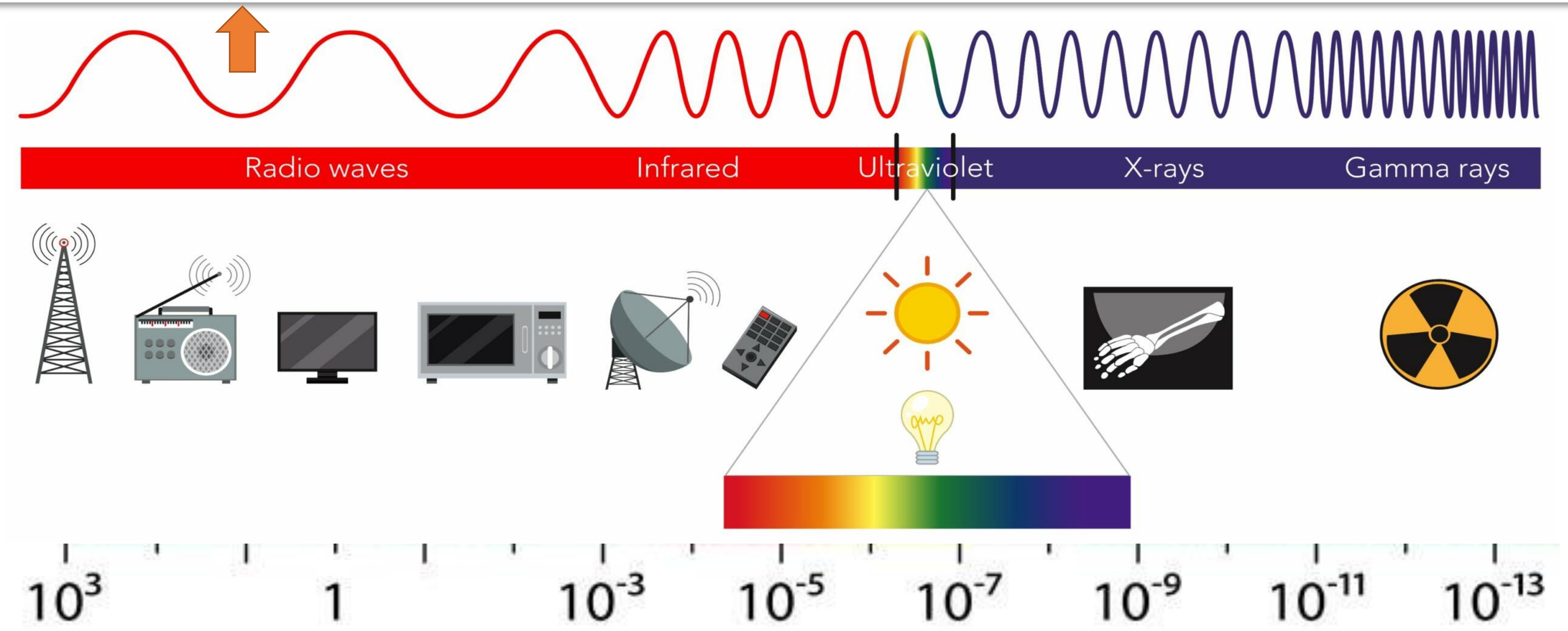
esa space solutions
Copernicus Academy
ÚSTAV GEOGRAFIE
Prírodovedecká fakulta UPJŠ v Košiciach

5. SAR and optical remote sensing for precision agriculture 1

SAR and optical for precise agriculture

RADAR SATELLITES
Weather & illumination independence
Penetration through cloud cover

Use: information about the vegetation structure and moisture content

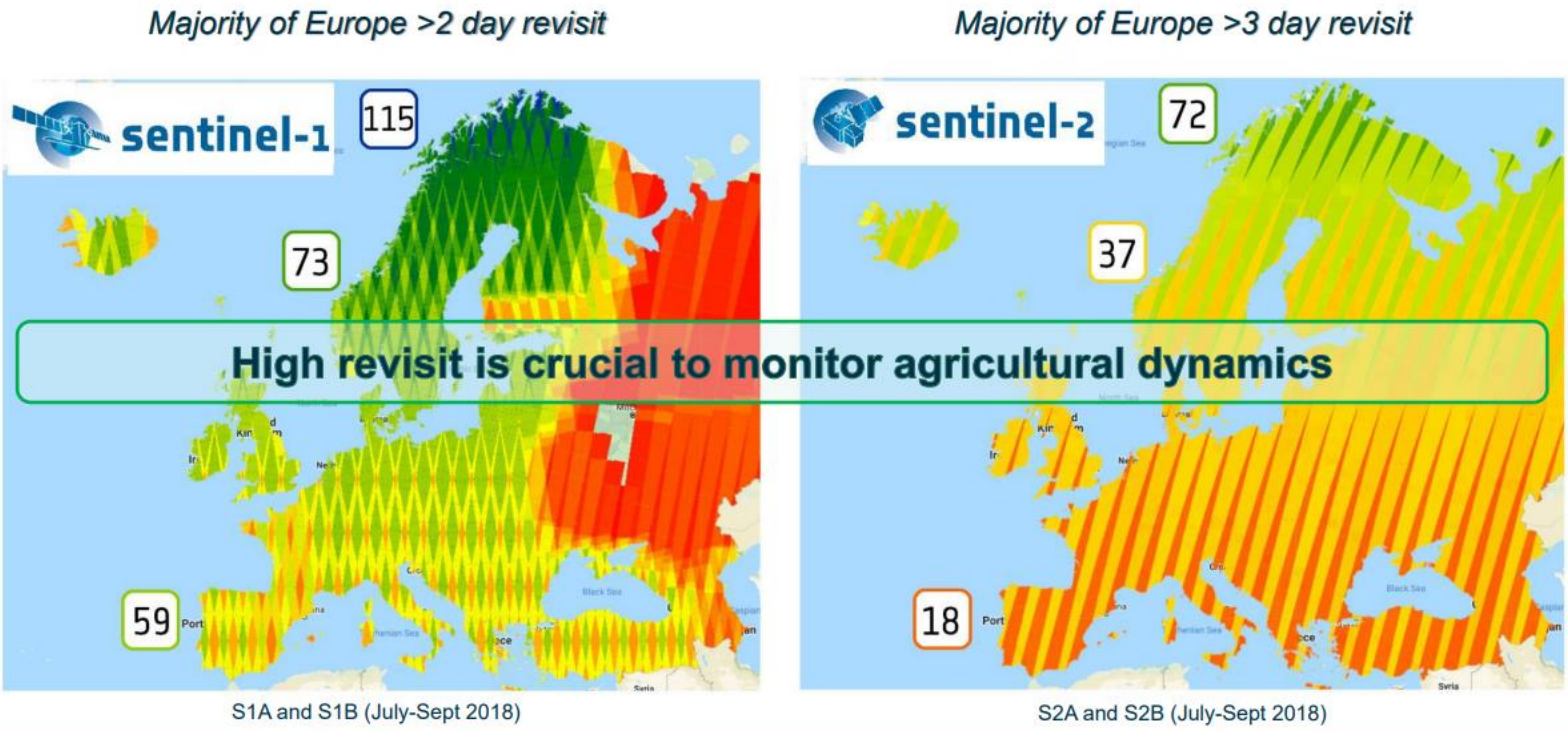


OPTICAL SATELLITES
Weather & illumination dependence
No penetration through cloud cover

Use: spectral (and chemical) properties of vegetation

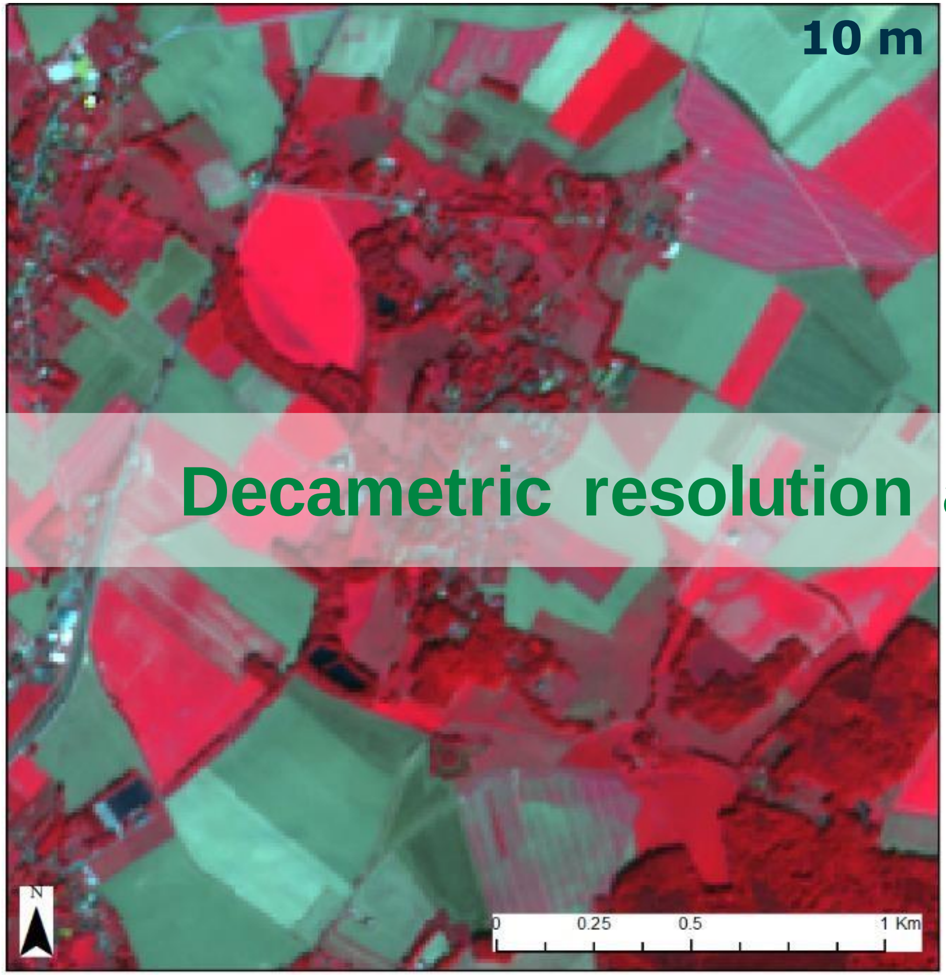
Source:https://cthrumetals.com/emi-shielding/

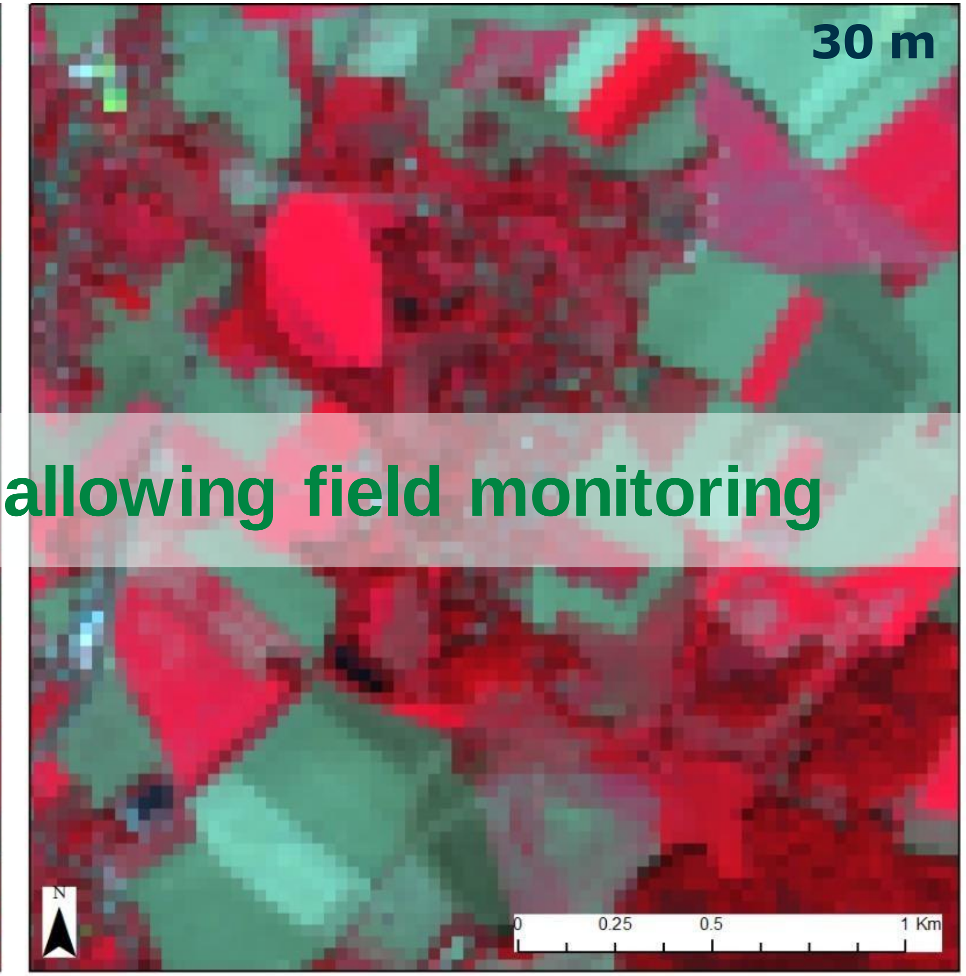
Sentinels – game changer for precision agriculture



https://eo4society.esa.int/training_uploads/LTC2022/2_Tuesday/13_LTC22_ppt_CropType_DianeH.pdf

