Introduction to Optical Remote Sensing for Agriculture and Water

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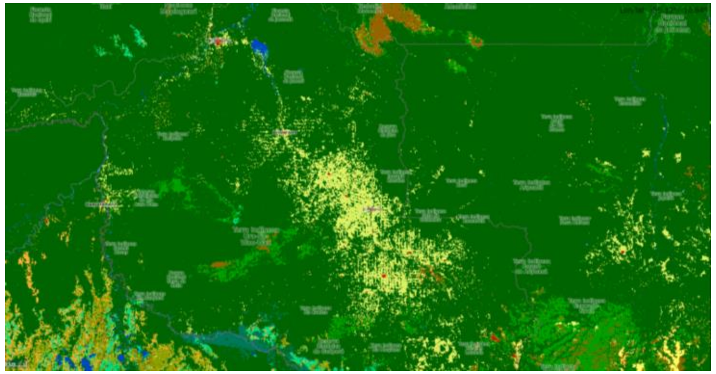
Outline

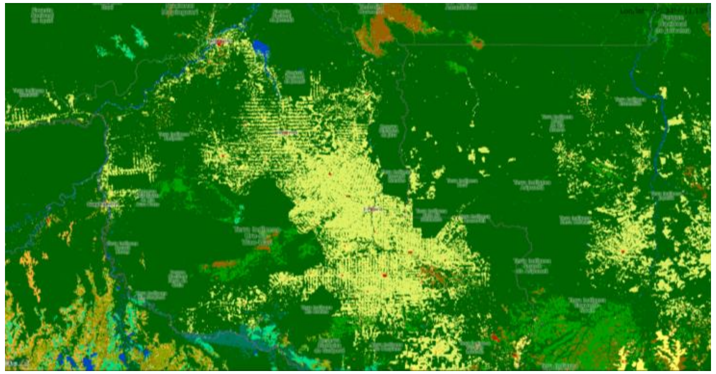
- Optical instruments
- The interaction of electromagnetic radiation with the surface
- Interaction with the atmosphere and how to apply correction
- Pre-processing of optical data
- Why use Time Series
- How to retrieve Vegetation Indices and Biophysical Variables

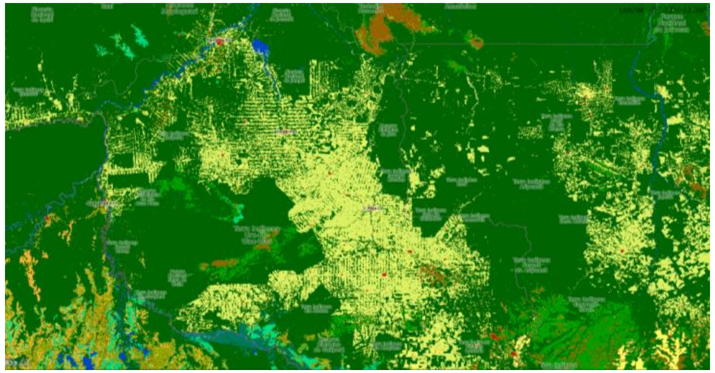
- Monitoring the water cycle over land
    - Rainfall and surface energy balance
    - Calculating water balance of a catchment
    - Water balance calculation methods and results
    - Soil moisture

Why use satellites for agriculture applications?

- Timely, objective, local to global coverage
- Useful for observing areas that are inaccessible
- Monitor plant growth and estimate crop productivity
- Assess soil moisture and irrigation requirements
- Identify soil and crop characteristics and conditions
- Better forecast precipitation and crop disease
- Maximize crop yields while reducing energy consumption
- Avoid waste of farm inputs (water, fertilizer, and pesticide)



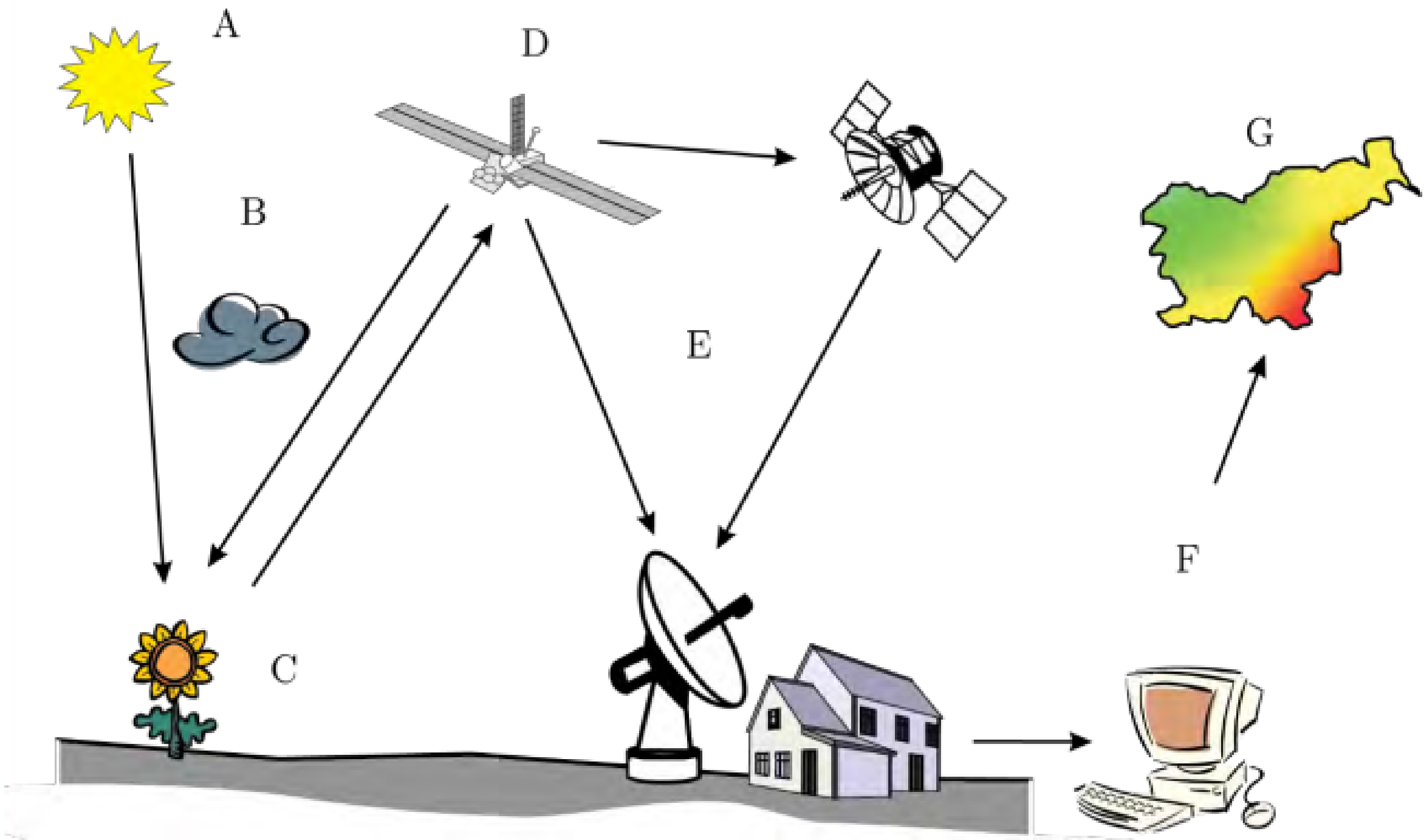




Evolution of agricultural operations in Rondonia Region, Brazil. Captured by ESA CCI LandCover project in 1992, 2002 and 2015.

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.



(A) Energy or Illumination Source

(B) Radiation and the Atmosphere

(C) Interaction with the Target

(D) Recording by the Sensor

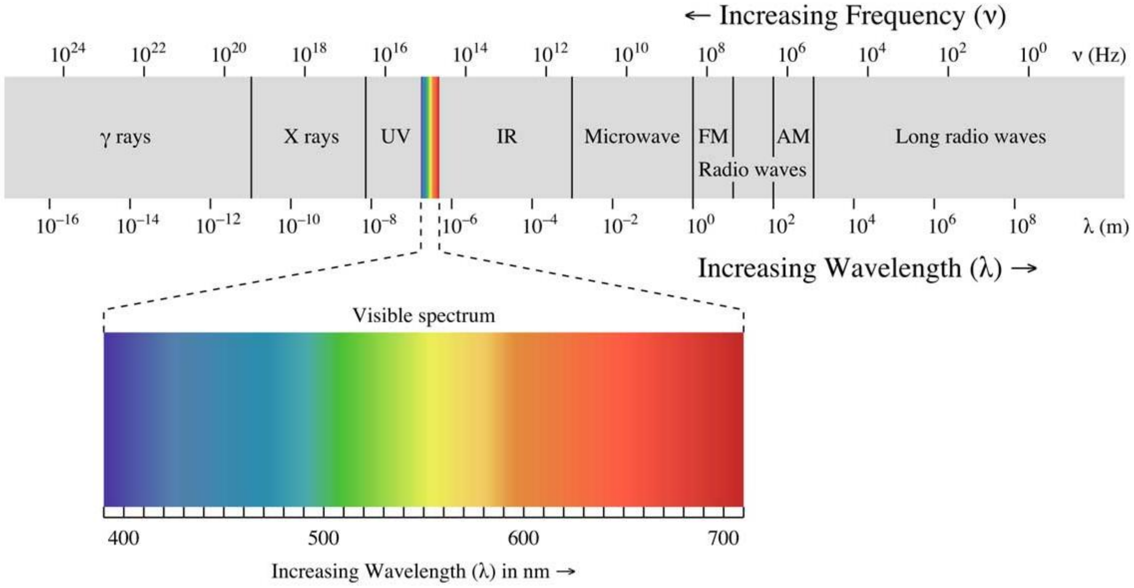
(E) Transmission, Reception, and Processing

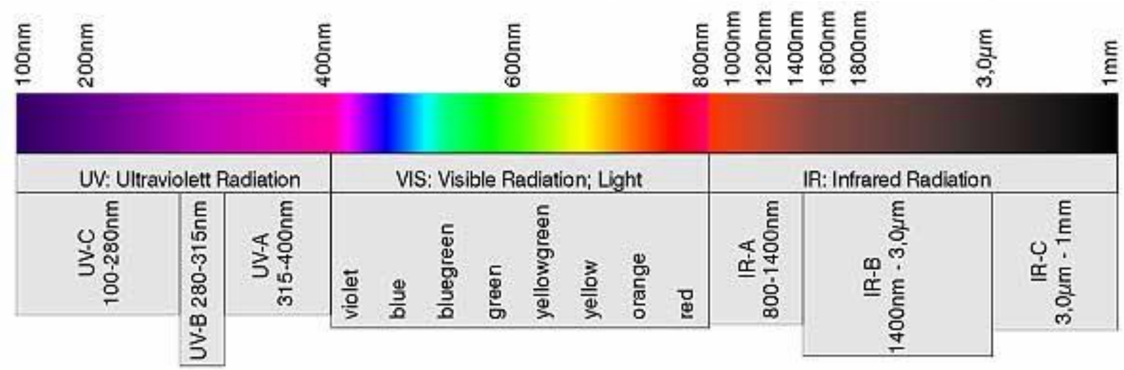
(F) Interpretation and Analysis

(G) Application

Spectrum EMR

The term **"optical radiation"** refers to electromagnetic radiation in the wavelength range between 100 nm and 1 mm. The terms **"light"** and **"visible radiation"** (VIS) refer to the wavelength range between 400 nm and 800 nm, which can be perceived by the human eye.



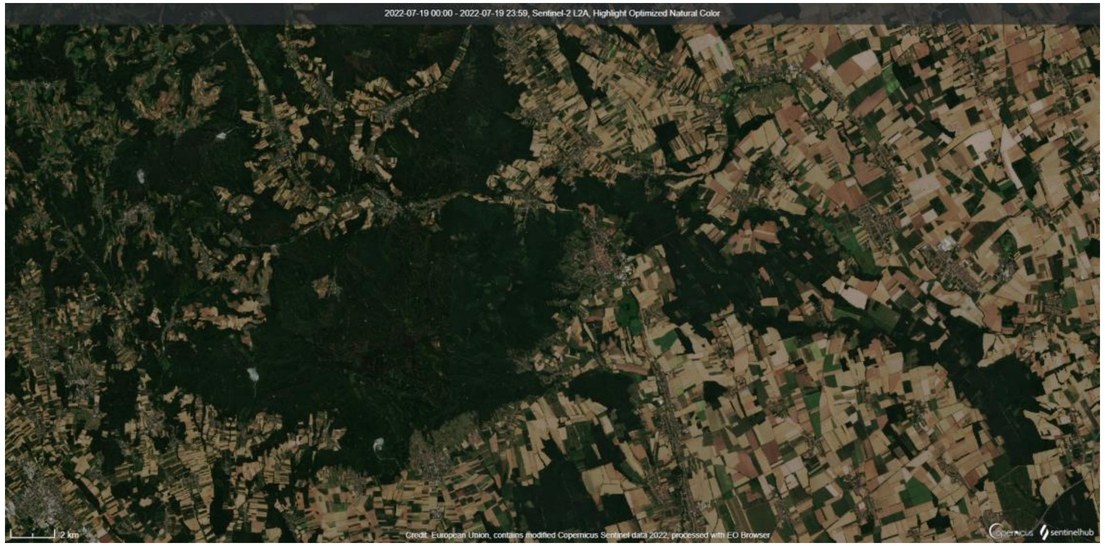


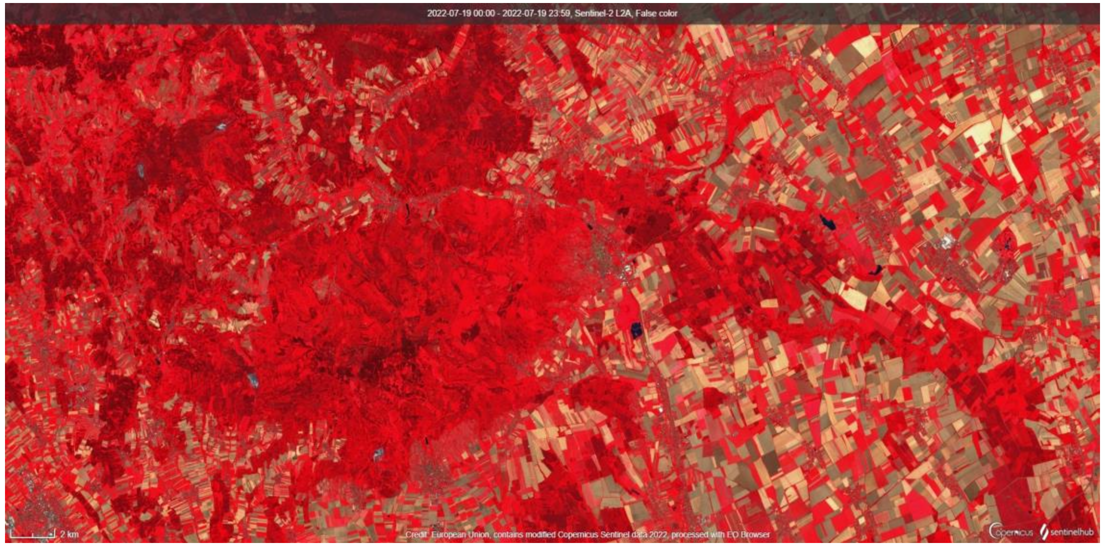
- **Visible (VIS)** 0.30 – 0.75 µm and 0.77 – 0.91 µm – perceived by the human eye
- **Near infrared (IR)** 1.55 – 1.75 µm and 2.05 – 2.40 µm
- **Thermal Infrared** 8.0 – 9.2 µm and 10.2 – 12.4 µm
- **Microwave (SAR)** 7,5–11,5 mm and 20 mm

The wavelength range of optical radiation (light-measurement.com)

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





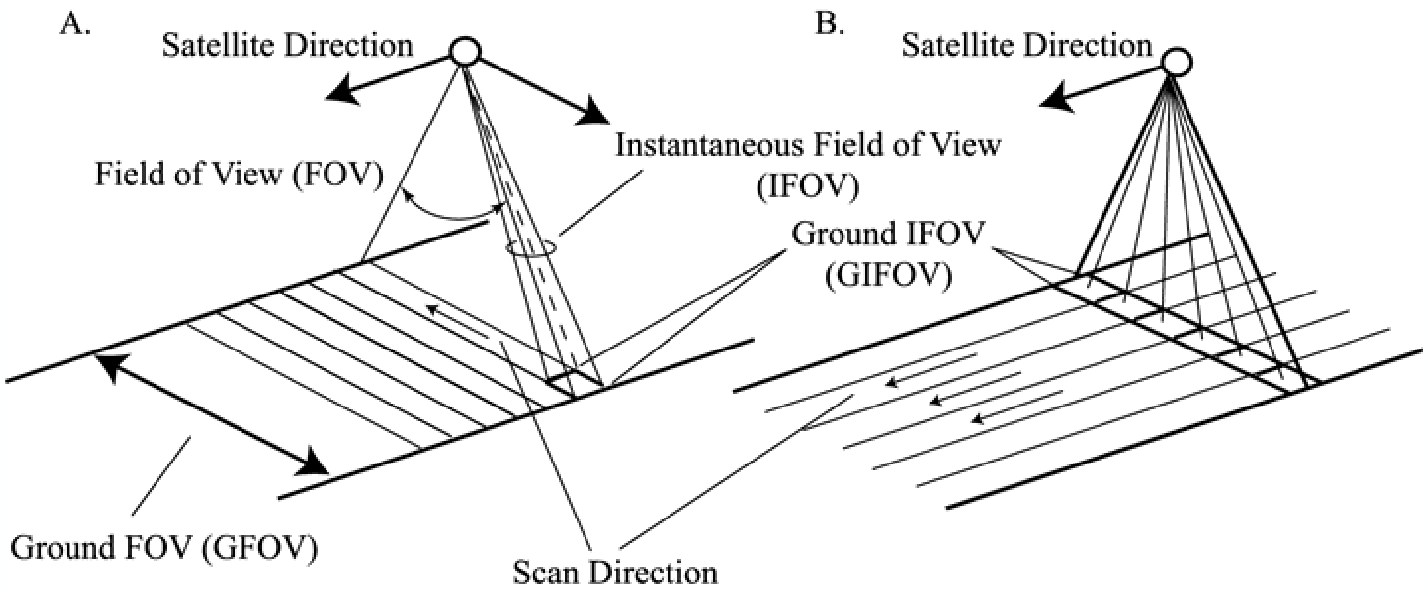
Optical scanners

Across track

- Landsat –up to 7

Along track

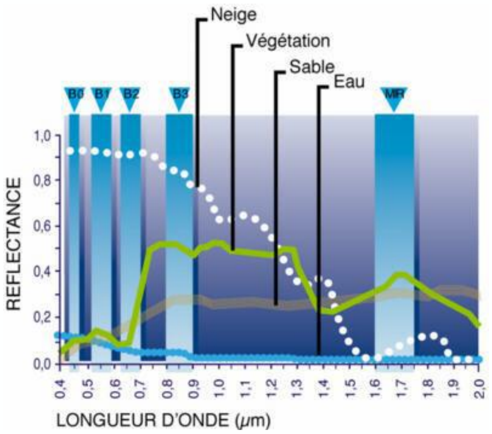
- All HR and VHR
- Sentinel-2
- Landsat 8



[An introduction to satellite sensors, observations and techniques (researchgate.net)](https://www.researchgate.net)

Optical land remote sensing: 40 years of digital evolution

Spectral Resolution



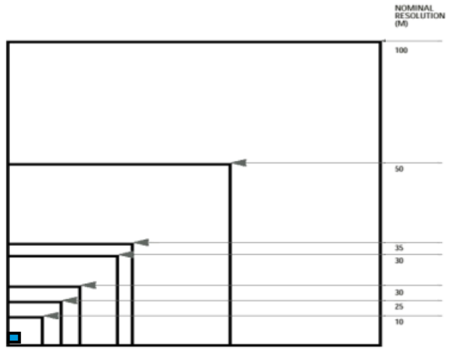
Radiometric Resolution

4 bits

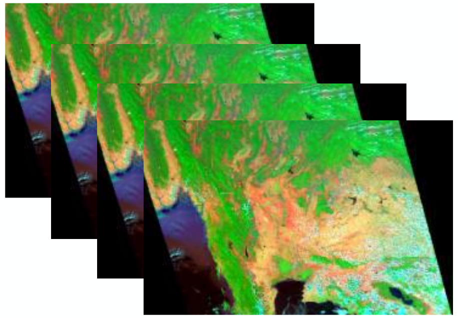
16 bits

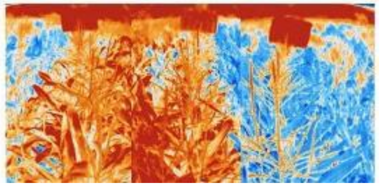
Unmanned Aerial Vehicle (UAV)

Spatial Resolution



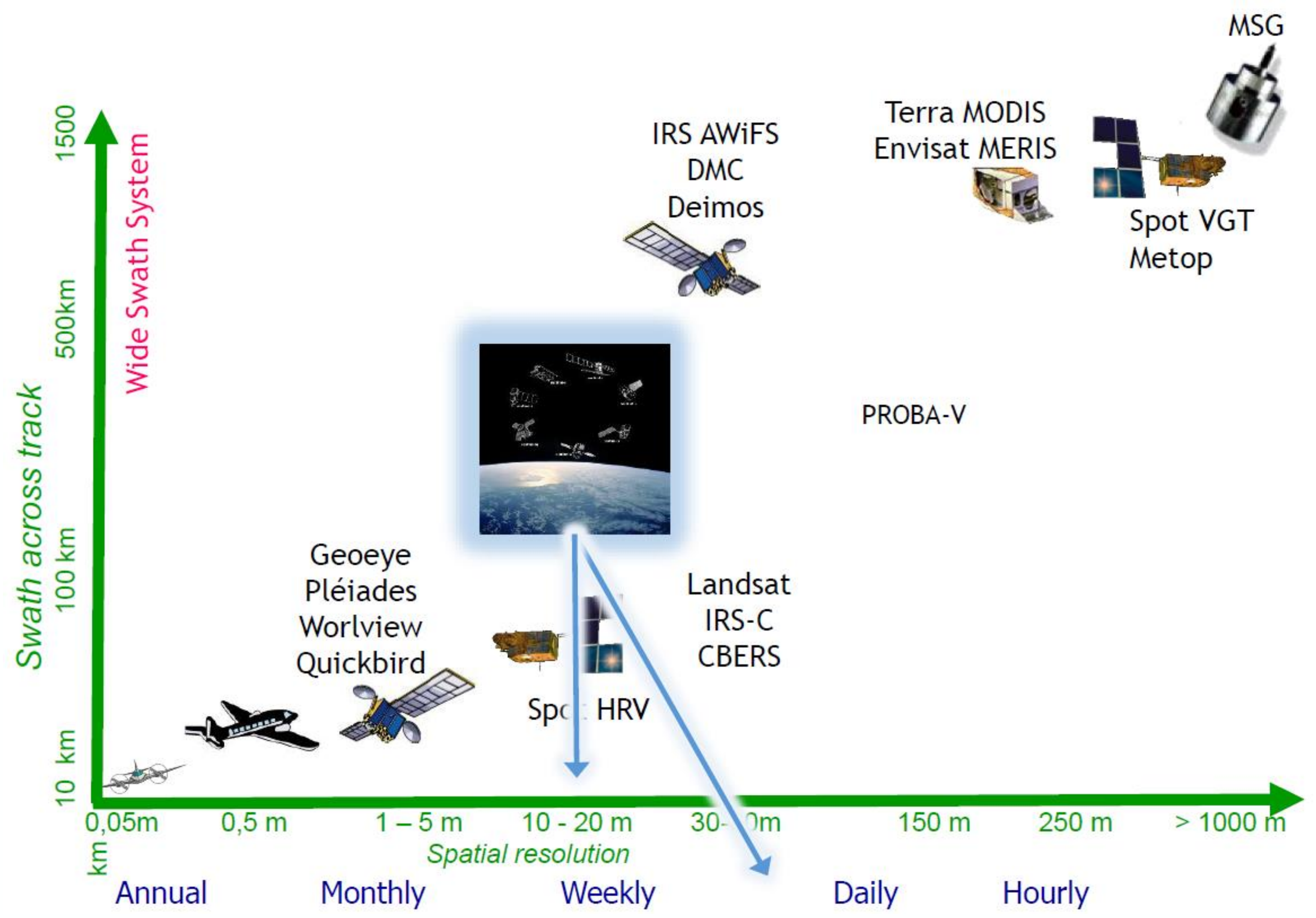
Temporal Resolution





Platform for phenotyping

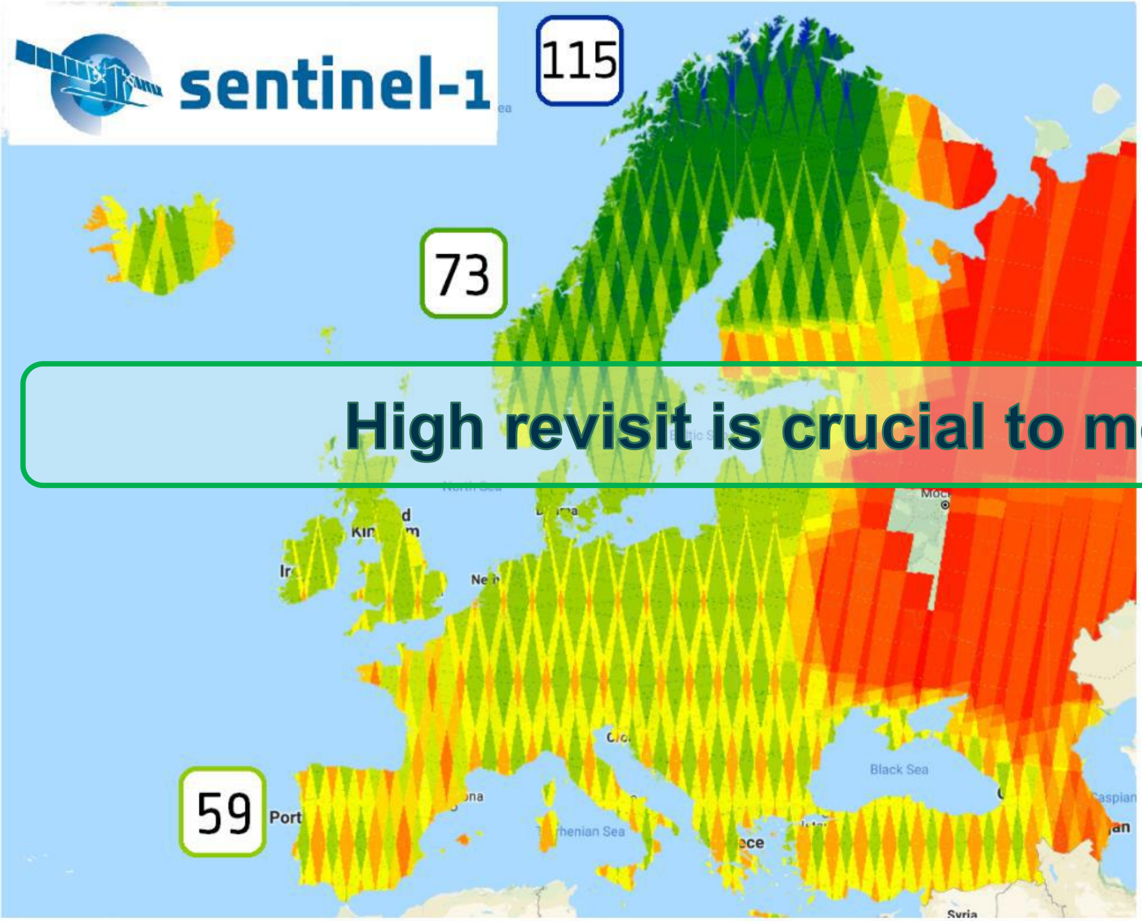
Optical land remote sensing



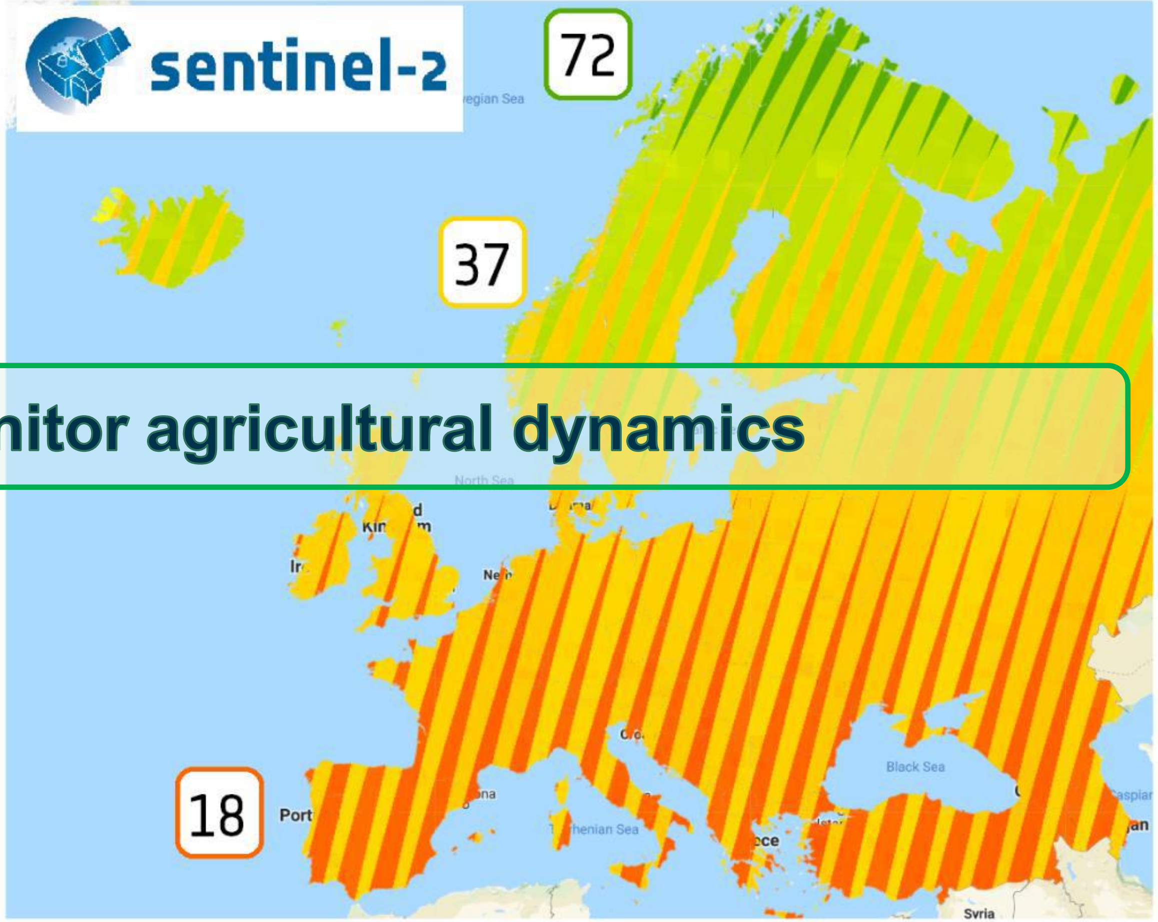
Sentinels as a game changer, especially for agriculture

