



5. SAR and optical remote sensing for precision agriculture 1

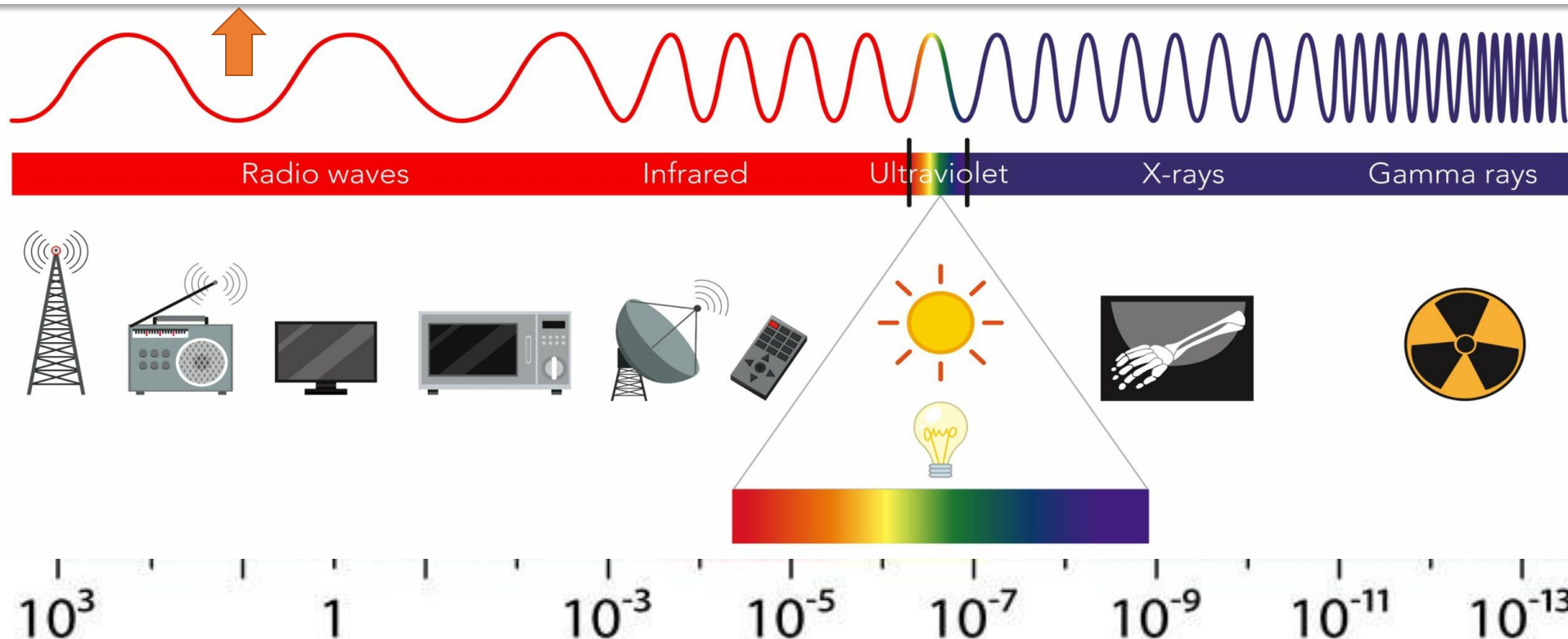


# SAR and optical for precise agriculture

## 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

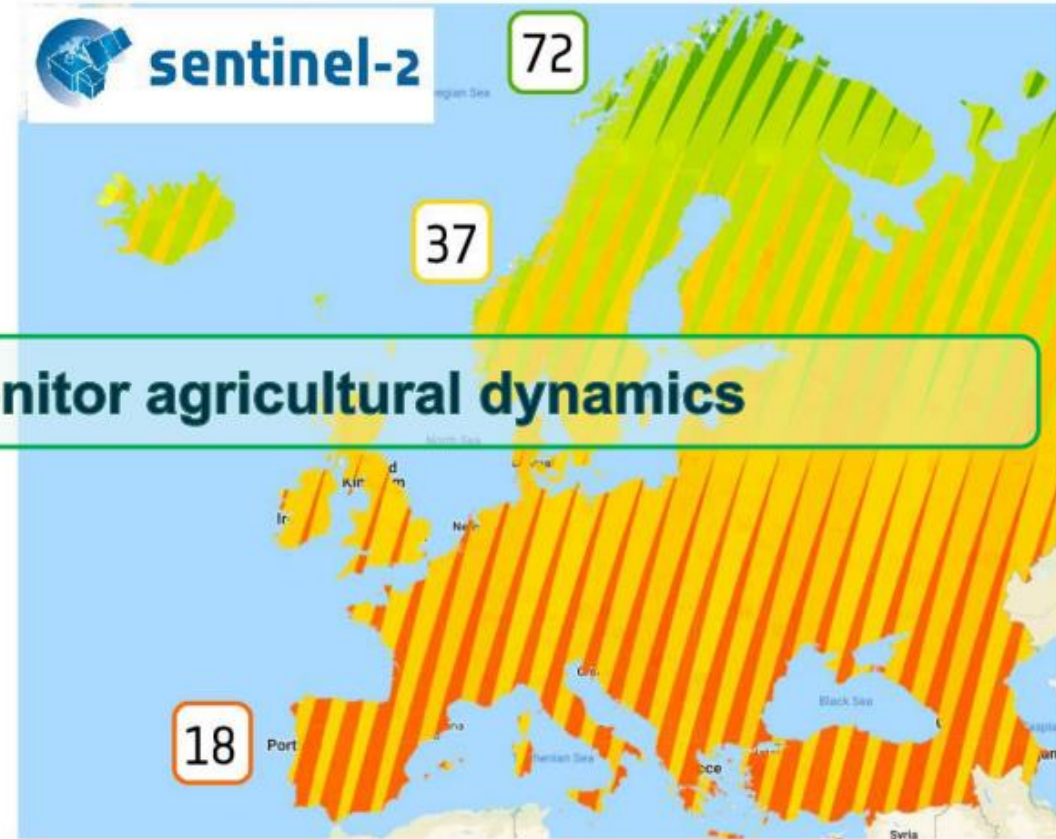
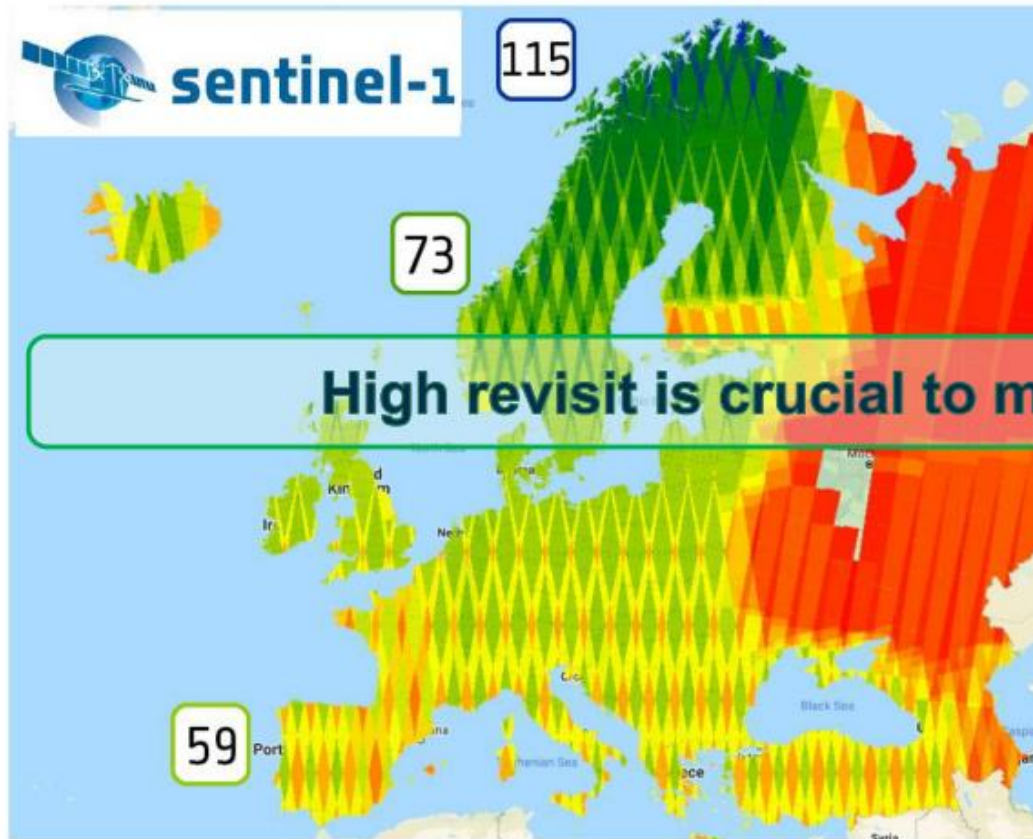
Use: spectral (and chemical) properties of vegetation