Sentinels – game changer for precision agriculture

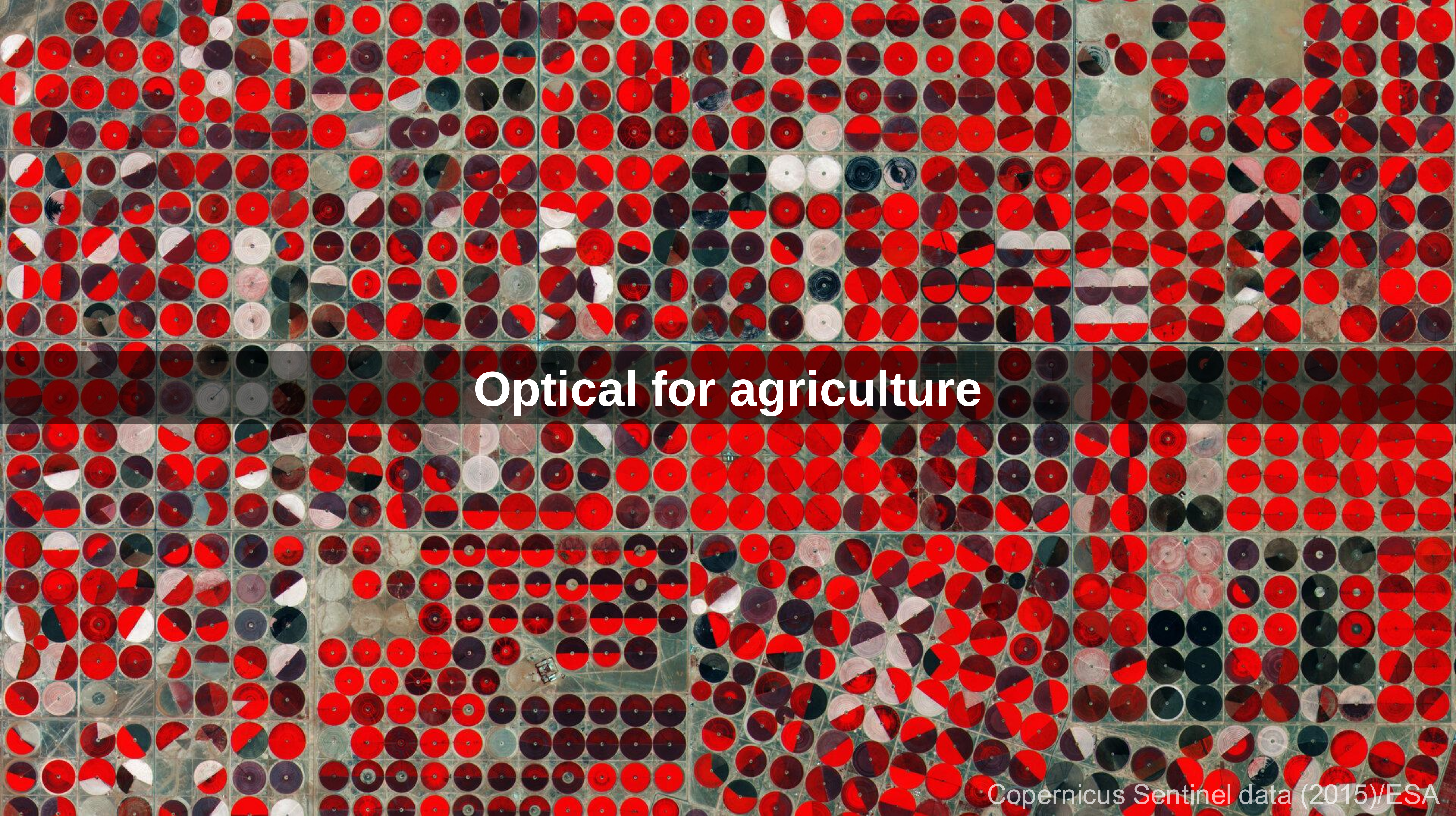




Decametric resolution allowing field monitoring

https://eo4society.esa.int/training_uploads/LTC2022/2_Tuesday/13_LTC22_ppt_CropType_DianeH.pdf

Optical for agriculture



From EO signal to agriculture information content

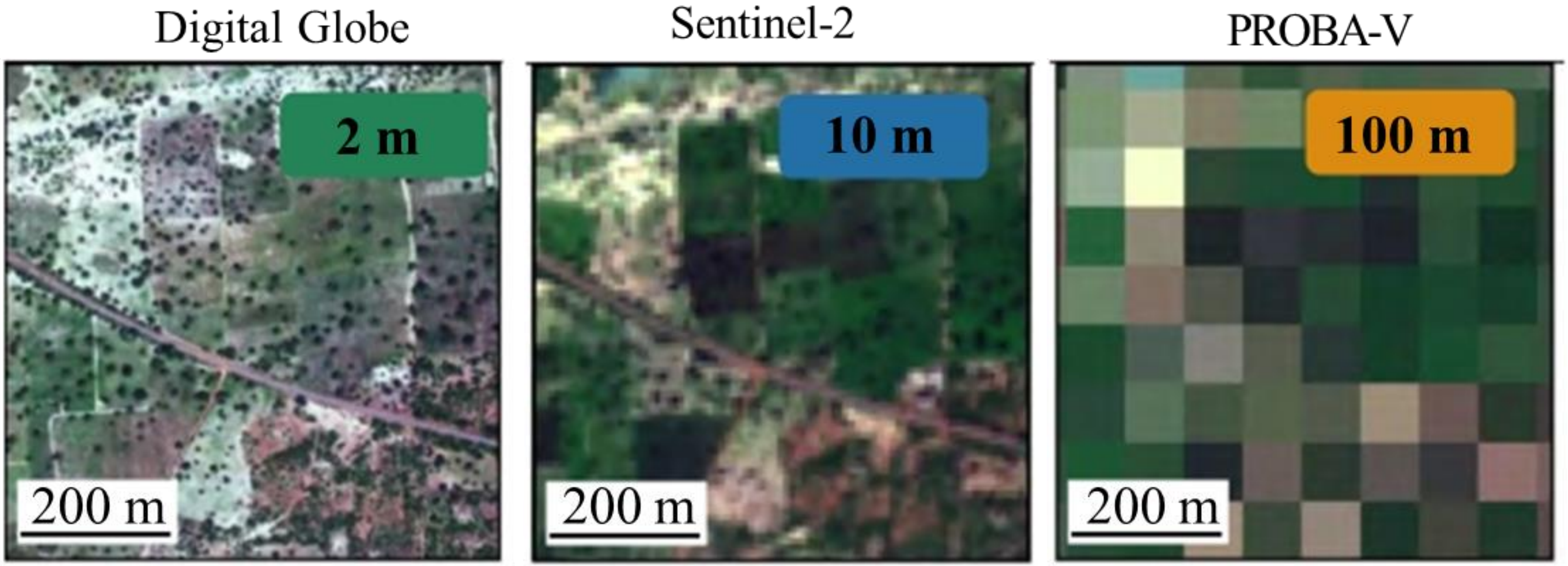
Spatial + spectral + temporal information content + Machine learning for classification

Satellite Service Provider	Type	Resolution		
		Spatial	Spectral	Temporal
Landsat (NASA)	Public	15m, 30m, 60m, 100m, 120m	Natural colour (Visible, NIR), Coastal aerosol, SWIR 1/2, Panchromatic, Cirrus, TIRS 1/2[63]	16-18 days
Sentinel (ESA)	**Public**	**5m, 10m, 20m, 60m**	**C-band, Natural colour (Visible, NIR, SWIR)**	**1-5 days**
Planet	Private	0.72m, 3m, 4.77m, 6.5m	Natural colour: Blue, Green, Red, Red-Edge, NIR	12 hours - 5 days
Maxar	Private	0.3m, 0.4m, 0.5cm, 0.6m, 1.2m, 2.0m	Panchromatic, 8 NIR bands (RGB, near-IR1/2, coast, yellow, red-edge), 8 SWIR bands, 12 CAVIS bands (for clouds, ice, and snow)	1-2 days