Majority of Europe >2 day revisit

Majority of Europe >3 day revisit



S1A and S1B (July-Sept 2018)

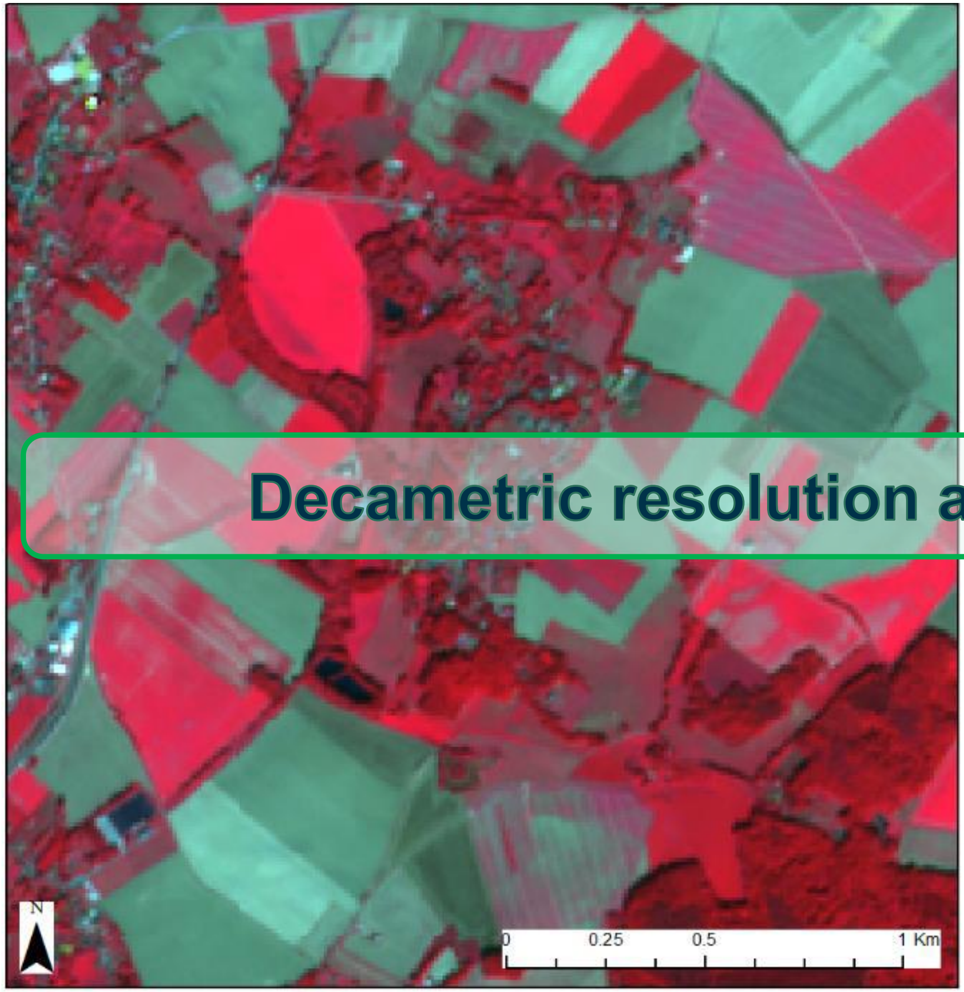


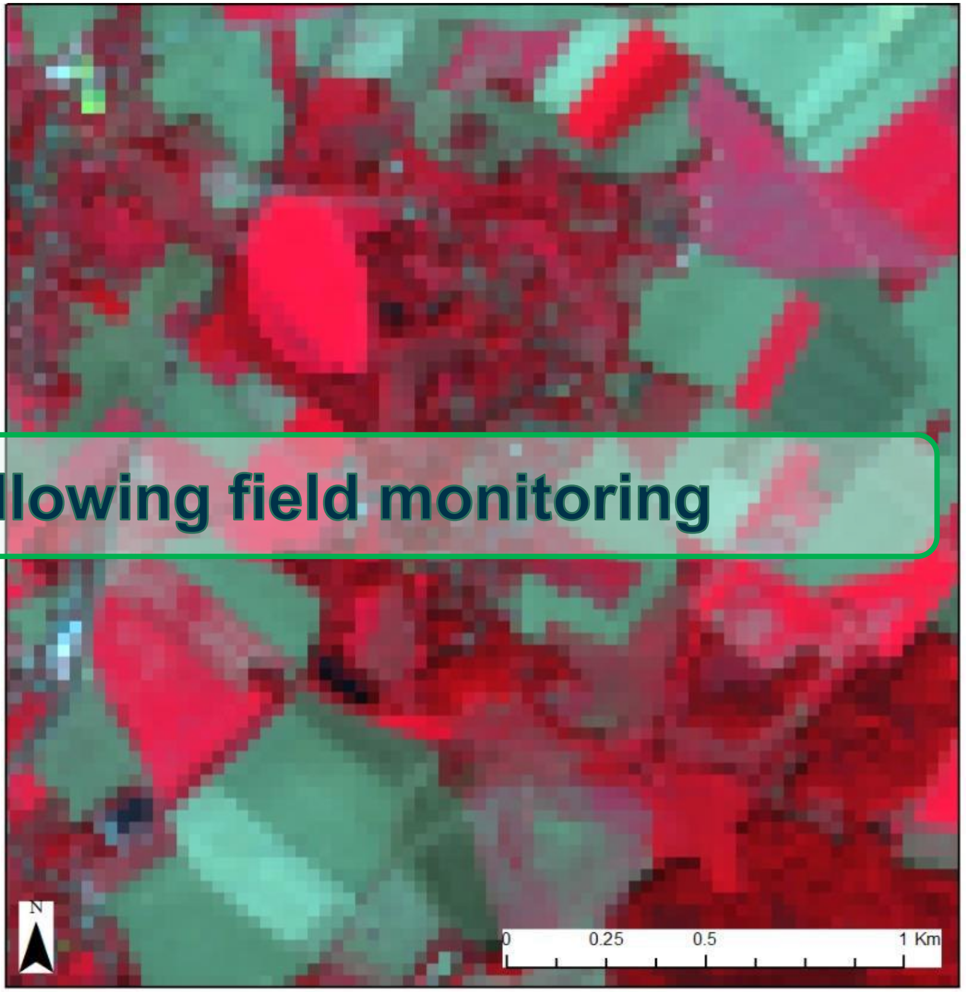
S2A and S2B (July-Sept 2018)

High revisit is crucial to monitor agricultural dynamics

Sentinels as a game changer, especially for agriculture

10 m

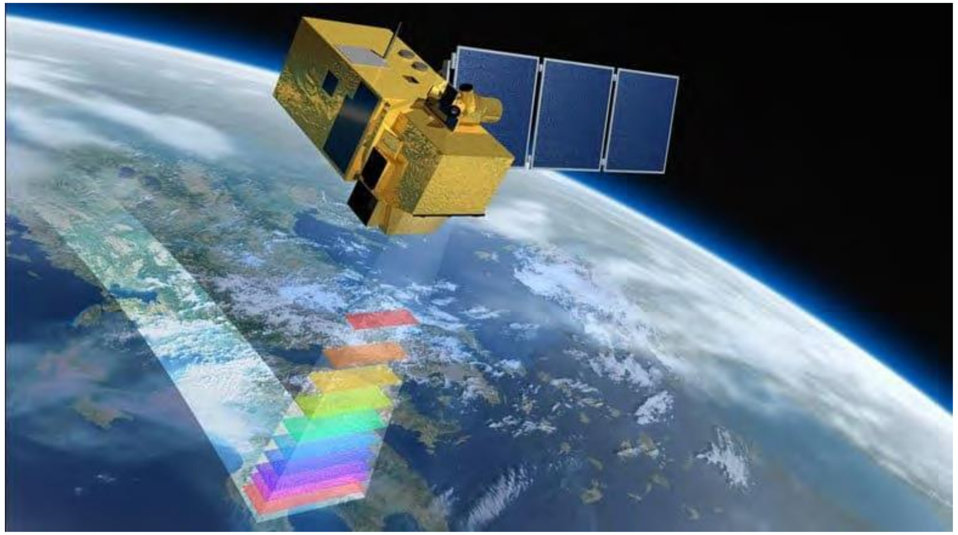


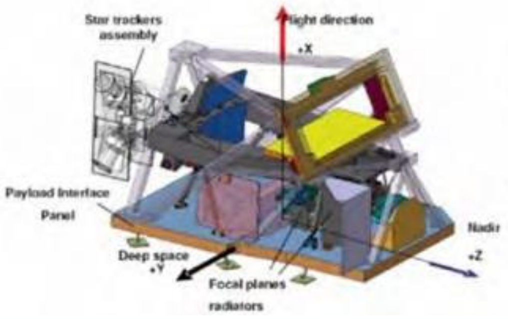


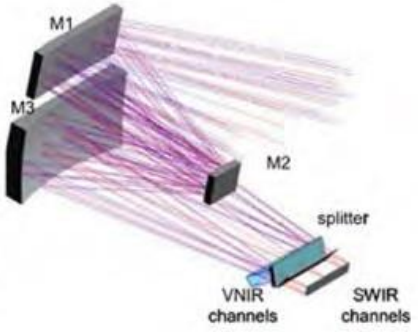
30 m

Decametric resolution allowing field monitoring

Sentinel-2 imaging

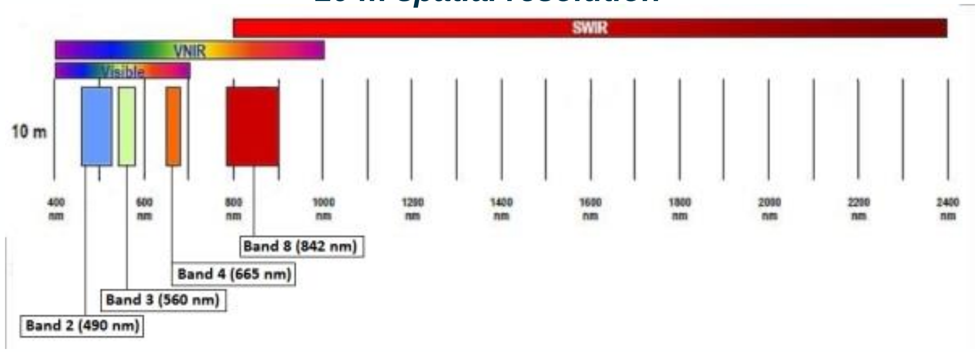




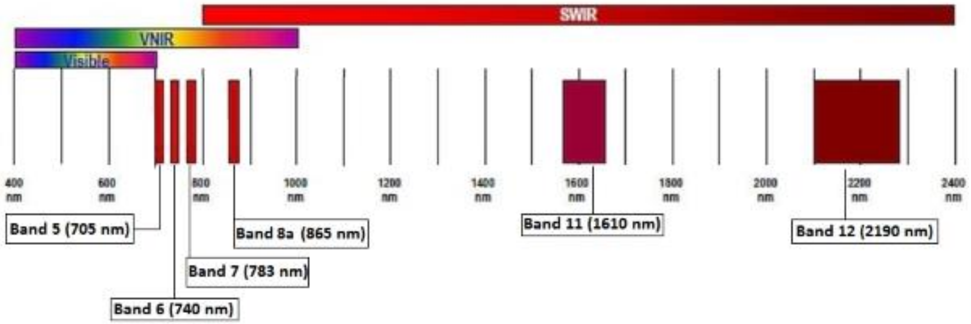


[MSI Instrument –Sentinel-2 MSI TechnicalGuide – Sentinel Online – Sentinel Online (copernicus.eu)]()

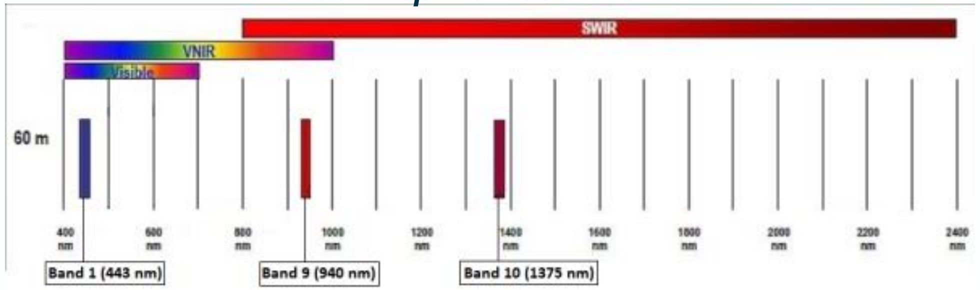
10 m spatial resolution



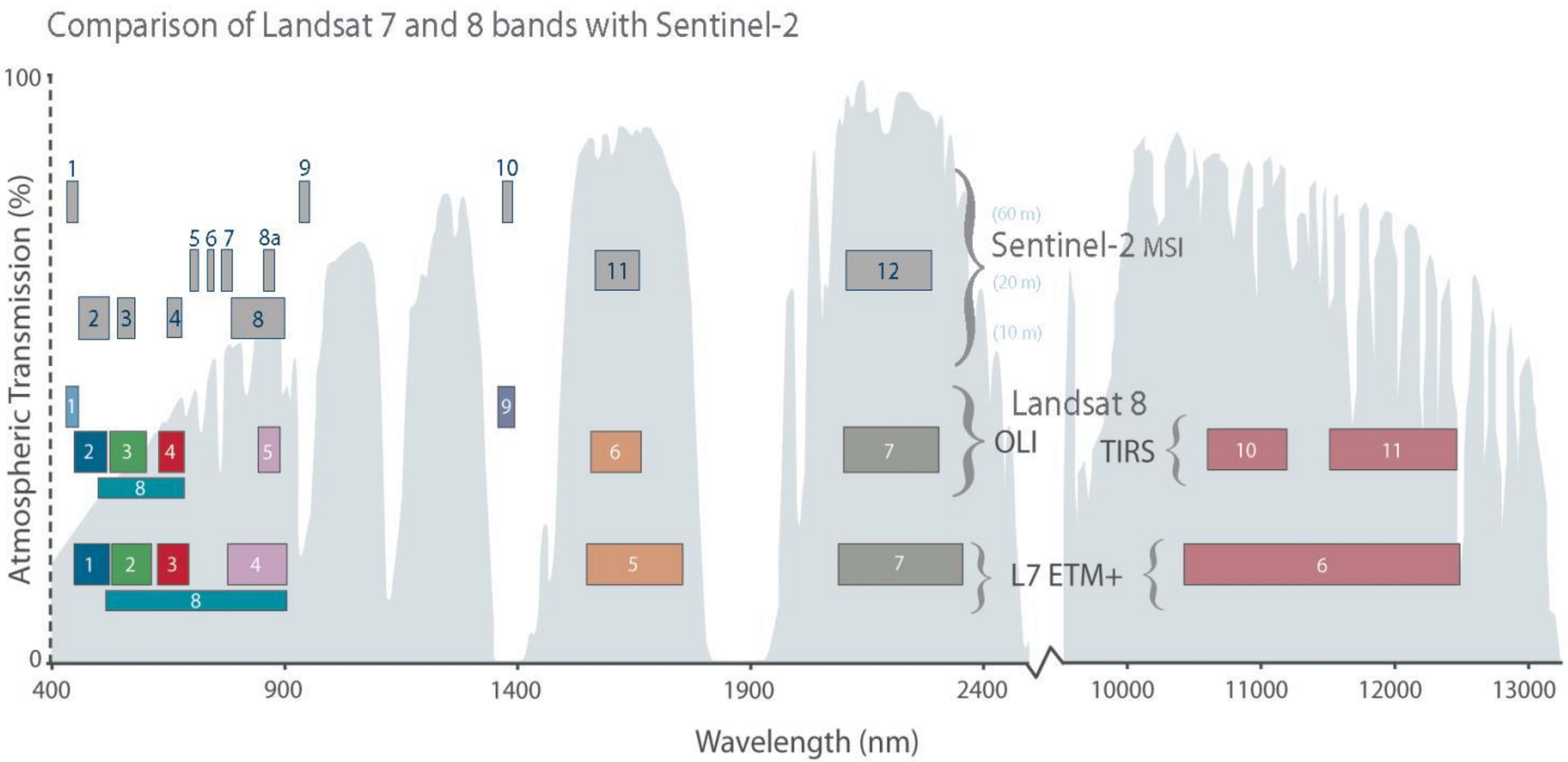
20 m spatial resolution



60 m spatial resolution

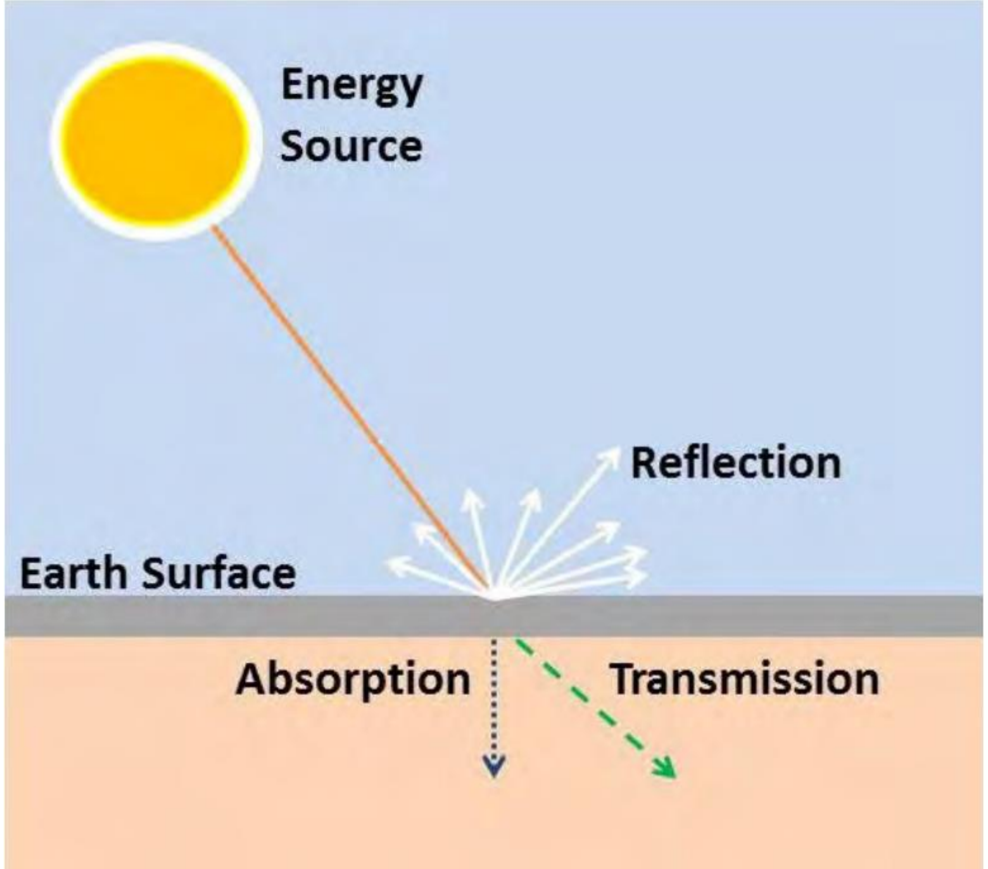


Comparison Sentinel-2 bands with Landsat-7 and 8



Interaction with the surface

- The interaction of electromagnetic 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.
- 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 …



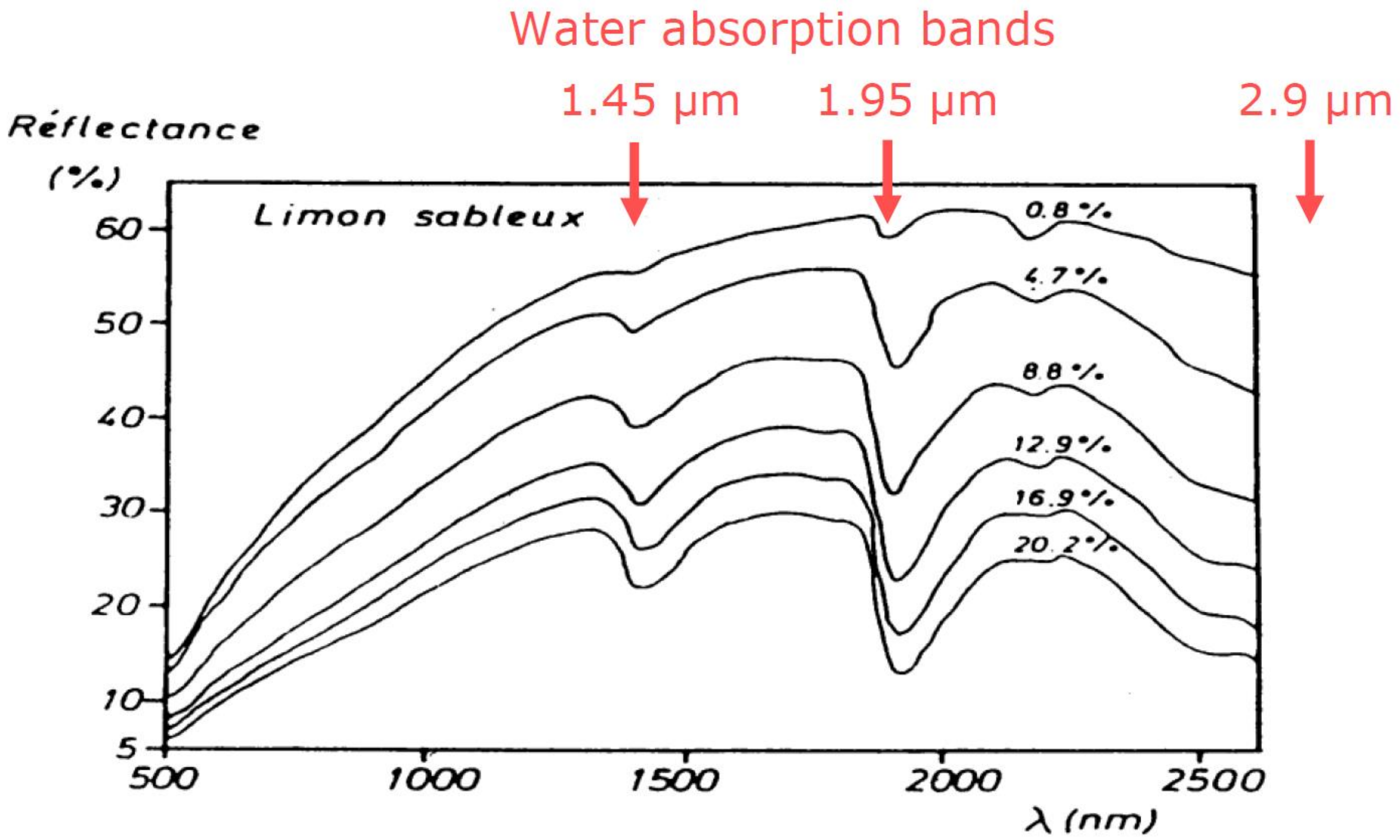
[Electro-Magnetic Radiation (EMR) Interaction with Earth Surface Features (gisoutlook.com)](gisoutlook.com)

Spectral signature of bare soil

Incident radiation can be:

- only related to soil-atmosphere interface (superficial layer - not related to soil depth)
- influenced by soil structure, texture and stony component, soil surface moisture and soil colour (org. matter, Fe, Ca)
- reflectance slightly increases from the visible to the IR

Growing and convex curve, evolving with wavelength



Spectral signature of water

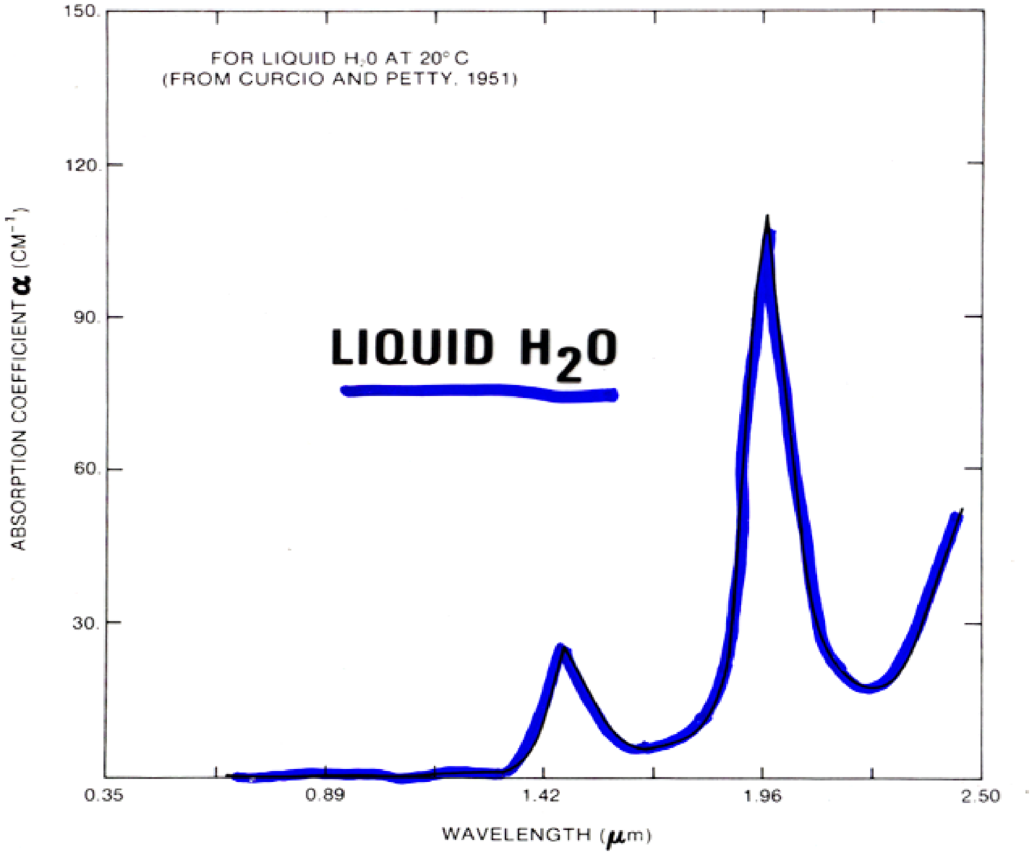
Incident radiation on liquid water is:

- partly reflected in a specular way
- partly refracted (and then absorbed or diffused)

Influence of the suspended elements on the optical properties (chlorophyll, mineral or organic matter)

Reflects mainly in the visible, almost not in the NIR; 3 typical absorption bands

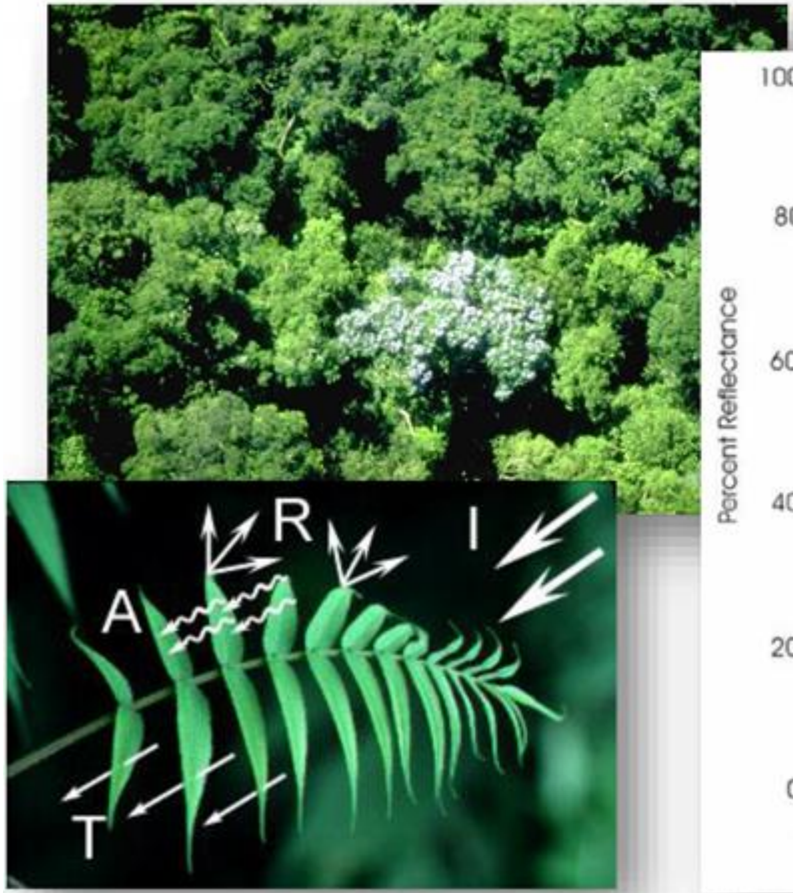
Growing absorption, almost exponential with wavelength

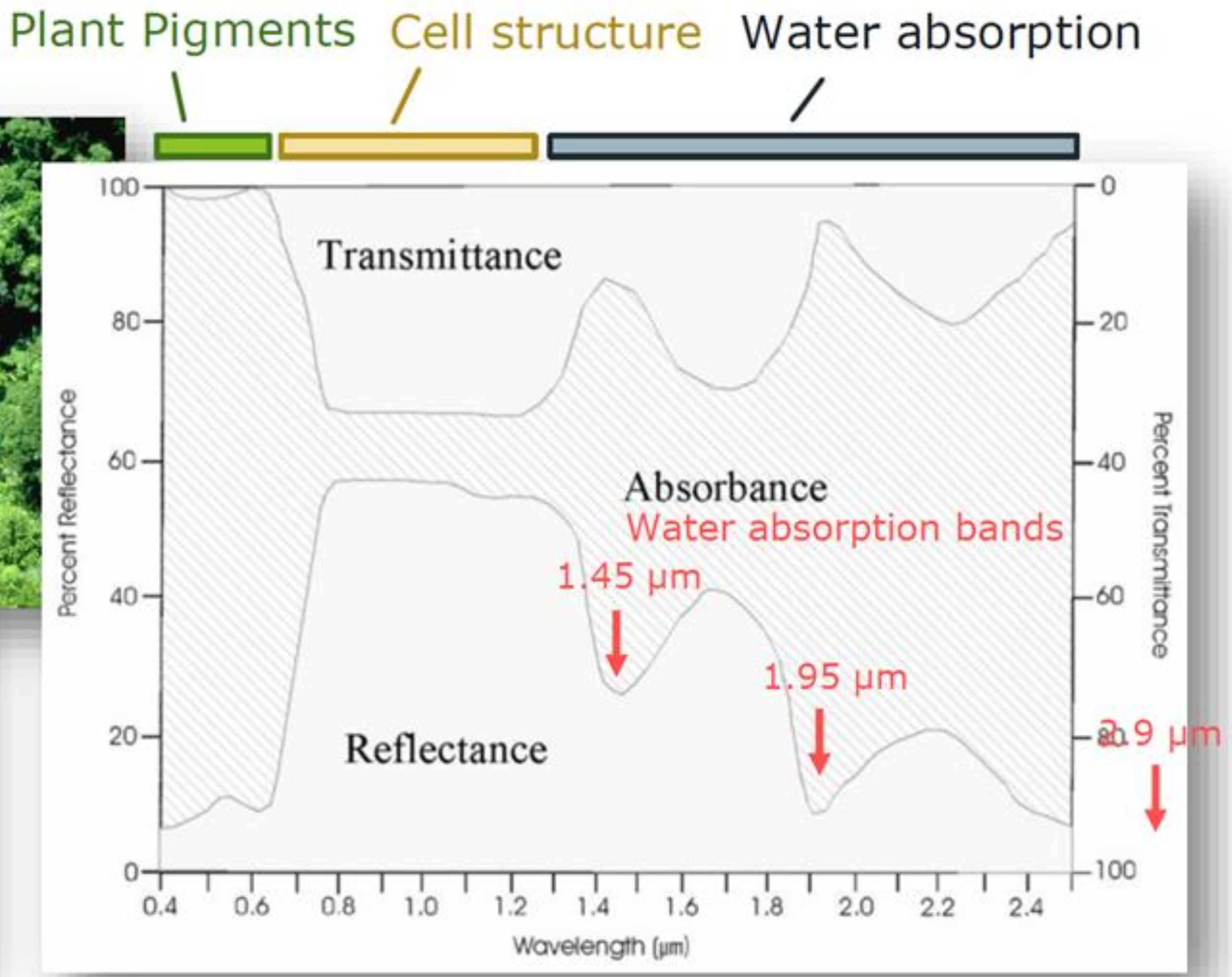


Spectral signature of green vegetation

Incident radiation
- Reflected
- Absorbed
- Transmitted
- Emitted

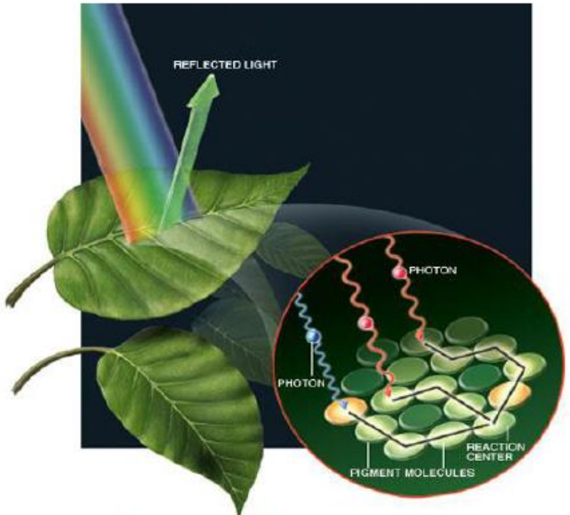
By plant tissues



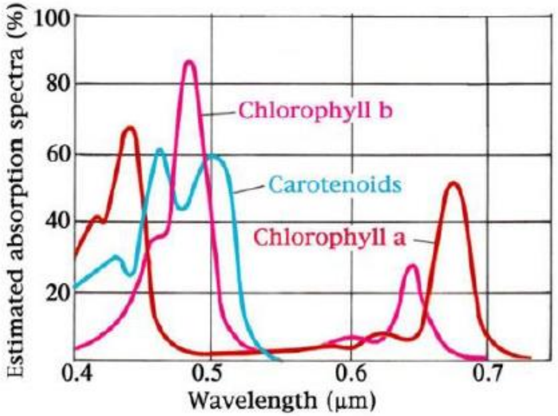


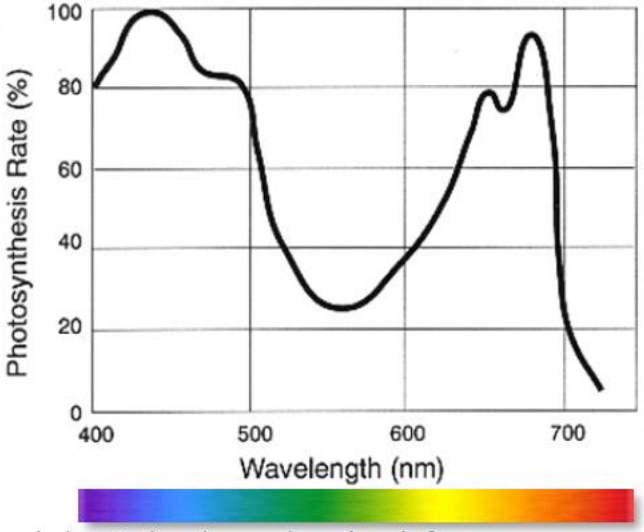
Spectral signature of the plants

Plant pigments



Source: Scientific American

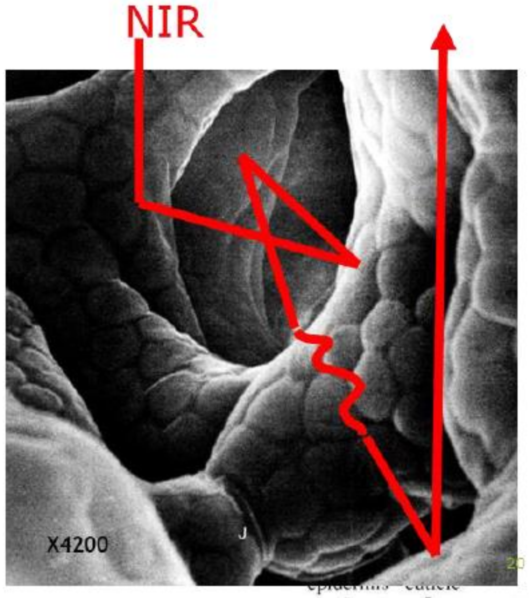


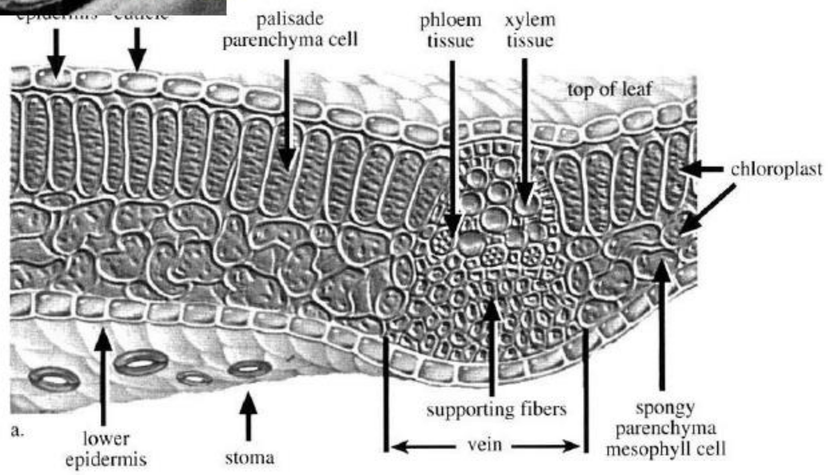


Source: http://www.life.uiuc.edu/govindjee/paper/gov.html, from "Concepts in Photobiology: Photosynthesis and Photomorphogenesis", Edited by GS Singhal, G Renger, SK Sopory, K-D Irrgang

Cell structure

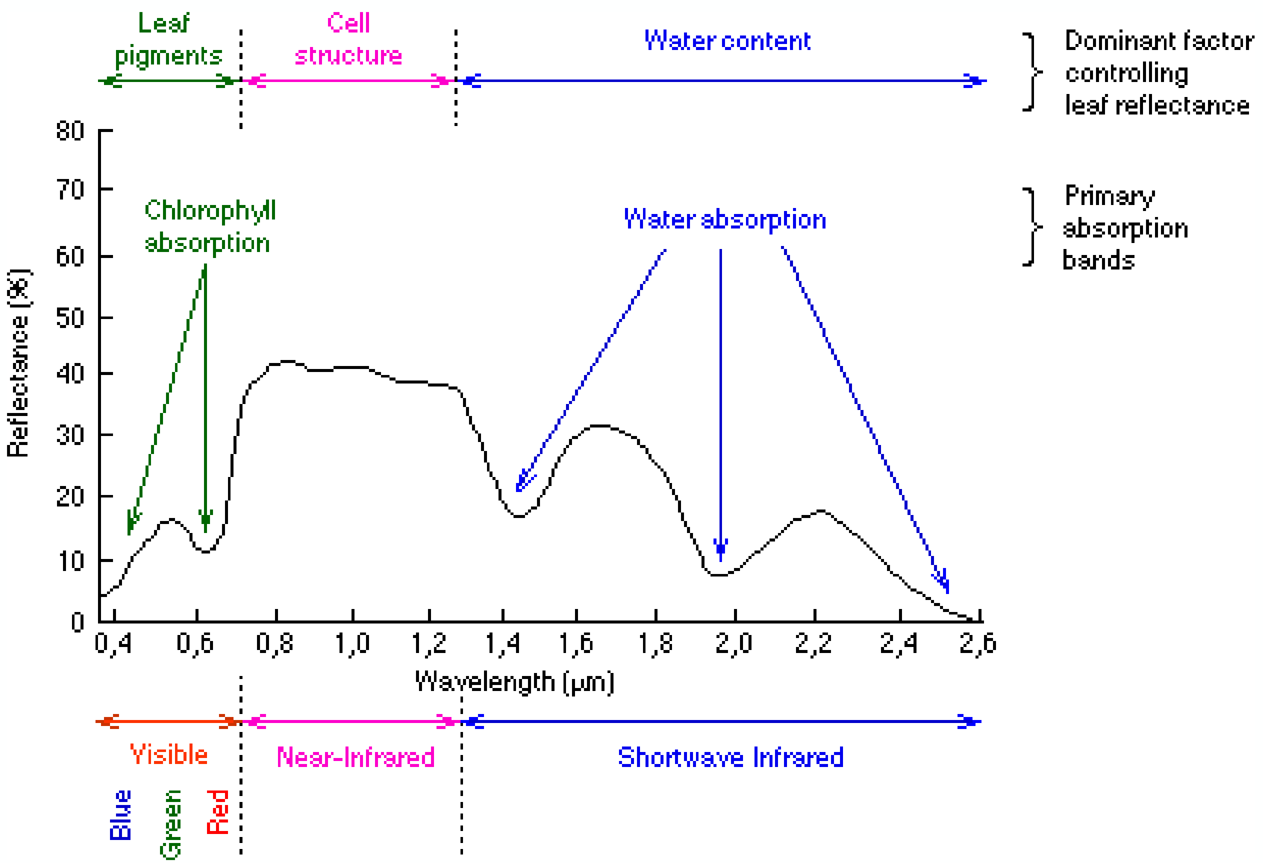
Strongly scatters NIR radiation to prevent cell damage





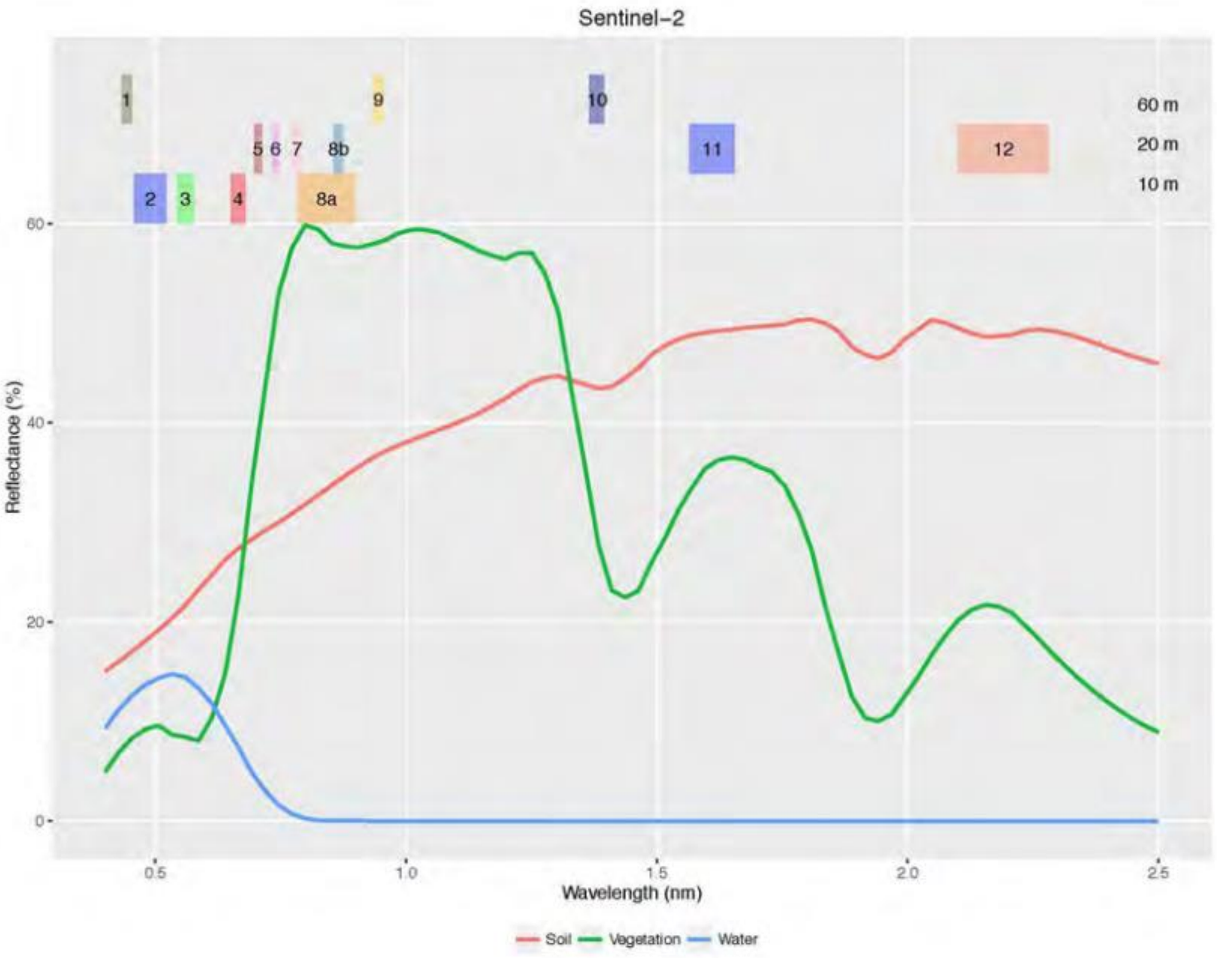
Vegetation spectra

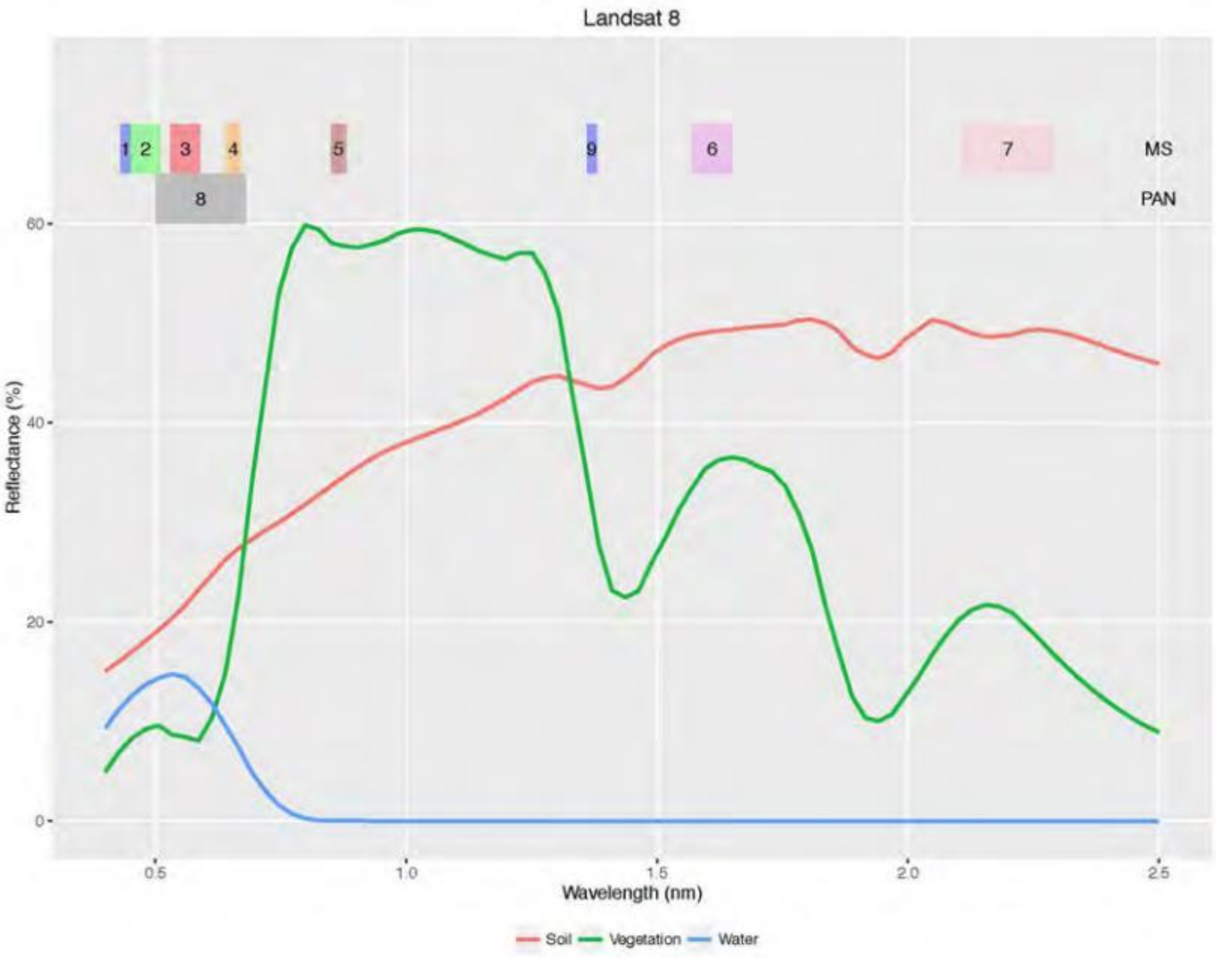
- Particular wavelengths are sensitive to particular chemicals and compounds
- Result in absorption features
- Make measurements related to those compounds
- Indices take advantage of these wavelength features



Interaction with vegetation and water

Sentinel-2 and Landsat 8 bands





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 (mono-temporal or multi-temporal)
- Atmospheric correction
- Reprojection
- Resampling
- Co-registration

Cloud detection and removal

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

An image pixel can be:

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

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

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

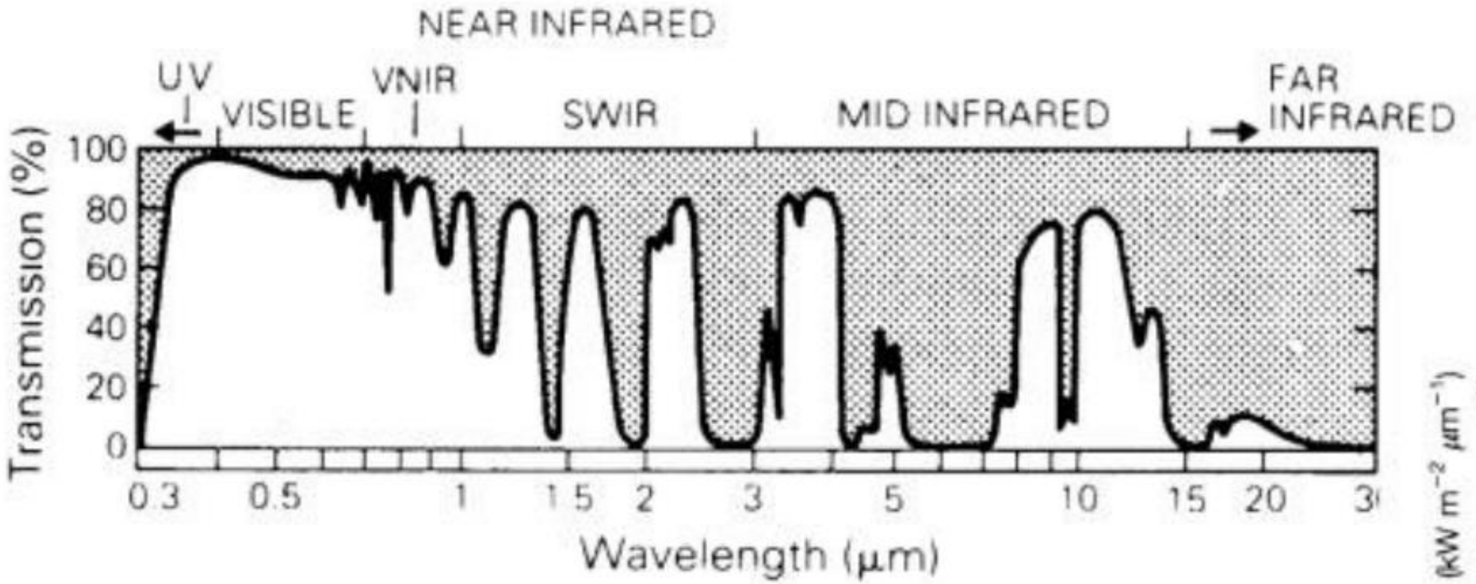
Interaction with the atmosphere

- 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.
- These effects are caused by the mechanisms of:
    - Scattering (Rayleigh – Mie)
    - Absorption

<u>Scattering</u> 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.