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

# Sentinels – game changer for precision agriculture

Majority of Europe >2 day revisit

Majority of Europe >3 day revisit



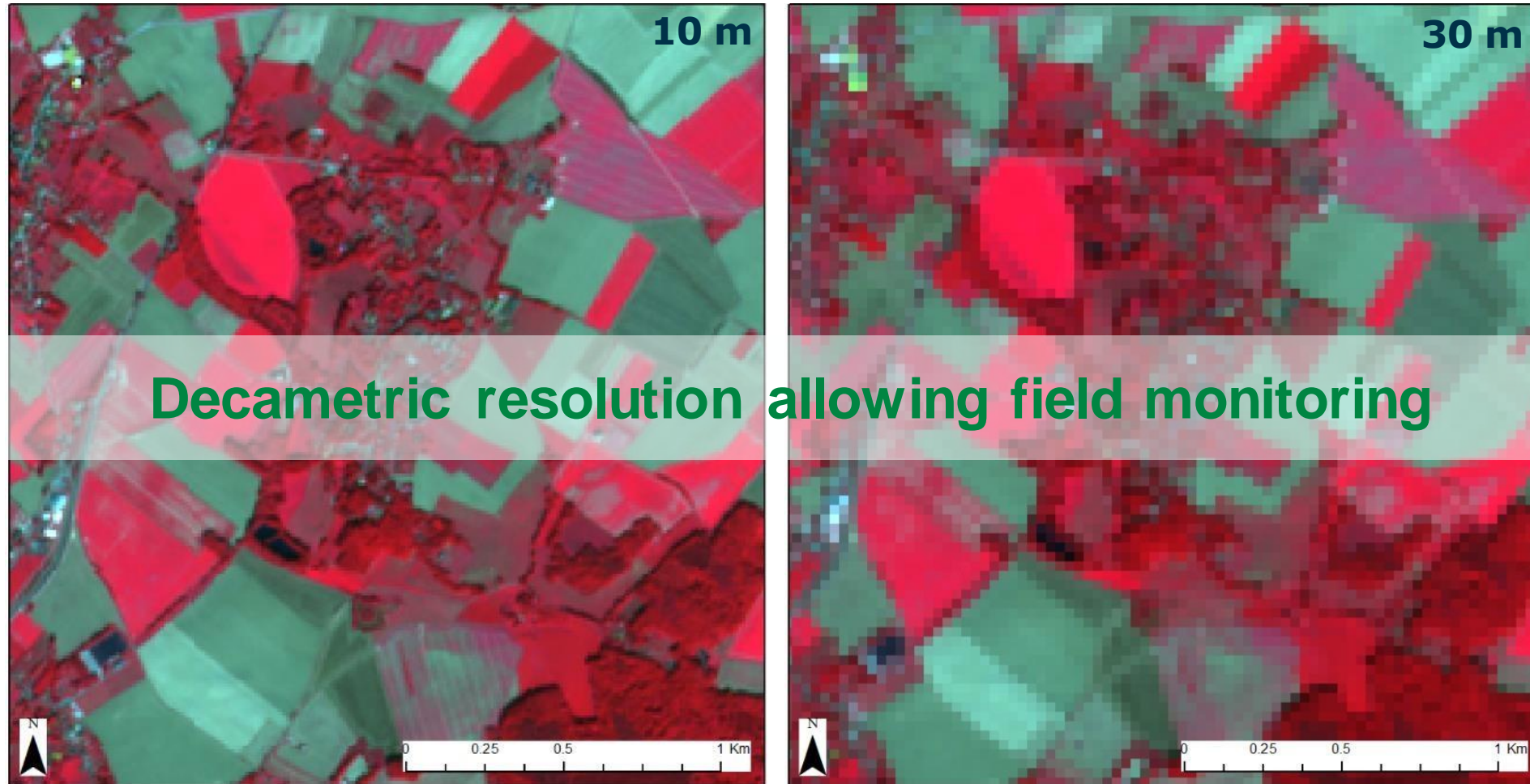
High revisit is crucial to monitor agricultural dynamics

S1A and S1B (July-Sept 2018)

S2A and S2B (July-Sept 2018)

# Sentinels – game changer for precision agriculture

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The image shows an aerial view of agricultural fields. A grid of circular markers is overlaid on the image, with each marker divided into two halves, one red and one white. The markers are arranged in a regular grid pattern, with some missing or obscured by the fields. The text "Optical for agriculture" is centered over the image in a white font.

# 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 <sup>63</sup>	16-18 days
<b>Sentinel (ESA)</b>	<b>Public</b>	<b>5m, 10m, 20m, 60m</b>	<b>C-band, Natural colour (Visible, NIR, SWIR)</b>	<b>1-5 days</b>
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, 0.5m, 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

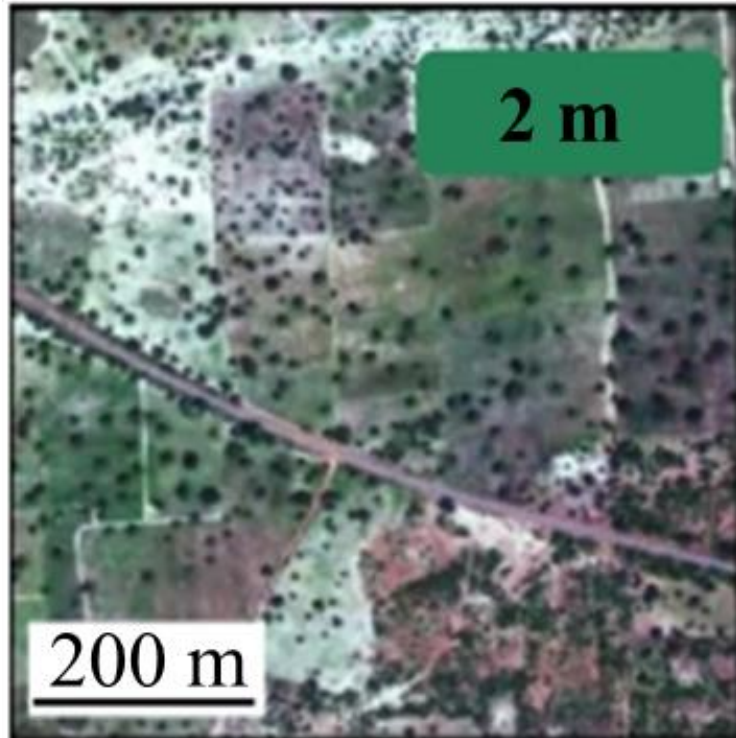
Resolutions offered by popular satellite imagery providers

# From EO signal to agriculture information content

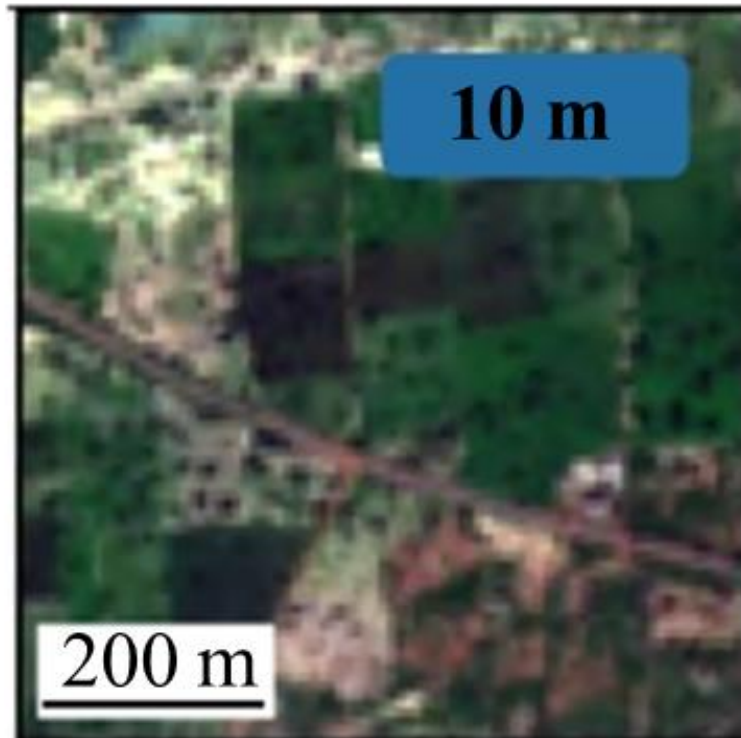
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## Spatial resolution