Resolutions offered by popular satellite imagery providers

From EO signal to agriculture information content

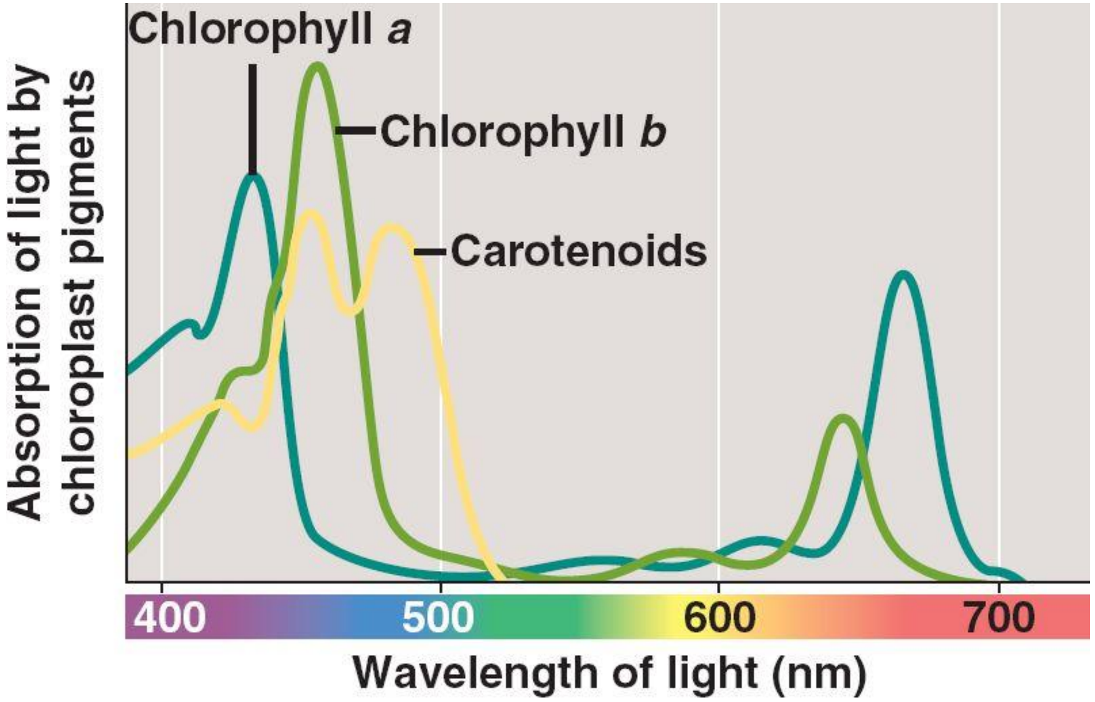
Spatial resolution



From EO signal to agriculture information content

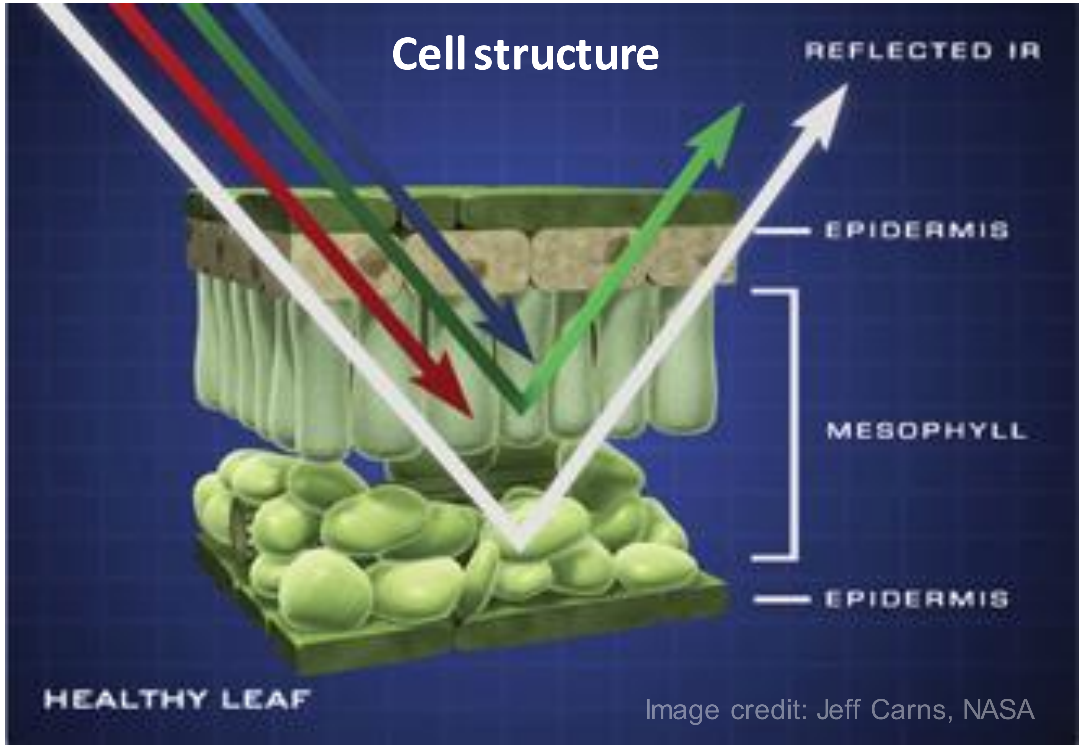
Spectral signature of the plants

Plant pigments

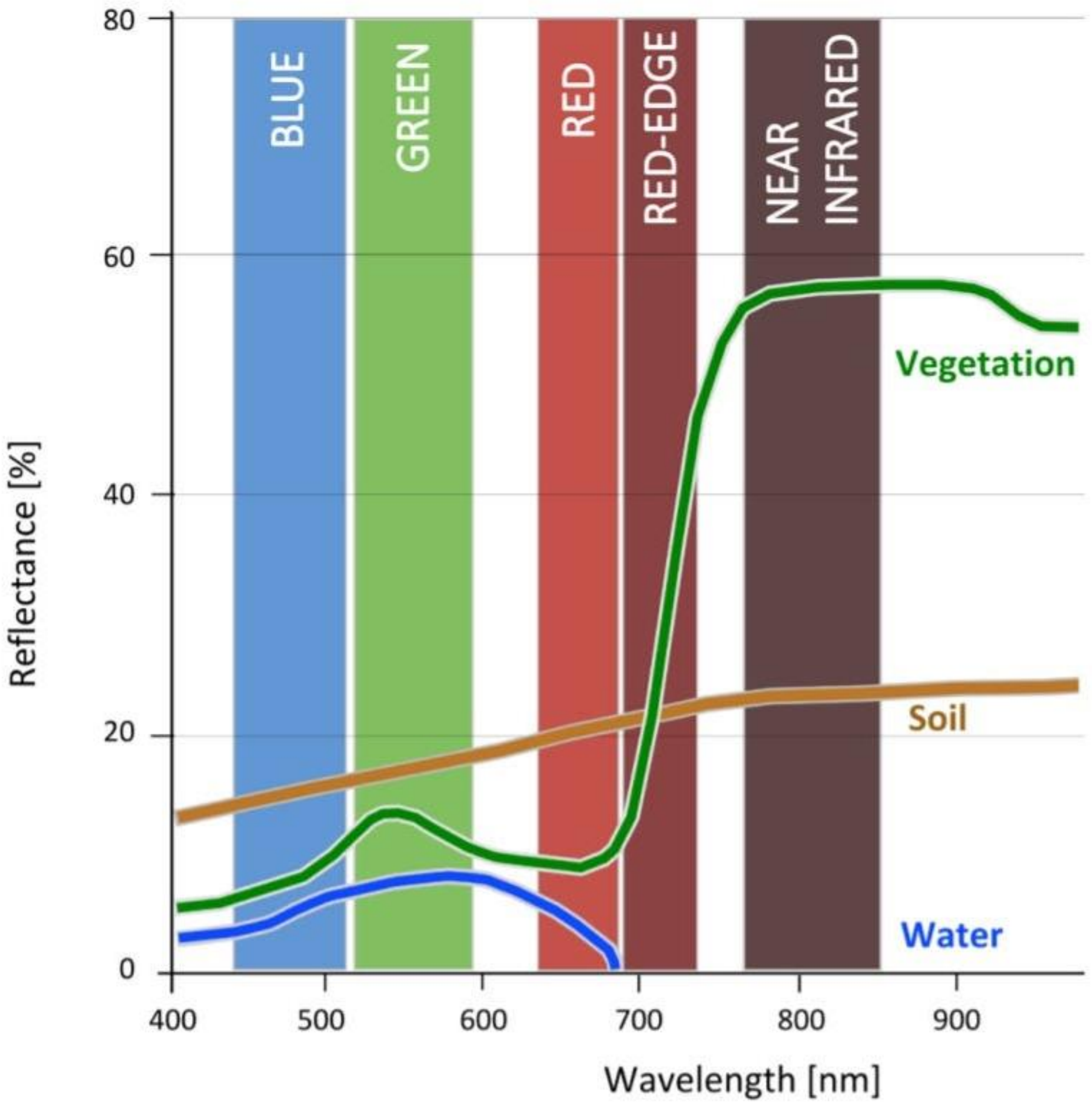


Chlorophyll predominately absorbs blue wavelengths (400-500 nm) and red (600-700 nm). Note that carotenoids absorb blue light as well as some green.

- Chlorophyll in the leaf preferentially absorbs blue and red light
- Green light is reflected (that's why healthy vegetation with lots of chlorophyll is green to our eyes)
- A healthy leaf cellular structure strongly reflects near-infrared light (to prevent cell demage)

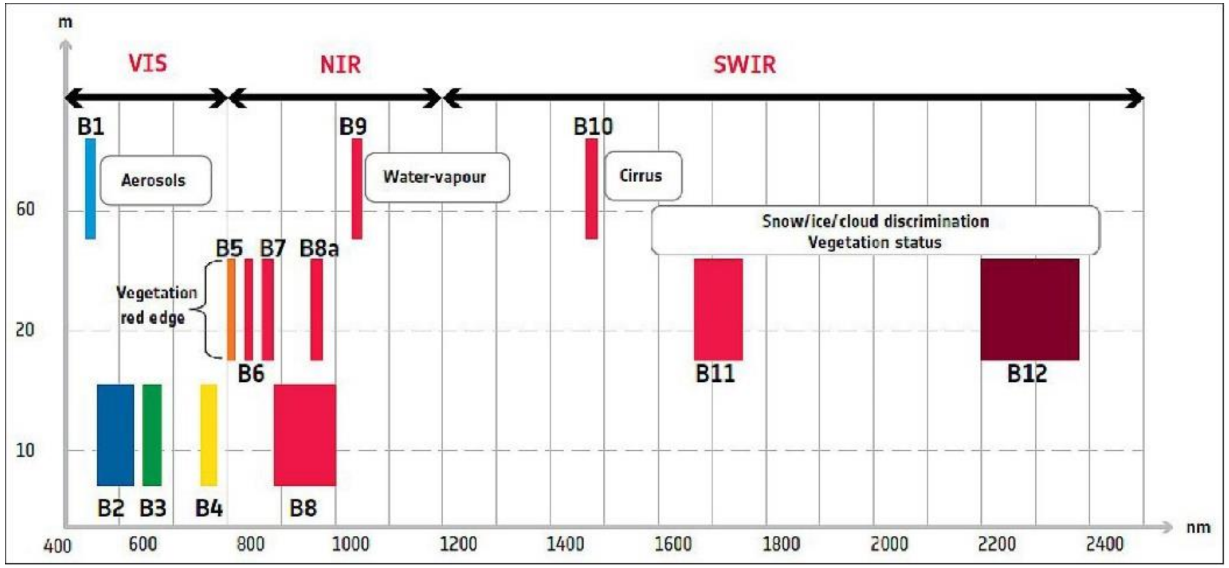


From EO signal to agriculture information content



RED EDGE

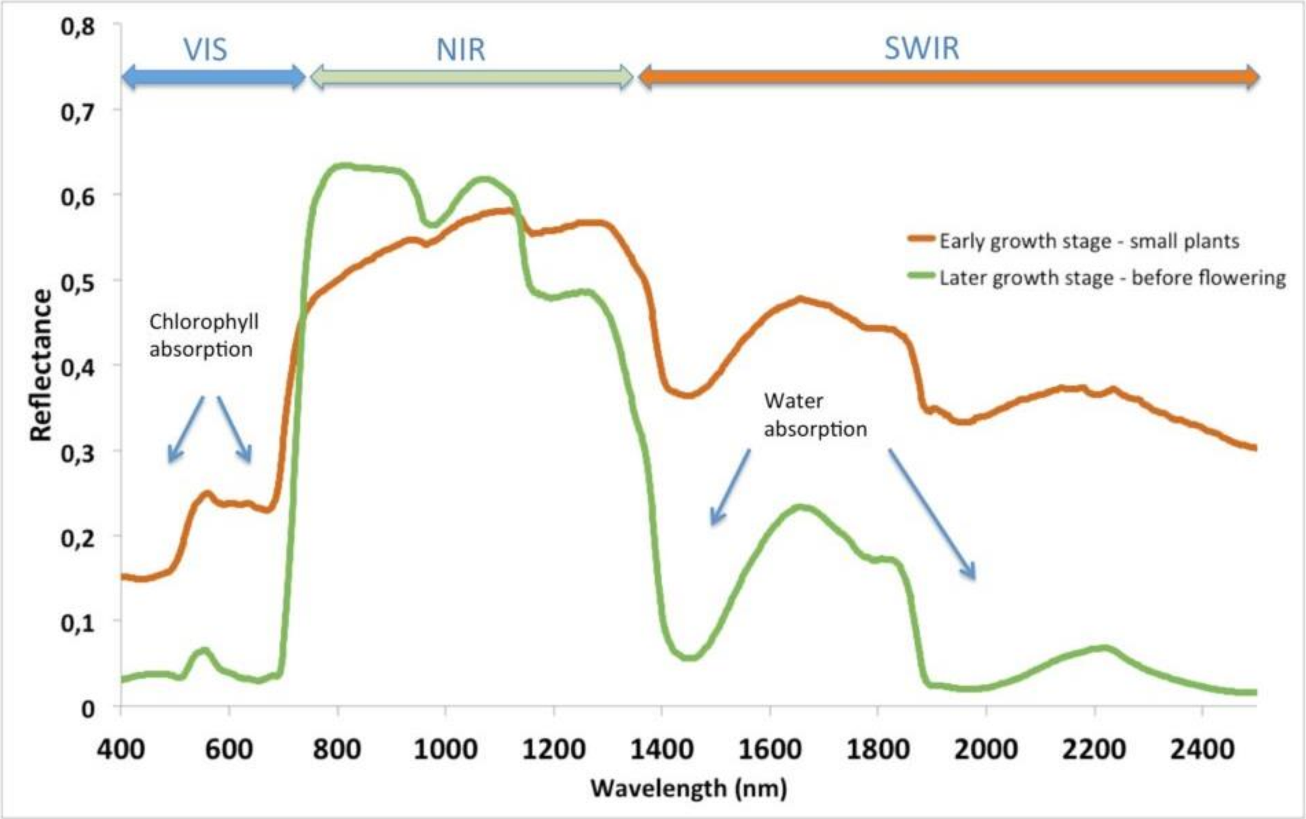
- The three 20m ‘red edge’ bands of Sentinel-2 provide key information on the state of vegetation
- Very narrow band (700 – 730 nm) corresponding to the red NIR transition zone
- Very sensitive to plant stress – provides information on the canopy chlorophyll and nitrogen content