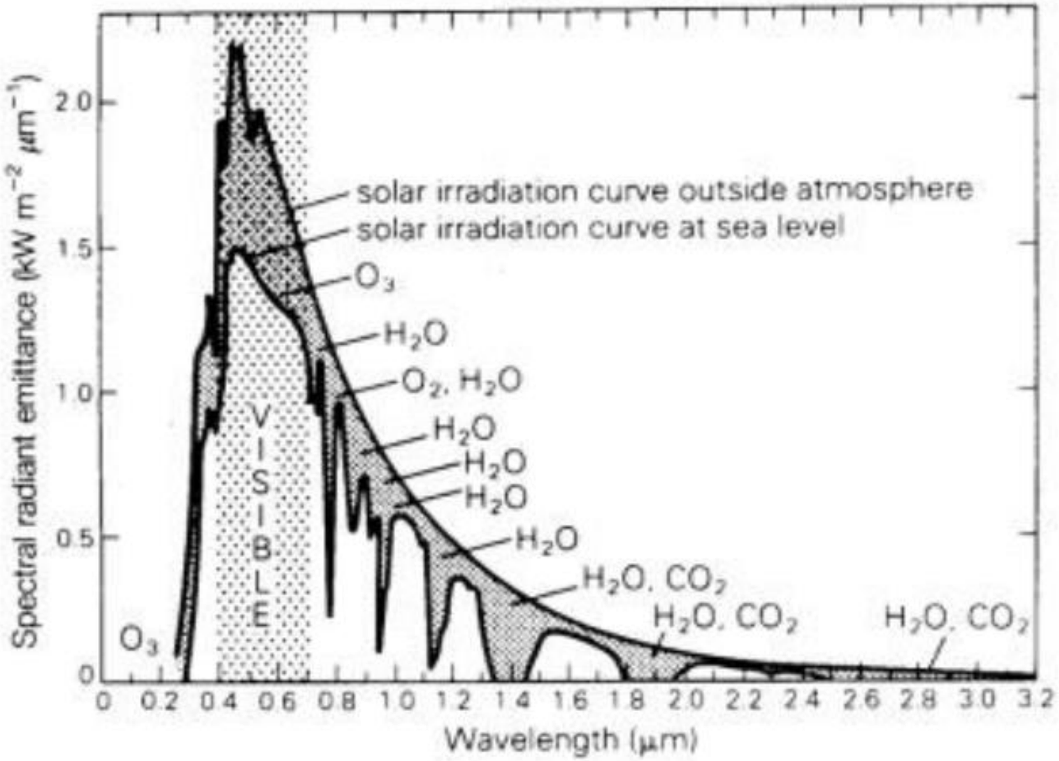
<u>Absorption</u> In contrast to scattering, this phenomenon causes molecules in the atmosphere to absorb energy at various wavelengths.

Atmospheric Windows



Some wavelengths are more effected by the atmosphere than others.

Those with little effect on signal are 'windows' for remote sensing.



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?

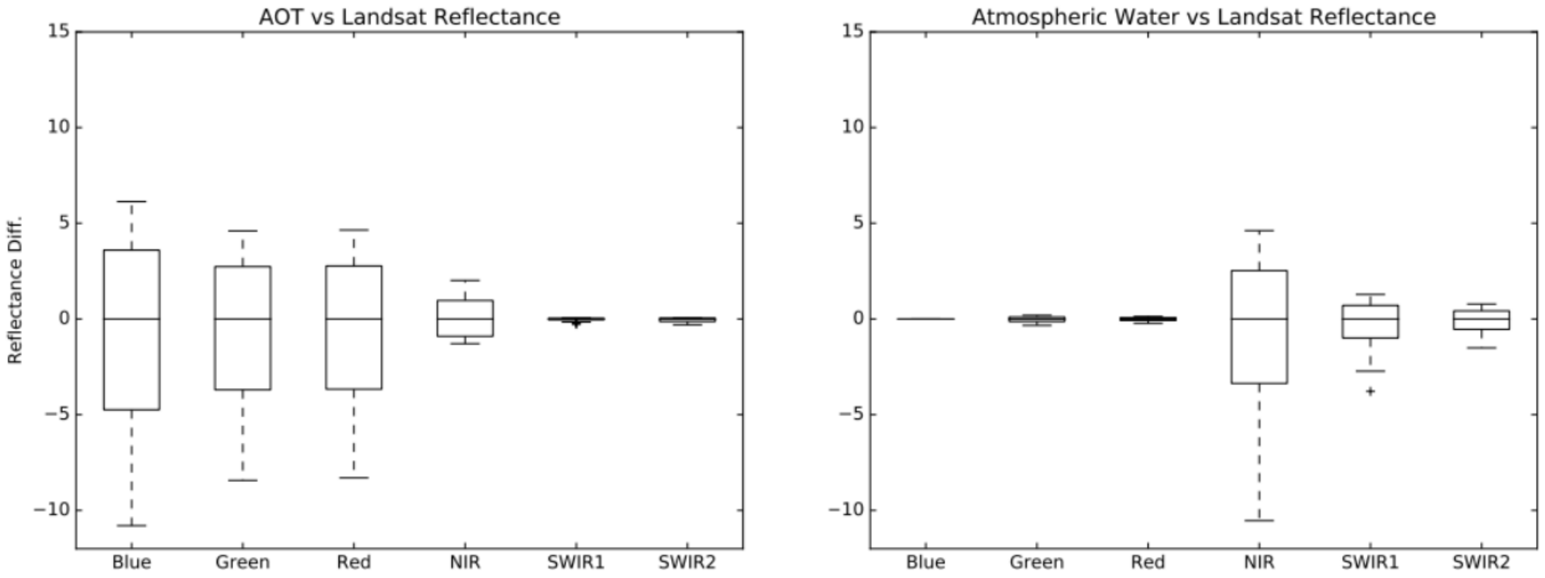
Aerosols

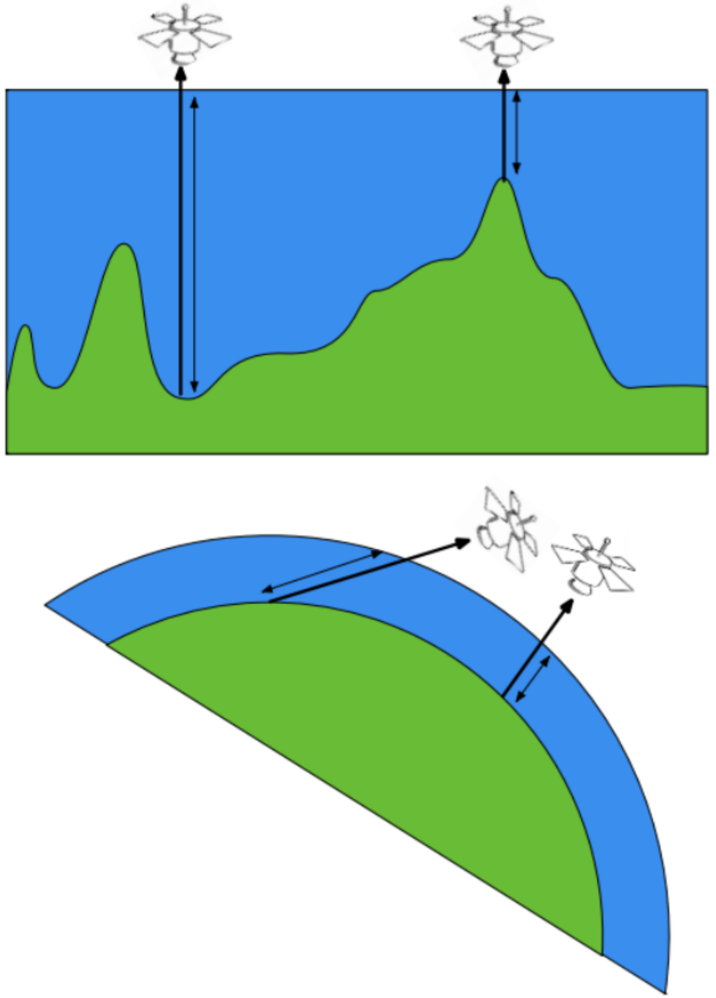
- E.g., fine dust, sea salt, water droplets, smoke, pollen, spores, bacteria.
- Has a significant effect on the visible wavelengths (Blue, Green and Red).
- Aerosol Optical Depth (AOD)
- Aerosol Optical Thickness (AOT)

Water Vapour

- Particularly, effects the SWIR bands

What effects atmospheric correction?





Relative contributions:

AOT = 80%

Water Vapour = 15%

Altitude = 4%

Cloud detection and removal

Sen2Cor (developed by Telespazio Germany)

It is a mono-temporal processor for Sentinel-2 L2A product generation and formatting. Uses a single L1C product as input data. The algorithm can create 4 different classes of clouds, together with classifications of shadows and ice. Additional outputs are Aerosol Optical Thickness (AOT) map, Water Vapour map, and Scene Classification map. The program is available as SNAP plugin.

MAJA (developed by CESBIO/CNES)

The most significant difference of MAJA is being a multi-temporal processor, which means that it uses multiple L1C images of the same area in time series, this method improves the accuracy of masking. It can process Landsat, Sentinel-2, and Venus products.

IdePix (developed by Brockmann Consult)

IdePix (Identification of Pixel) is a pixel identification tool. It needs a Sentinel-2 L1C product for masking. Like Sen2Cor, it is available as a SNAP plugin. So that it has similar advantages of Sen2Cor in terms of user-friendliness. In the output, the program provides one class for each pixel.

Fmask (developed by USGS)

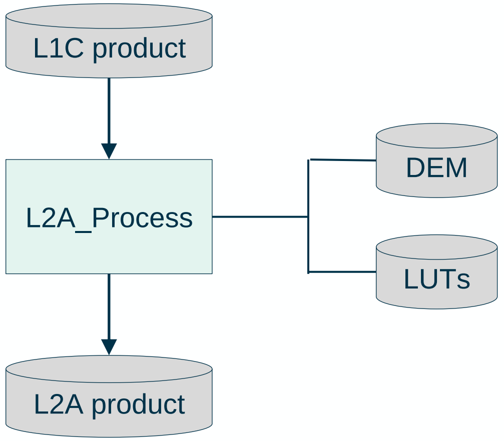
It is a pixel-based mono-temporal processor. Single L1C product is the input. It was initially developed for Landsat images but later extended for S2 images. Cloud, cloud shadow, snow, and water masking are possible with it. The program needs MATLAB environment.

Sentinel Hub's Cloud Detector

It is a single scene, a pixel-based program by a combination of Fmask, Sen2Cor, MAJA, and machine learning. It is available as a python package and doesn't have a GUI. The code is easy to follow with Jupyter-Notebook.

Sen2Cor – Overview

- Single image processing algorithm with orthorectified L1C granule in input
- Cloud Screening and Classification
- Atmospheric Correction over land surface (inherited from ATCOR DLR)
- Radiative Transfer code: LibRadtran (Look-Up-Tables)
- Python application:
    - Command line tool
    - Plug-in of SNAP
    - Integrated in S2 Ground Segment
- Processing configuration: 3 XML files

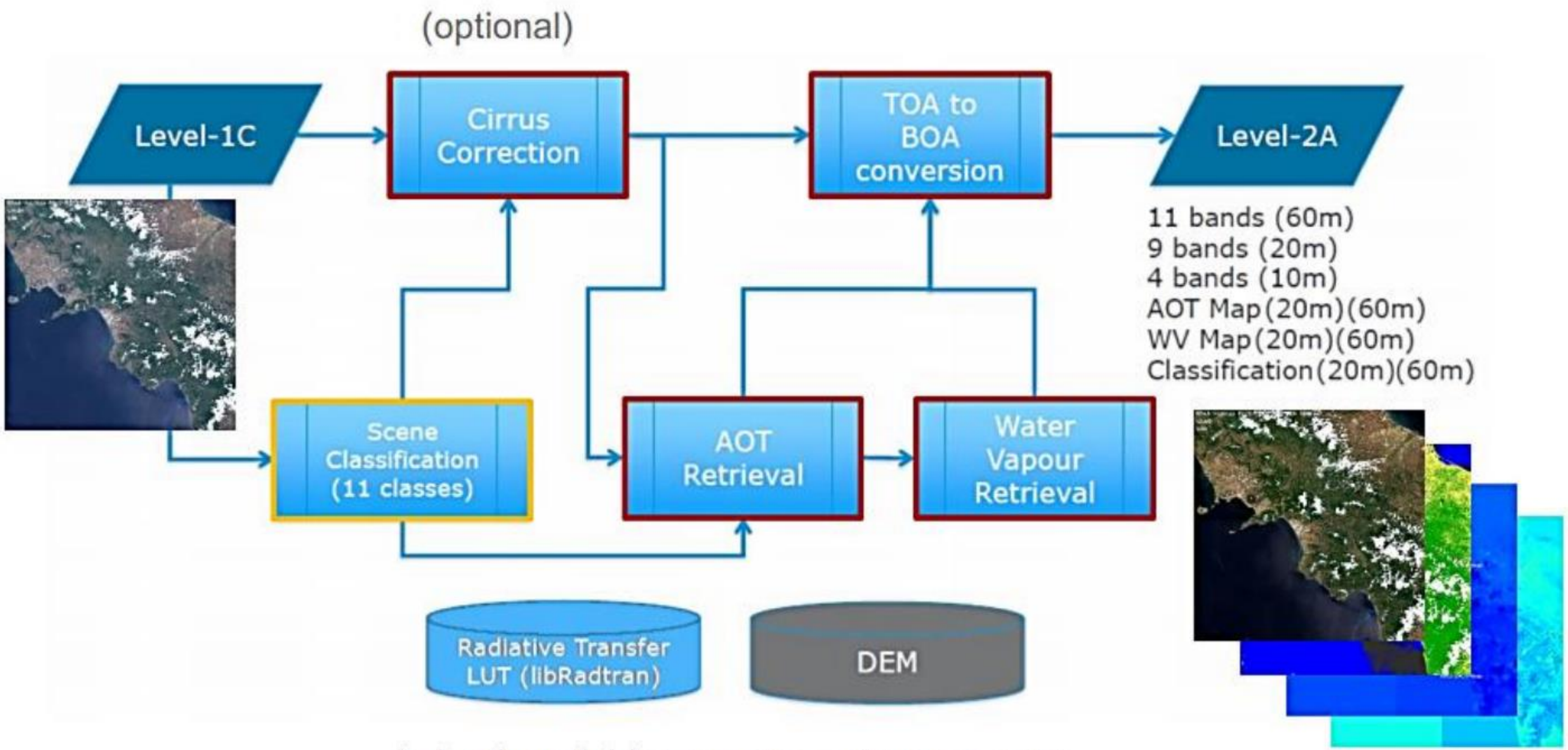


Using the Copernicus DEM@90m, the only differences between L2A "Toolbox" and L2A "Core" Products are reported in the table

Category of Difference	Difference	L2A Toolbox	L2A Core Products
Product Format	HTML Folder	No	Yes
	Manifest	Same Set of Items but arranged in different order	
	Product Quality Metadata	Copied from L1C	Generated by L2A On-line Quality Check (OLQC)
	JPEG2000 encoding library	OpenJPEG	Kakadu
	Processing baseline	99.99	Official, e.g. 04.00

The evolution of the processing baseline used to process Sentinel-2 L2A Core Products in Ground Segment are reported in the L2A Data Quality Report

Sen2Cor – Main Processing Steps



- **Look-up tables** (rural & maritime aerosols)
- **DEM** (default: SRTM v4 CGIAR) (or DTED provided by user)

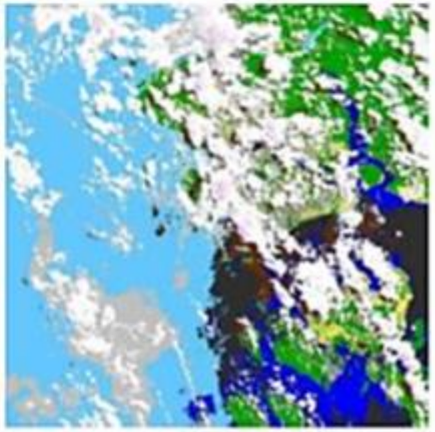
Sen2Cor – Cloud Screening and Classification

ESA CCI Support

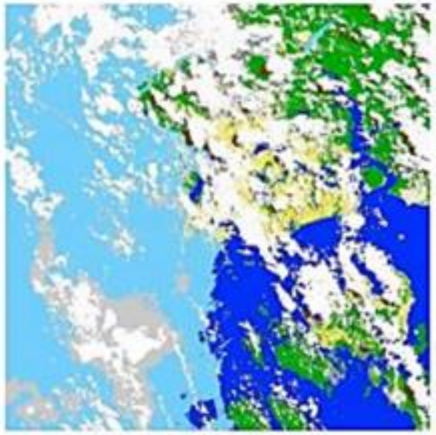
Satellite : S2A
Level: 1C
Type: RGB composition
Tile: 48NUG
Date: 20170730
Area: Singapore

ESA CCI Data Package:

- ESA CCI Land Cover (300 m)
- ESA CCI Water Bodies (150 m)
- ESA CCI Snow Occurrence (500 m)



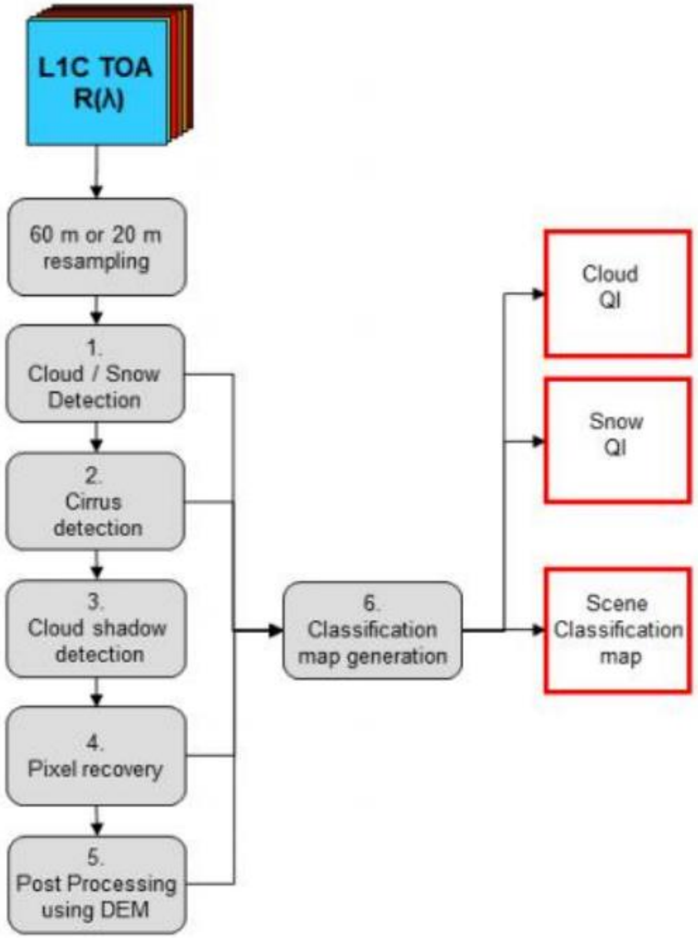
Without ESA CCI



With ESA CCI

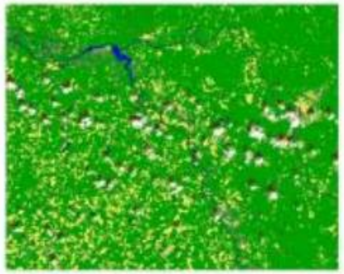
- Introduced with Sen2Cor version 2.5
- Water detection improved
- Bright targets (urban and soils)
  Less false cloud detection
- Activated in Sentinel-2 PDGS in October 2018 (L2A PB 02.09).

Sen2Cor – Cloud Screening and Classification



Cloud Confidence QI

Snow Confidence QI



Scene Classification

Label	Classification
0	NO_DATA
1	SATURATED_OR_DEFECTIVE
2	DARK_AREA_PIXELS
3	CLOUD_SHADOWS
4	VEGETATION
5	NOT_VEGETATED
6	WATER
7	UNCLASSIFIED
8	CLOUD_MEDIUM_PROBABILITY
9	CLOUD_HIGH_PROBABILITY
10	THIN_CIRRUS
11	SNOW

Sentinel-2 L2A data overview

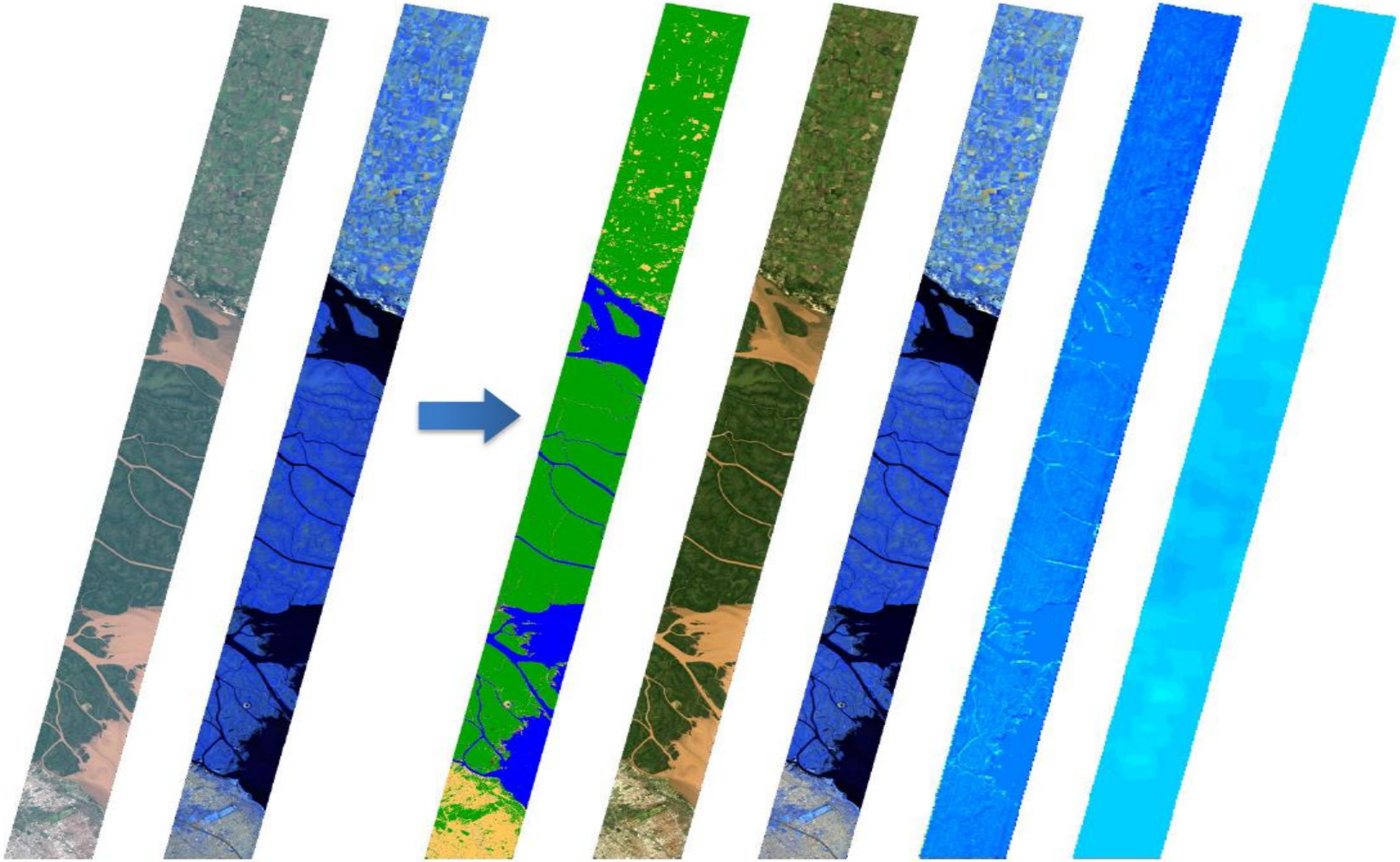
From left to right:

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*



Reprojection, resampling and co-registration

Reprojection

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

Resampling

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

Nearest Neighbour:

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

Bi-linear interpolation:

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

Cubic convolution:

- Pros: 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, even if the input data come from the same satellite/constellation, the coregistration is need specially if you work with VHR and HR data.

Why use time series

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

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

Time Series of Satellite observations offer opportunities:

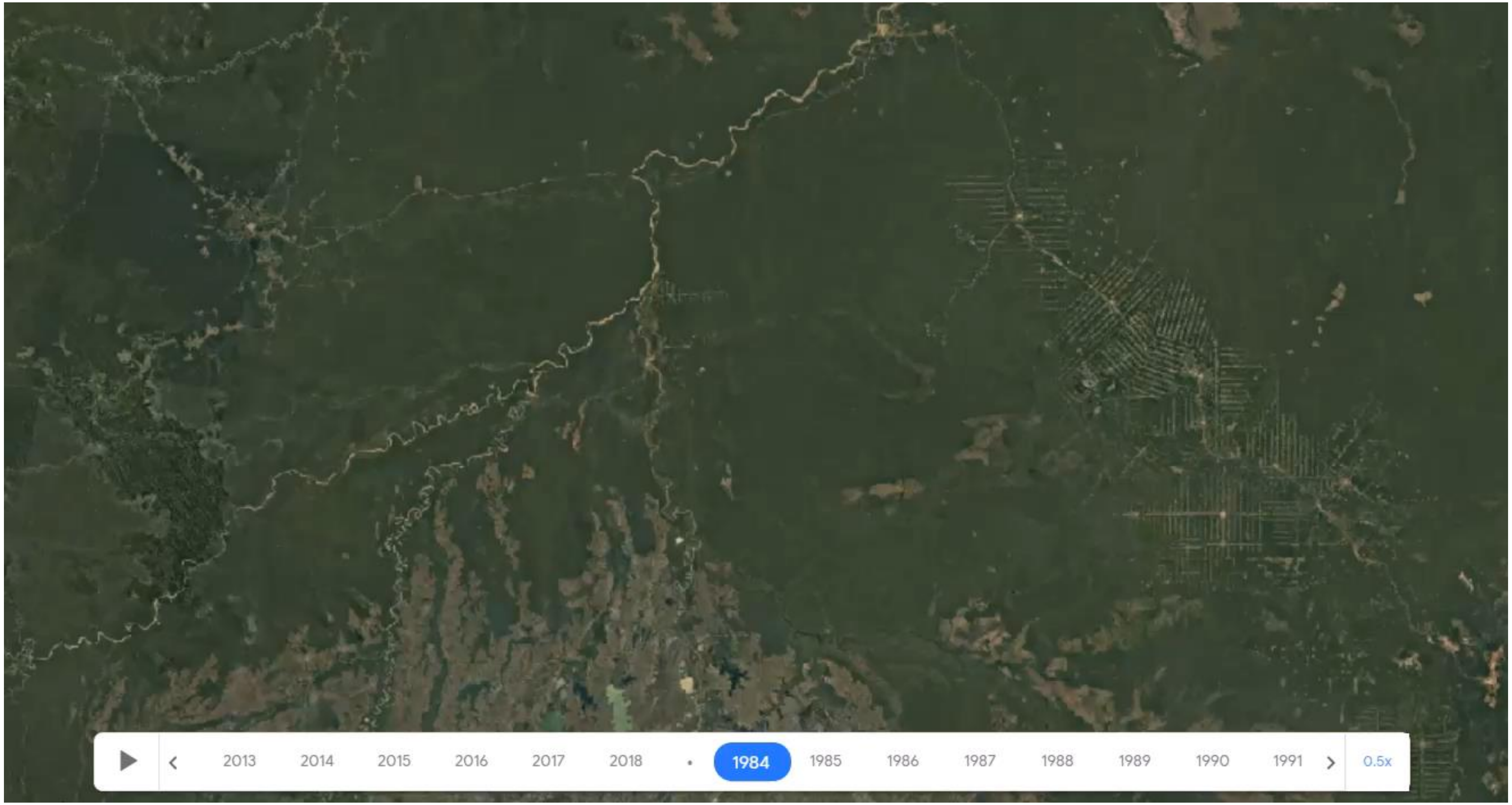
- for understanding how Earth is changing
- for determining the causes of these changes
- for predicting future changes

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.

