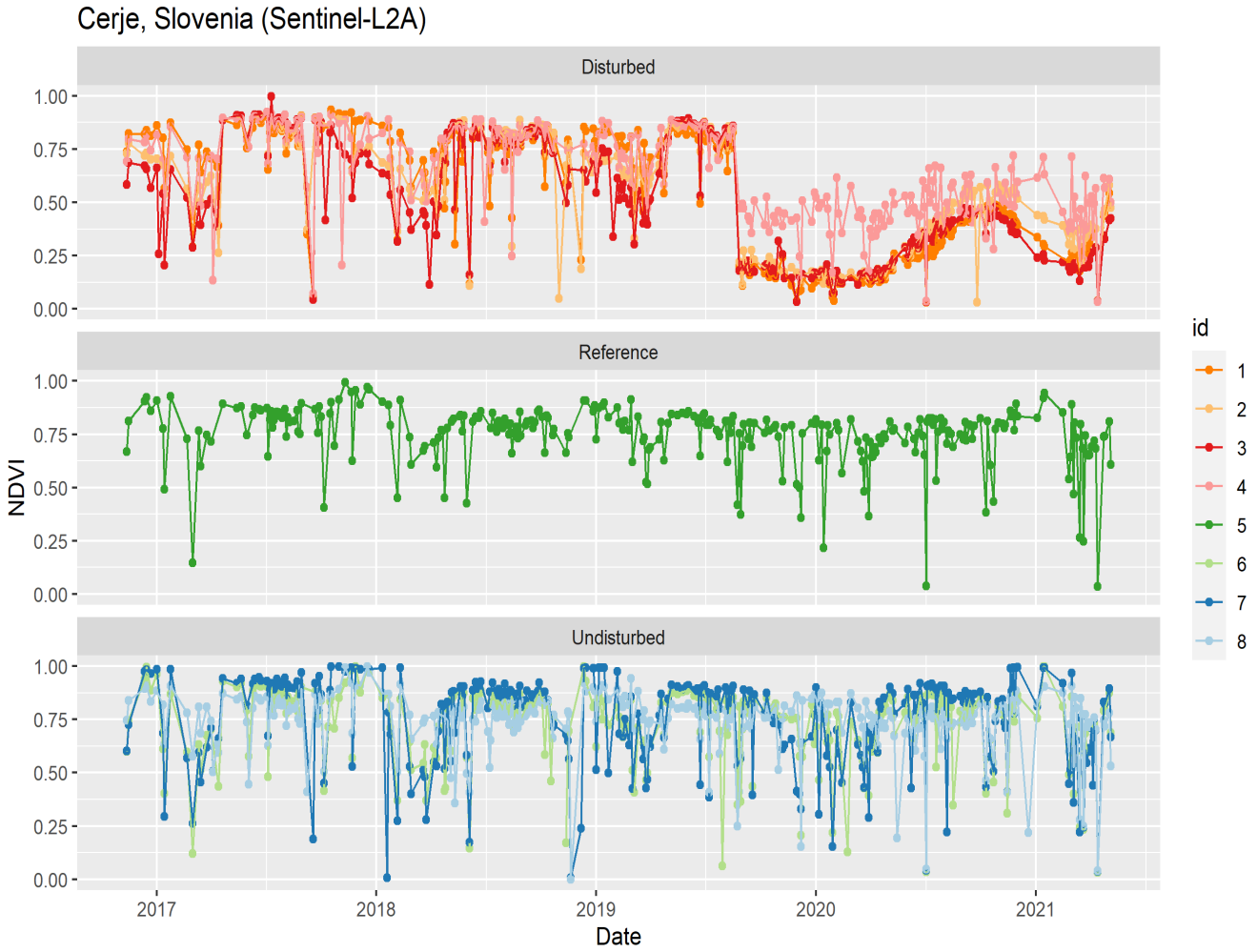
oak



robinia

spruce

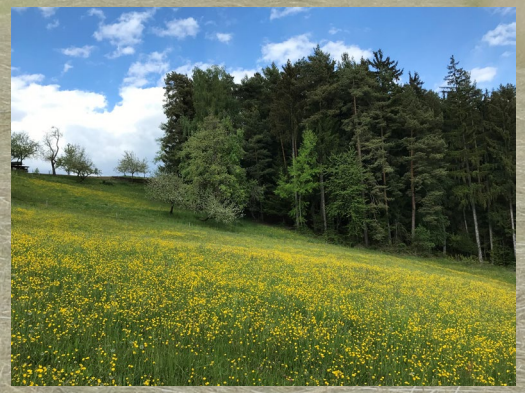
Disturbances



Intensive and extensive grassland

- Species-rich grasslands are increasingly under threat
- Extensive grasslands are among the most threatened ecosystems