From EO signal to agriculture information content

Spectral indices - to extract specific signal from spectral signature

- Particular wavelengths are sensitive to particular chemicals and compounds
- Indices take advantage of these wavelength features



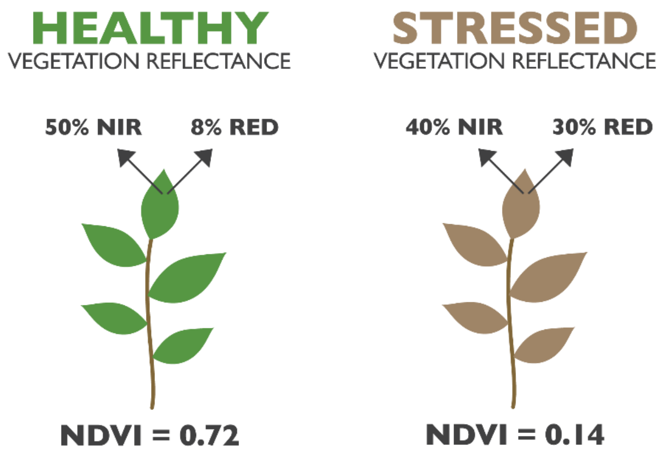
Vegetation indices:

- 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
- …

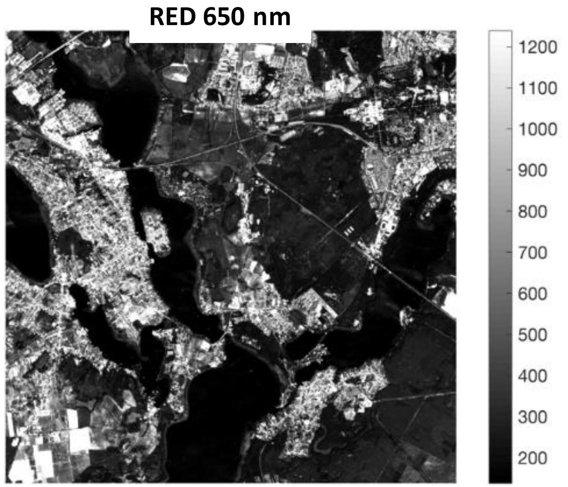
From EO signal to agriculture information content

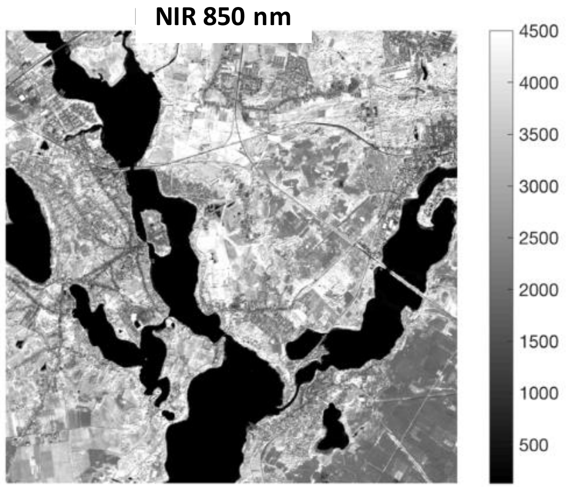
NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI)

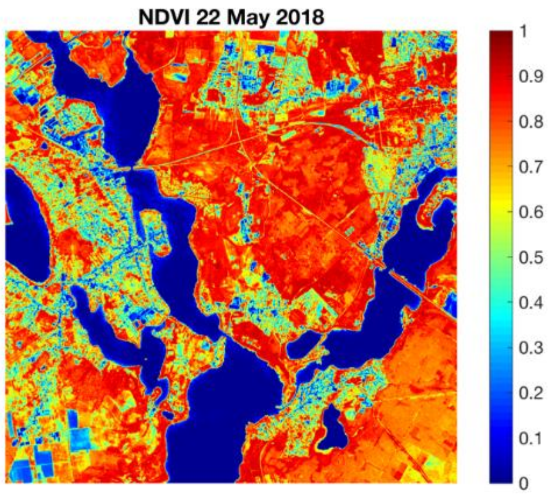
- Very popular in eco/geosciences
- Output values between -1.0 and 1.0
- Very low values (0.1 and below) = barren areas of rock, sand, snow
- Moderate values (0.2 to 0.3) = shrub and grassland
- High values (0.6 to 0.8) = temperate and tropical rainforests



$$NDVI = \frac{NIR - RED}{NIR + RED}$$







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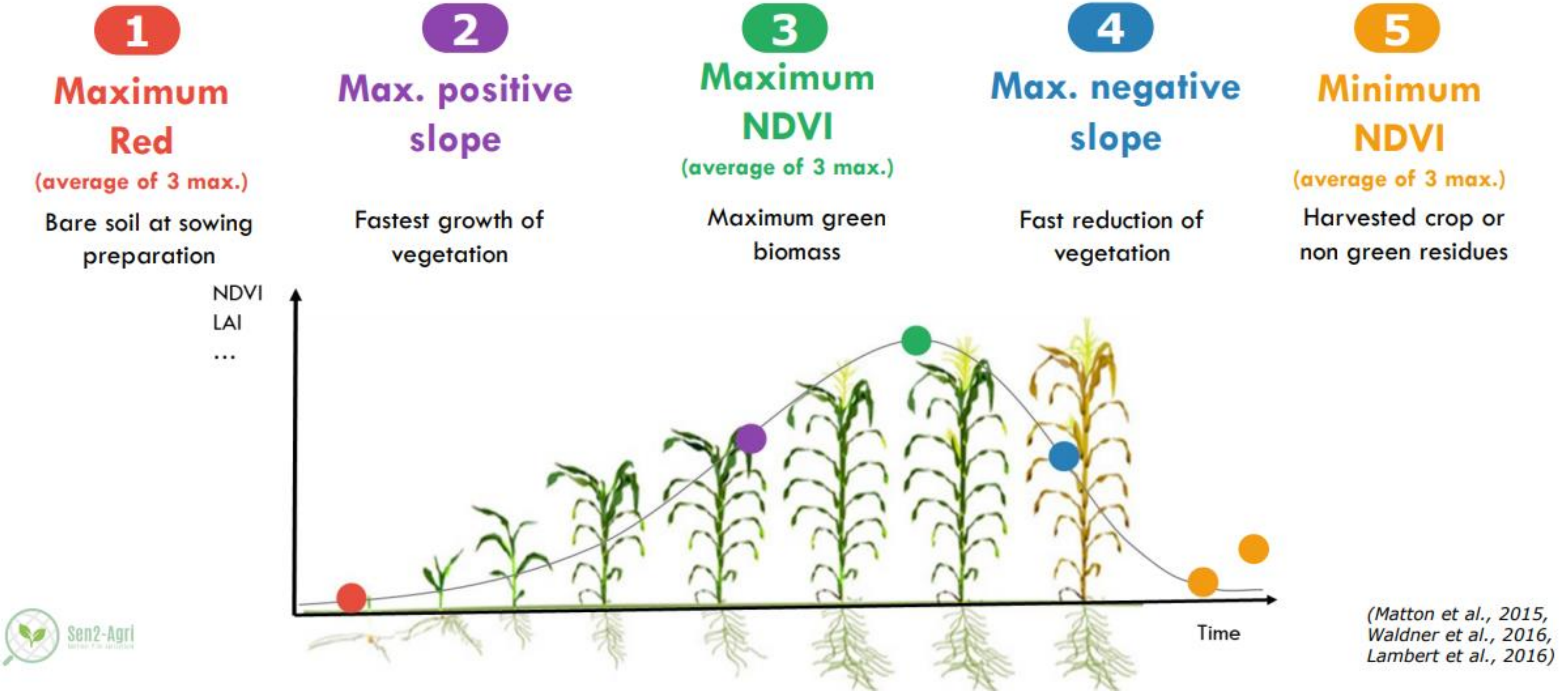
NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI)



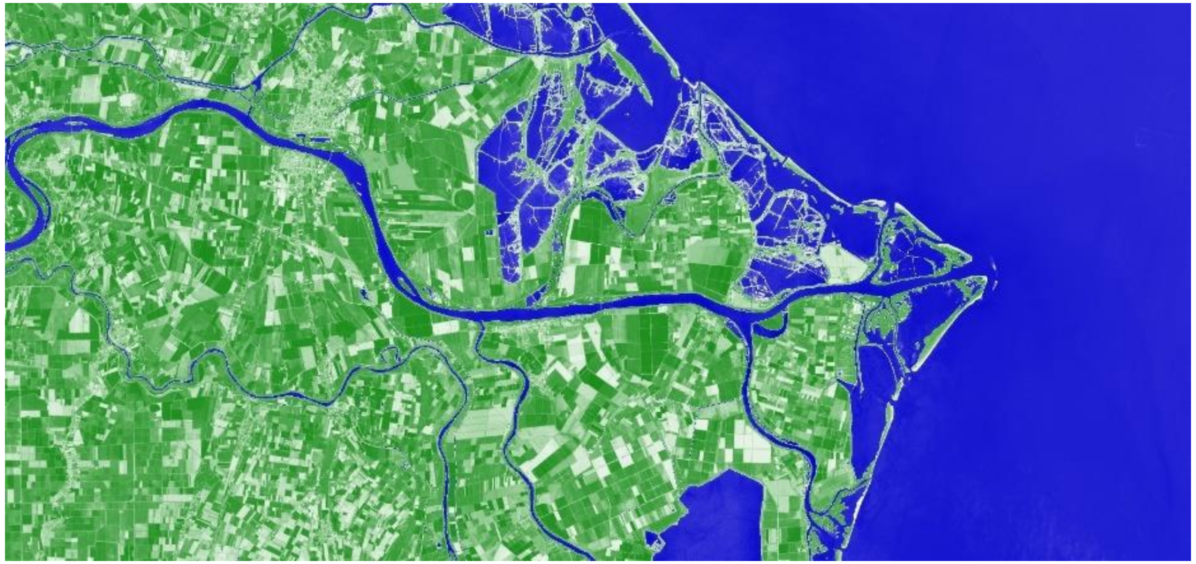
(Matton et al., 2015, Waldner et al., 2016, Lambert et al., 2016)

https://eo4society.esa.int/training_uploads/LTC2022/2_Tuesday/13_LTC22_ppt_CropType_DianeH.pdf

From EO signal to agriculture information content

NORMALIZED DIFFERENCE WATER INDEX (NDWI)

- Highly correlated with canopy water content and more closely tracked changes in plant biomass than the NDVI
- Used to monitor changes related to water content in water/plant bodies
- As water bodies strongly absorb light in visible to infrared electromagnetic spectrum, NDWI uses green and near infrared bands to highlight water bodies
- Index values greater than 0.5 usually correspond to water bodies. Vegetation usually corresponds to much smaller values and built-up areas to values between 0 - 0.2



NDWI of Italy. Acquired on 2020-08-01.