Theewaterskloof Dam change by S2 time series

Rondônia deforestation by Landsat time series



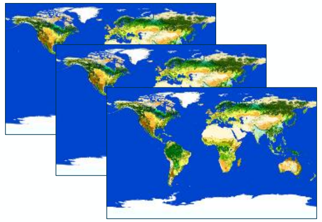
ESA CCI LandCover

Medium Resolution Land Cover products [300m]

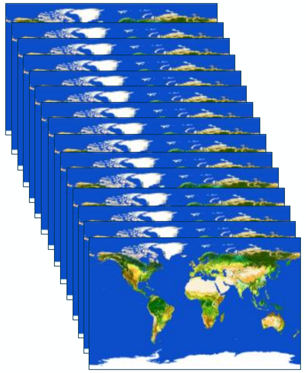
GlobCover 2005

GlobCover 2009

CCI LC epoch maps
2000 – 2005 - 2010



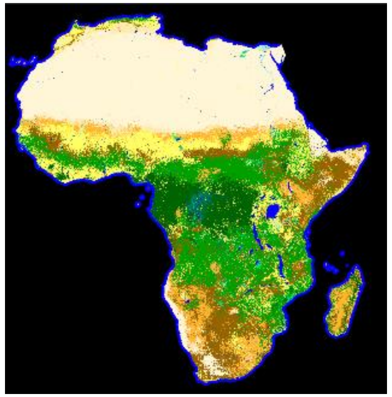
CCI LC yearly maps
1992 » 2015



From 2016 onwards C3S

High Resolution Land Cover products

S2A Prototype LC map - Africa 2016 @20m



S2A/B Prototype LC map
Mexico & Central America 2016-2017 @10m

ESA WorldCover 2020 & 2021

Temporal metrics to capture the time series information

Example of specific set of metrics (features) designed for crop monitoring

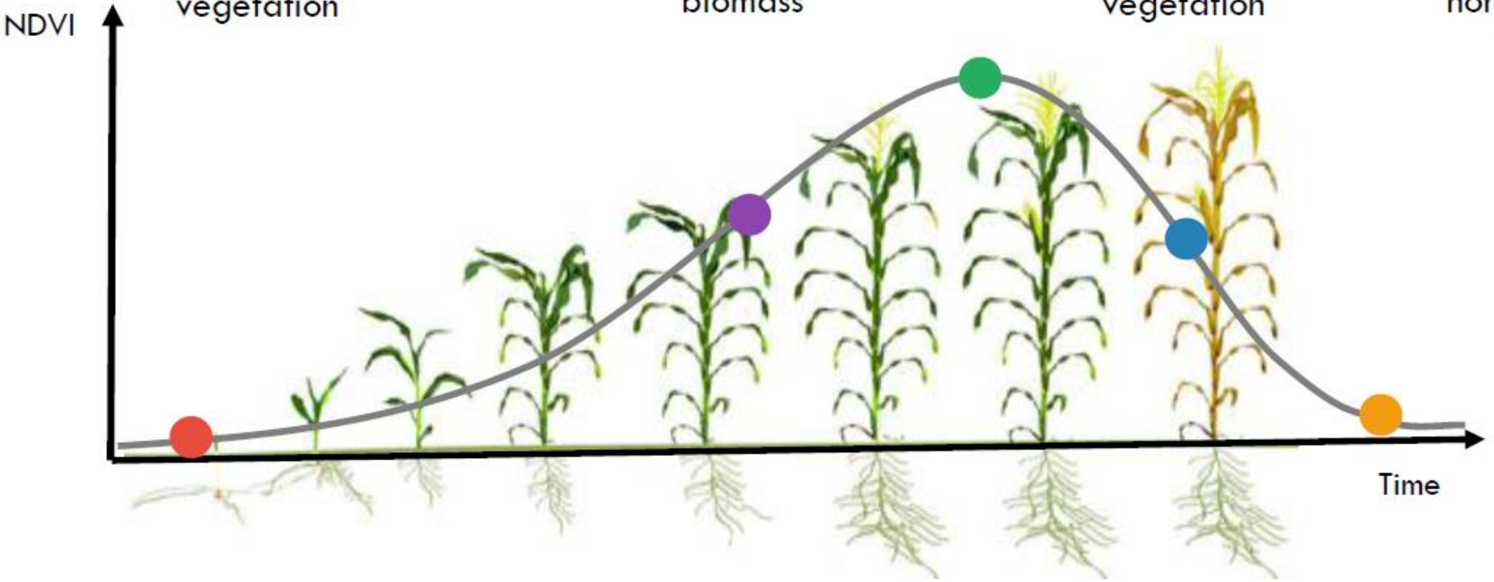
1 Maximum Red (average of 3 max.)
Bare soil at sowing preparation

2 Max. positive slope
Fastest growth of vegetation

3 Maximum NDVI (average of 3 max.)
Maximum green biomass

4 Max. negative slope
Fast reduction of vegetation

5 Minimum NDVI (average of 3 max.)
Harvested crop or non green residues



(Matton et al., 2015, Waldner et al., 2016, Lambert et al., 2016)

Vegetation Indices

A vegetation index is a quantitative measure used to measure biomass or vegetative vigour, usually formed from combinations of several spectral bands, whose values are added, divided, or multiplied in order to yield a single value that indicates the amount or vigour of vegetation.

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

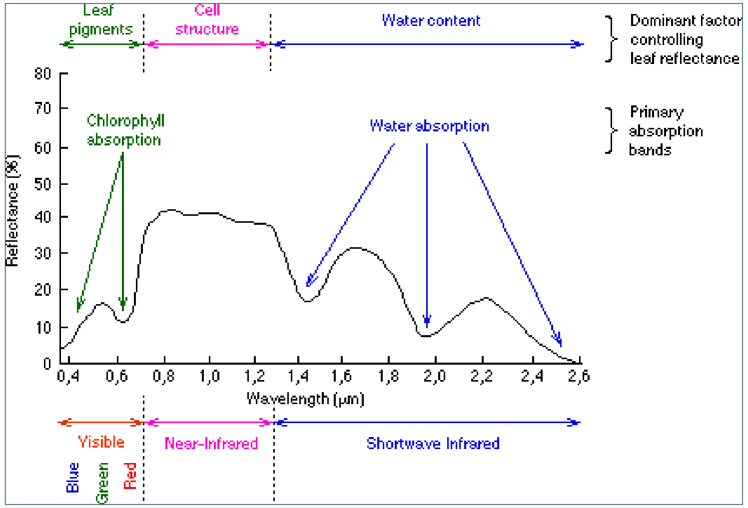
Normalized Difference Vegetation Index (NDVI)

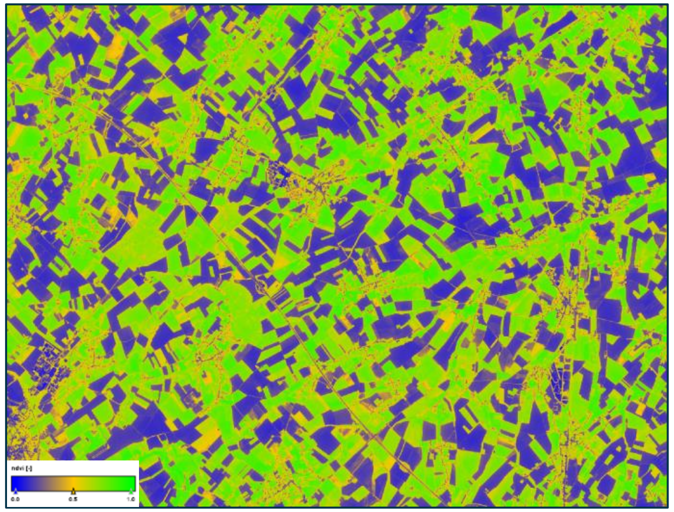
The Normalized Difference Vegetation Index (NDVI) algorithm exploits the strength and the vitality of the vegetation on the earth's surface.

Even if it is an old and classic method it is still much used to estimate the health of green vegetation and post processed high definition images for precision agriculture.

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

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

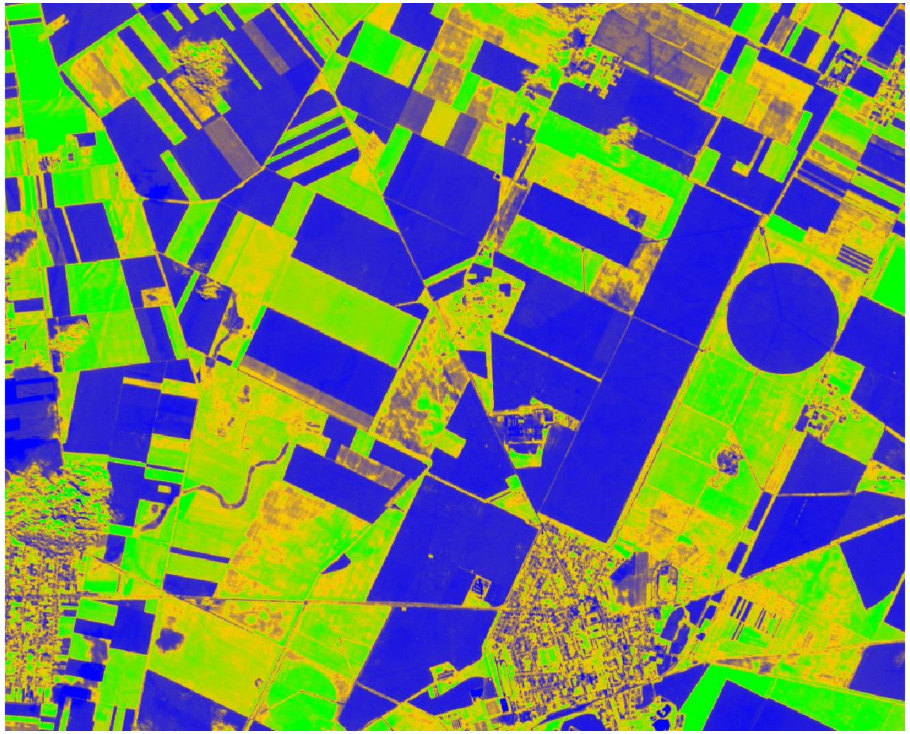




Enhanced Vegetation Index (EVI)

The enhanced vegetation index (EVI) is an 'optimized' vegetation index designed to enhance the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmosphere influences. EVI is computed following this equation:

$$EVI = G \times \frac{(NIR - Red)}{(NIR + C_1 \times Red - C_2 \times Blue + L)}$$



where:

- NIR/red/blue are atmospherically-corrected and partially atmosphere corrected (Rayleigh and ozone absorption) surface reflectances
- L is the canopy background adjustment that addresses non-linear, differential NIR and red radiant transfer through a canopy
- C1, C2 are the coefficients of the aerosol resistance term, which uses the blue band to correct for aerosol influences in the red band.

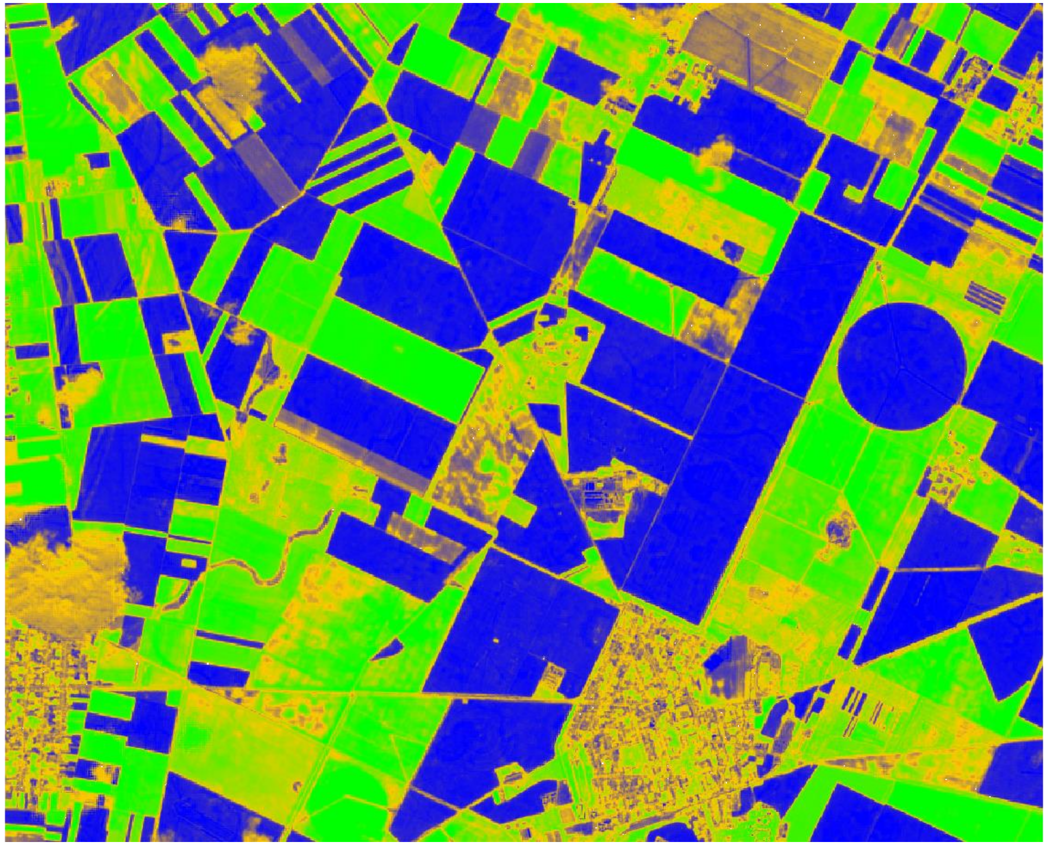
The coefficients adopted Sentinel-2 are: L=1, C_1 = 6, C_2 = 7.5, and G (gain factor) = 2.5.

Normalized Difference Moisture Index (NDMI)

The Normalized Difference Moisture Index (NDMI) detects moisture levels in vegetation using a combination of near-infrared (NIR) and short-wave infrared (SWIR) spectral bands. It is a reliable indicator of water stress in crops.

NDMI can detect water stress at an early stage, before the problem has gone out of hand. Further, using NDMI to monitor irrigation, especially in areas where crops require more water than nature can supply, helps to significantly improve crop growth.

$$NDMI = \frac{NIR - SWIR_1}{NIR + SWIR_1}$$



Biophysical Variables

SNAP L2B processor uses NN to estimate the biophysical variables, for each product, one particular network will be calibrated. Two main steps are foreseen:

- Training the neural network (Generating training data base; Defining the neural network architecture; Calibrating the network)
- Operational use of the neural network (Input consistency with the training data base; Output consistency with expected range; Quality indicators)

***LAI** - Leaf Area Index*

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

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

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

***FVC** - Fraction of Vegetation Cover*

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

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

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

***CWC** - Canopy Water Content*

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

Biophysical Variables of interest for agriculture

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

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

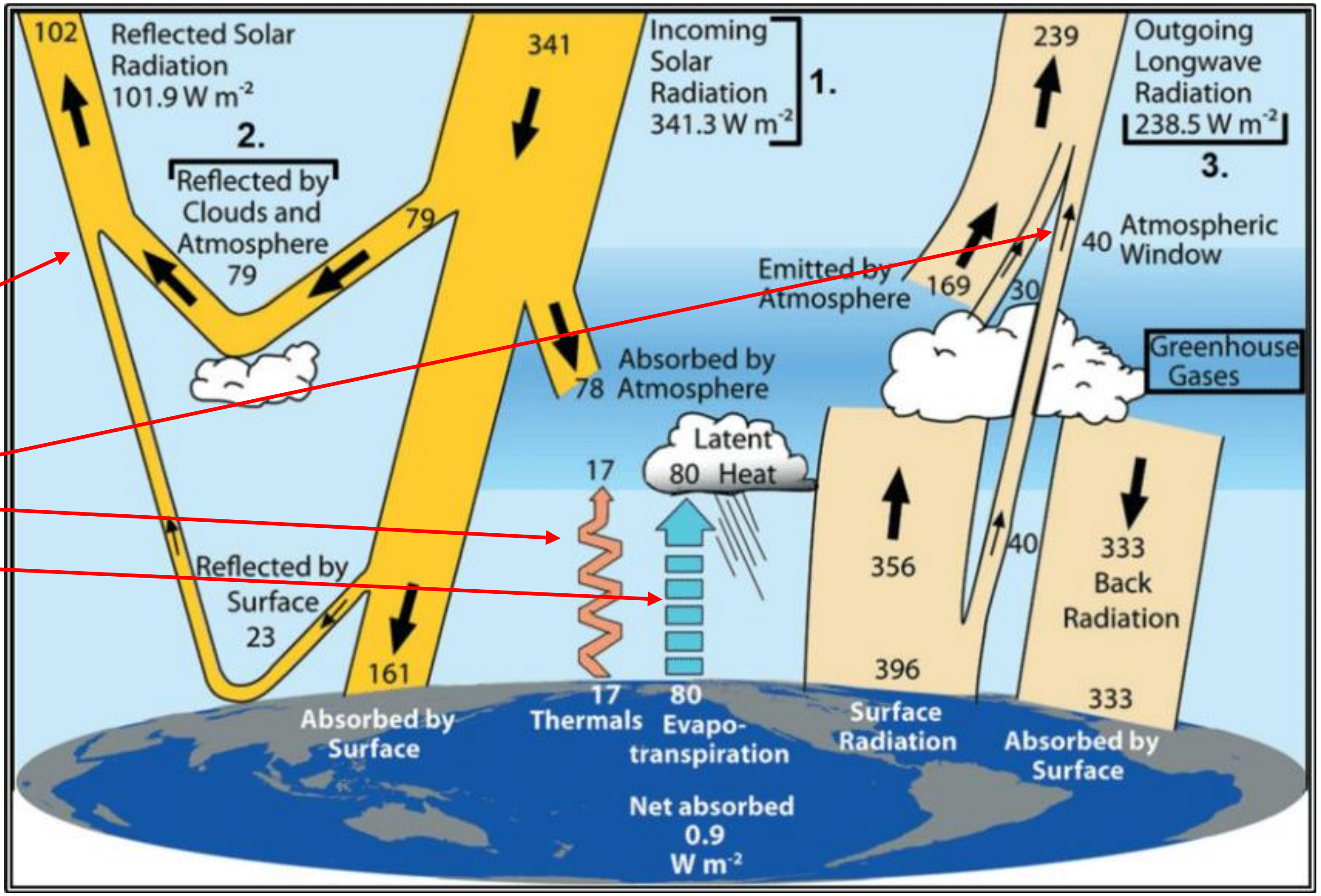
Monitoring the water cycle over land

Rainfall and surface energy balance

Earth’s global energy budget

- Numbers may slightly vary by different sources
- Role of atmosphere (greenhouse gases, atmospheric windows f(λ))
- Three forms of flux leave the surface:
  - Convective
  - Latent
  - Radiant

    (this is what we measure with EO)



Source: Trenberth, Fasullo & Kiehl (2009)

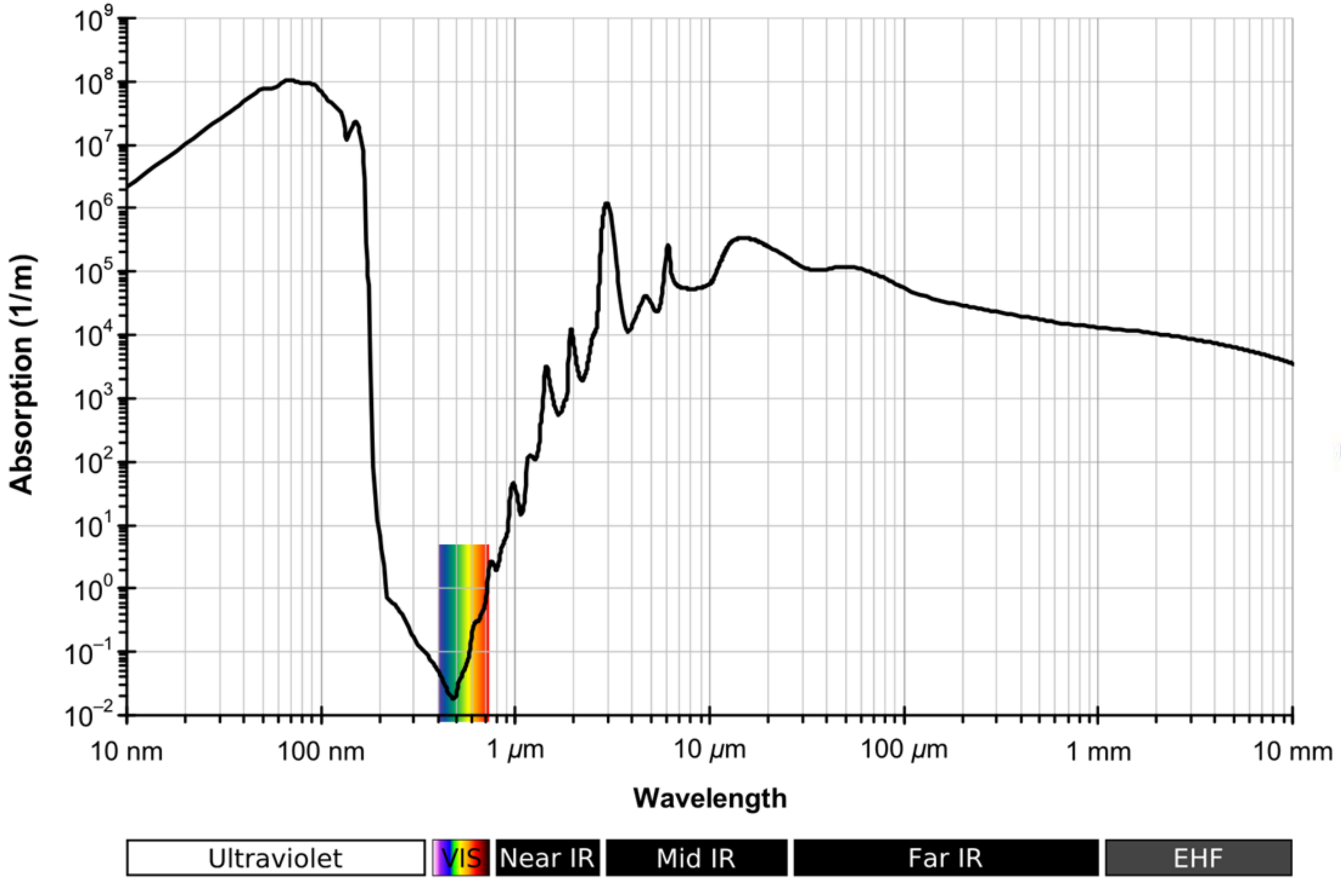
Remote Sensing data analysis

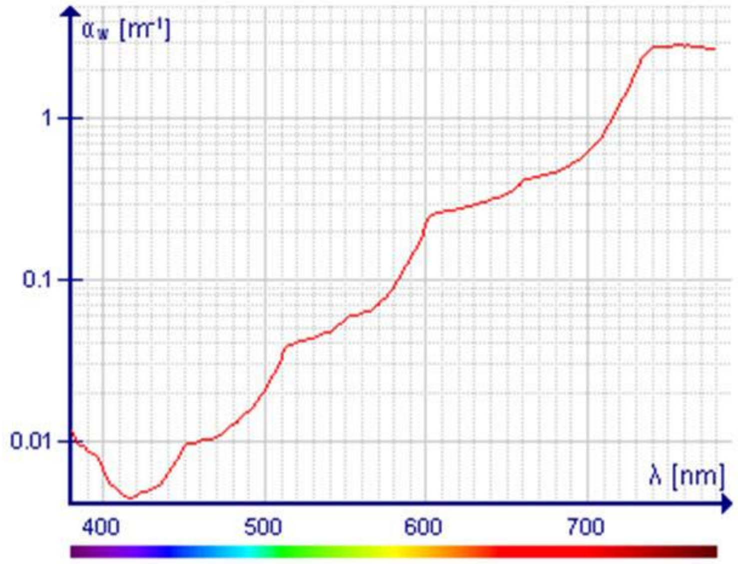
Deduction of data/information related to a selected field of interest (e.g., soil moisture) from the measured data (e.g., microwave intensity):

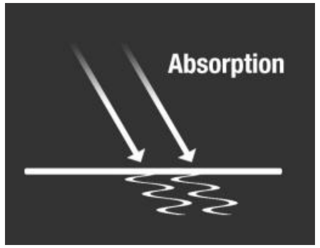
- Depends on the interaction between the analysed object of interest (e.g., top layer of the soil) and the measured physical signal (e.g., microwave backscatter)

- Usually needs auxiliary data related to:
  - Geometry of the measurement;
  - Known distortions/noises
    - Atmospheric effects,
    - Measurement system noises, etc;
  - Additional data not measurable by RS (e.g., incident energy from external source, air temperature, wind).