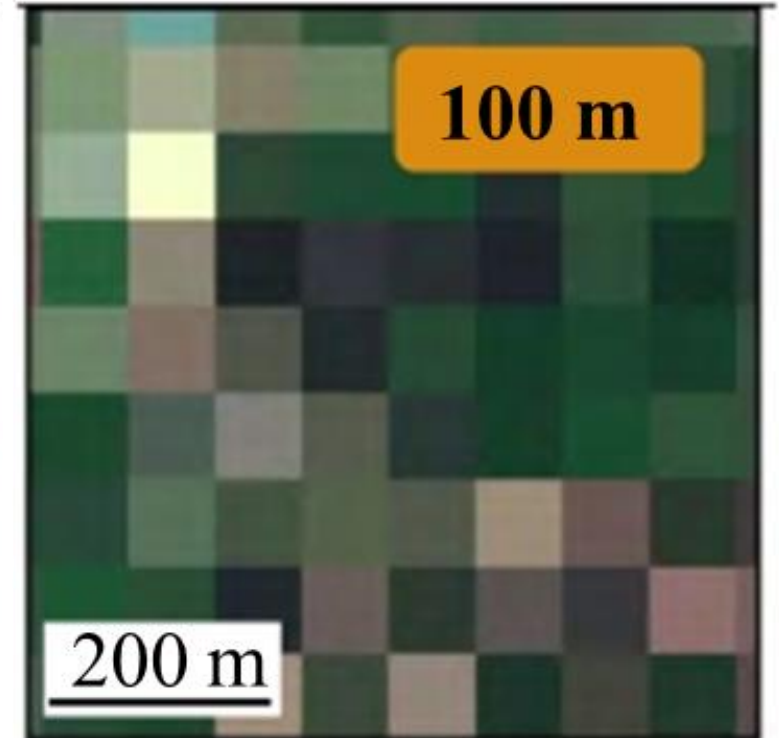
Digital Globe



Sentinel-2



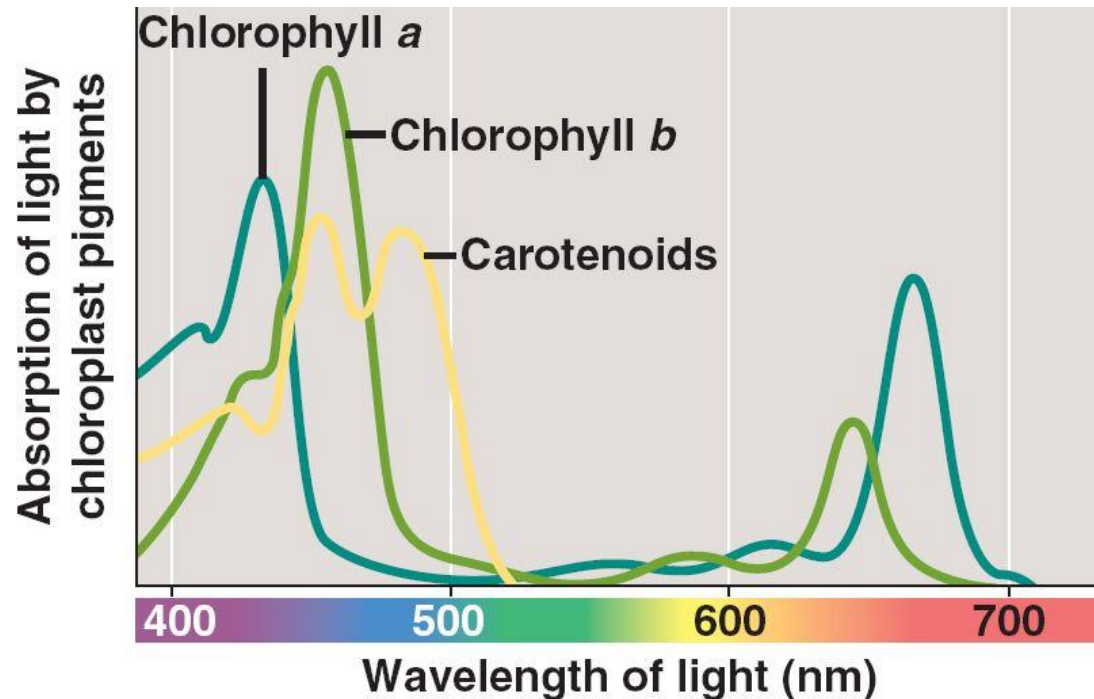
PROBA-V



# From EO signal to agriculture information content

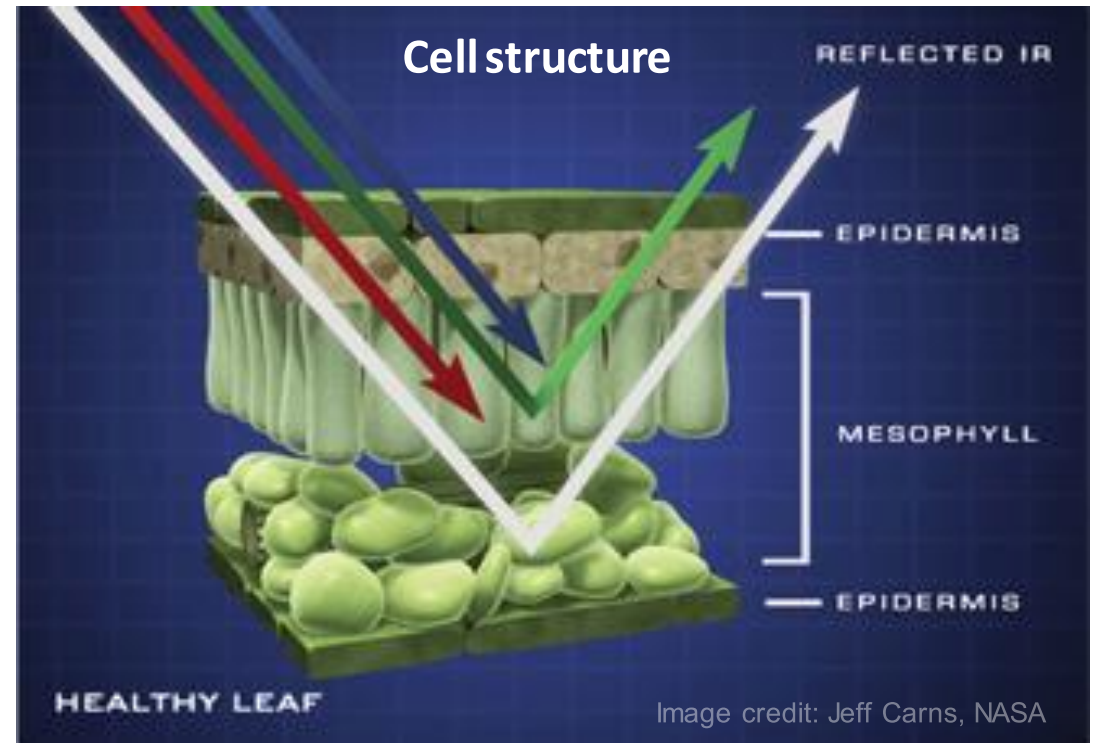
## Spectral signature of the plants

### Plant pigments



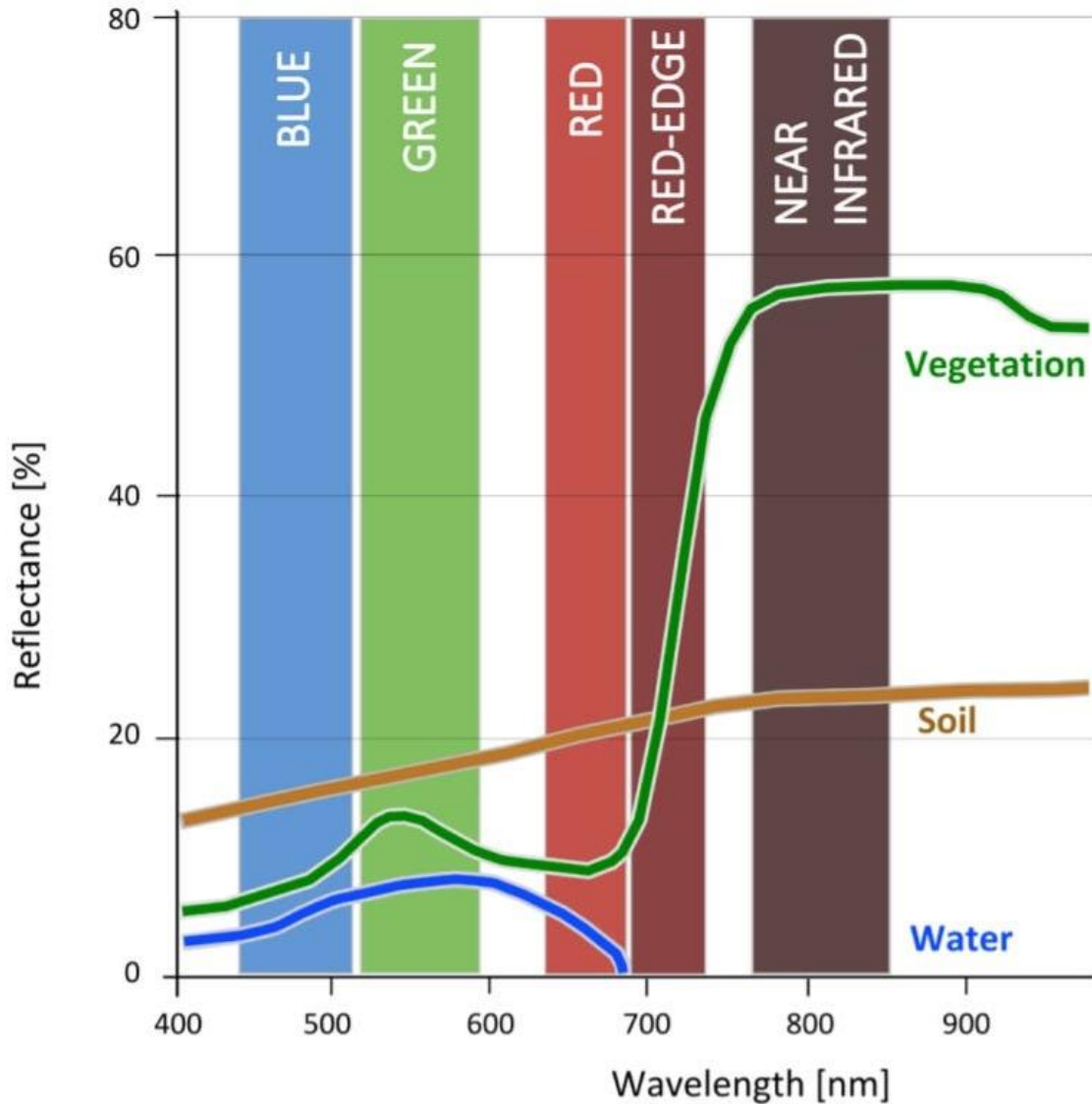
Chlorophyll predominately absorbs blue wavelengths (400-500 nm) and red (600-700 nm). Note that carotenoids absorb blue light as well as some green.

- 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 damage)