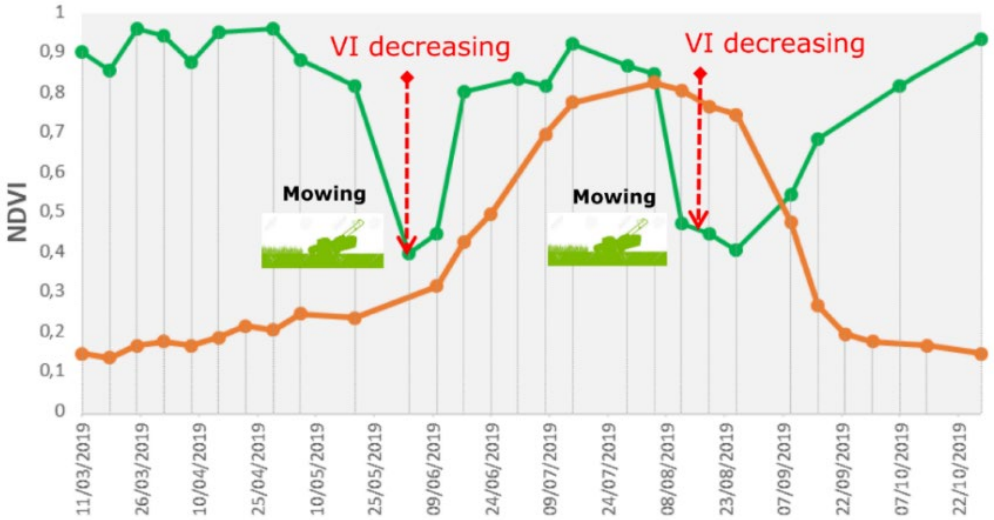


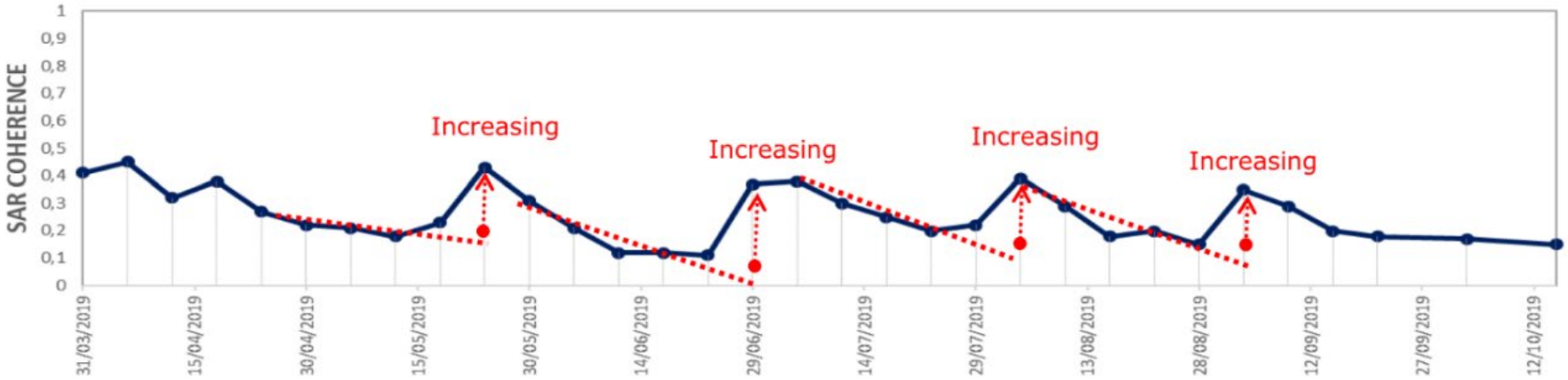


Intensive and extensive grassland

- number of mowings
- date of first mowing
- annual grassland development from satellite data

NDVI





Coherence

[Sentinel-2 for Agriculture]

Case study

- study of the applicability of Sentinel-1 and Sentinel-2 data for the separation of intensive and extensive grasslands
- time series analysis with machine learning define a procedure for annual surveys (monitoring) of grasslands in Slovenia
- support to the spatial trend of development (conservation of grassland biodiversity)

- → Contribution to the establishment of more effective monitoring in the national monitoring scheme for grasslands and protected environments