Interaction of liquid water and VIS – IR - TIR





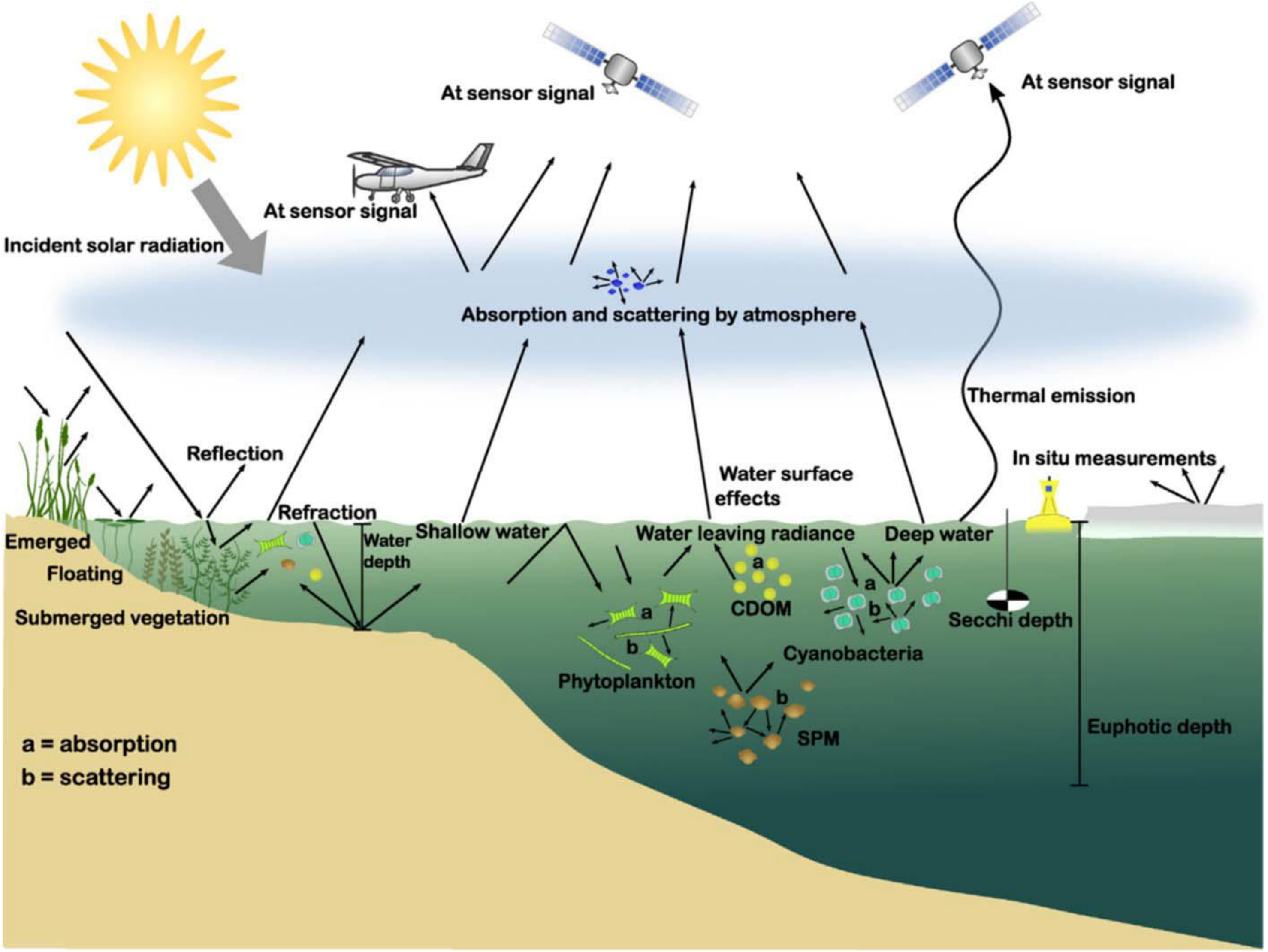


Absorption

- Low at the shorter λ in VIS
- Quickly increased from blue to TIR

Sources:
Kebes at English Wikipedia
NASA (2010)

Interaction of real water bodies and VIS



Complex interactions:

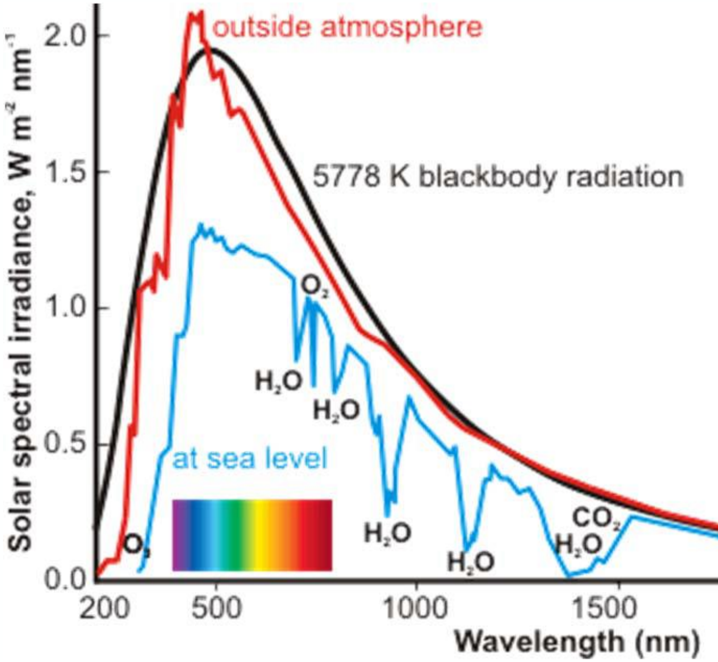
Reflection and refraction at the surface

Absorption by water and other dissolved and suspended/floating constituents

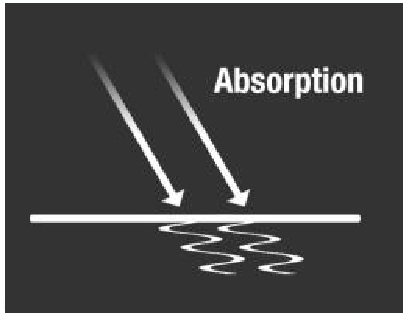
Scattering (backscatter) by suspended/floating constituents

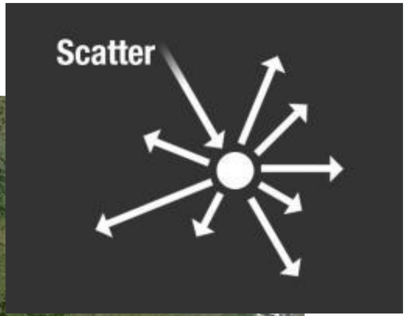
Source: Dörnhöfer & Oppelt (2016)

Interaction of water in the atmosphere and VIS - IR



Source: Chaplin (2018)





Absorption by vapour (gas), scattering by droplets (liquid and ice)

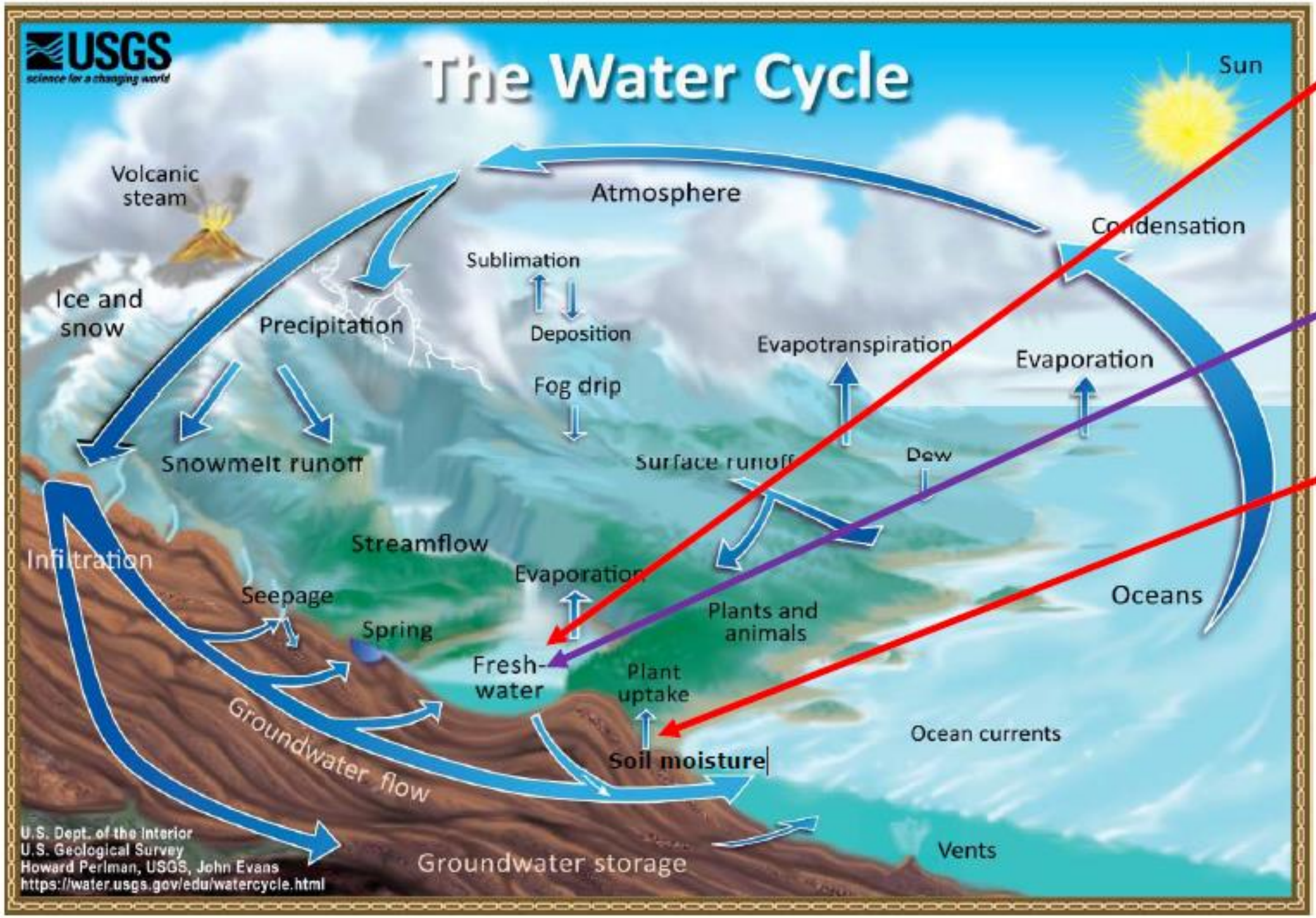
Source: www.wikiwand.com

Water and microwave

- H2O is a dipol molecule
- Effects microwave emission/backscatter
- The dielectric constant of water (~80) is very different from other natural materials of the surface (e.g. soil particles ~4)

- Problem: besides the dielectric properties, geometry of the surface (surface rougness) and scattering geometries effect the signal

Water cycle – how RS can see the state variables 1



Water surface:

- Radar backscattering
- Optical / thermal

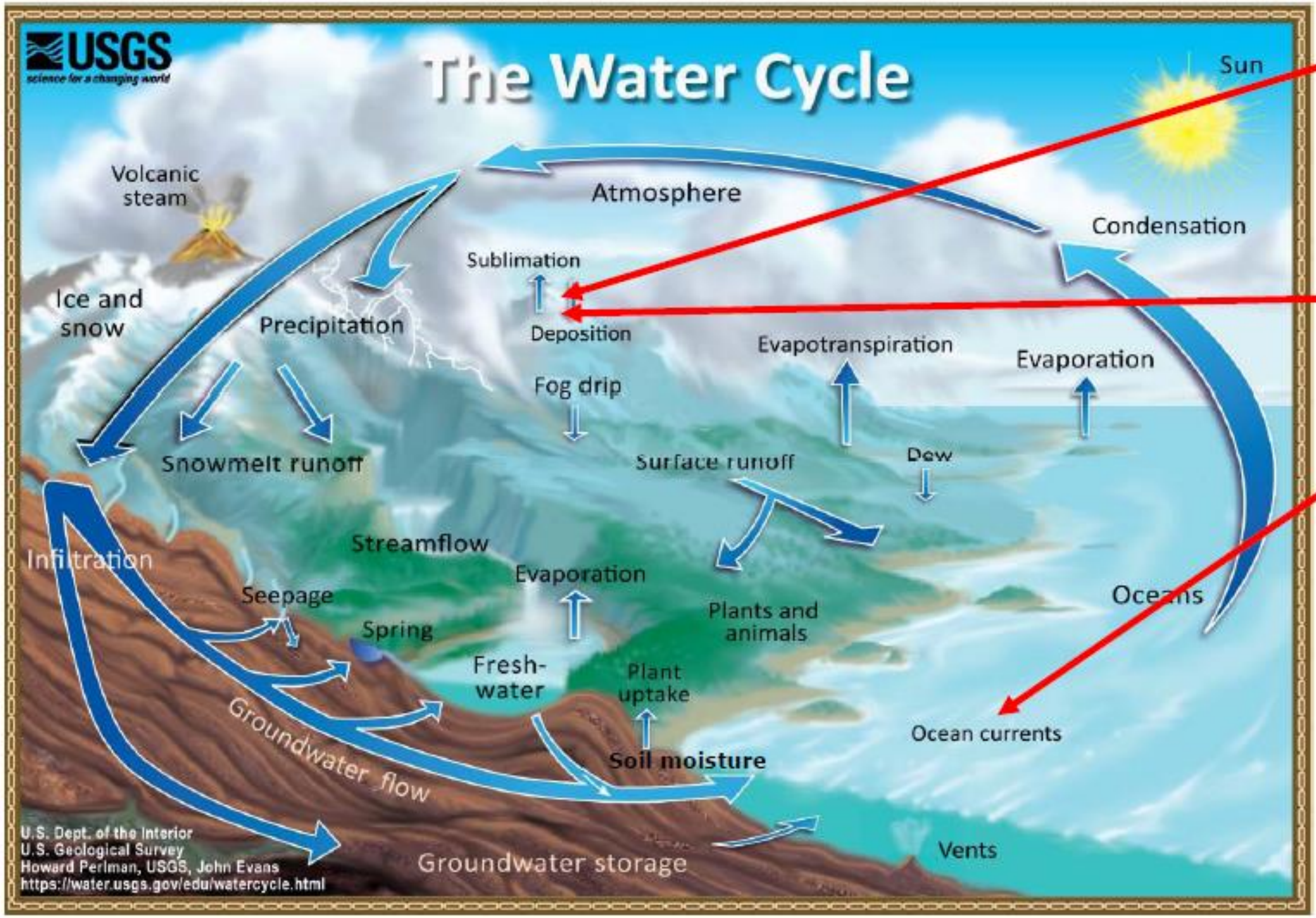
Water body volume:

- Proxy (water surface)

Soil moisture:

- Microwave (active/passive)

Water cycle – how RS can see the state variables 2



Ice/snow cover:

- Optical / thermal
- Microwave a/p

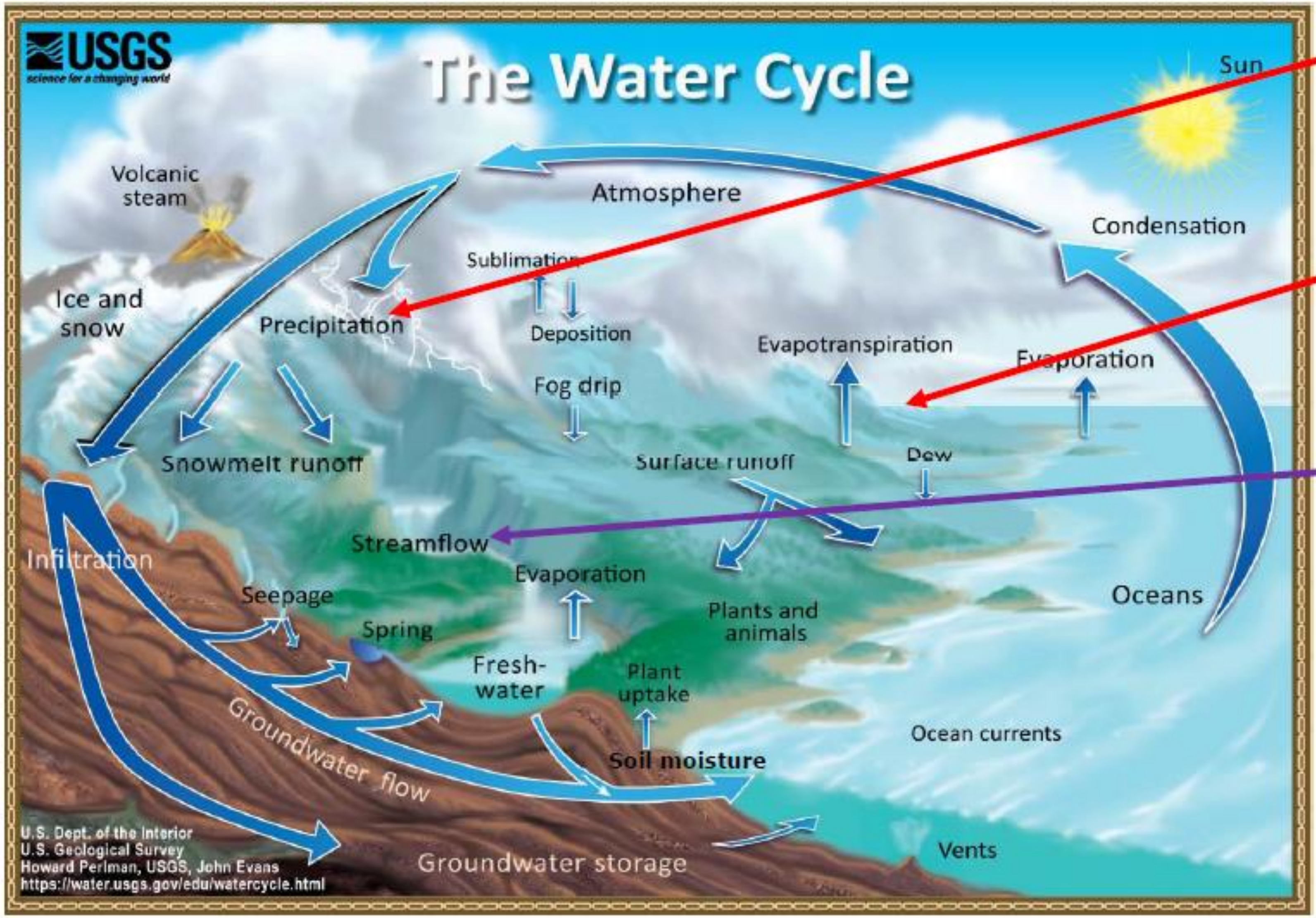
Snow water equivalent:

- Microwave a/p

Water quality:

- Optical / thermal

Water cycle – how RS can see the fluxes 1



Precipitation:

- Radar
- Cloud properties (T)

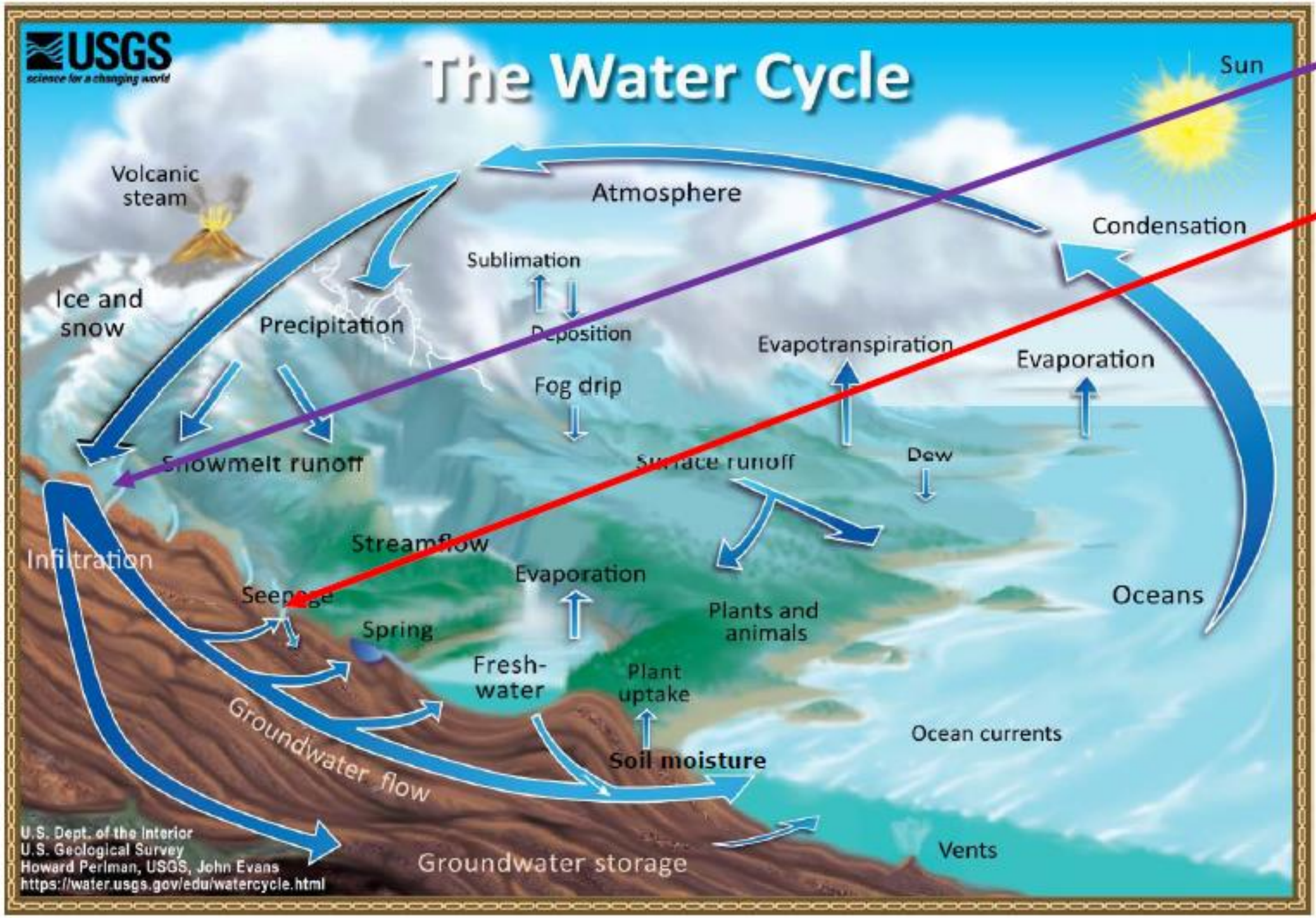
Evapo(transpi)ration:

- Estimation via land cover
- Surface energy balance

Streamflow (surface runoff):

- Proxy (water stage)

Water cycle – how RS can see the fluxes 2



Infiltration:

- Regional water balance

Seepage:

- Thermal
- Proxies (vegetation)

In general: simple and complex fluxes:

- Integration of RS & models

Precipitation mechanisms

Related to uplift of moist air

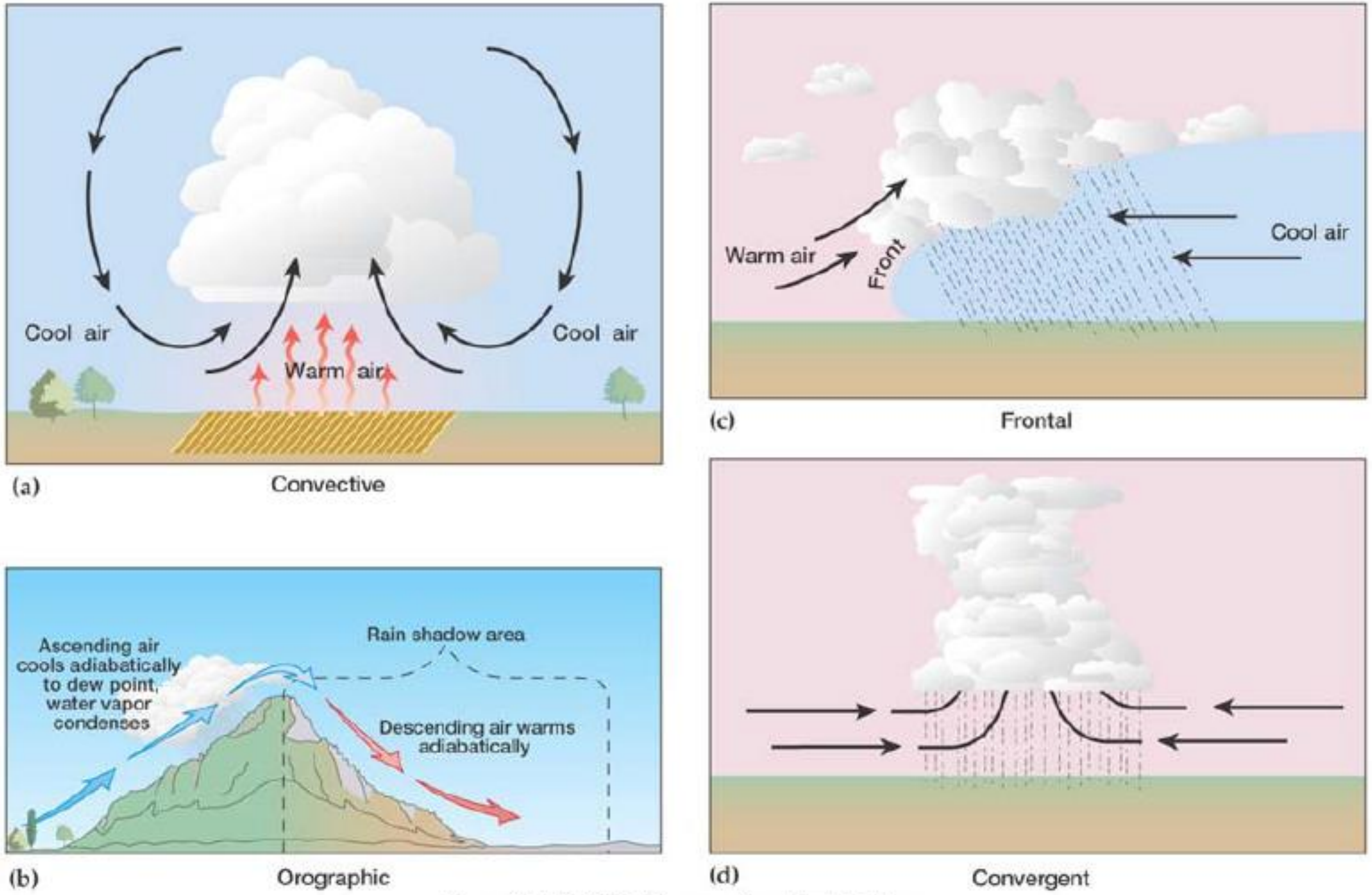
a) Convective uplift (e.g., summer storms)

b) Orographic

c) Frontal (cold, warm and occluded)

d) Convergent (cyclonic)

Various meteorological circumstances result in different forms of precipitation, e.g., drizzle, rain (liquid); snow, hale (solid)



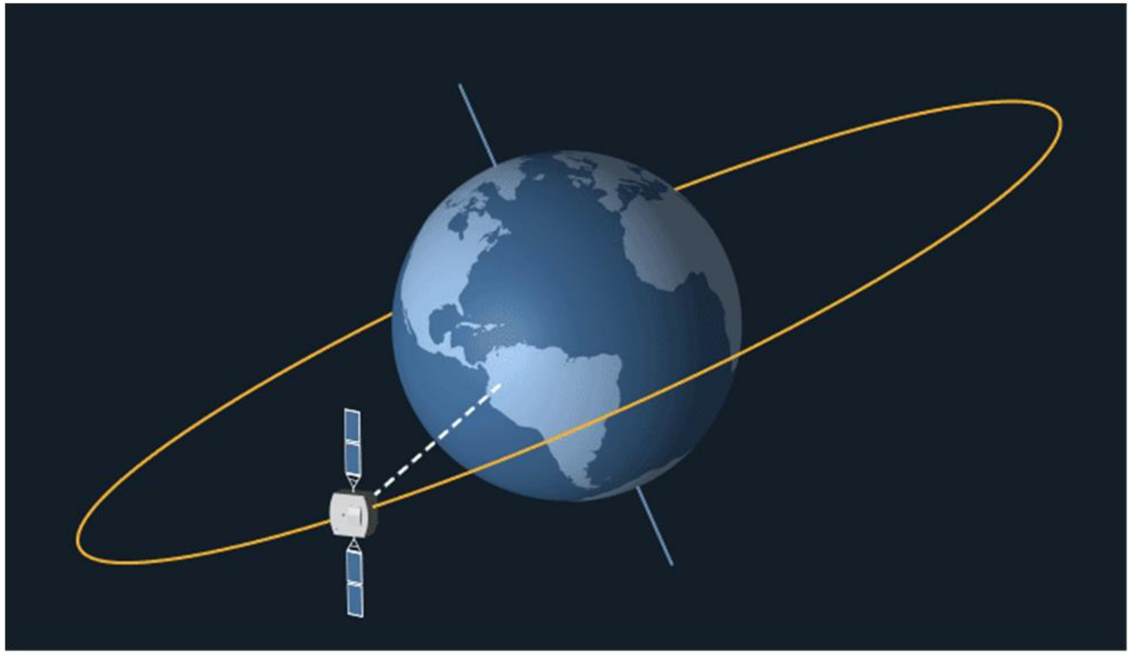
Source: http://web.gccaz.edu/...

Satellite remote sensing of precipitation: orbits

Geostationary orbit:

- 36,000 km above the Equator
- 1-10 km spatial resolution
- 15-30 minutes temporal resolution
- Increasing geometric distortion towards the poles due to Earth curvature

Source: http://www.seos-project.eu/...



(Quasi)polar orbit:

- 200-1000 km above surface
- 1-1000 m spatial resolution
- 1-14 days temporal resolution (depending on constellation & geographic location)
- Less geometric distortion in an image due to Earth curvature

Source:https://dlmultimedia.esa.int/…

Precipitation – VIS / IR techniques

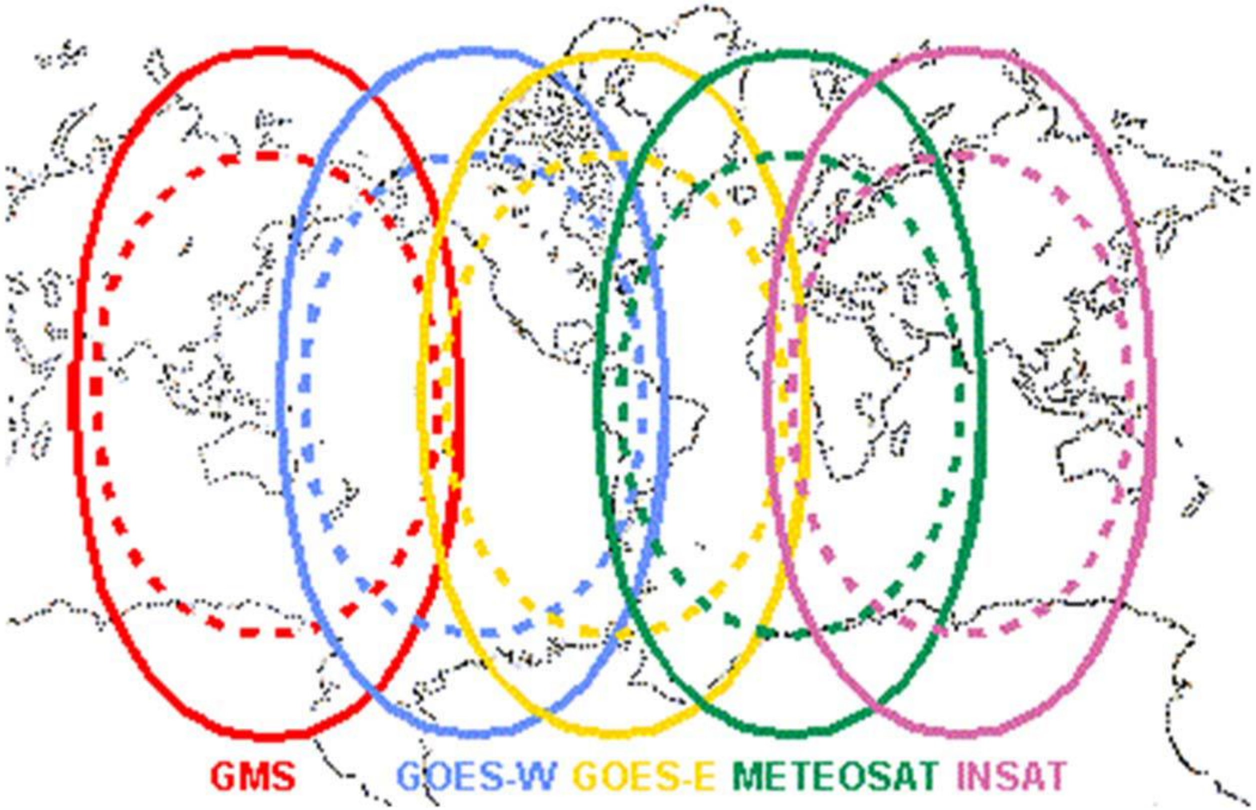
Based on outgoing long-wave radiation (OLR)

- Basis: Precipitation leading to outgoing longwave radiation different from normal background
- Empirical relationship: P~OLR
- Example: IR bands of AVHRR or NOAA-series satellites for OLR, explained 40% of the areal average rainfall variability.