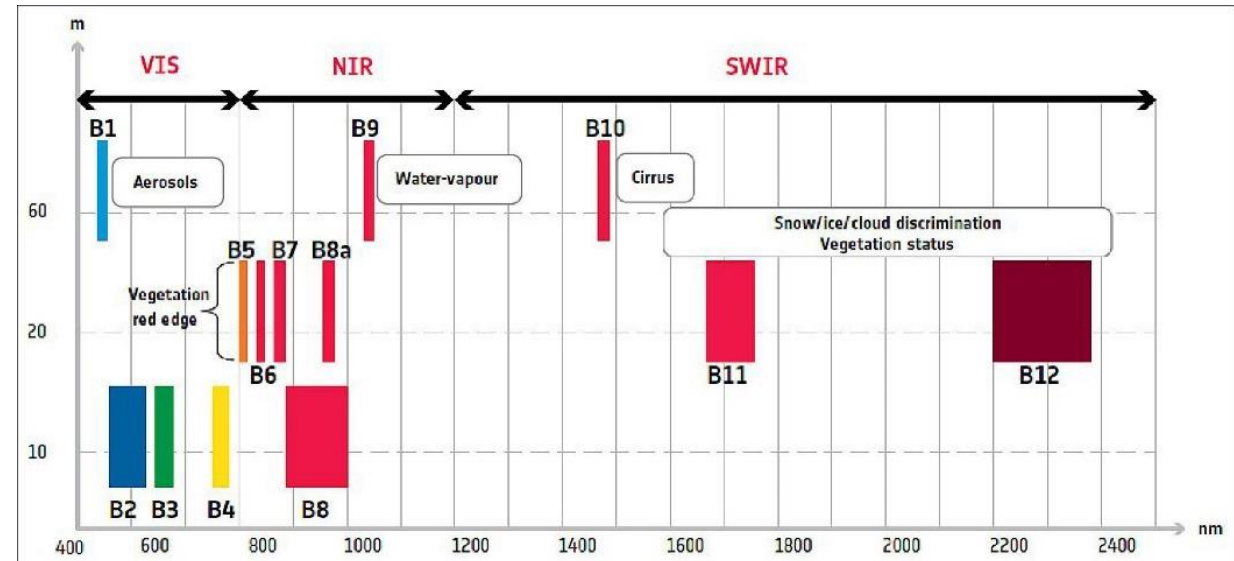


# From EO signal to agriculture information content



## RED EDGE

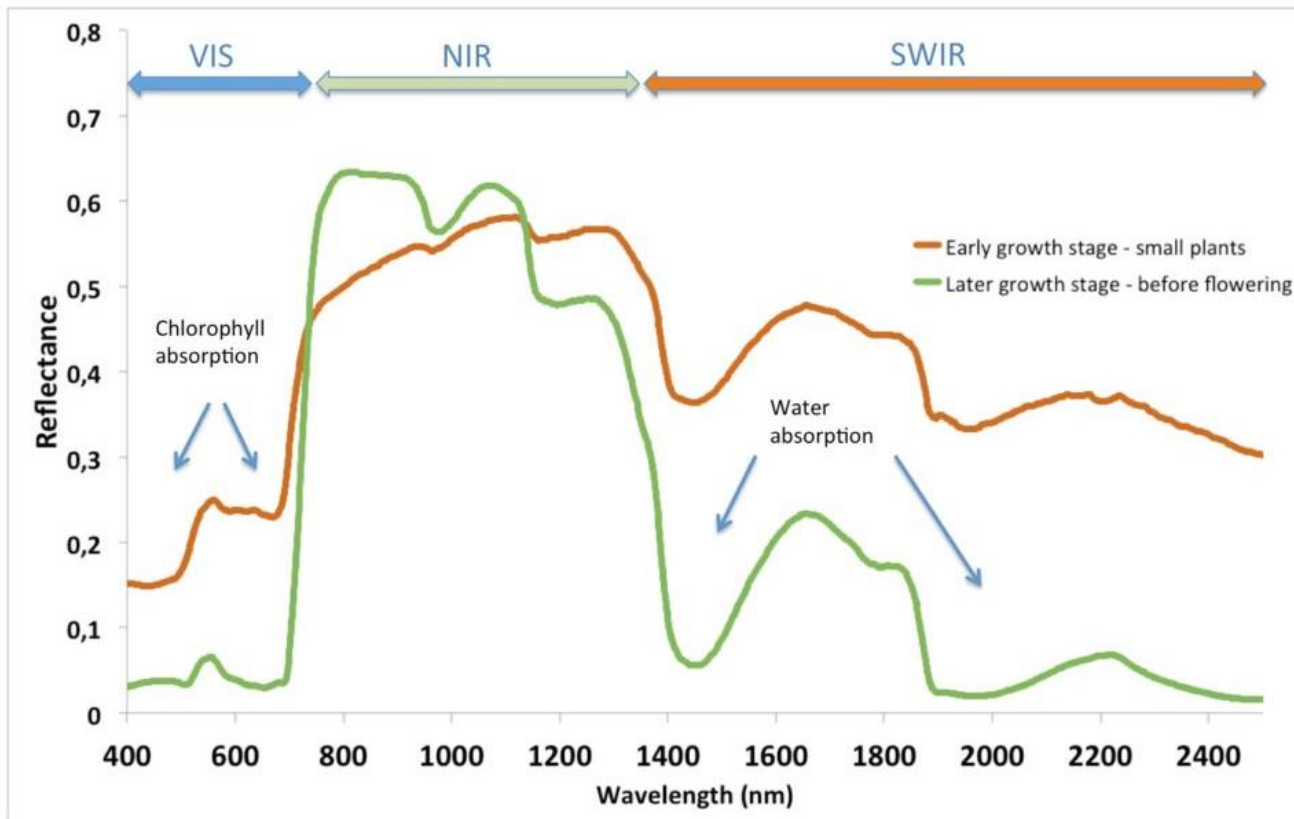
- The three 20m 'red edge' bands of Sentinel-2 provide key information on the state of vegetation
- Very narrow band (700 – 730 nm) corresponding to the red NIR transition zone
- Very sensitive to plant stress – provides information on the canopy chlorophyll and nitrogen content



# 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

**HEALTHY**  
VEGETATION REFLECTANCE

50% NIR 8% RED



NDVI = 0.72

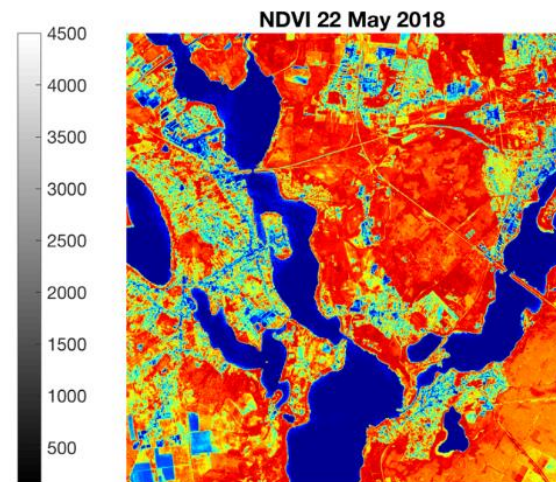
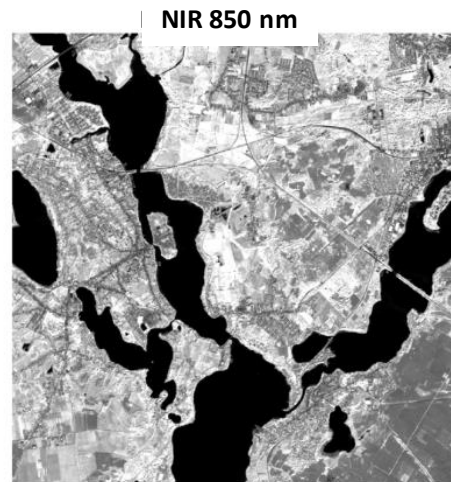
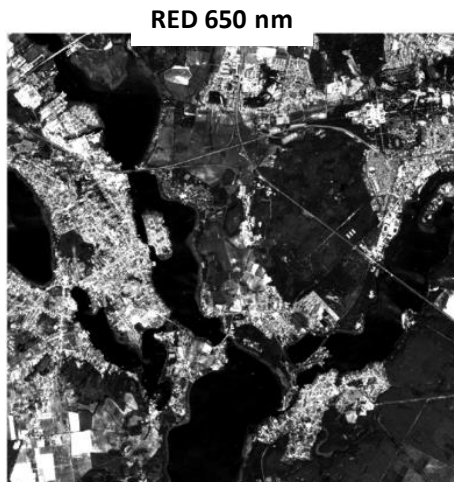
**STRESSED**  
VEGETATION REFLECTANCE

40% NIR 30% RED



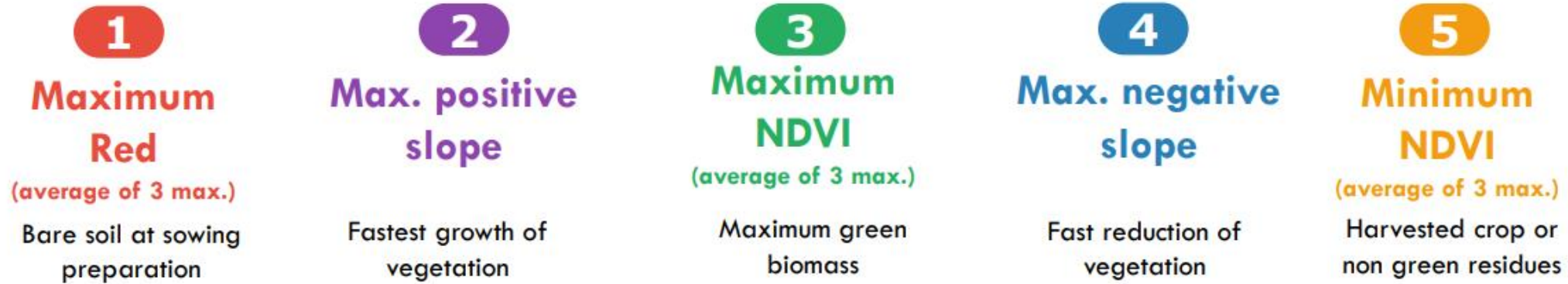
NDVI = 0.14

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



# From EO signal to agriculture information content

## NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI)



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

# 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.

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

# From EO signal to agriculture information content

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## LIST OF INDICES FOR AGRICULTURE MONITORING USING SENTINEL-2 DATA

### *Vegetation indices*

- *DVI, RVI, PVI*
- *NDVI, WDV, 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*

