# 6. Precision agriculture mapping using multispectral data

# From EO signal to agriculture information content

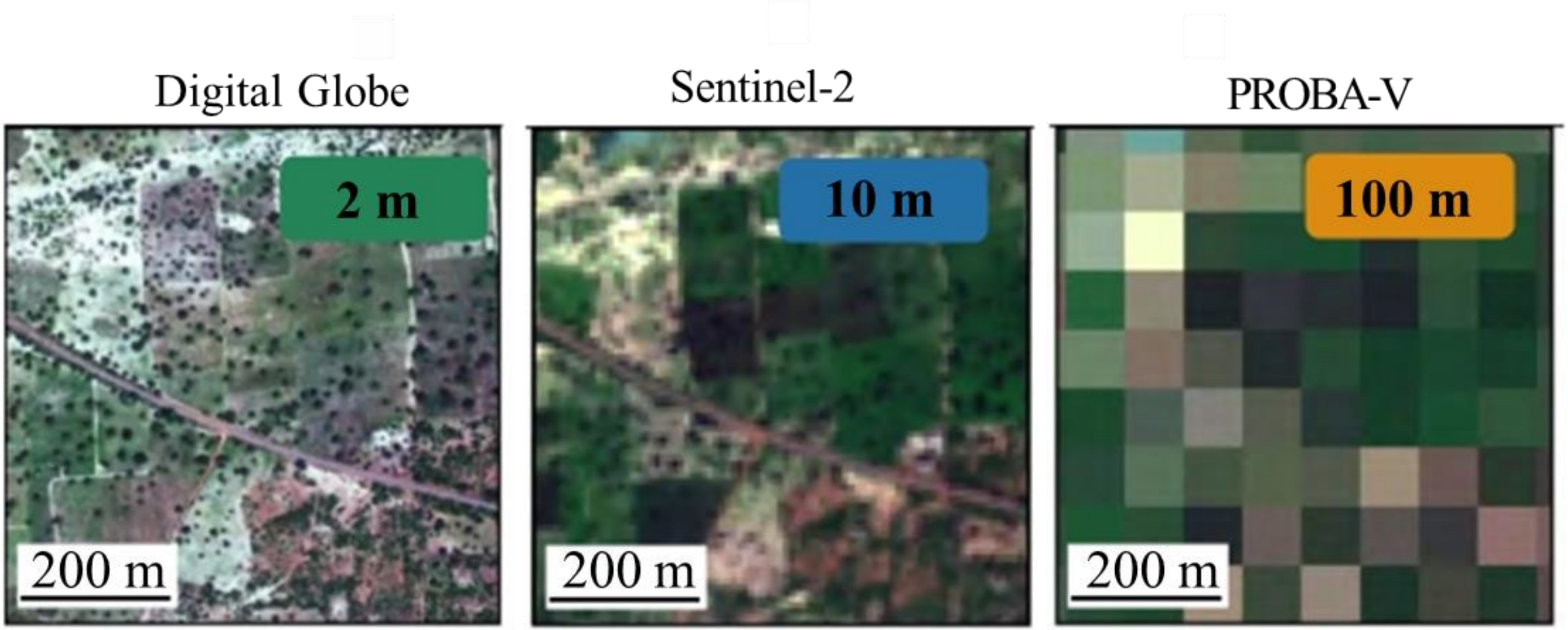
Spatial + spectral + temporal information content + Machine learning for classification