Rainfall VIS / IR

GOES Precipitation Index (GPI)

- Basis: cold cloud-top temperature proportional to precipitation
- For pixels of cloud-top temperature (CCTs) less than 235 K are classified as raining pixel, and assigned a rainfall rate of 3 mm/hr
- Reproduce climate-scale precipitation patterns for tropics and sub-tropics
- But problematic for orographic and high-latitude precipitation



Passive microwave techniques

- Rain droplets scatter microwave

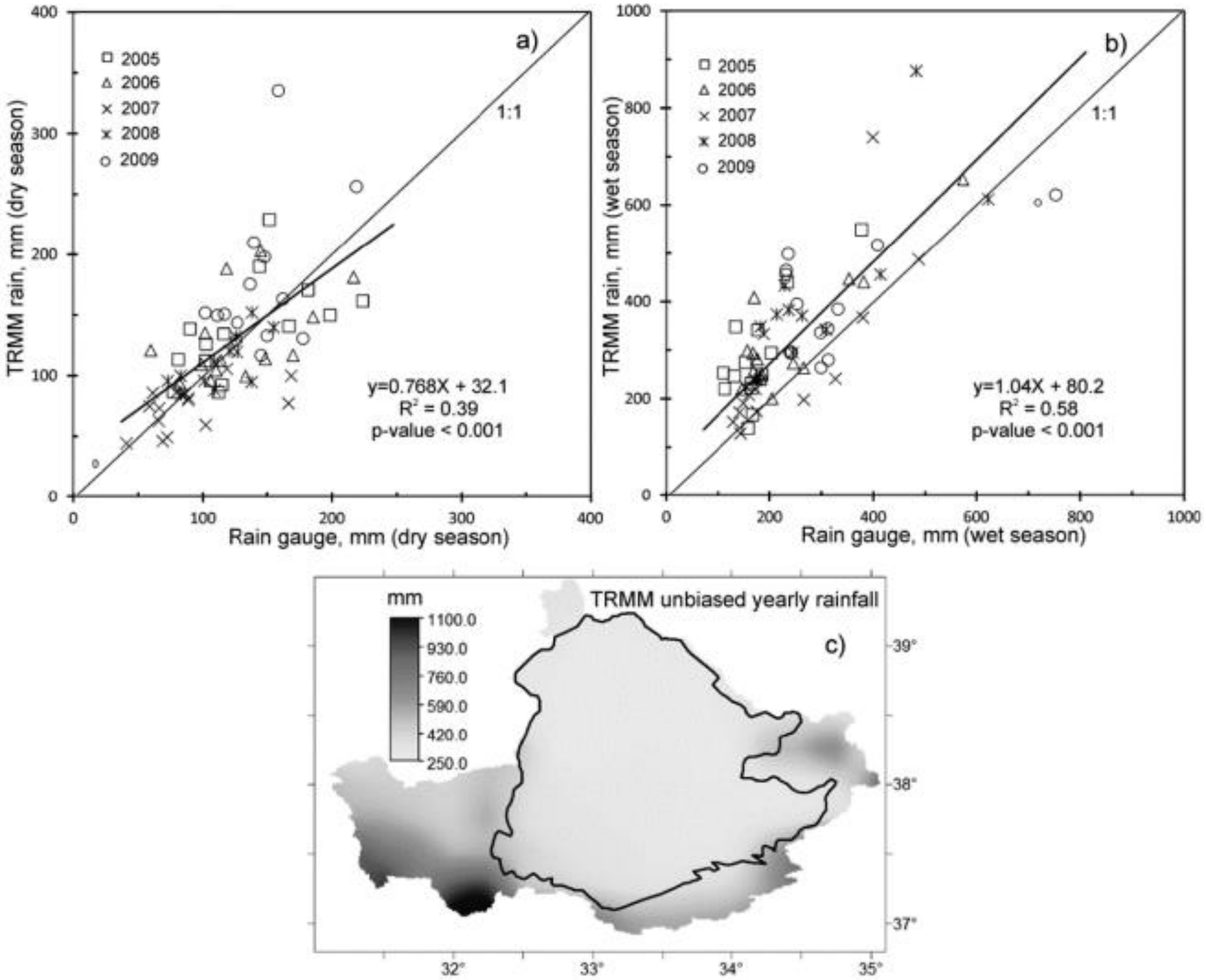
1) Over ocean clouds emit additional energy to the background, i.e., are „warmer" than the background

2) Over land the signal emitted by the surface is attenuated in the rain baring clouds

- The signal represents the whole air column, not only the rain at the surface.

- Coarse resolution (10-50 km)

Tropical Rainfall Measuring Mission data vs. raingauge

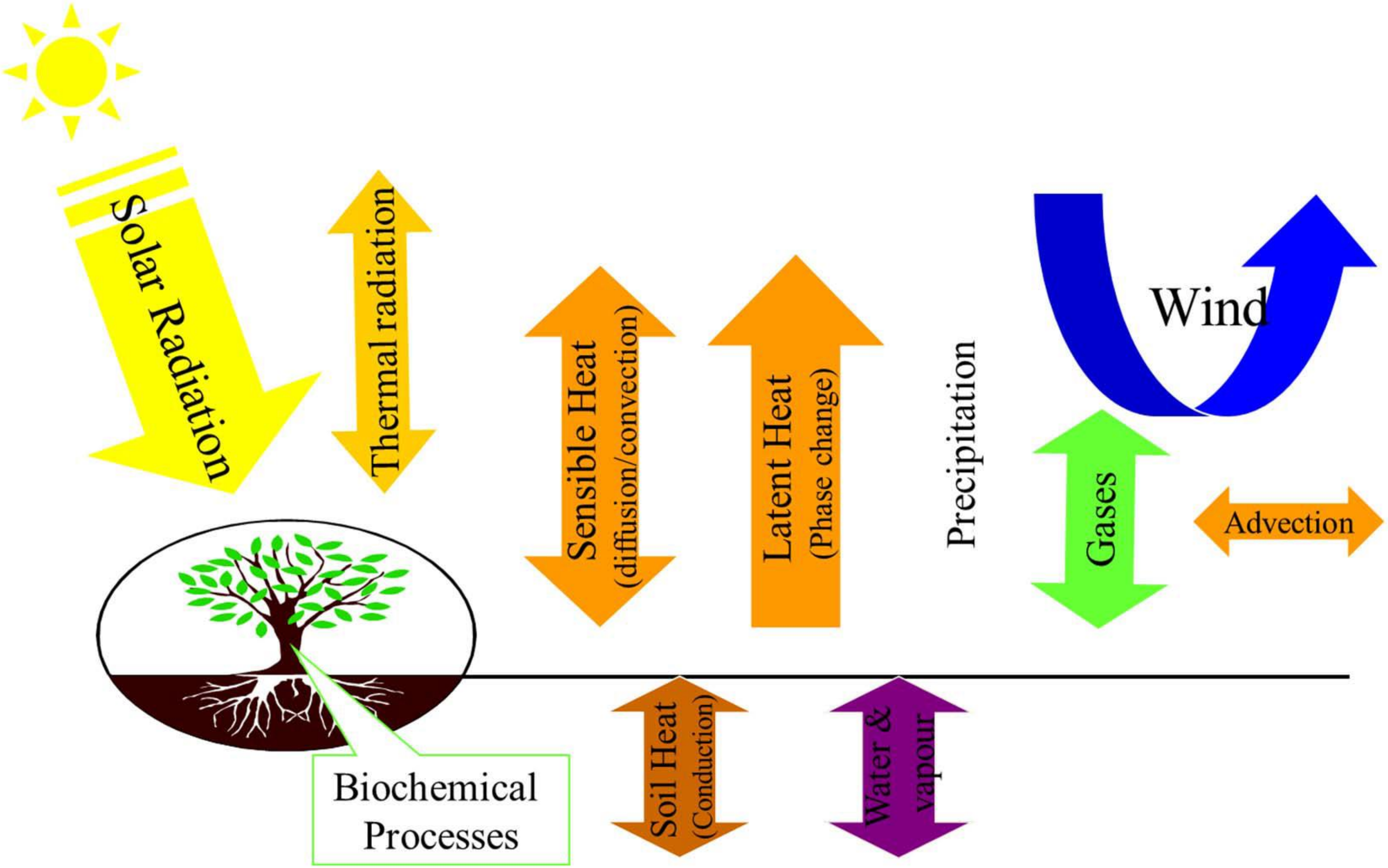


- TRMM PR (precipitation radar) - First rainfall radar
- 3 hourly and 7 day accumulated data
- Longer accumulation (>1 month) improves correlation with in situ gauge data
- Example: Konya basin, Turkey

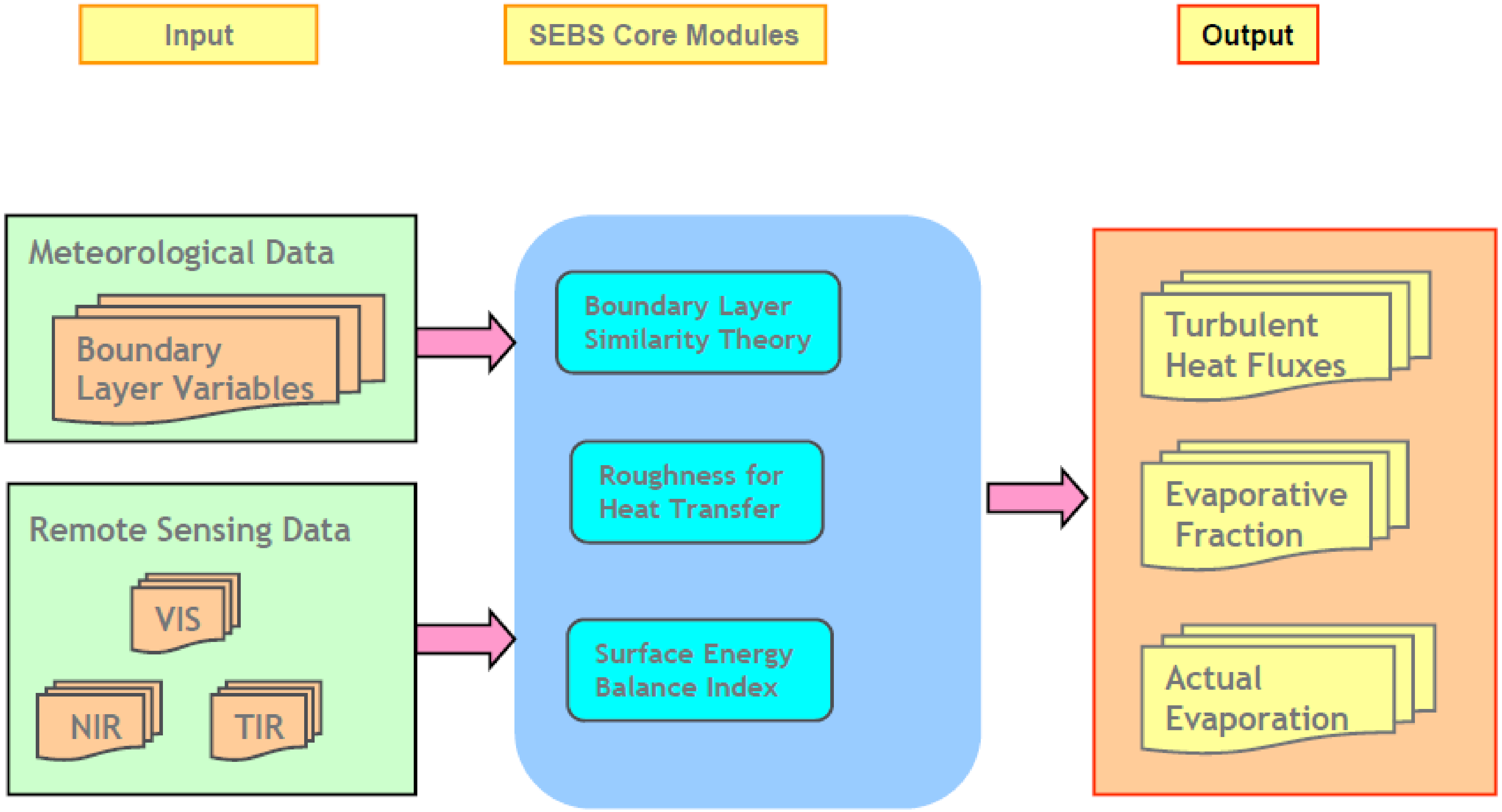
Source: Gokmen et al. (2013)

Surface energy balance - Evapotranspiration

Schematization of fluxes



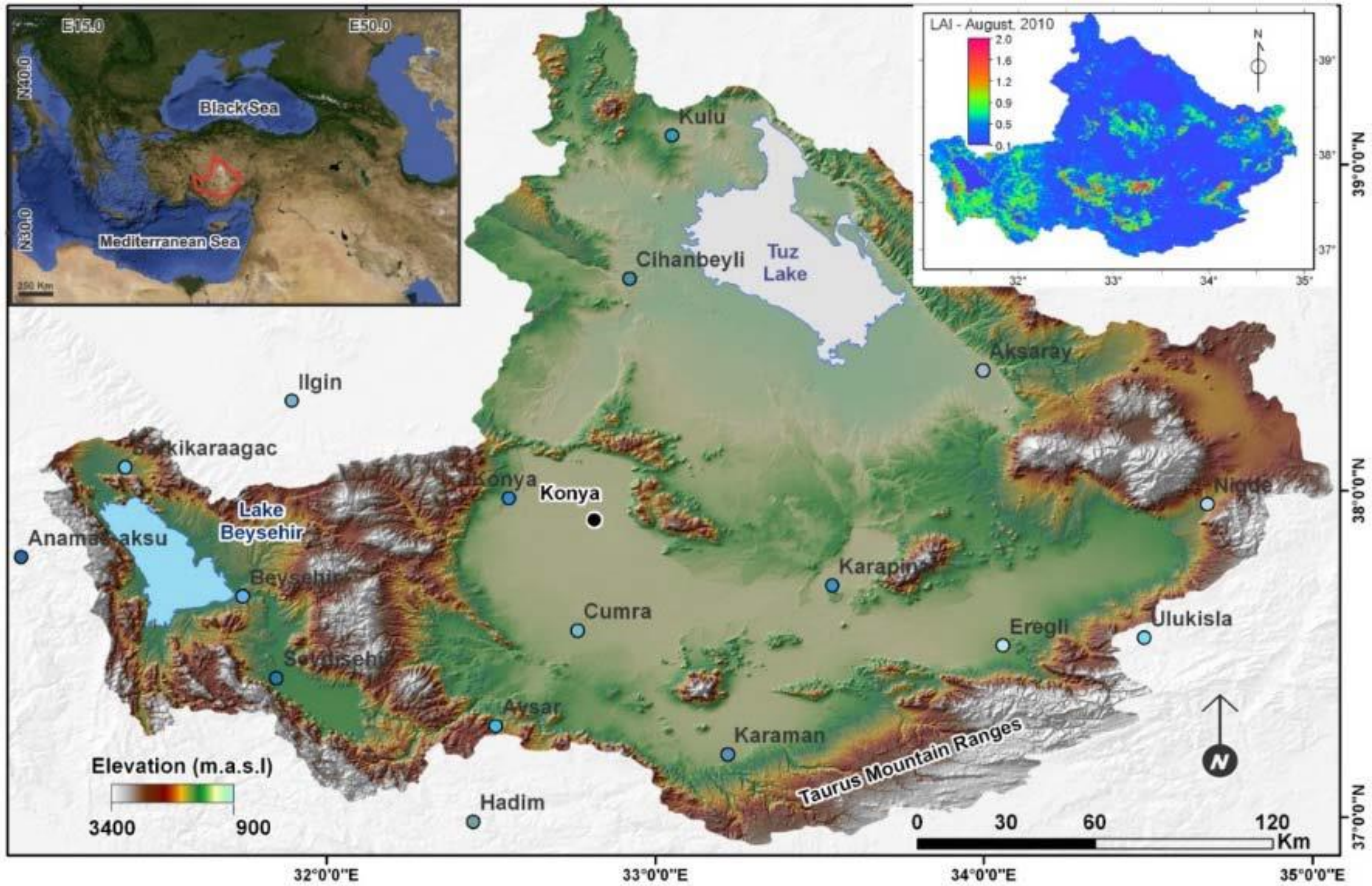
SEBS – Surface Energy Balance System



Case study: Konya Basin, Turkey

CALCULATING WATER BALANCE OF A CATCHMENT

The Konya closed basin, Turkey



Location, DEM and LAI of the Konya closed basin (KCB).
Locations of 18 meteorological stations are shown on the map.

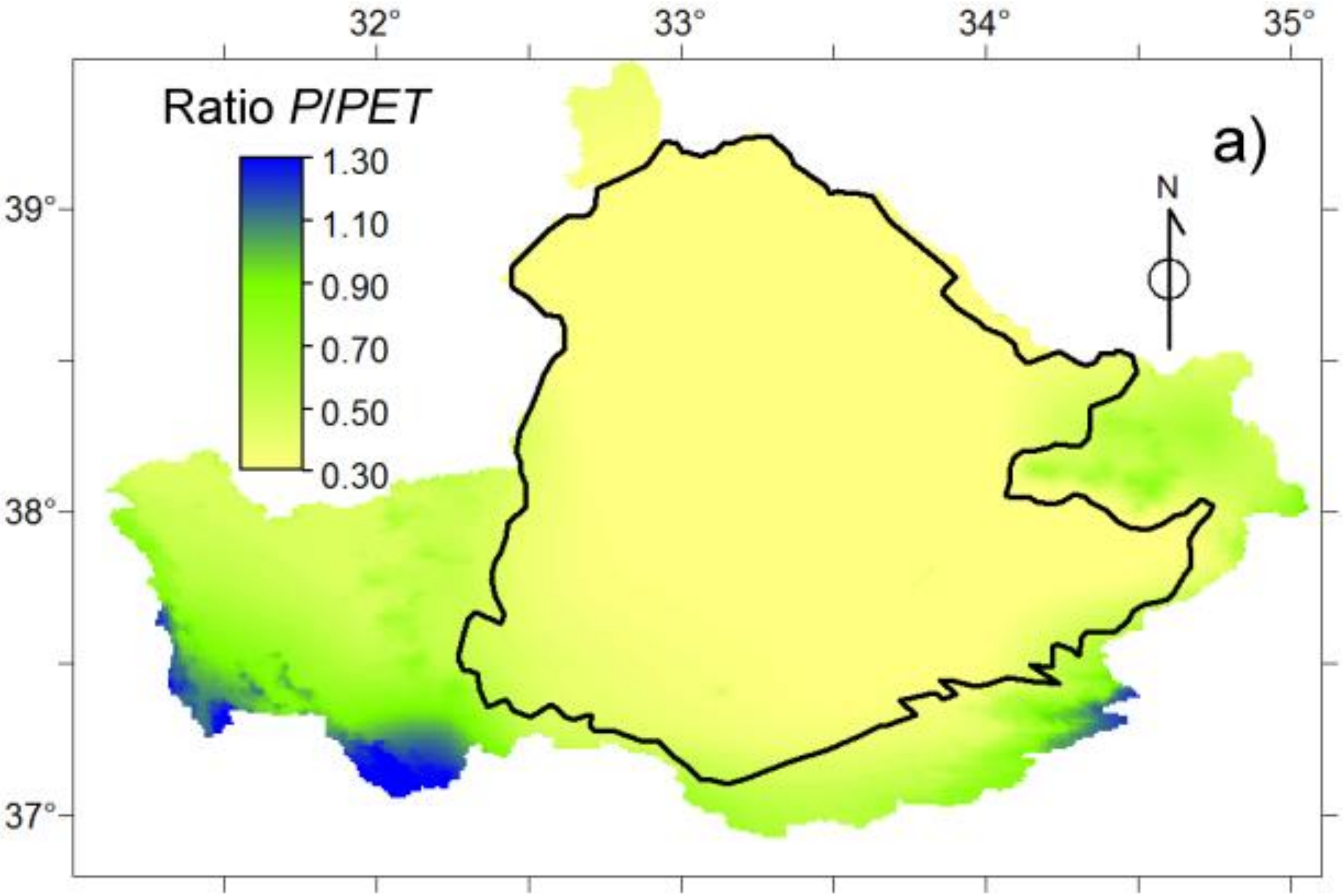
Elevation:	900 – 3.534 m.a.s.l.
Surface area:	54.000 km2
Climate:	Arid to semi-arid
	P ≈ 350 mm/year
	PET ≈ 1400 mm/year

Land cover: shows a strong contrast between intensively irrigated agricultural lands and the sparse steppe areas.

Water resources:

Groundwater (GW) is the main source for irrigation. The surface water is comparably limited and managed through man-made reservoirs for supplying additional irrigation (15-20%)

Problem: water limited region with very few in situ measurements

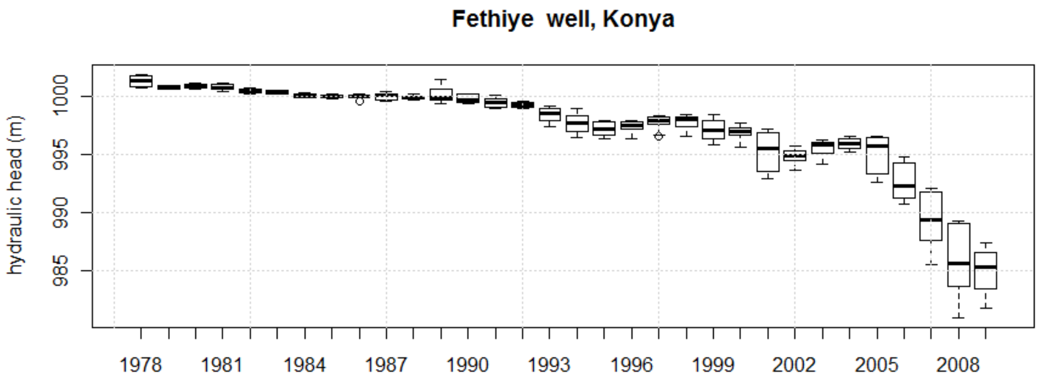


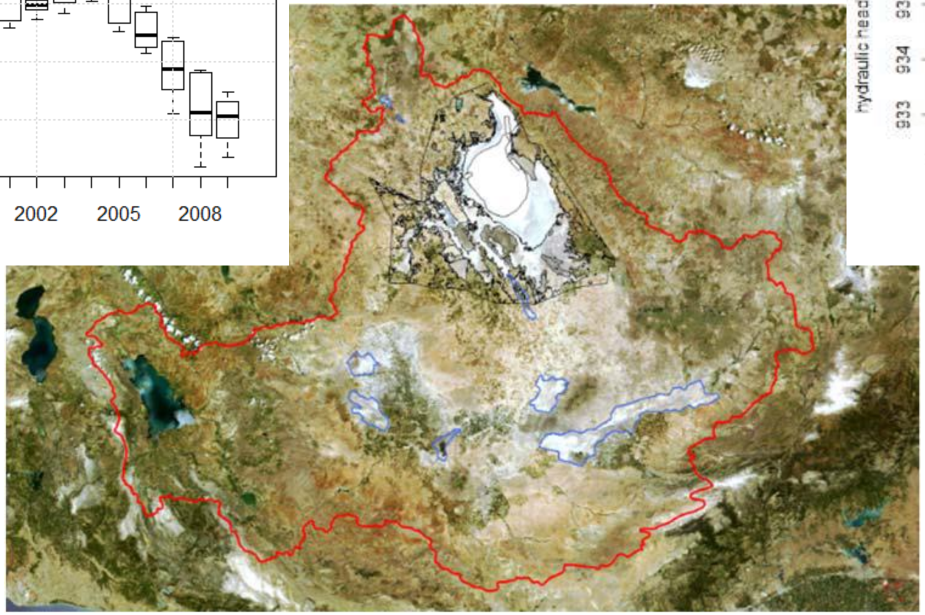
Parsons and Abrahams (1994): water limtited region is, where P-PET<0.75

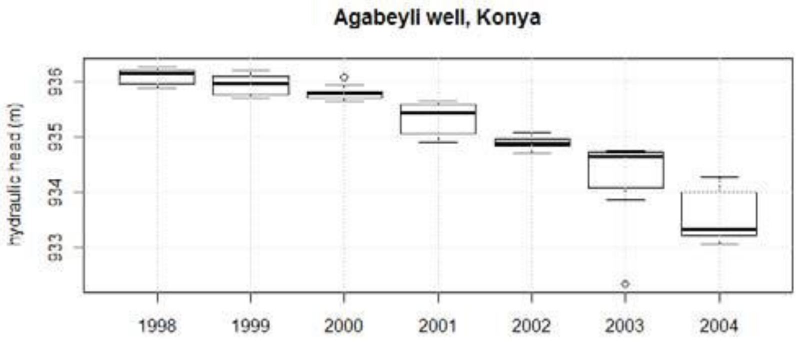
GW depletion due to intensive irrigated agriculture

Groundwater resources under strong anthropogenic influence:

Groundwater abstraction for irrigation, approximately 1 m $year^{-1}$ groundwater head decline over the last few decades (Bayari et al., 2009).