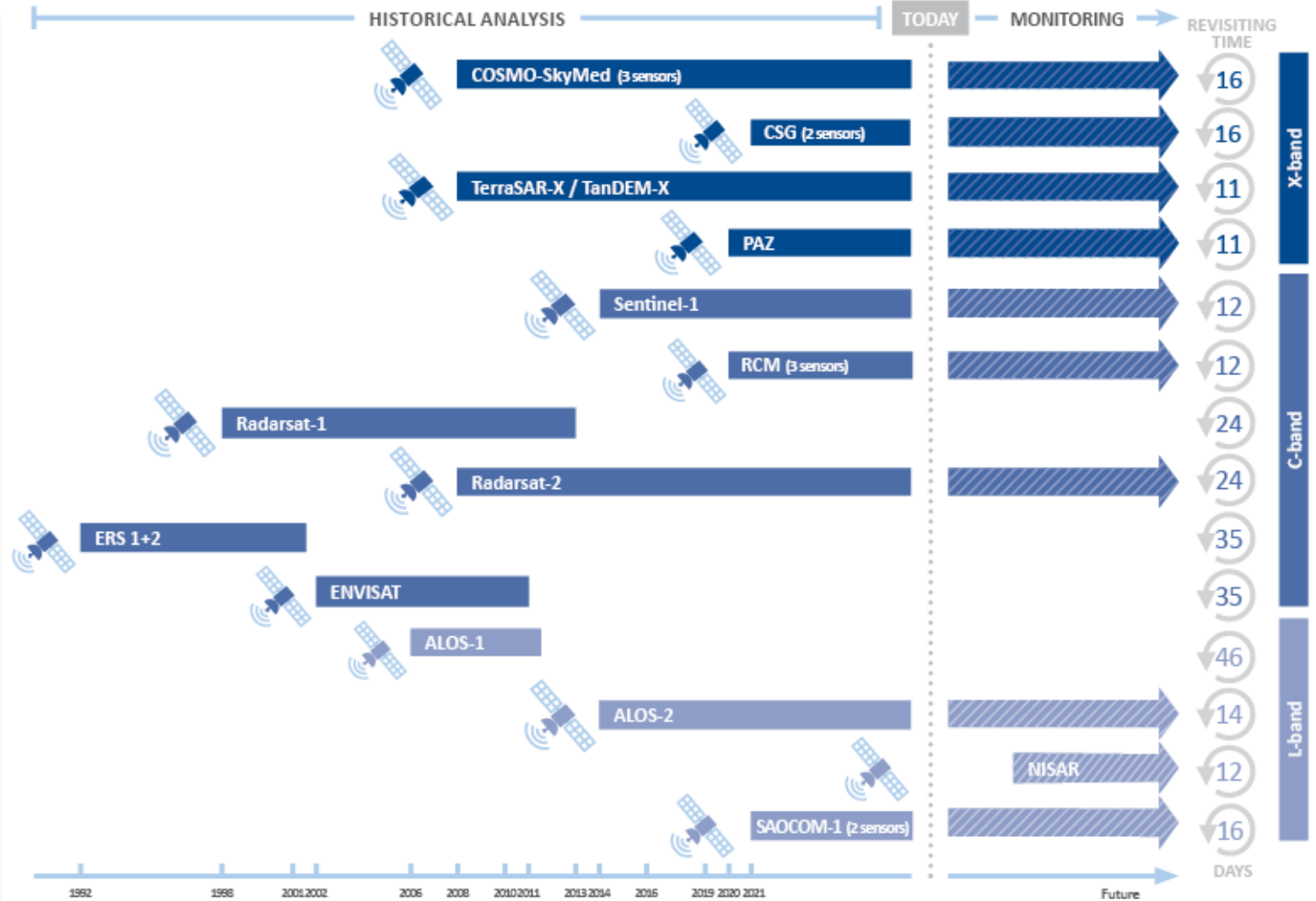


**Radar for agriculture**

# 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





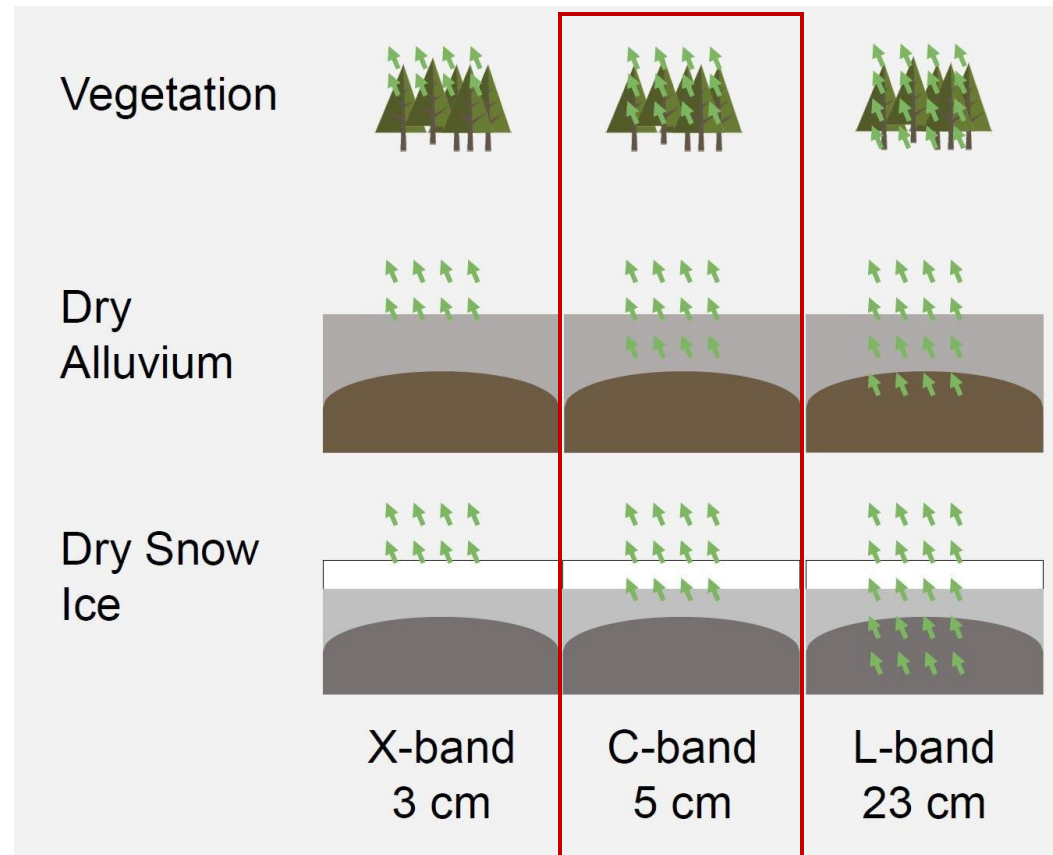
# Radar Parameters to Consider in Precise Agriculture

## 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

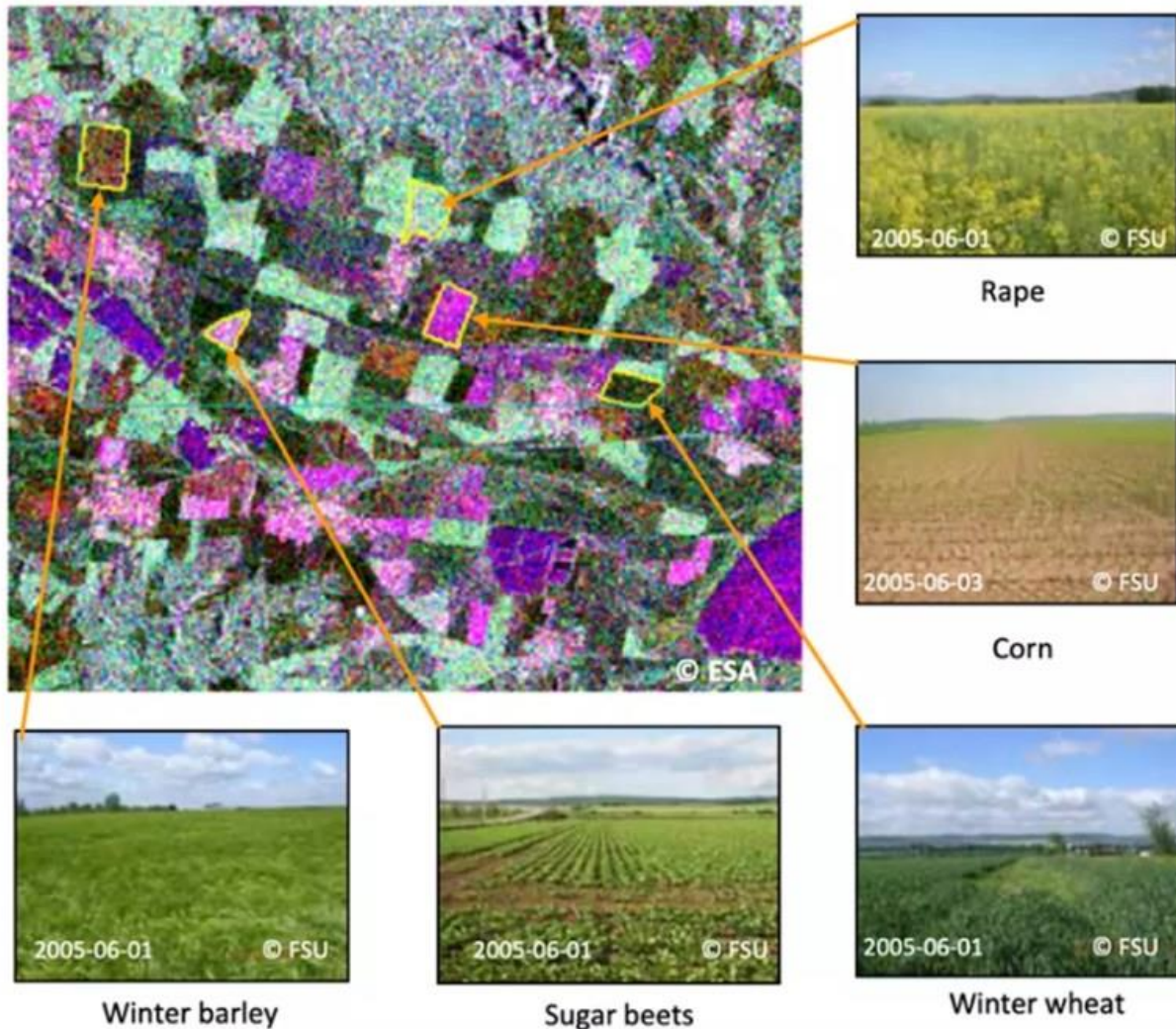
- For agricultural monitoring we need enough penetration into canopy (L- or C-band), but not too deep so that we have soil interference (C- or X-band for lower biomass)



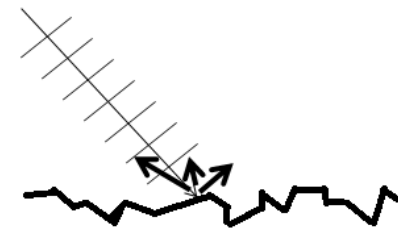
Source: <https://medium.com/@preet.balaji20/decoding-synthetic-aperture-radar-sar-remote-sensing-sar-series-part-1-getting-started-d3409eb3b2e3>

# Radar Parameters to Consider in Precise Agriculture

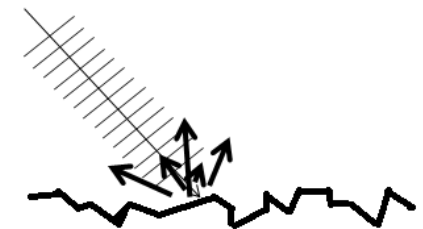
## Radar backscattering



- The intensity of backscattered energy typically increases with surface roughness