Resolutions offered by popular satellite imagery providers

| 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 |

# From EO signal to agriculture information content

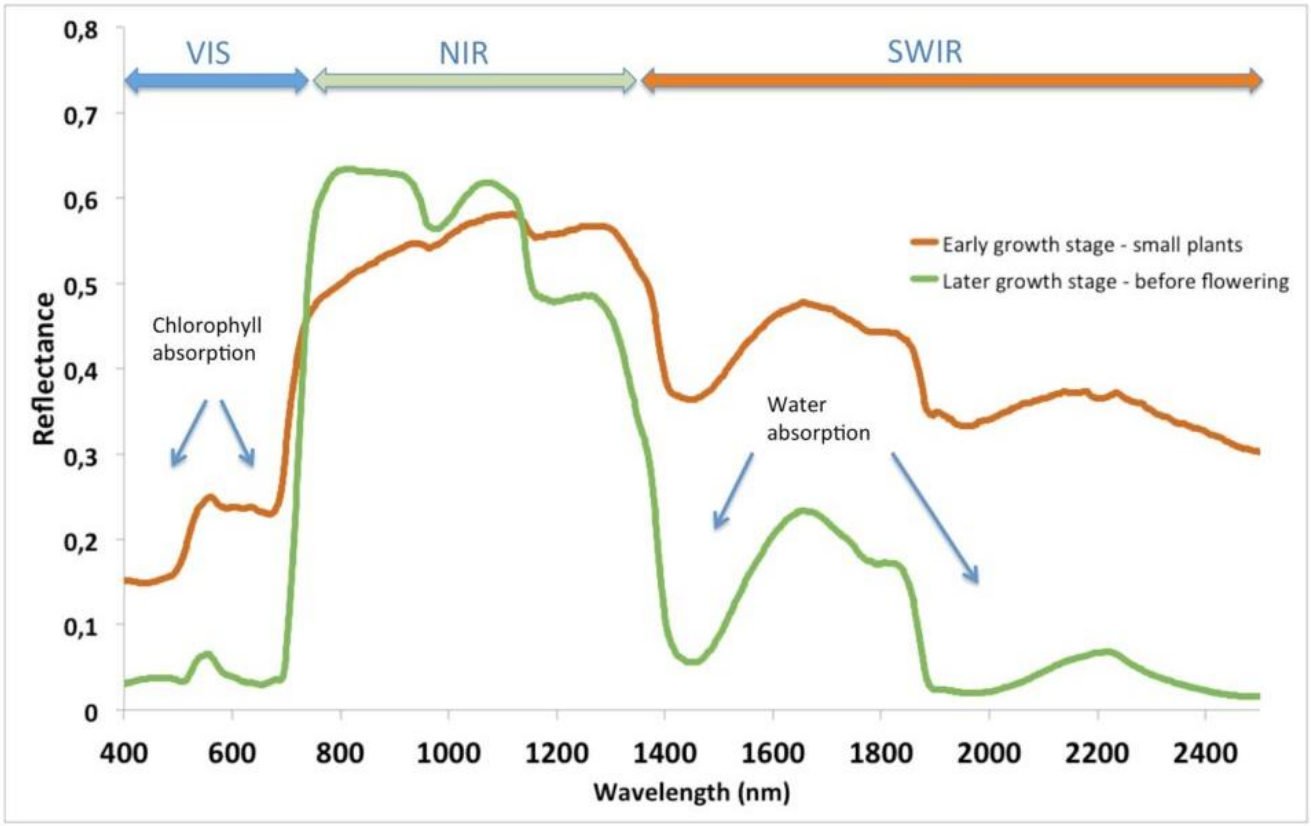