$$NDWI = \frac{(NIR - SWIR)}{(NIR + SWIR)}$$

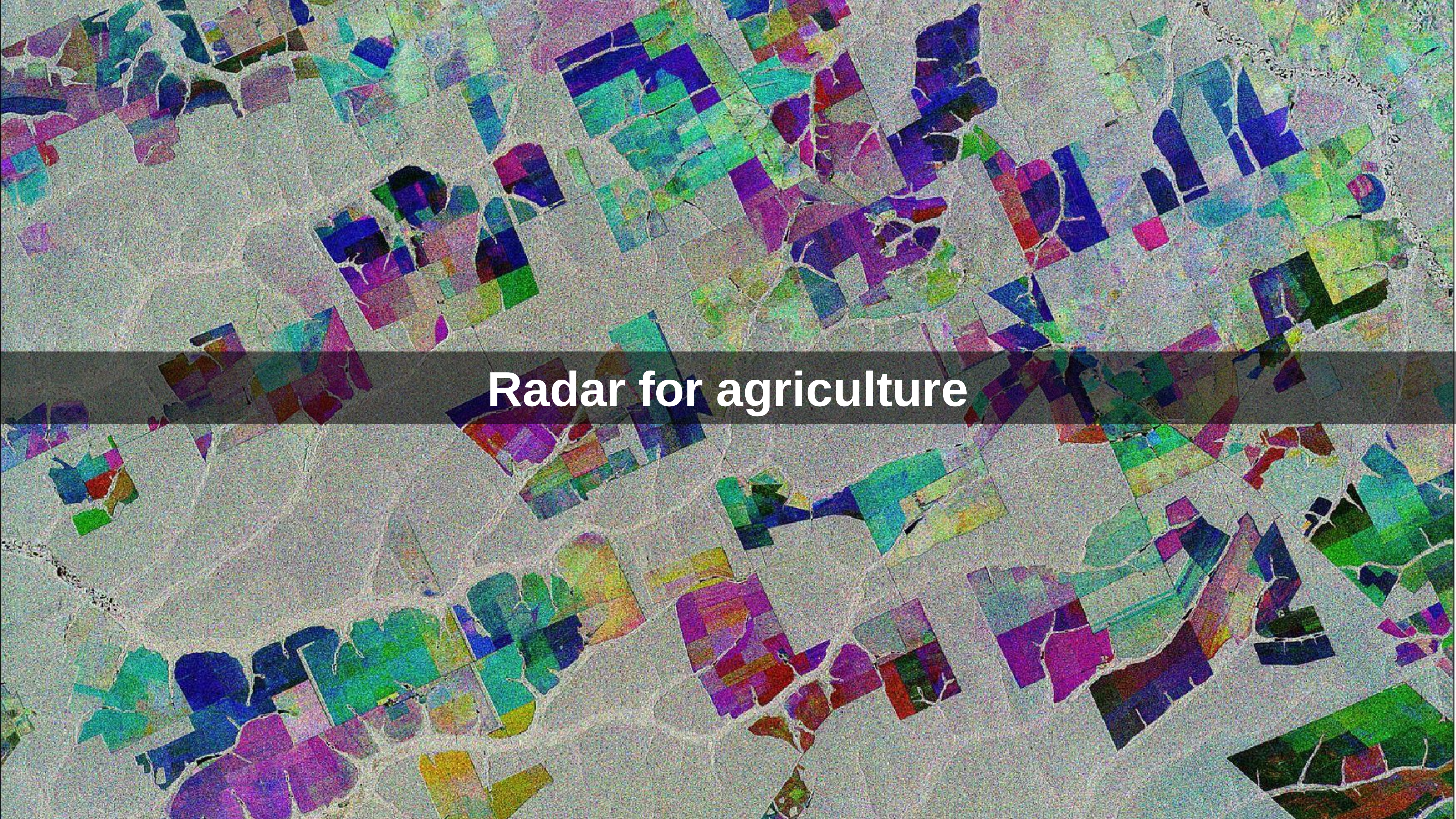
From EO signal to agriculture information content

LIST OF INDICES FOR AGRICULTURE MONITORING USING SENTINEL-2 DATA

- *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*

https://eo4society.esa.int/training_uploads/LTC2022/2_Tuesday/13_LTC22_ppt_CropType_DianeH.pdf

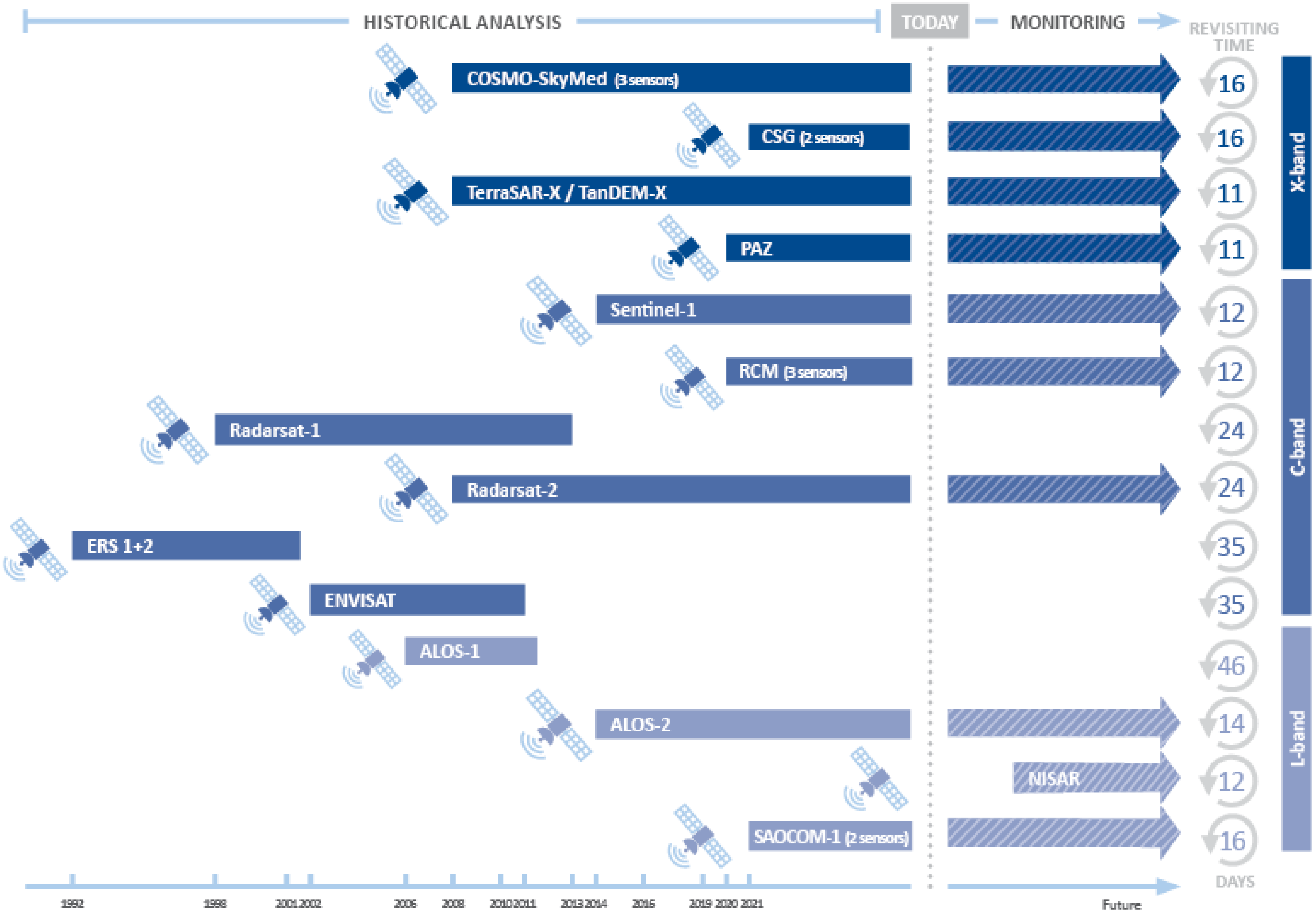
Radar for agriculture



SAR sensors for agriculture

Main satellites carrying SAR sensors:

- ENVISAT ASAR - spaceborne SAR operated by the ESA
- ERS-1, ERS-2 SAR - operated by ESA
- SENTINEL-1A -B (ESA, Copernicus program)
- RADARSAT-1, 2- spaceborne SAR operated by the Canadian Space Agency (CSA).
- ALOS-PALSAR 2 - SAR L- band operated by the Japanese Space Agency
- COSMO SKY_MED - X band operated by Italian Space Agency for civil protection purposes
- TERRASAR-X - X band operated by DLR



https://site.tre-altamira.com/company/our-technology/

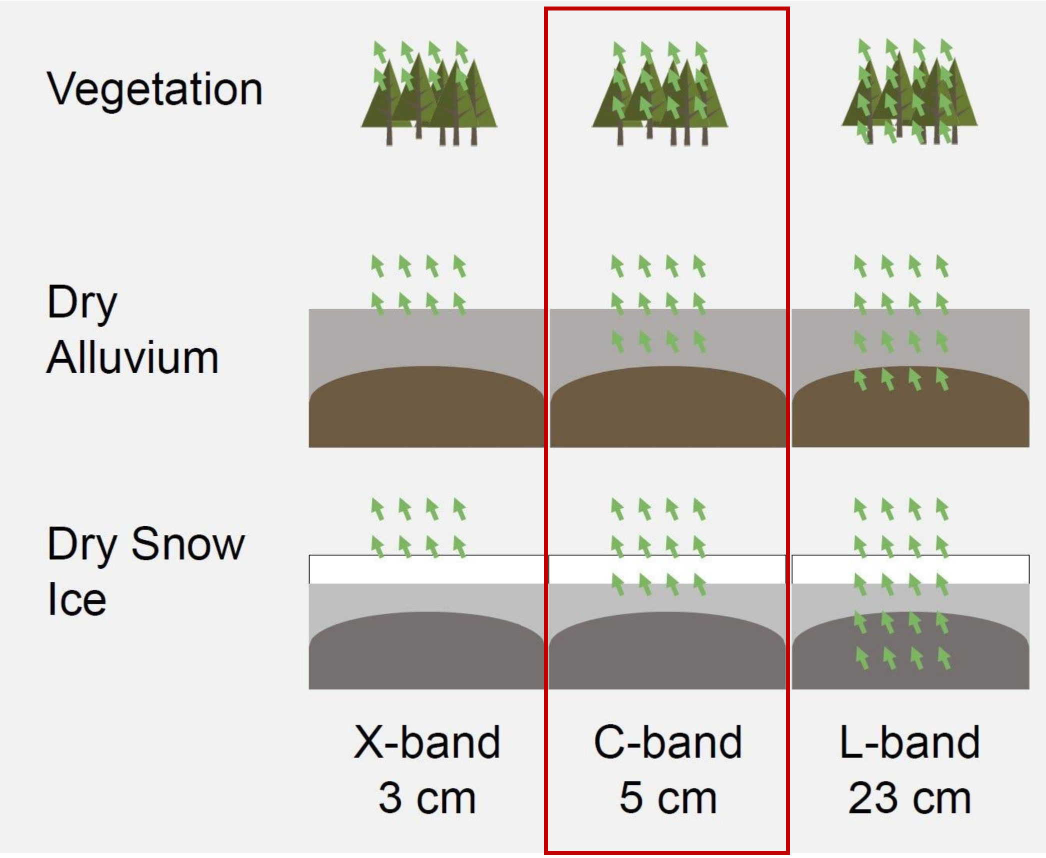
Radar Parameters to Consider in Precise Agriculture

Penetration through vegetation as a Function of Wavelength and dielectric characteristics

- The penetration depth is depending on **wavelength** and **dielectric characteristics** of objects
- Penetration is the predominant consideration when selecting a wavelength
- Typically, longer wavelengths result in greater penetration into the target