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

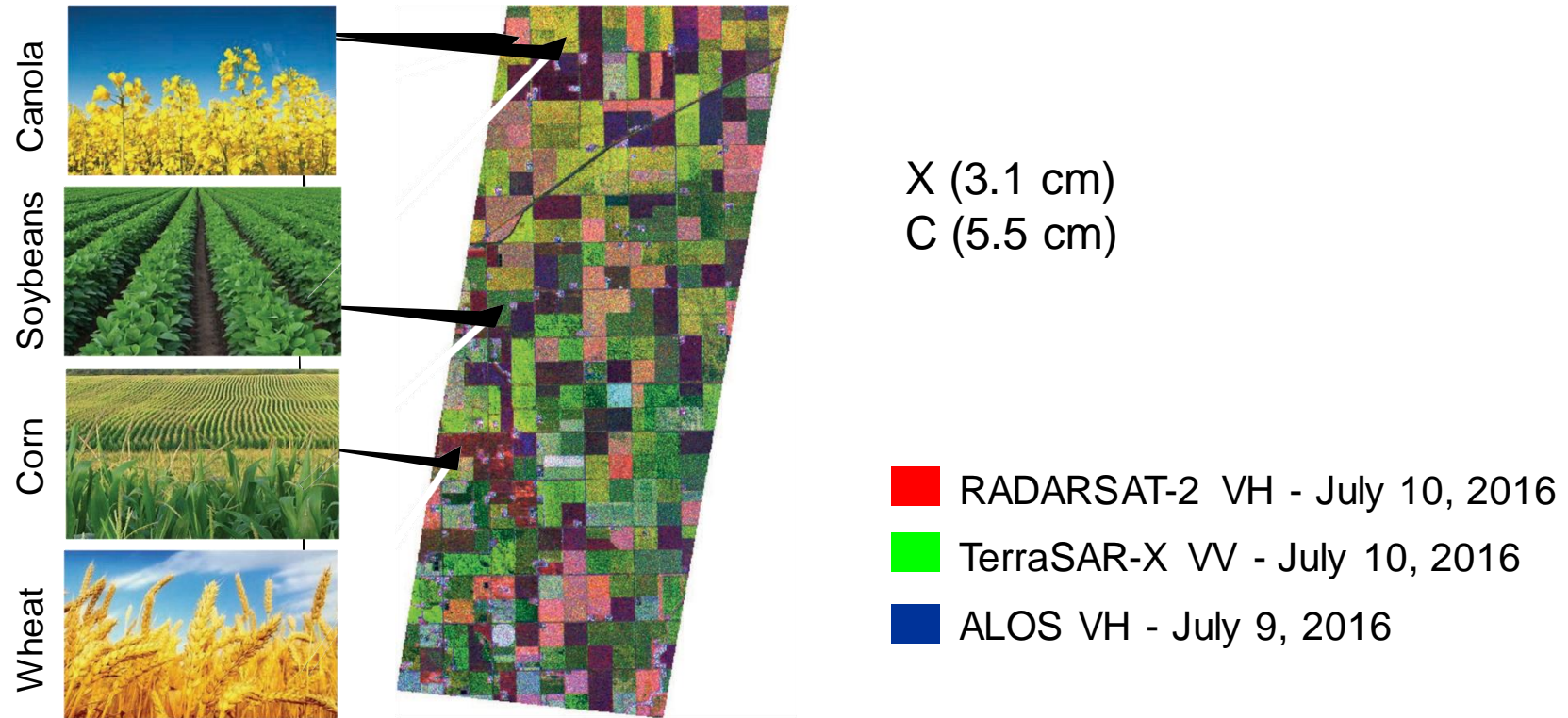


The surface appears rough to shorter wavelength  
=> Backscattering increases

- SAR responds to changes in structure and moisture

# 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



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

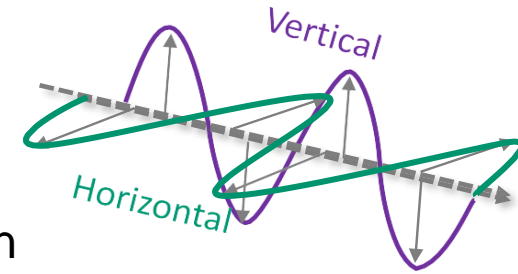
# Radar Parameters to Consider in Precise Agriculture

## Polarisation

### The radar signal is polarised:

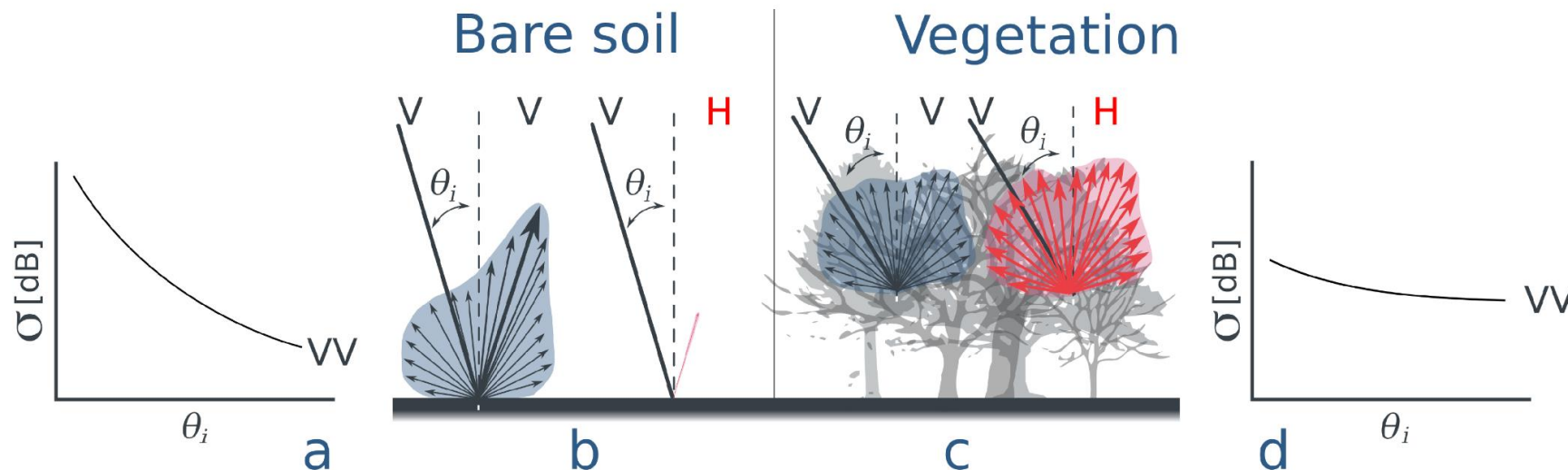
Radar: **transmits** a EMW in a given polarization

**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

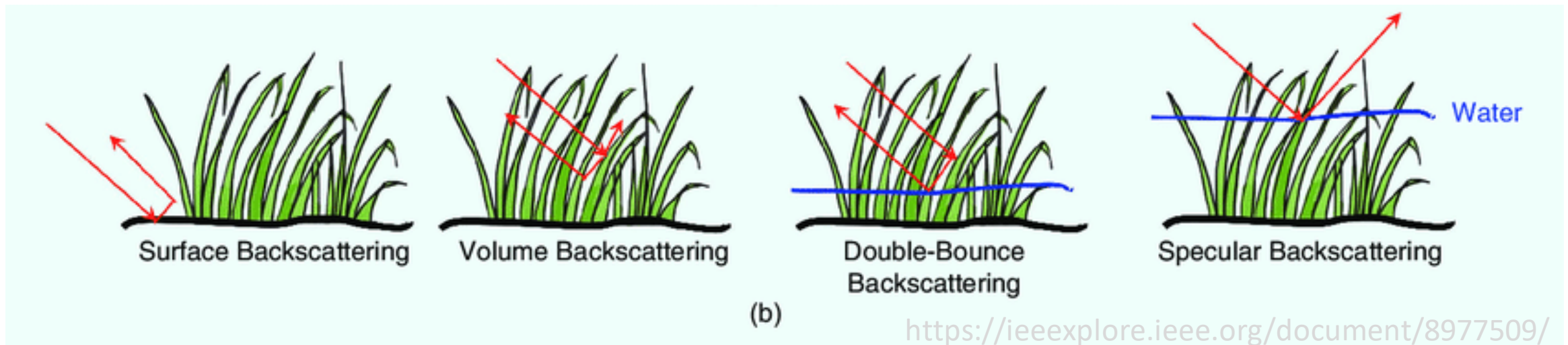
## Vegetation effects

Scattering of longer-wavelength microwaves is driven by:

- orientation of leaves, stems
- the volume of water in the vegetation

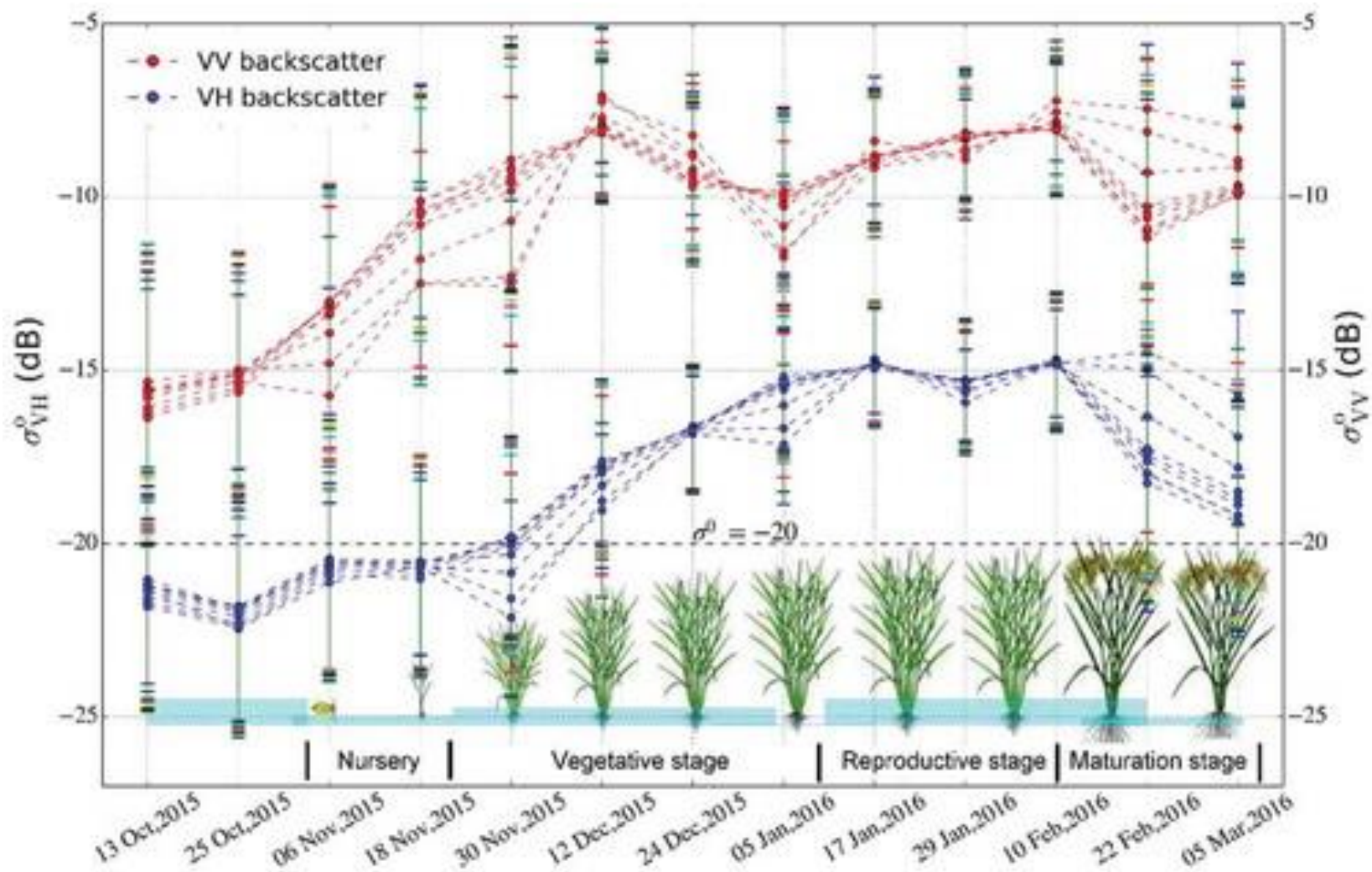
These scattering effects determine how much of the energy will return back to the SAR sensor and how the phase between e.g. H and V components will change