**Spatial resolution**



# 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



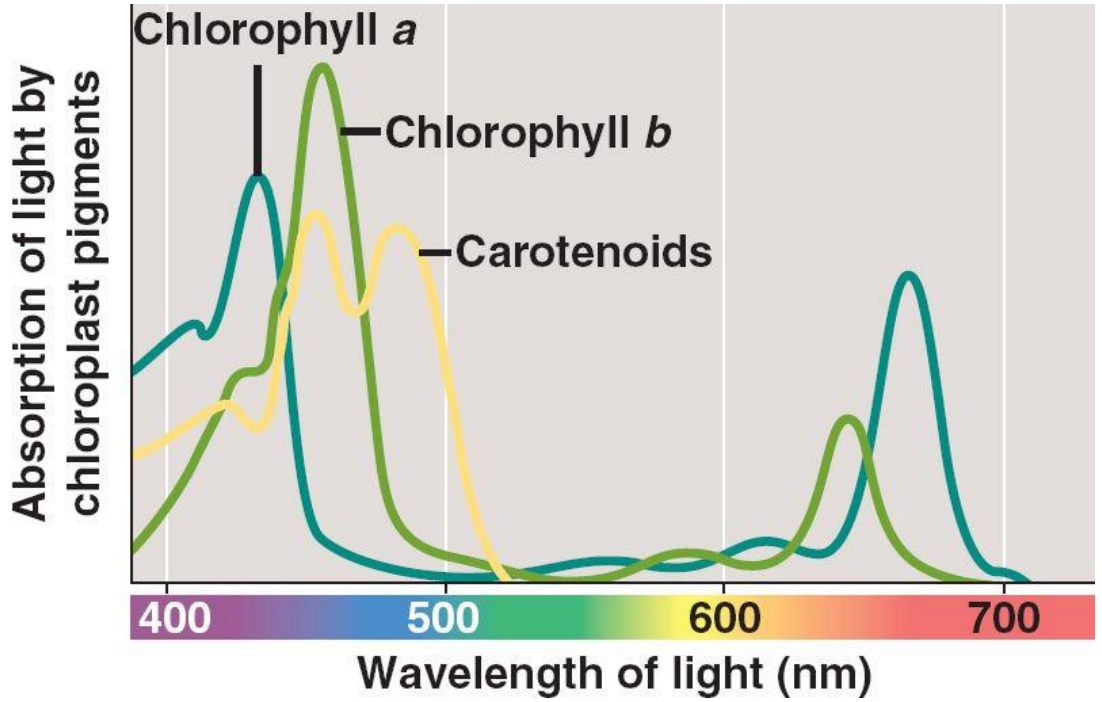

**Vegetation indices:**

- 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

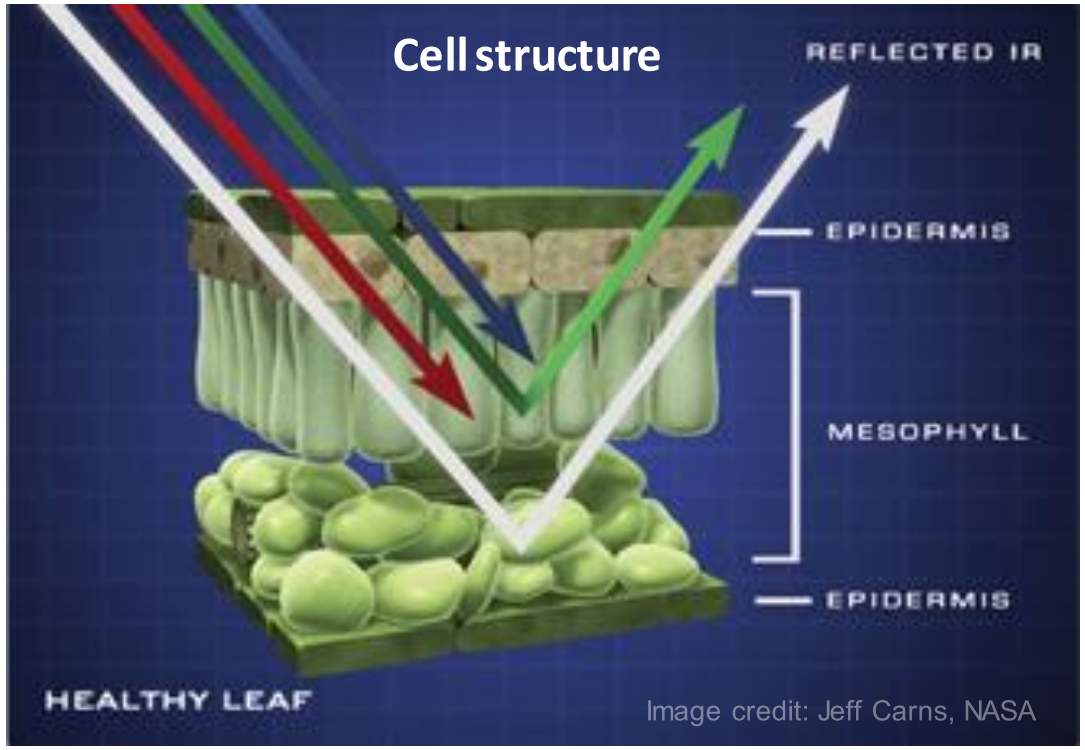