Agricultural monitoring

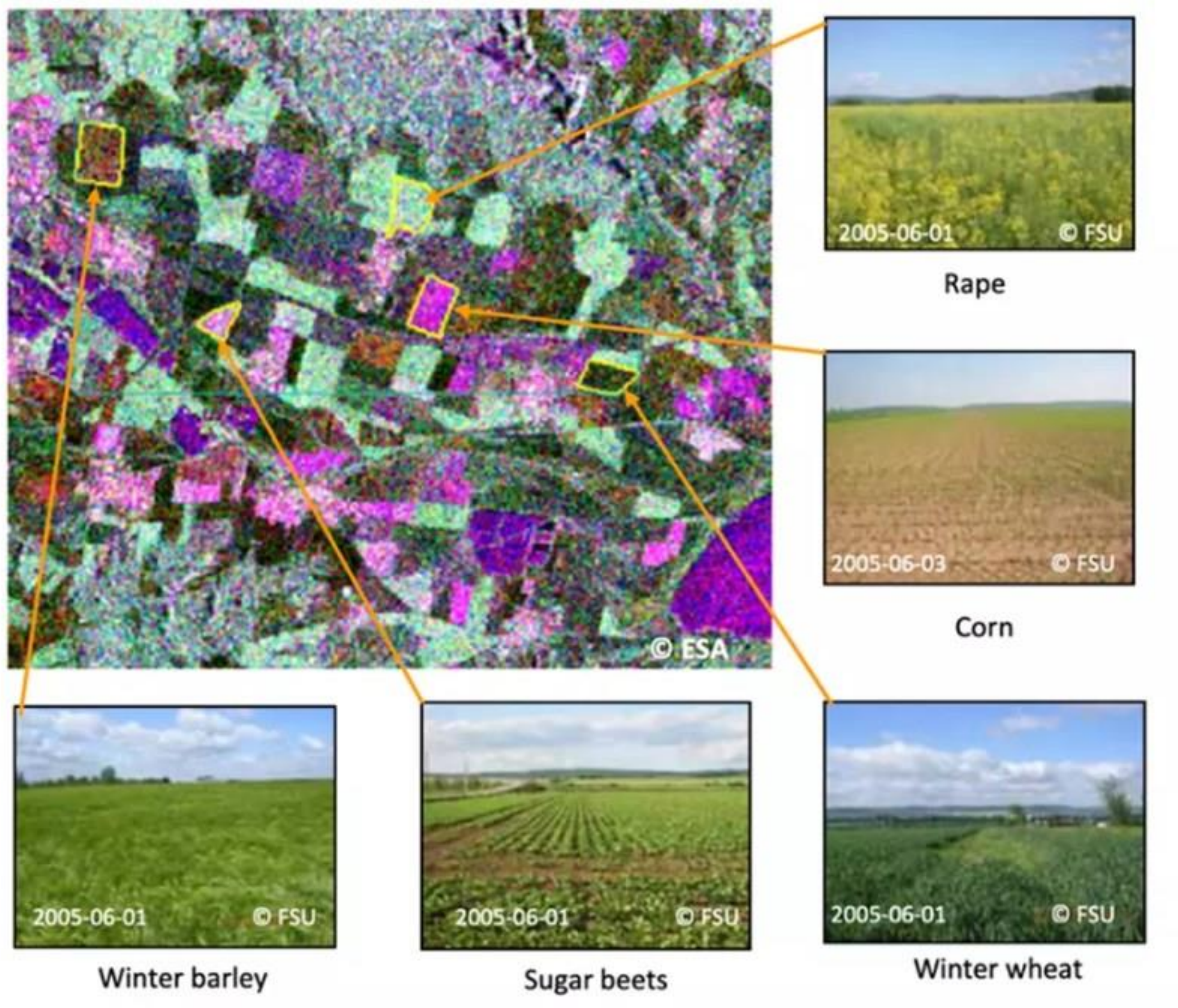
- For agricultural monitoring we need enough penetration into canopy (L- or C-band), but not to deep so that we have soil interference (C- or X-band for lower biomass)



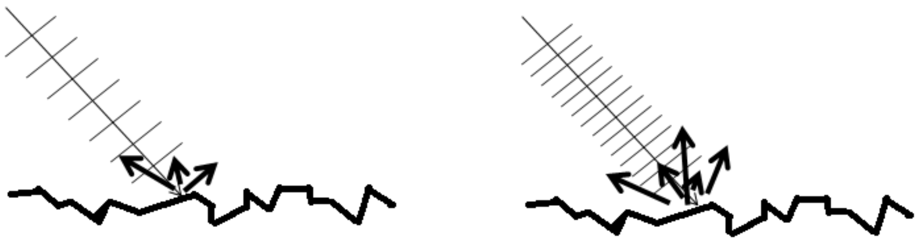
Source:https://medium.com/@preet.balaji20/decoding-synthetic-aperture-radar-sar-remote-sensing-sar-series-part-1-getting-started-d3409eb3b2e3

Radar Parameters to Consider in Precise Agriculture

Radar backscaterring



- The intensity of backscattered energy typically increases with surface roughness



The surface appears smooth to long wavelength
=> Backscattering is low

The surface appears rough to shorter wavelength
=> Backscattering increases

- SAR responds to changes in structure and moisture

https://appliedsciences.nasa.gov/sites/default/files/2020-11/SAR_Part3.pdf,
https://www.groundstation.space/tech/sar-satellites-for-agriculture/

Radar – Multiple frequencies

- **Classification is best with higher frequencies (shorter wavelengths**) as this provides best opportunity for multiple scattering within the canopy
- X-Band provides excellent classification results

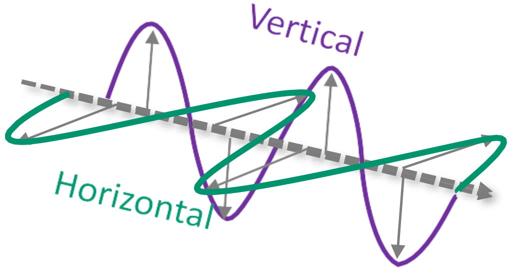
X (3.1 cm)
C (5.5 cm)

RADARSAT-2 VH - July 10, 2016
TerraSAR-X VV - July 10, 2016
ALOS VH - July 9, 2016

Integration of Data from RADARSAT-2, ALOS, and TerraSAR-X, Manitoba (Canada)

Radar Parameters to Consider in Precise Agriculture

Polarisation

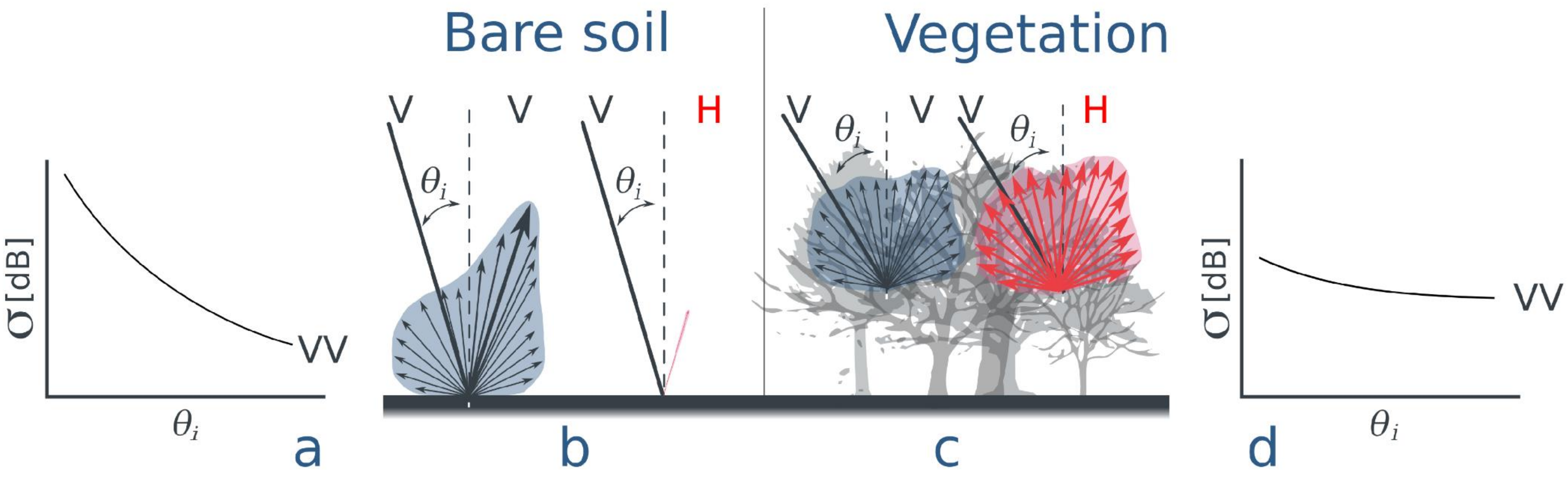


The radar signal is polarised:

Radar: ***transmits*** a EMW in a given polarization
measures the backscattered wave contribution in a given polarization

Vegetation has a predominant vertical structure:

- V-polarized waves align closely with this structure - increased scattering
- H-polarized waves encounter less interaction with the vertically oriented target, allowing more energy to penetrate through the canopy and reach the ground



Scattering mechanisms of VV and VH polarized backscatter, where (**a**,**b**) show the relation between backscatter and incidence angle and scattering mechanisms for bare soils, and (**c**,**d**) the relation between backscatter and incidence angle and scattering mechanisms for vegetation.
https://www.mdpi.com/2072-4292/12/20/3404

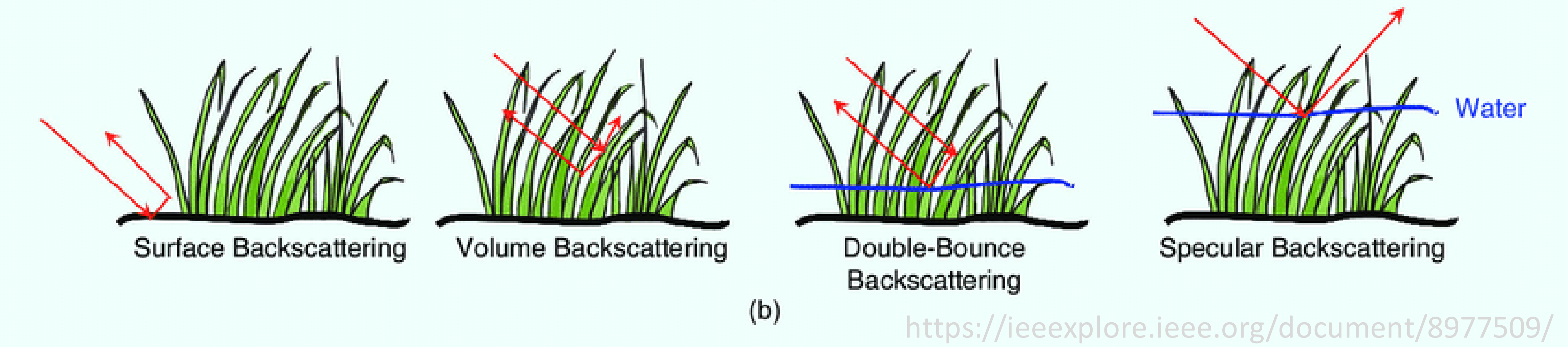
Radar Parameters to Consider in Precise Agriculture

Vegetation effects

Scattering of longer-wavelength microwaves is driven by:
- orientation of leaves, stems
- the volume of water in the vegetation