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



# Radar Parameters to Consider in Precise Agriculture

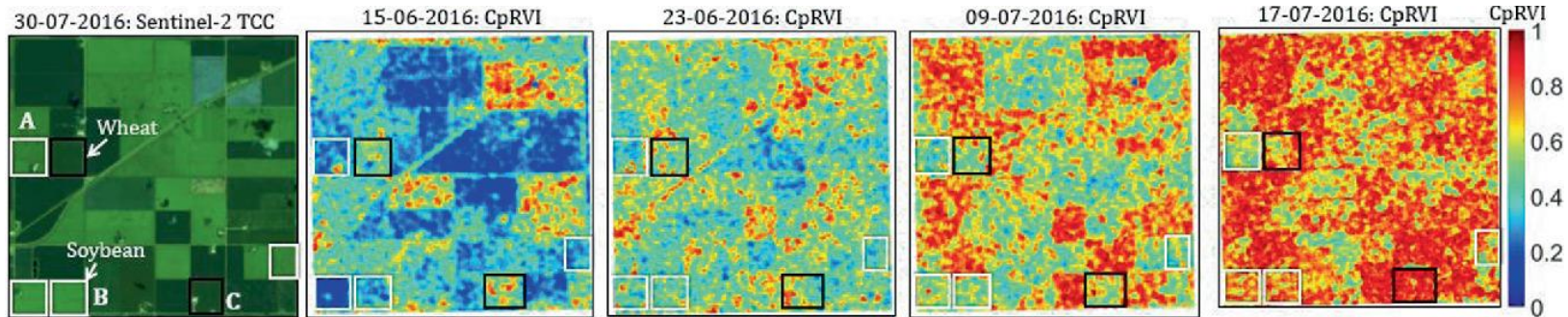
## Density of SAR time series



- SAR backscattering
- SAR coherence

# Radar and Optical in Precise Agriculture - Applications

## Spatio-temporal variations

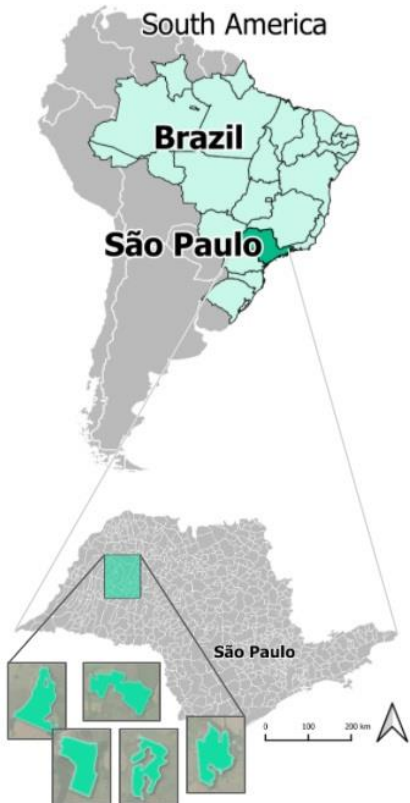


- Combined use of SAR and Optical data
- Spatio-temporal variations of CpRVI within the wheat and soybean fields. The black and white polygons show the sampling fields of wheat and soybean, respectively. The field photos during the campaign at specific instances are presented for wheat and soybean.

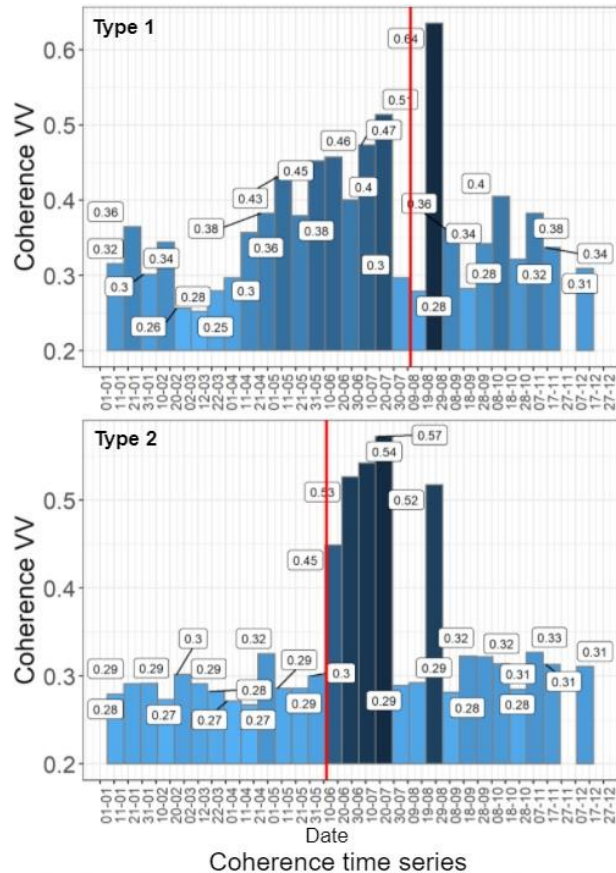
# Radar and Optical in Precise Agriculture - Applications