## Spectral signature of the plants

### Plant pigments

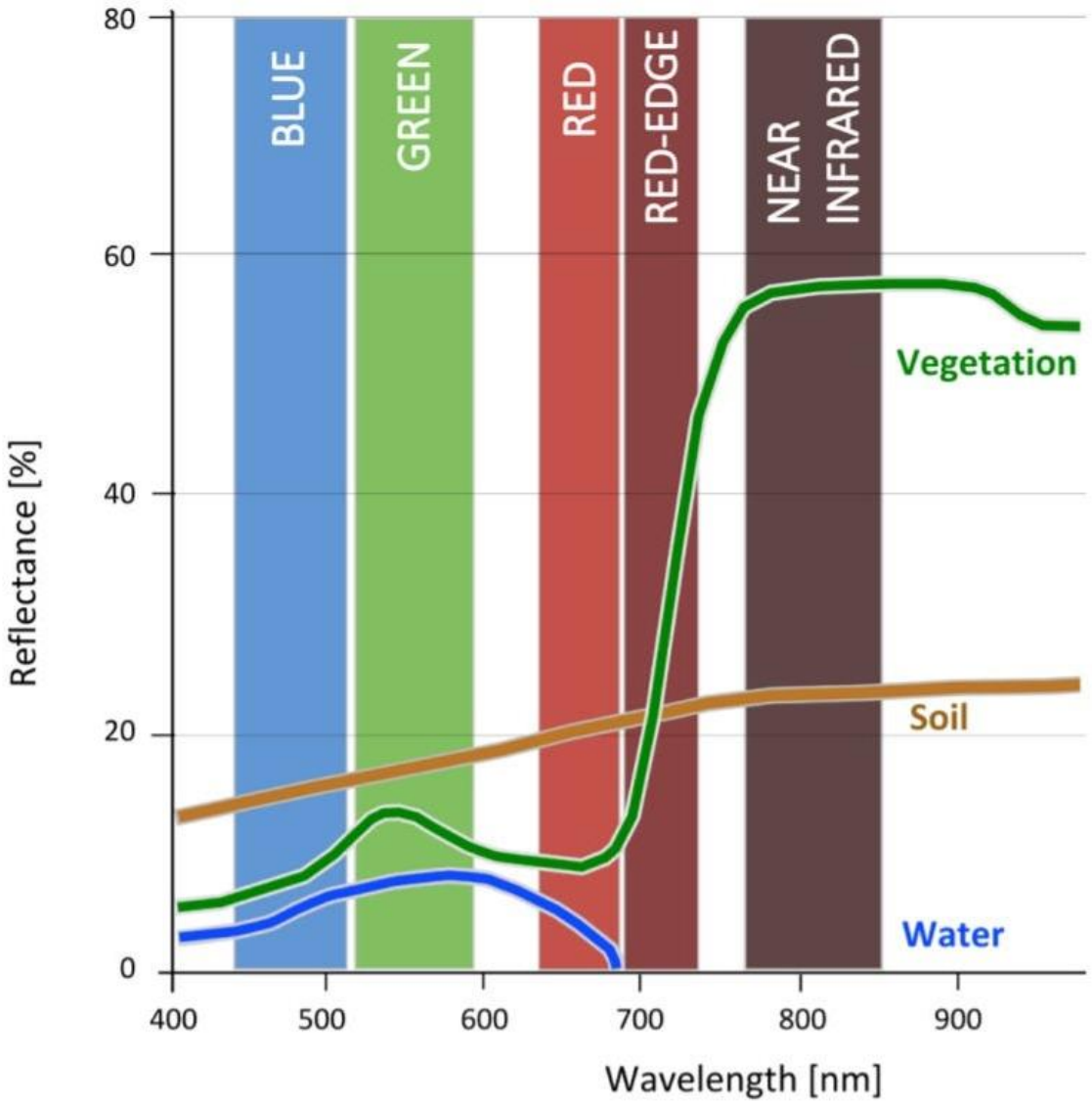



Chlorophyll predominately absorbs blue wavelengths (400-500 nm) and red (600-700 nm). Note that carotenoids absorb blue light as well as some green.