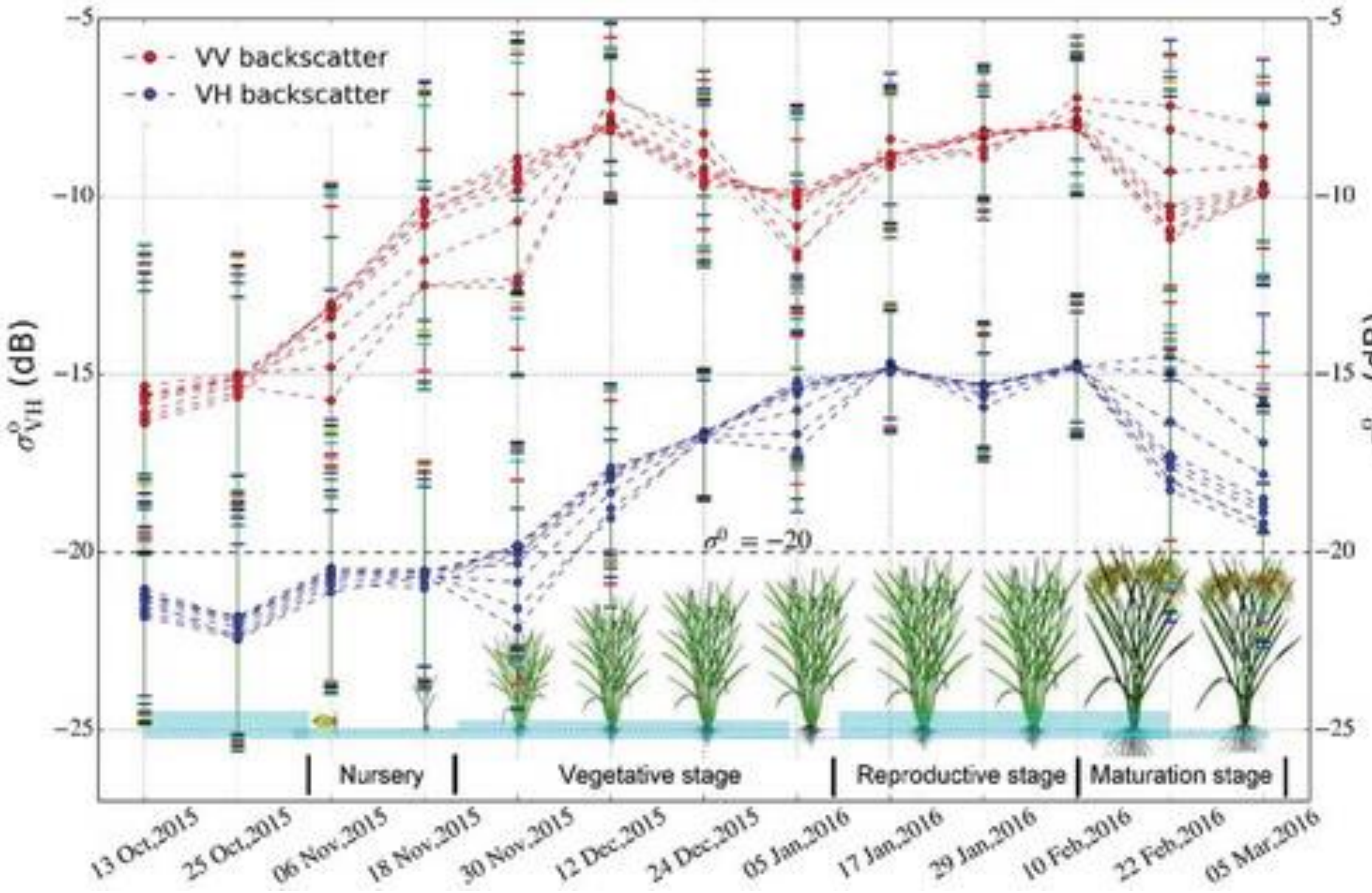
These scattering effects determine how much of the energy will return back to the SAR sensor and how the phase between e.g. H and V components will change

Following a wave into a canopy, it may scatter as below:



Radar Parameters to Consider in Precise Agriculture

Density of SAR time series

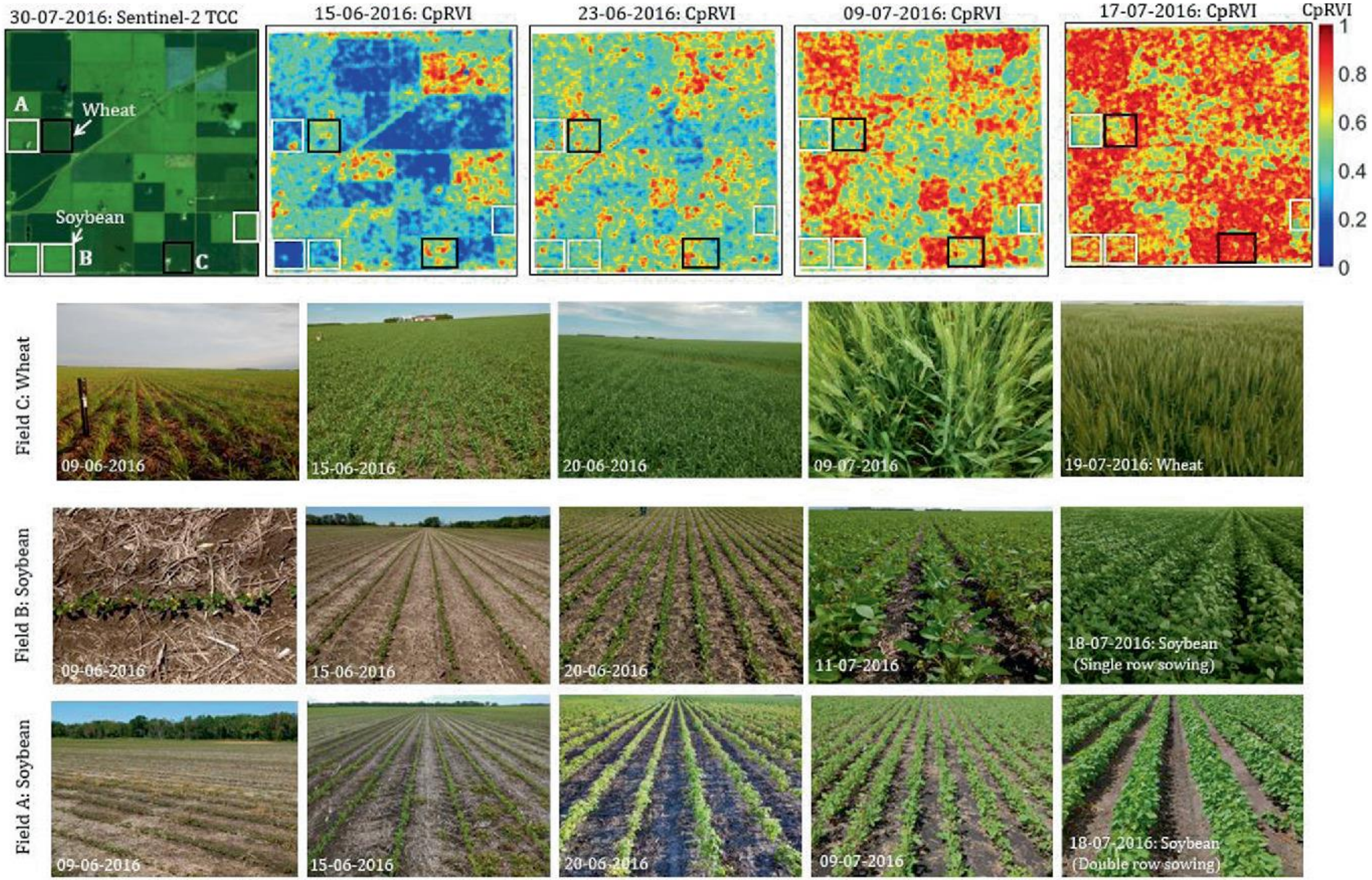


- SAR backscattering
- SAR coherence

https://www.tandfonline.com/doi/full/10.1080/2150704X.2016.1225172

Radar and Optical in Precise Agriculture - Applications

Spatio-temporal variations



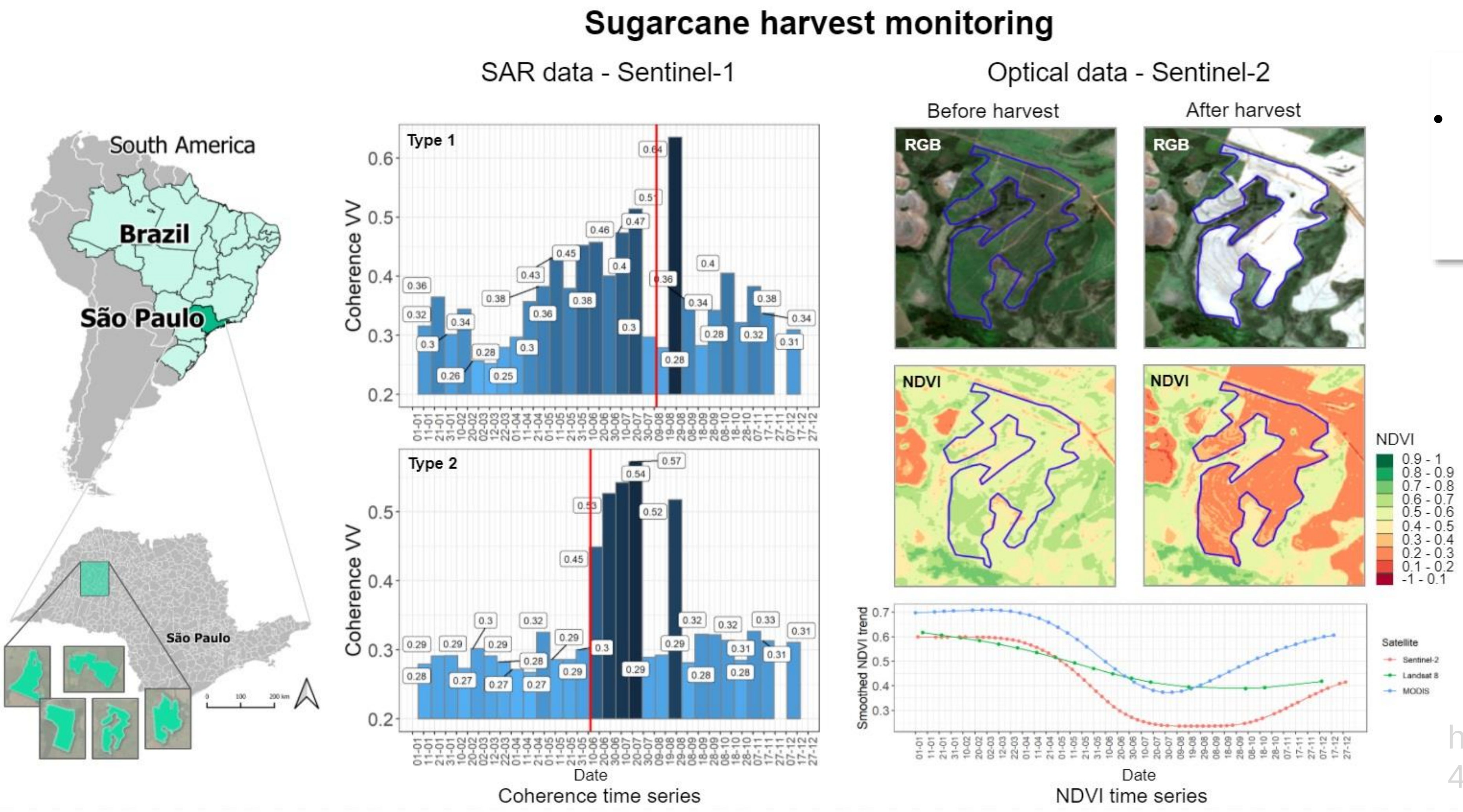
- Combined use of SAR and Optical data

- Spatio-temporal variations of CpRVI within the wheat and soybean fields. The black and white polygons show the sampling fields of wheat and soybean, respectively. The field photos during the campaign at specific instances are presented for wheat and soybean.