Data prepration

- Atmospheric and topographic corrections
- Cloud mask
- NDVI
- MSAVI2
- EVI

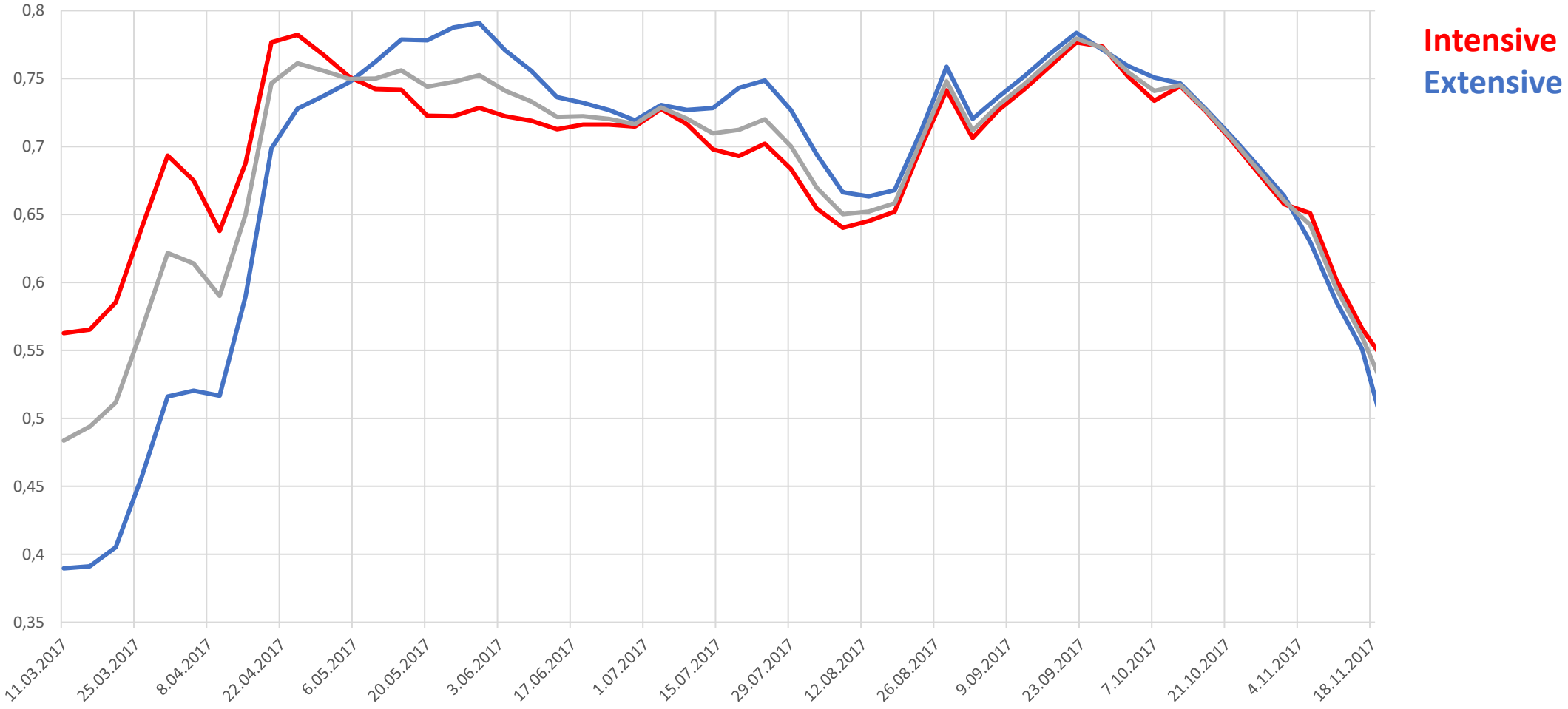
- Sigma
- Coherence

- Reference land use for masking

- Reference mapping data

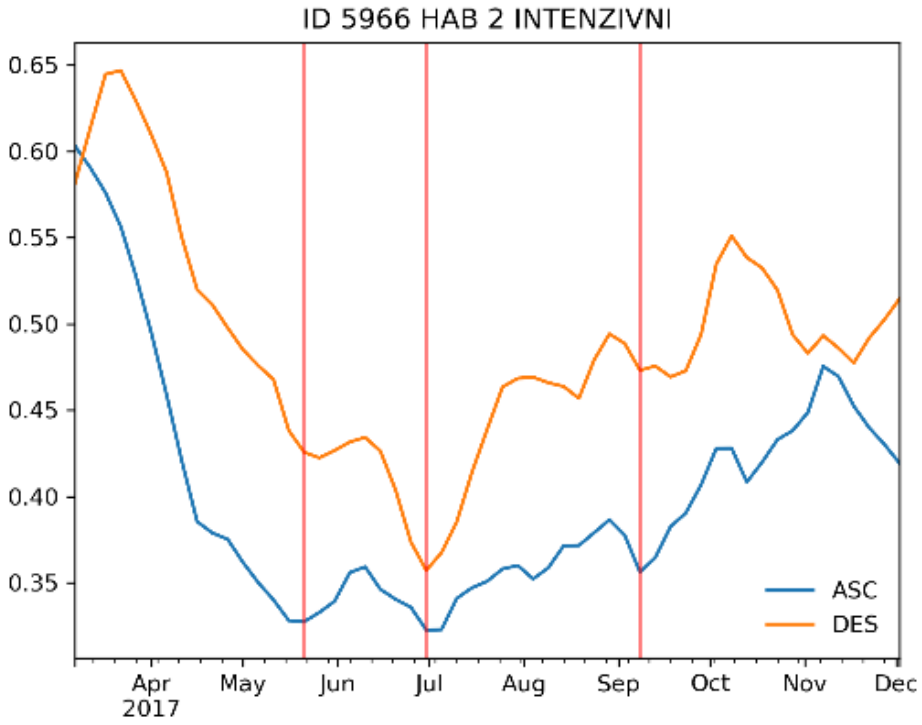
- Relief and products
- Segmentation