- 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)

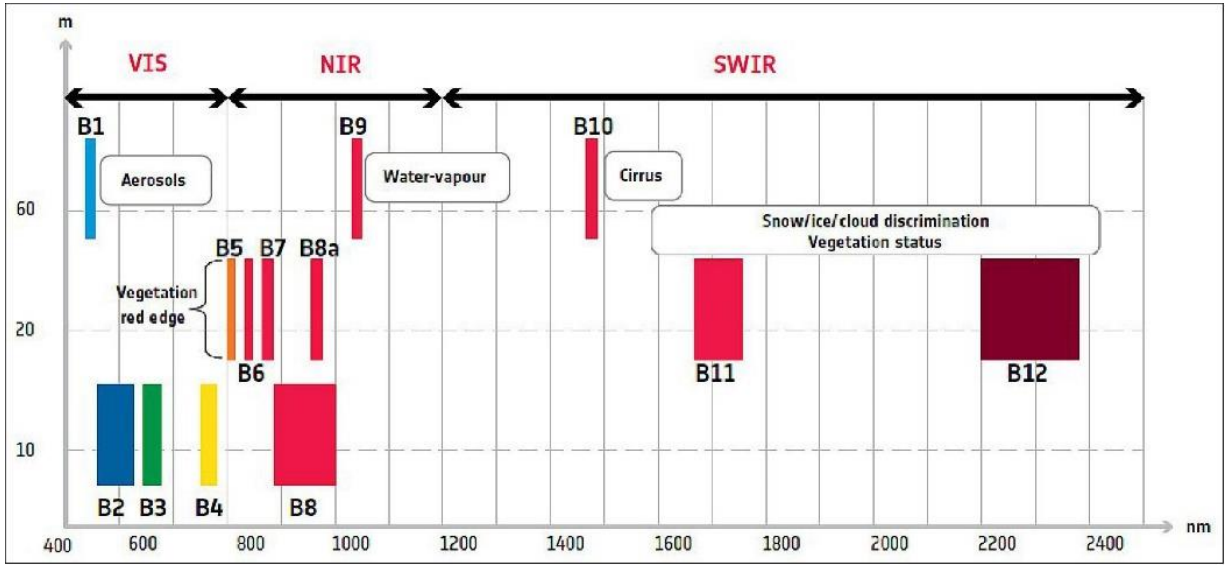


# From EO signal to agriculture information content




**RED EDGE**

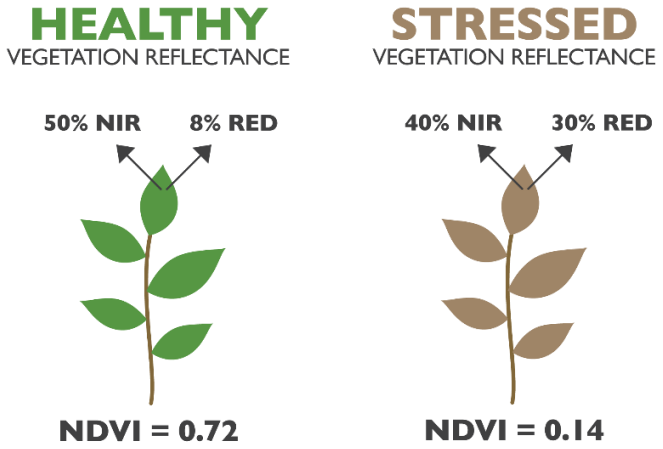
- The three 20m ‘red edge’ bands of Sentinel-2 provide key information on the state of vegetation
- Very narrow band (700 – 730 nm) corresponding to the red NIR transition zone
- Very sensitive to plant stress – provides information on the canopy chlorophyll and nitrogen content