## Harvest monitoring

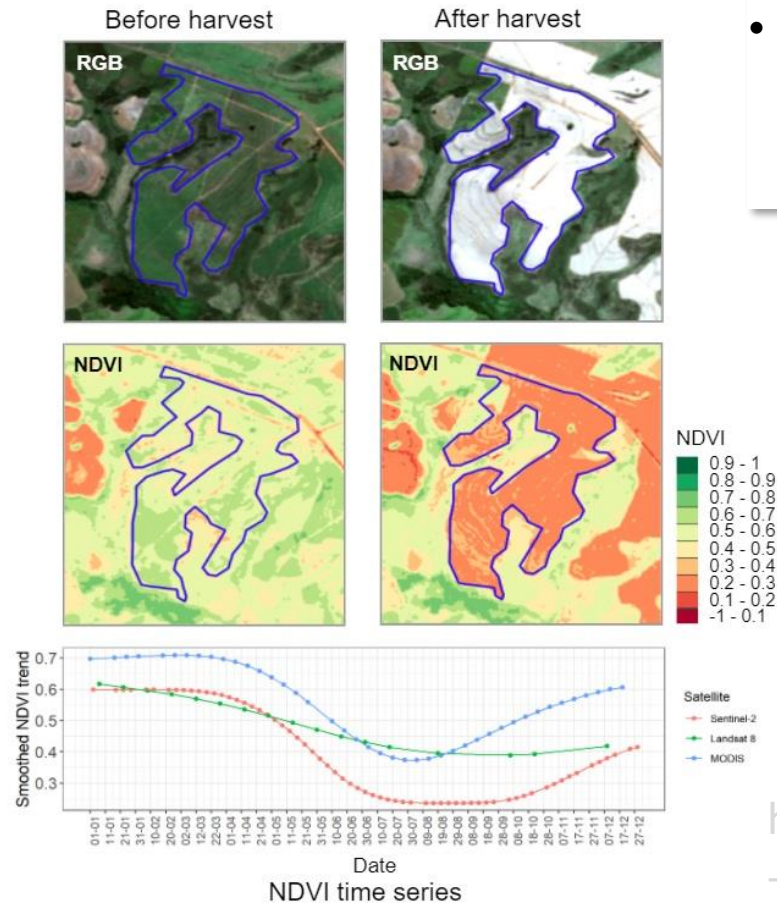
### Sugarcane harvest monitoring



SAR data - Sentinel-1



Optical data - Sentinel-2



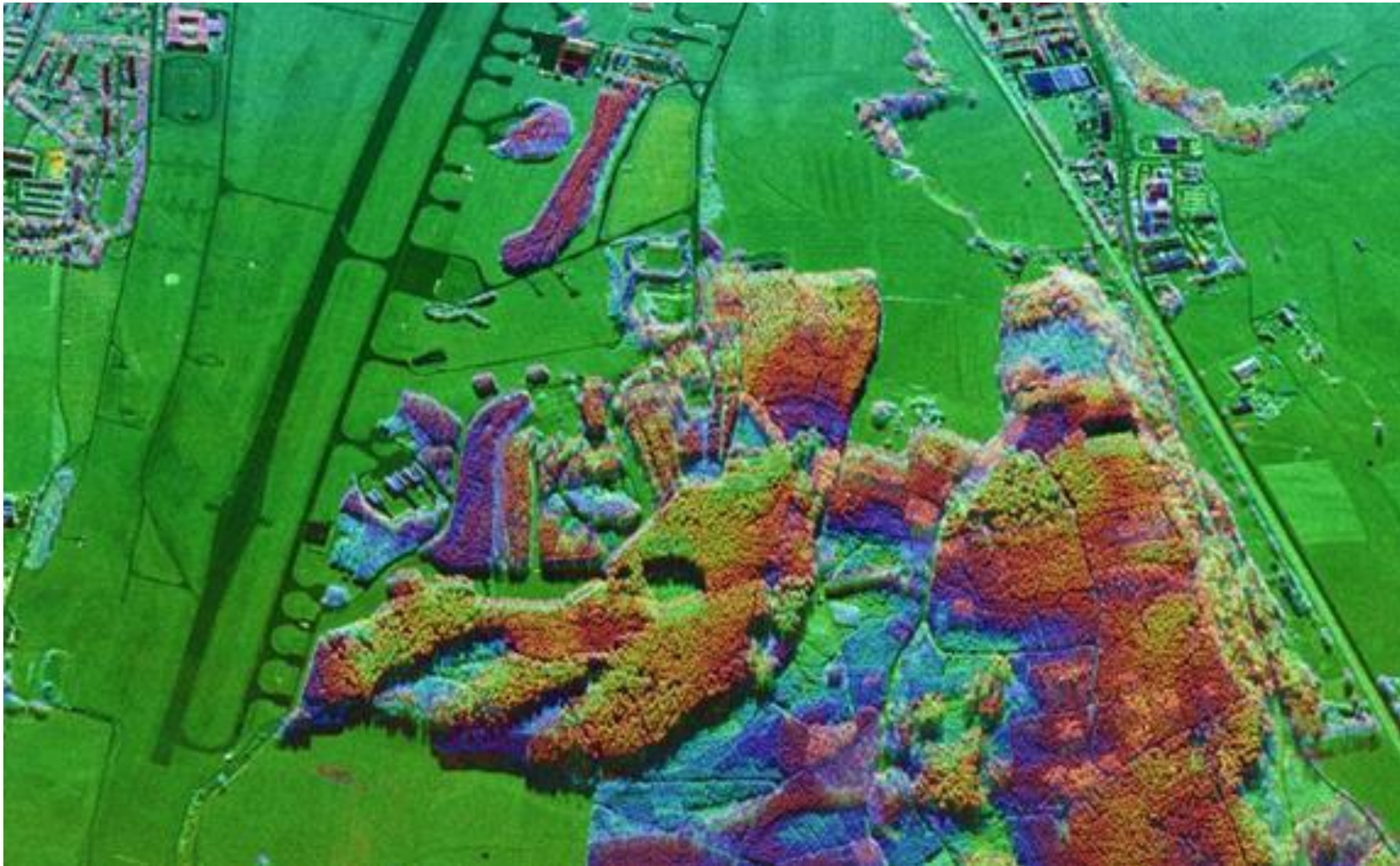
- Combined use of SAR and Optical data for harvest monitoring



# Radar and Optical in Precise Agriculture - Applications

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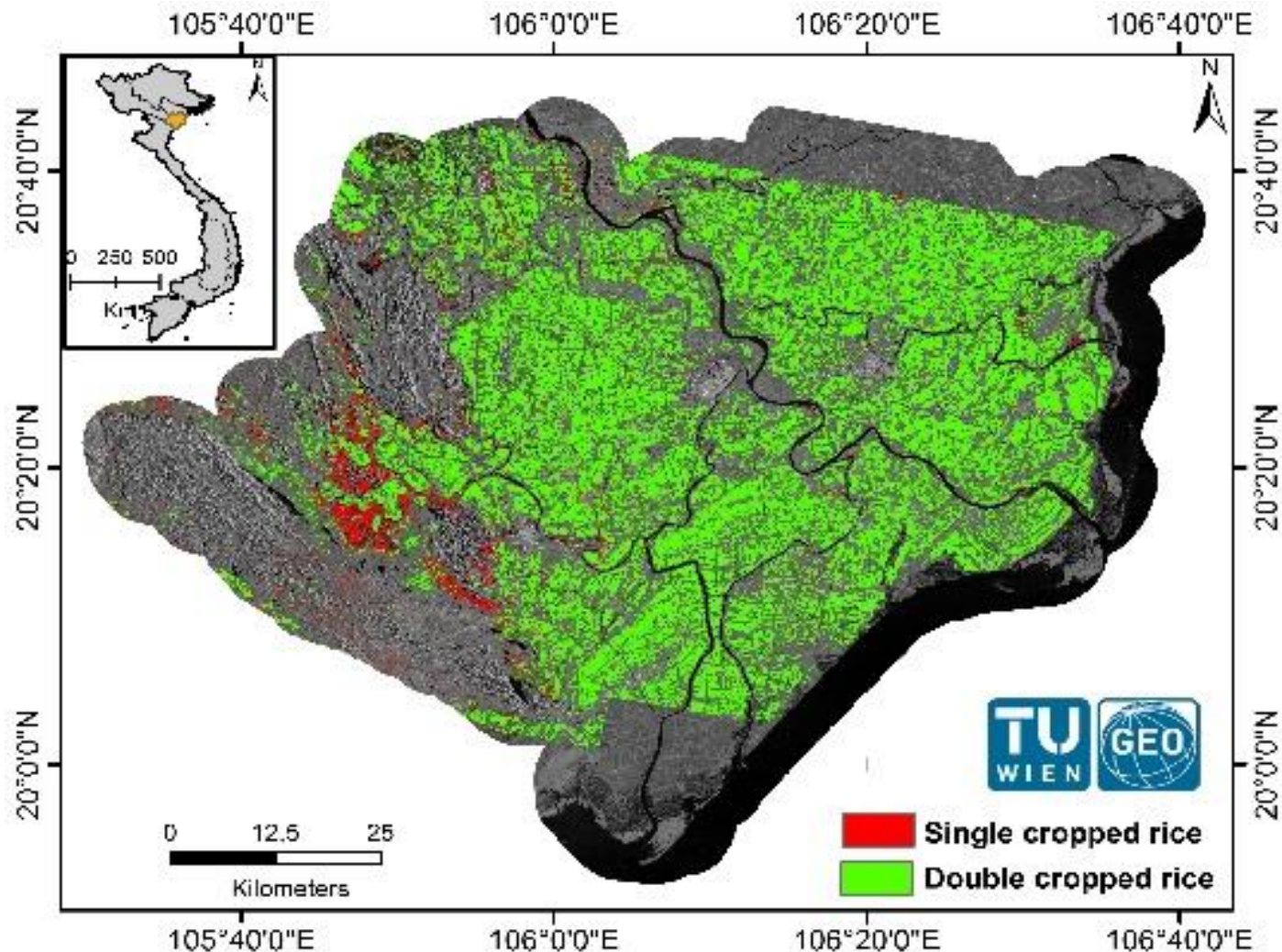
## Estimation of crop condition using POLinSAR



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



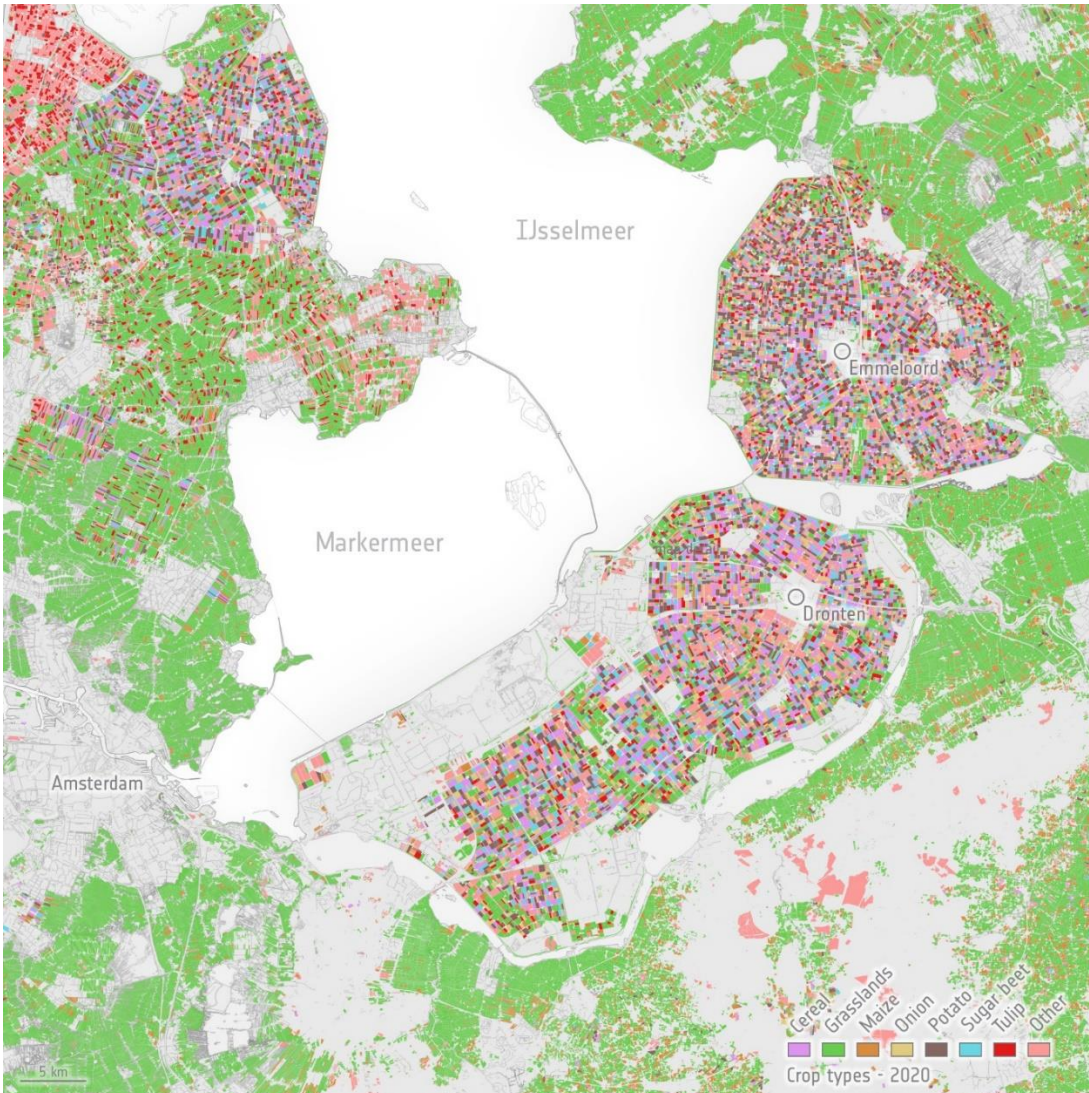
### Rice-cropping systems in Vietnam's Red River Delta

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 Netherlands 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

Thank you for the attention