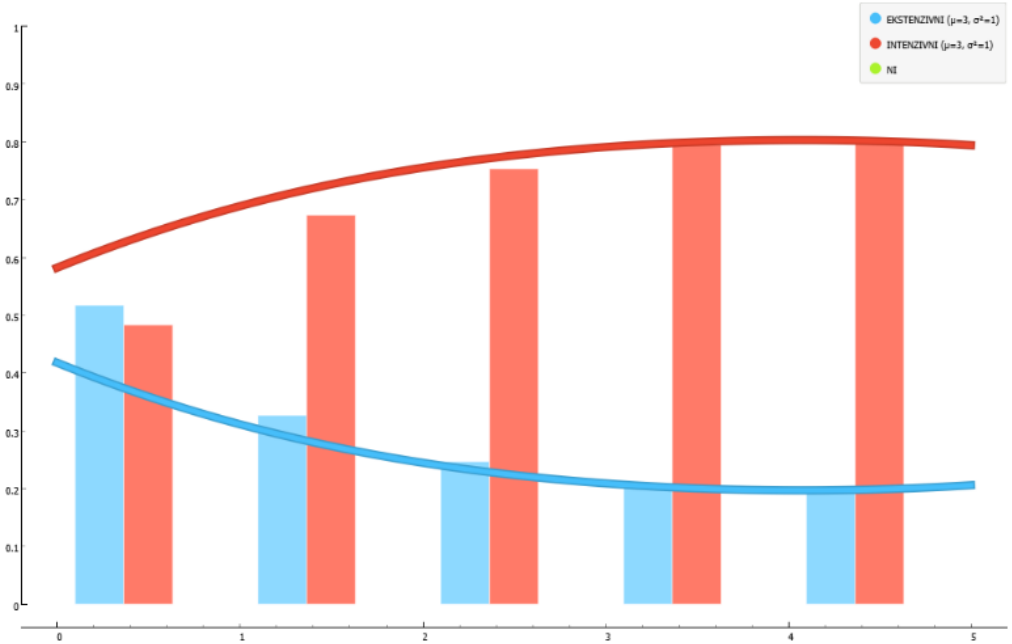
NDVI evolution curve on training samples



Mowing detection

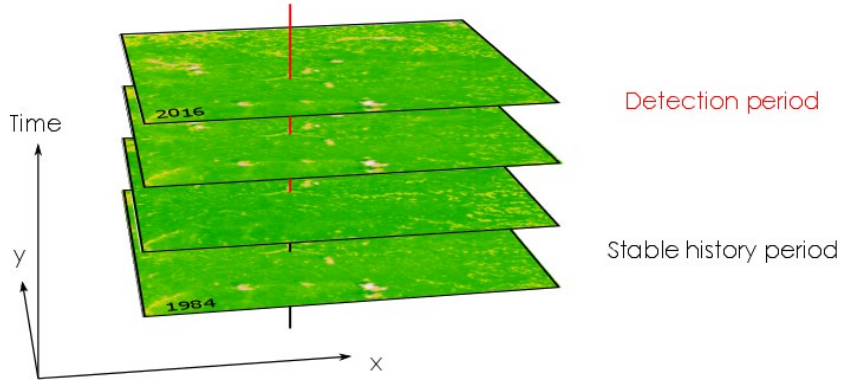
- detects coherence increase
- logical conditions and outputs the corresponding mowing dates
- number of mowings



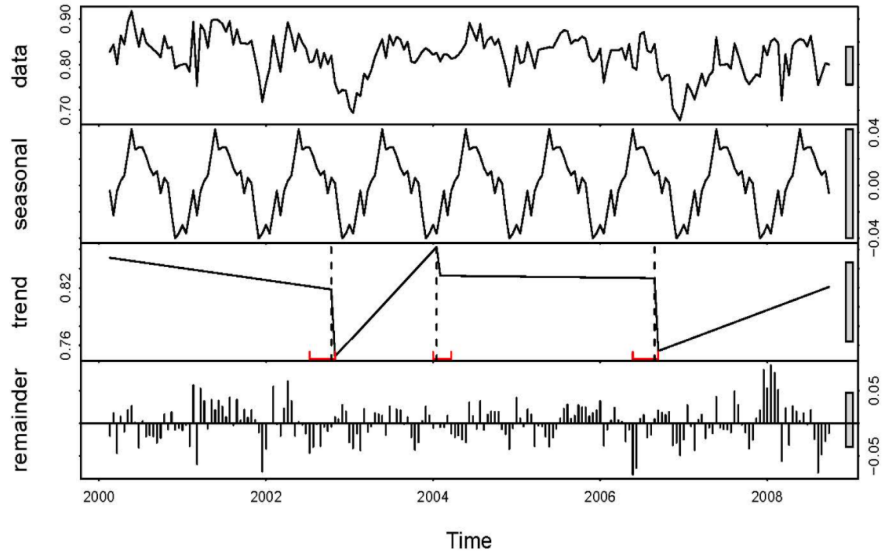


Long Term Satellite Image Time Series

- Identify changes over time with long term satellite data sets
- Normalised Difference Vegetation Index (NDVI) as an input variable
- Time series processing methods and algorithms
- Temporal changes in trend and seasonal components, breakpoint detection