https://link.springer.com/chapter/10.1007/978-981-16-4424-5_7/figures/18

Radar and Optical in Precise Agriculture - Applications

Harvest monitoring

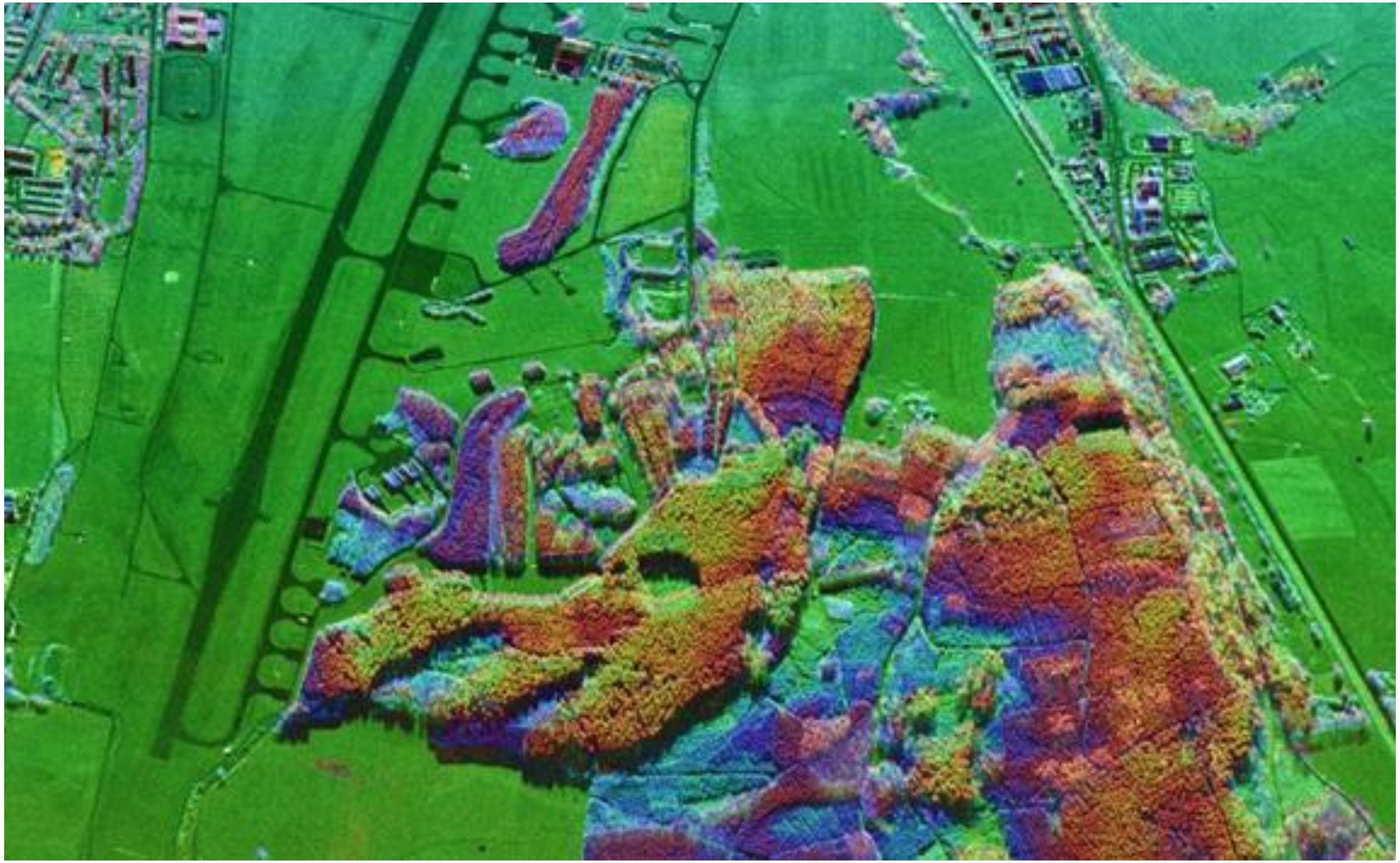


- Combined use of SAR and Optical data for harvest monitoring

https://www.mdpi.com/2072-4292/12/24/4080#

Radar and Optical in Precise Agriculture - Applications

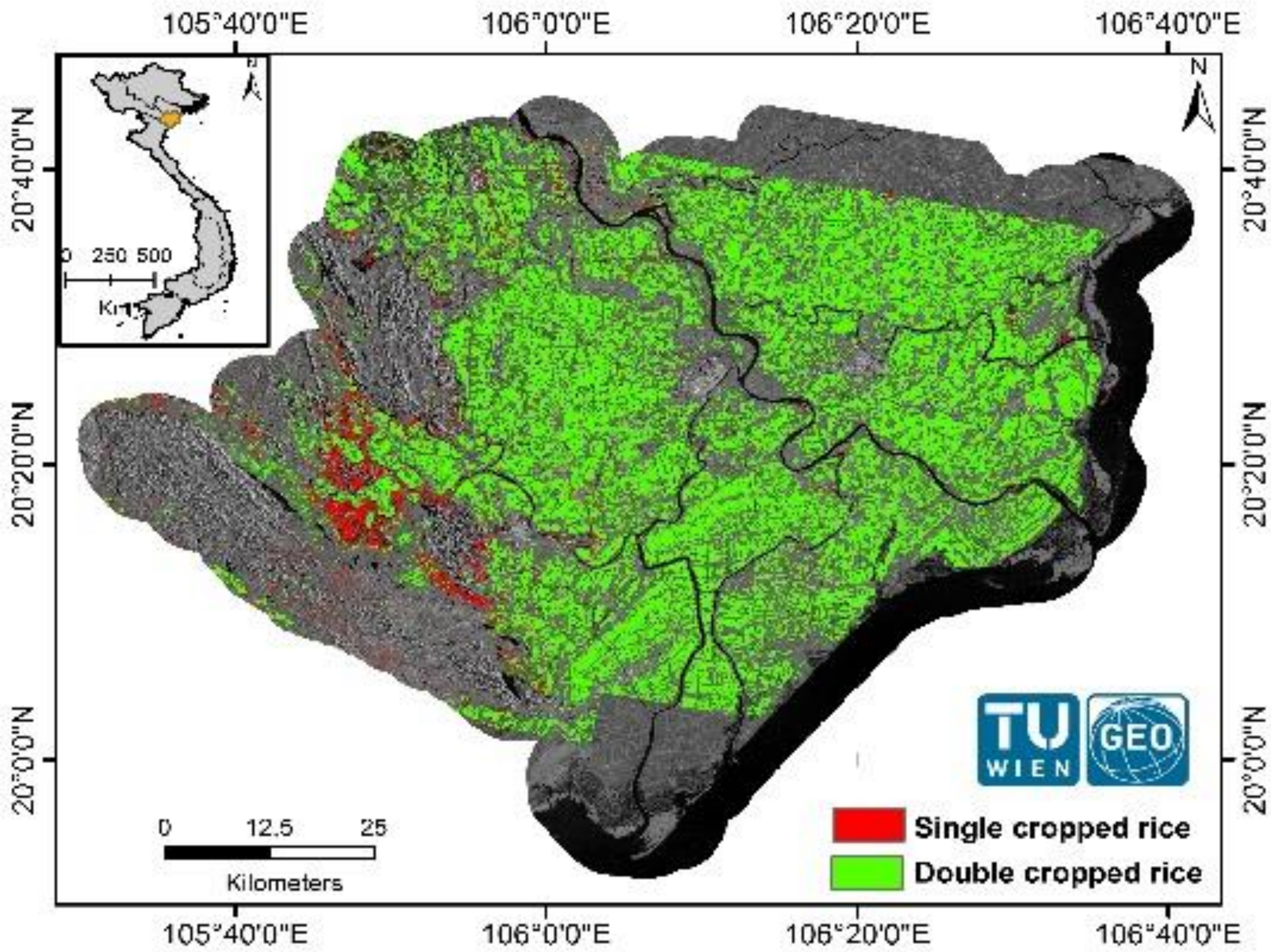
Estimation of crop condition using POLinSAR



POLinSAR, a technique that combines polarimetry, involving varying the orientation of radar signals, with interferometry, which analyzes phase differences in the signal, to generate differential range and range-change measurements from two or more images captured by synthetic aperture radars (SARs). This combined approach enables the visualization of the Earth in three dimensions. CREDIT: ESA

Radar and Optical in Precise Agriculture - Applications

Cropping systems



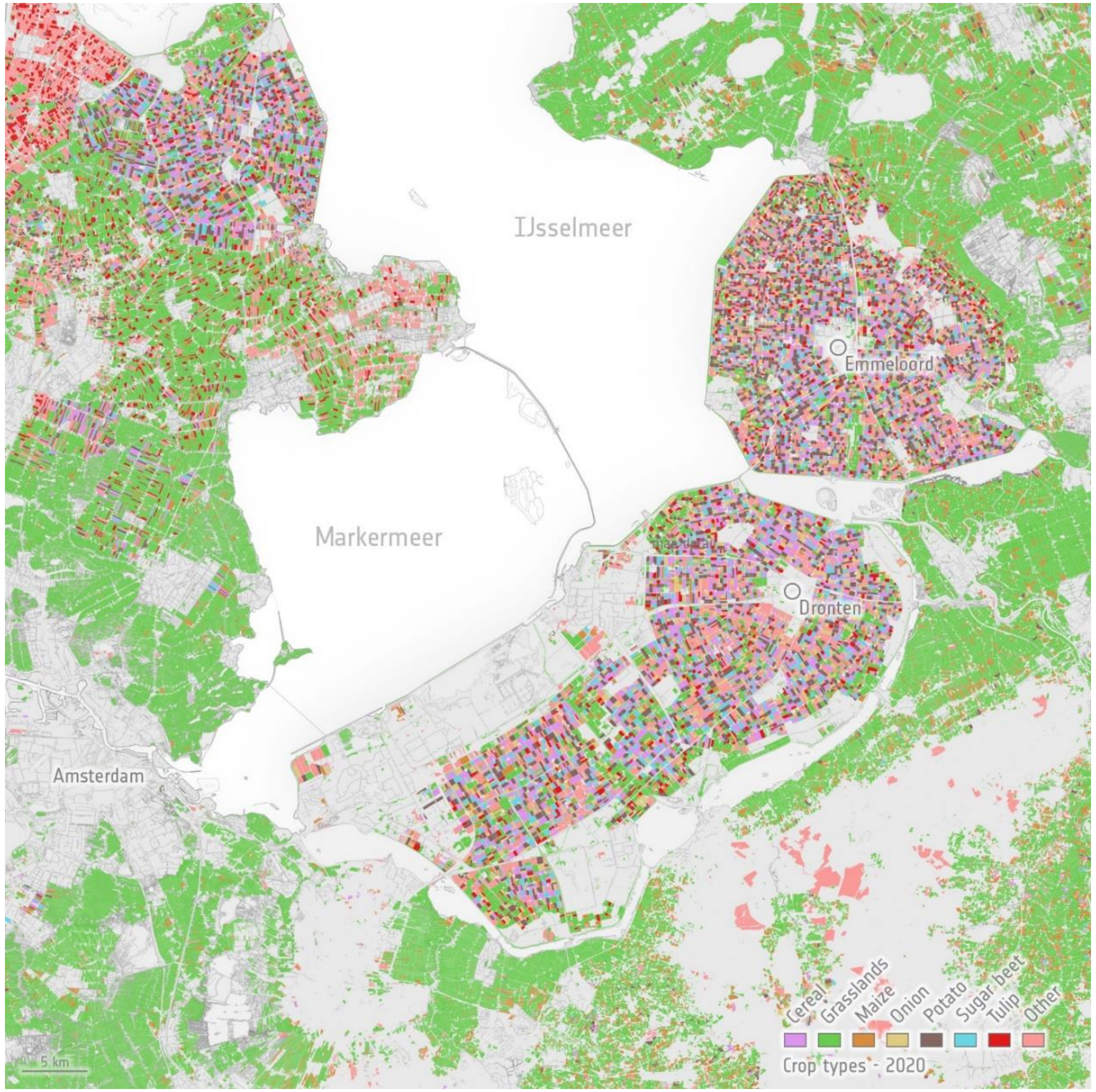
Rice-cropping systems in Vietnam's Red River Delta

Intra-annual Sentinel-1 data from January 2015 to December 2015 were used to produce rice-cropping systems map in the Red River Delta, Vietnam. In this case study, a significant area of rice paddies grows two crops per year (green). The remaining areas, in mountainous and riverine regions (red), are where the long-term flooded or saturated soil conditions permitted only one crop of rice per year.

CREDIT
contains modified Copernicus Sentinel data (2015–16)/TU Wien

Radar and Optical in Precise Agriculture - Applications

Monitoring of crop types



Crop type for all agricultural parcels Flevoland in the Netherlands

This figure zooms in on Flevoland in the Netherland to illustrate individual crop parcels. ESA worked with the Delft University of Technology in the Netherlands to develop Agricultural Sandbox NL, which makes use of radar data from Copernicus Sentinel-1 and optical, or camera-like, data from Copernicus Sentinel-2 and reduces terabytes of satellite data to just 10 gigabytes per year. Importantly, this dataset tool makes these data perfect for non-expert data users in the agriculture sector.

CREDIT
ESA/Crop Parcel Base Register, Dutch Ministry of Economic Affairs and Climate Policy

For more information, see the tutorial:
[5. Crop Classification with S1 and S2 data using the SNAP software]

Thank you for the attention