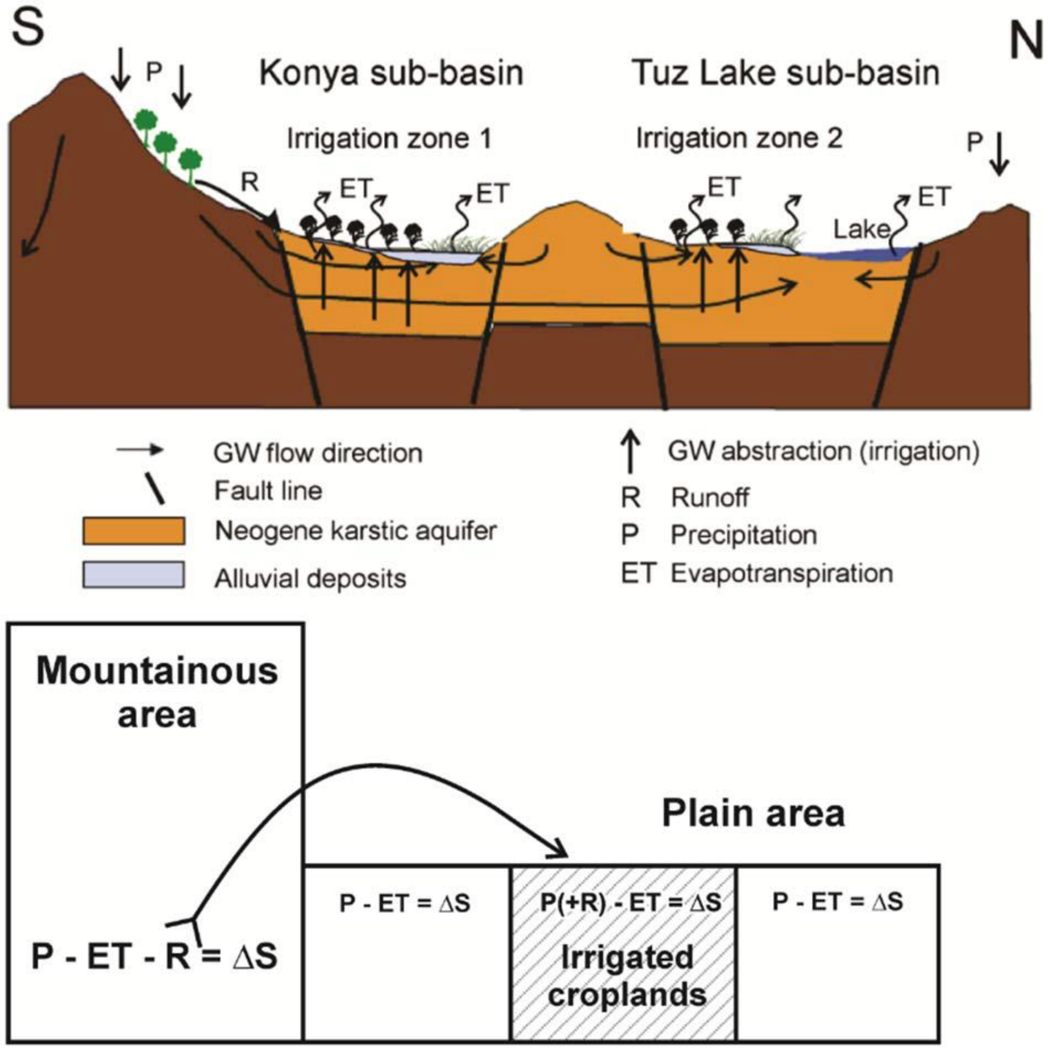




Earth observation supported regional water balance calculations

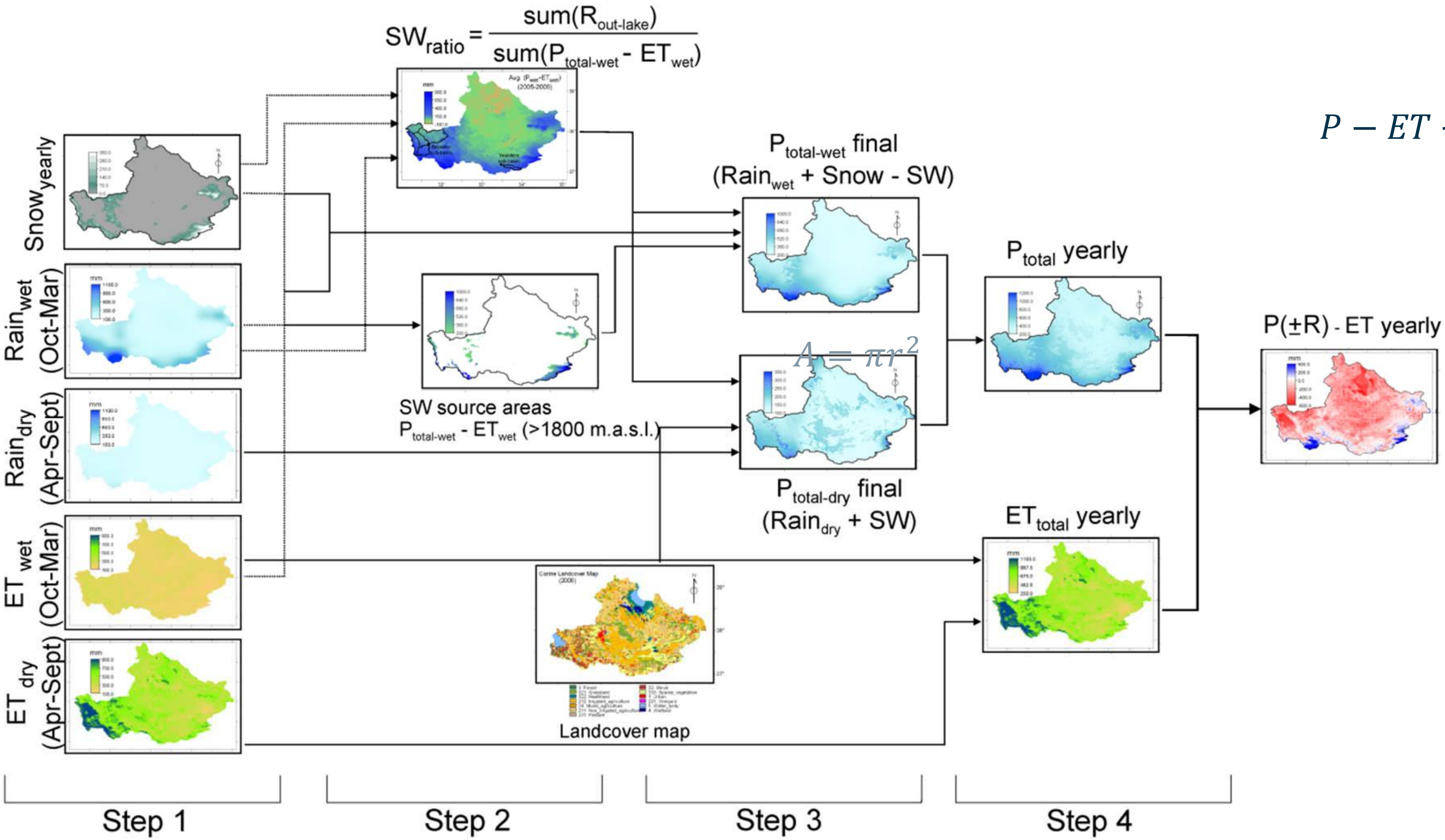
WATER BALANCE CALCULATION METHODS

Conceptual model for the water balance calculations



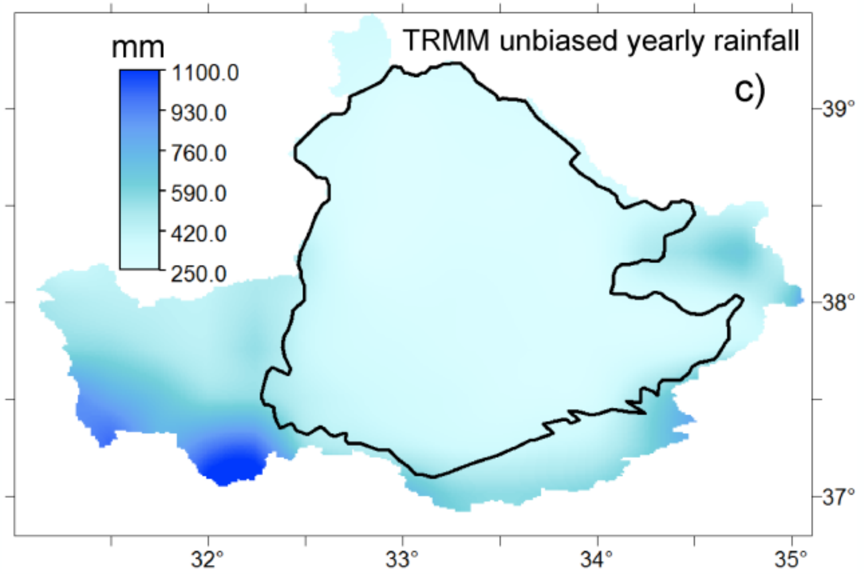
Spatially distributed water balance calculations

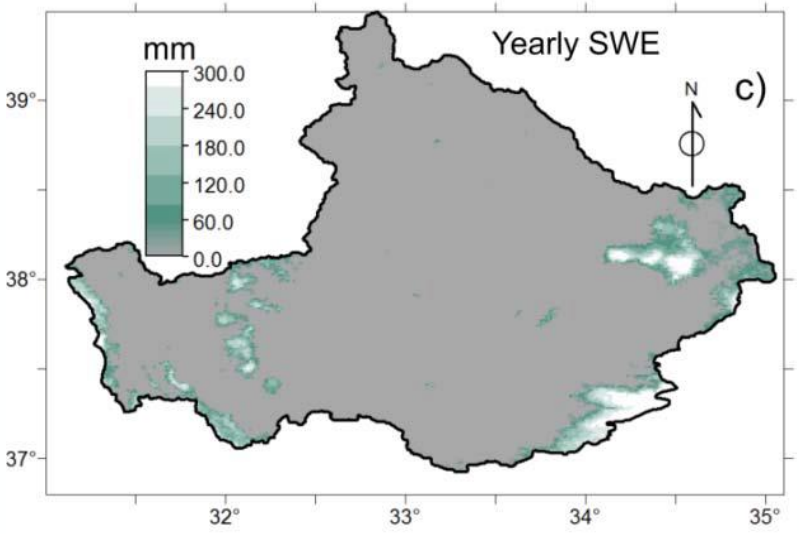
$$P - ET - R \pm \Delta S = 0$$

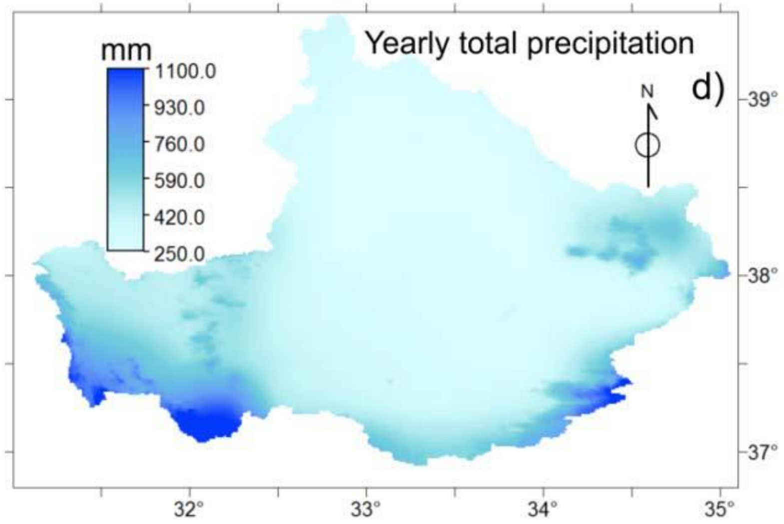


WATER BALANCE RESULTS

Spatial distribution of precipitation

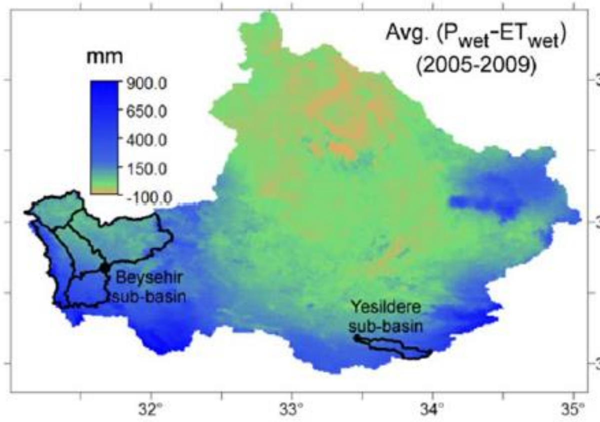


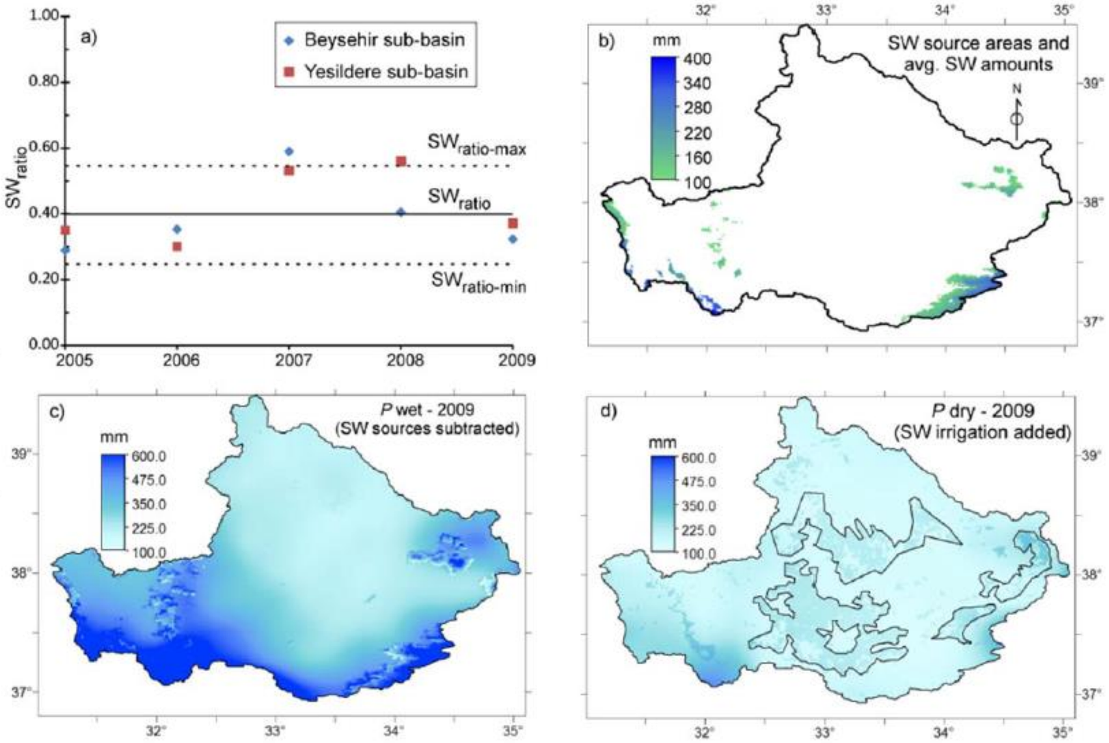


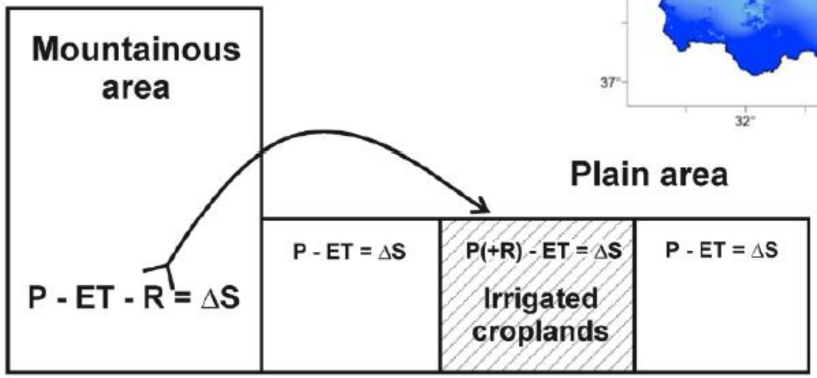


- TRMM is not sensitive to snowfall
- Snow can be observed in the visible bands
- In situ SWE was used for characterizing snow

Snowmelt distribution via reservoirs







$$SWratio = \frac{\sum R_{outflow}}{\sum P_{wet} - \sum ET_{wet}}$$

Defines the processes on the boundary between air and the land surface

Many slides by Rogier van der Velde (indicated)

SOIL MOISTURE

Remote sensing of soil moisture

"Direct" measurements

- Microwave
  - Active - SAR
  - Passive – scatterometers, radiometers

Comment: Top 2-5 cm, shallower than 10 cm

- Optical (visible/near infrared)
  - Using solar radiation as a direct energy source

Comment: Surface information

Root zone through assimilation/modelling

- Microwave: SMAP root zone product (modelling/assimilation)
- Thermal infrared techniques
  - Through assimilation/modeling to get root-zone soil moisture
  - Indirectly root-zone soil moisture

Global soil moisture data of ESA – combined passive and active method

esa https://esa-soilmoisture-cci.org/ climate change initiative

European Space Agency

ESA | CCI | Aerosol | Cloud | CMUG | Fire | GHG | Glaciers | Ice Sheets | Land Cover | Ocean Colour | Ozone | Sea Ice | Sea Level | SST

Soil Moisture CCI

Navigation

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Consortium

TU WIEN GEO CESBIO eodc ETH zürich

Version v07.1 is now available!

Submitted by admin on Sat, 2022-05-21 13:34

Climate Change Initiative

The new ESA CCI SM version **v07.1** is now available!

The highlight of this version is the improved temporal and spatial coverage due to the inclusion of 3 new active and passive sensors (observations from ascending **and** descending overpasses for **all** sensors are merged in this version for the first time). Validation shows that the new version is the most accurate ESA CCI SM product so far. It provides global data from 1978 to 2021.

Download ESA CCI Soil Moisture v07.1 from FTP server

Register now to gain access via SFTP, and take a look at the Frequently Asked Questions and Documentation! **Read more »**

ESA CCI SM v06.1 now available!

Submitted by Tracy Scanlon on Mon, 2021-04-19 17:03

Climate Change Initiative

The new ESA CCI SM version, v06.1 is now available! This is the most accurate ESA CCI SM product so far and provides global data from 1978 to 2020 **Read more »**

v05.2 release: ESA CCI SM now including SMAP data!

Submitted by Adam Pasik on Tue, 2020-09-08 15:14

We are thrilled to announce the public release of a new version of the ESA CCI SM dataset (v05.2). The scientific advancements include refined radiometer data retrieval algorithm, improved intercalibration of AMSR-2 in the PASSIVE product and perhaps most excitingly- the highly anticipated inclusion of SMAP data! **Read more »**

ESA CCI Soil Moisture in State of the Climate in 2019 BAMS report

Submitted by Adam Pasik on Thu, 2020-08-13 08:00

American Meteorological Society's 2019 State of the Climate report was published yesterday with a contribution on global soil moisture conditions provided by our team.

Report features ESA CCI Soil Moisutre v04.7 COMBINED data, download the full report at: https://www.ametsoc.org/index.cfm/ams/publications/bulletin-of-the-american-meteorological-society-bams/state-of-the-climate/ **Read more »**

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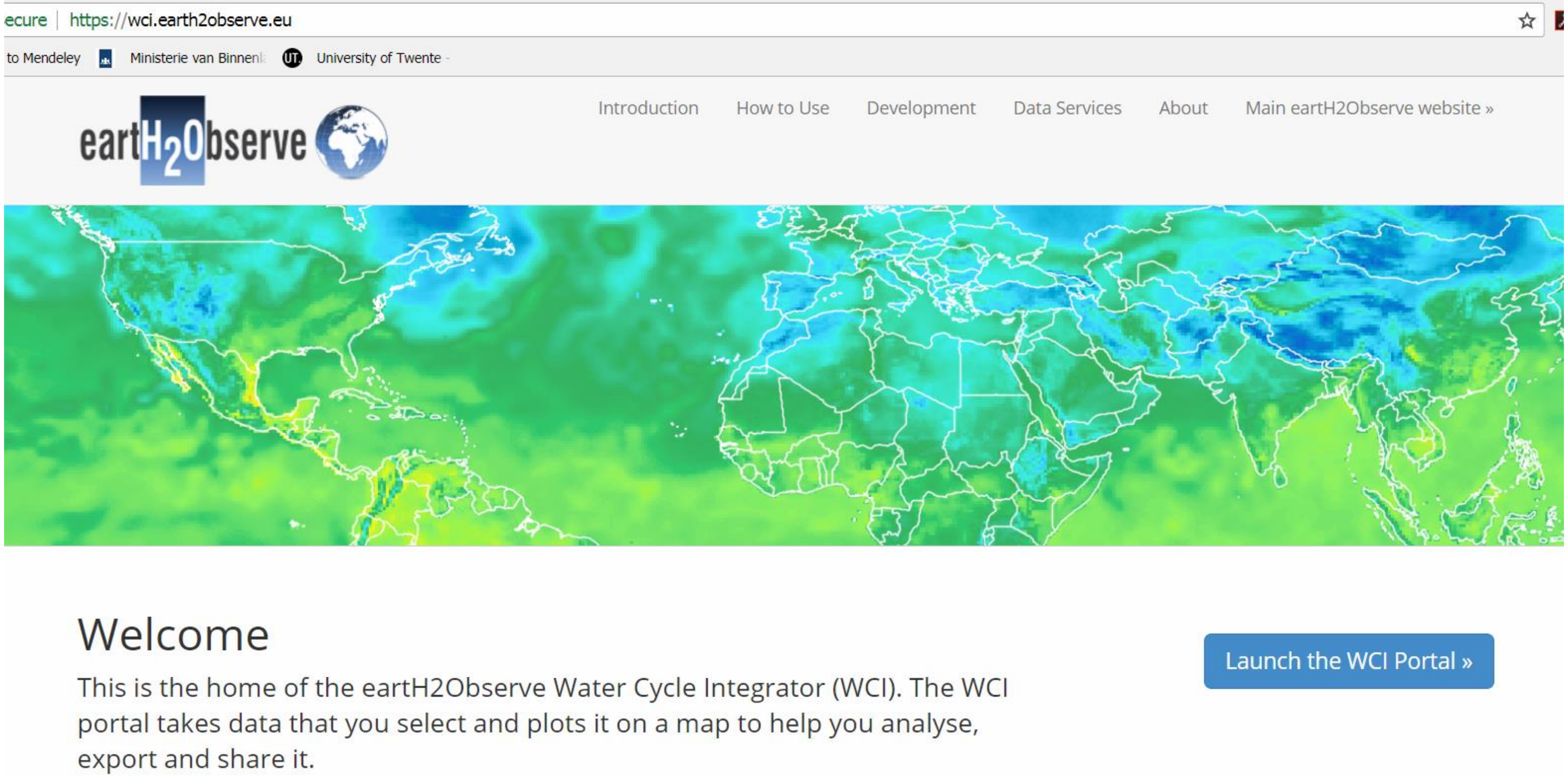
- Version v07.1 is now available!
- Data (CCI SM v07.1)
- Overview
- ESA CCI SM v06.1 now available!

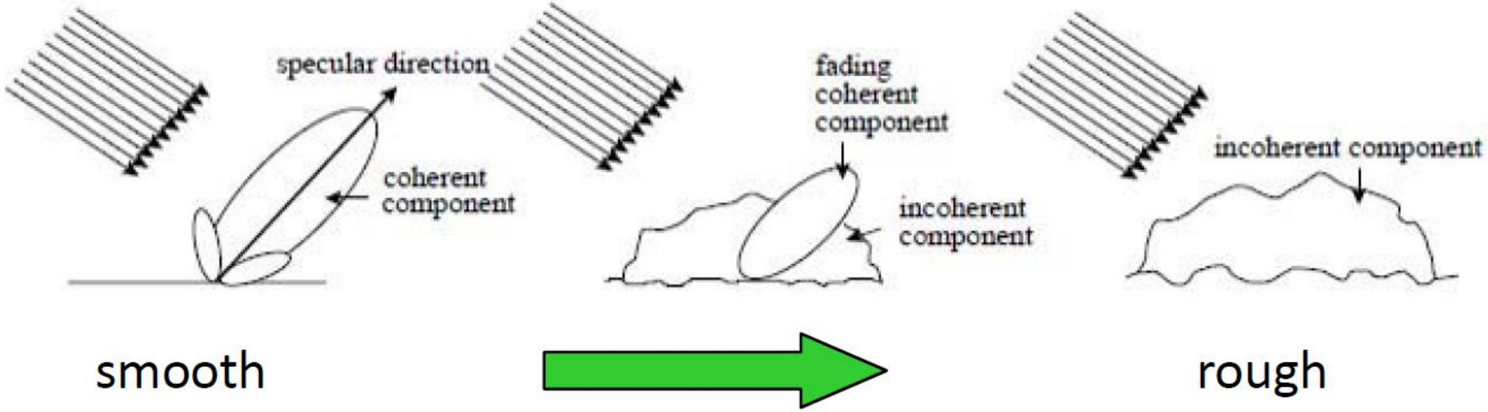
ESA Water Cycle Integrator



Effect of land on microwave observation

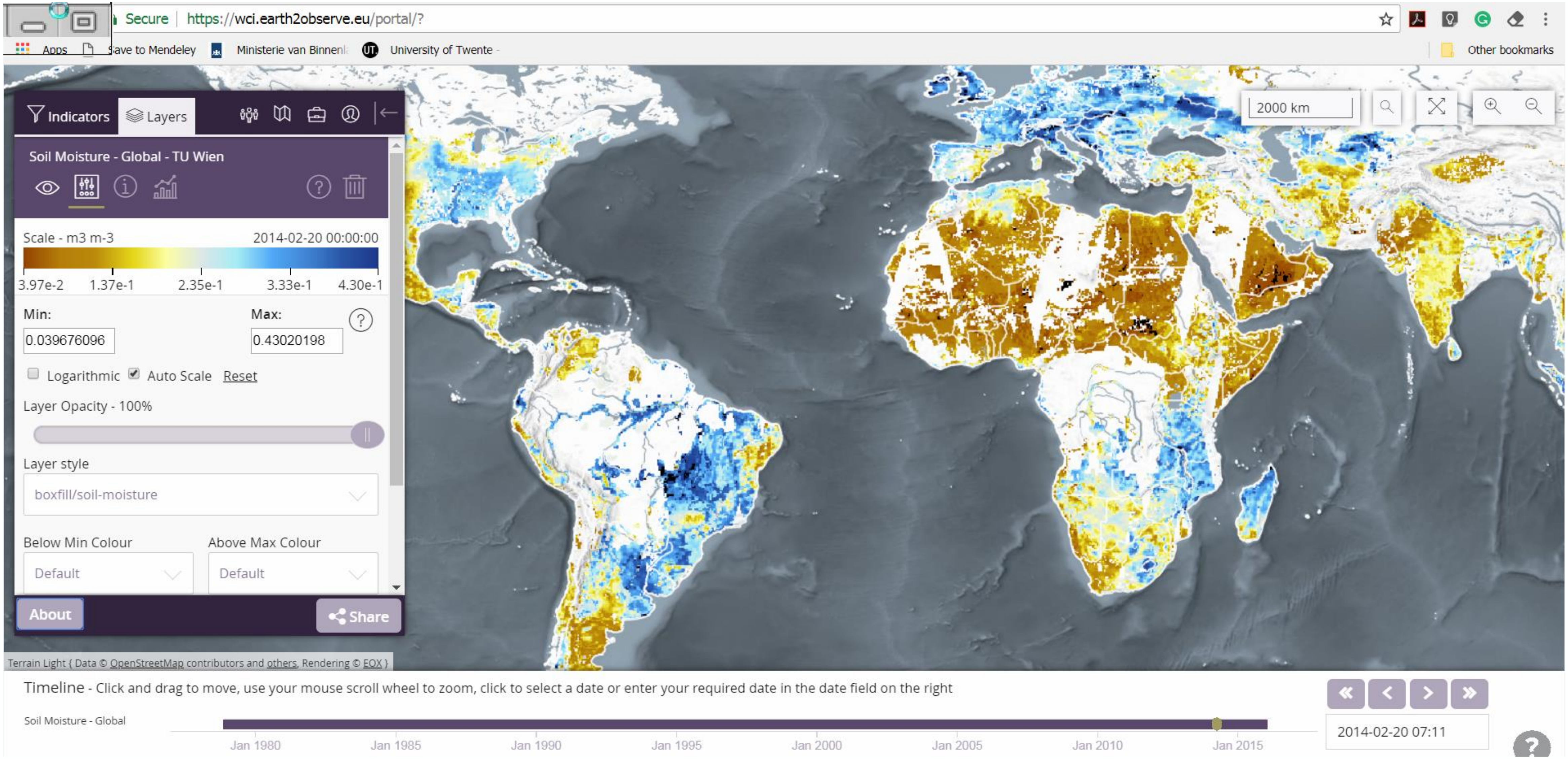
Microwave measurements are affected by:

1. *Dielectric properties* (or electric permittivity, ε): is a measure for the electromagnetic density of an object and indicative for the strength of the reflection (ε for dry soil is ~ 3 and ε for water is 80).
2. *Geometric properties*: defined by the shape of an object and determines the direction of scattering.



Rogier van der Velde

ESA Water Cycle Integrator – example: soil moisture



Thank you for your attention