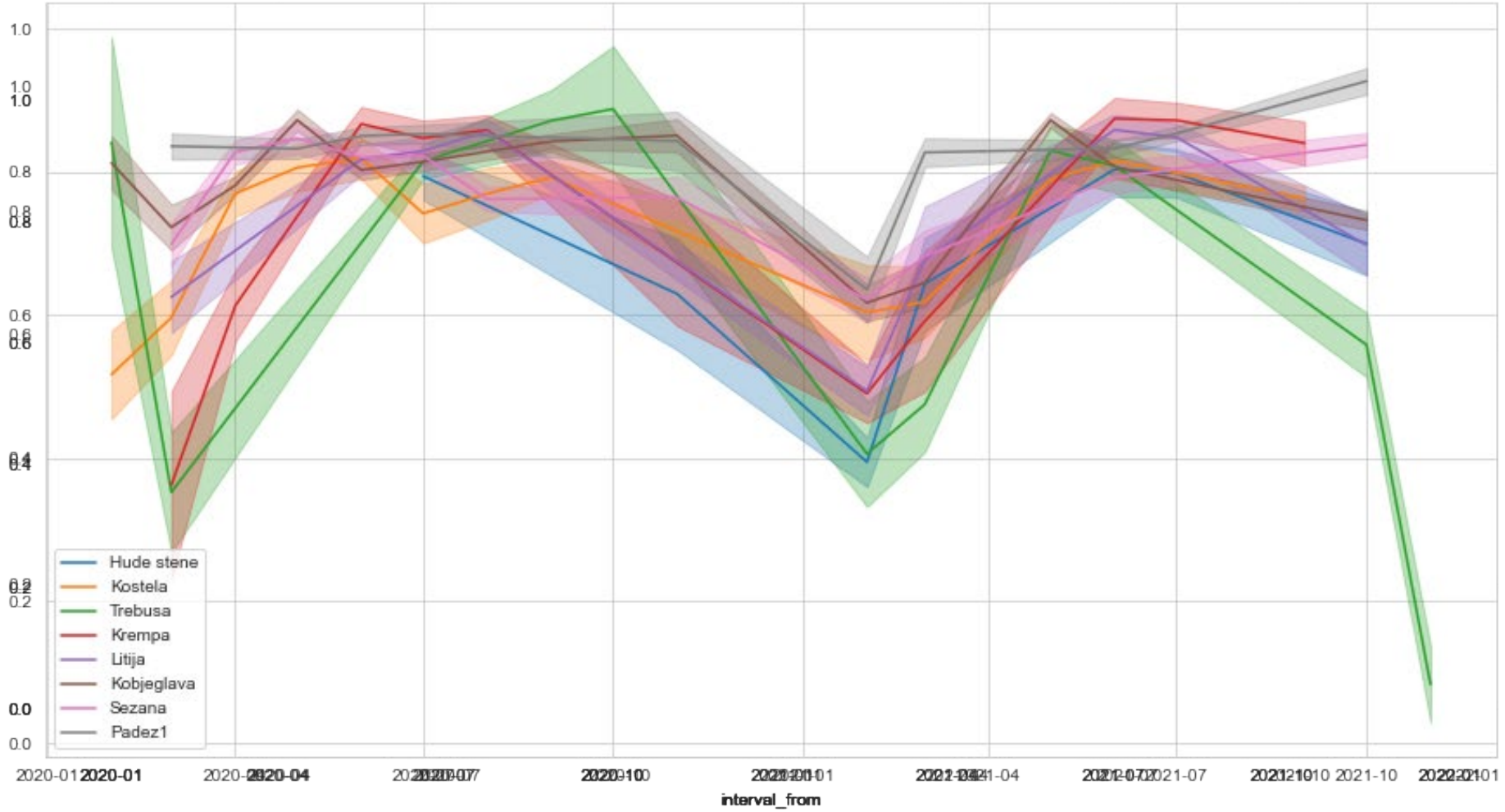
BFAST



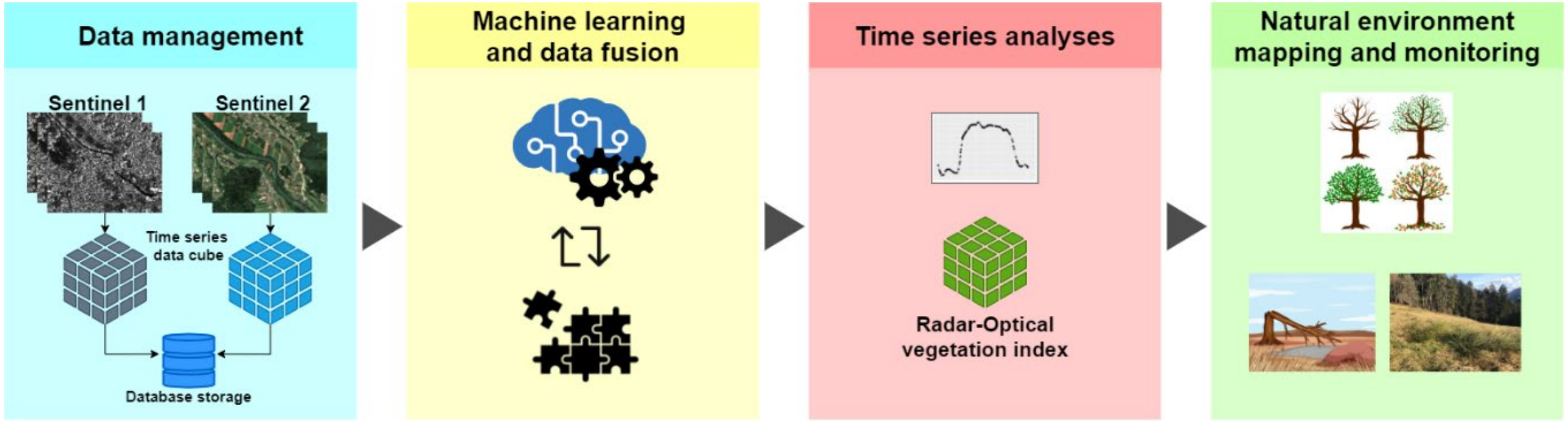
[Break Detection for Satellite Time Series Data — BFAST 0.7 documentation]

Time interpolation/agregation

- No
- 5 D
- 10 D
- 1 M



SAR/Optical integration



Conclusions

- We have dense (weekly, multispectral) and long (several decades) time series from multiple satellite systems
- Freely and openly available
- ARD is needed, but generating the ARD products is challenging, it is likely that in the future ARD data will be prepared by the data providers
- Vegetation observation benefits hugely with time series of optical and SAR data
- Time series analysis is complex and requires knowledge from several disciplines
- Artificial intelligence is providing answers to some of the problems

Practicals

- Sentinel-1 processing with SNAP
- Using EO-Learn to process Sentinel-2 Time Series

References

- Concepts and methods for optical pre-processing and time series quality analysis, Pierre Defourny, Fabrizio Ramoino, Olivier Hagolle, LTC 2019
- Intro: Optical Remote Sensing and Atmospheric Correction, Pete Bunting, LTC 2018
- Remote Sensing for Earth Observation (soton.ac.uk)
- Optics or Radars? What is Better for the Earth Observation Purposes? - Defence24.com
- Earth Observation from Space: the Optical View - eo science for society (esa.int)
- Spectral Signature Cheatsheet - Spectral Bands in Remote Sensing - GIS Geography