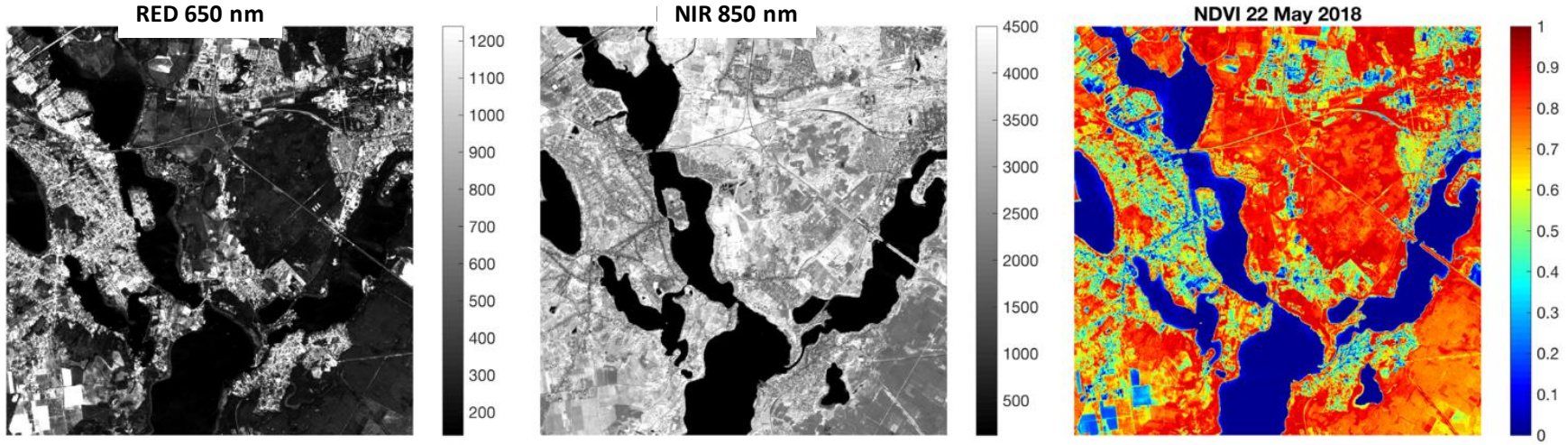
# From EO signal to agriculture information content

## 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



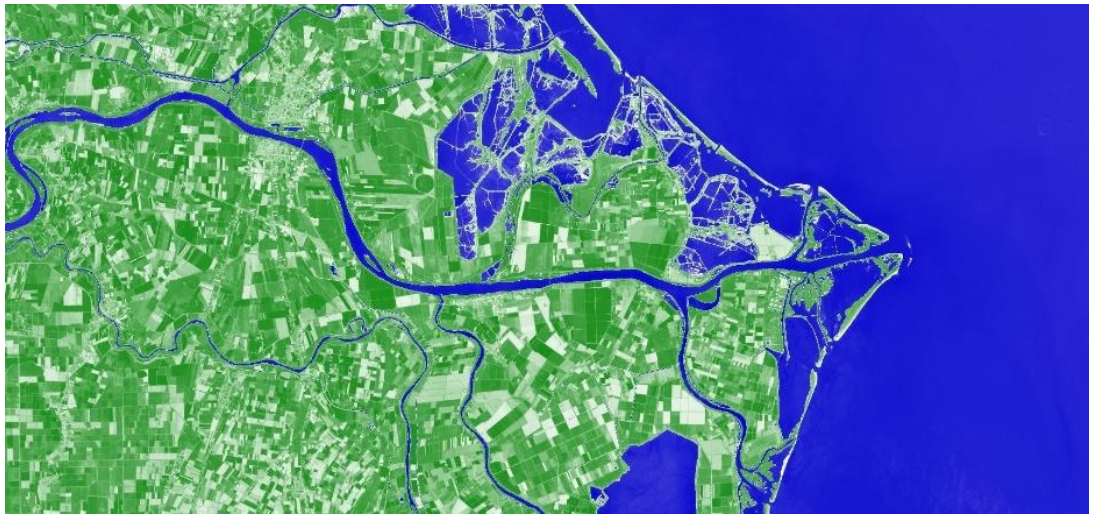

$$NDVI = \frac{NIR - RED}{NIR + RED}$$



# 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

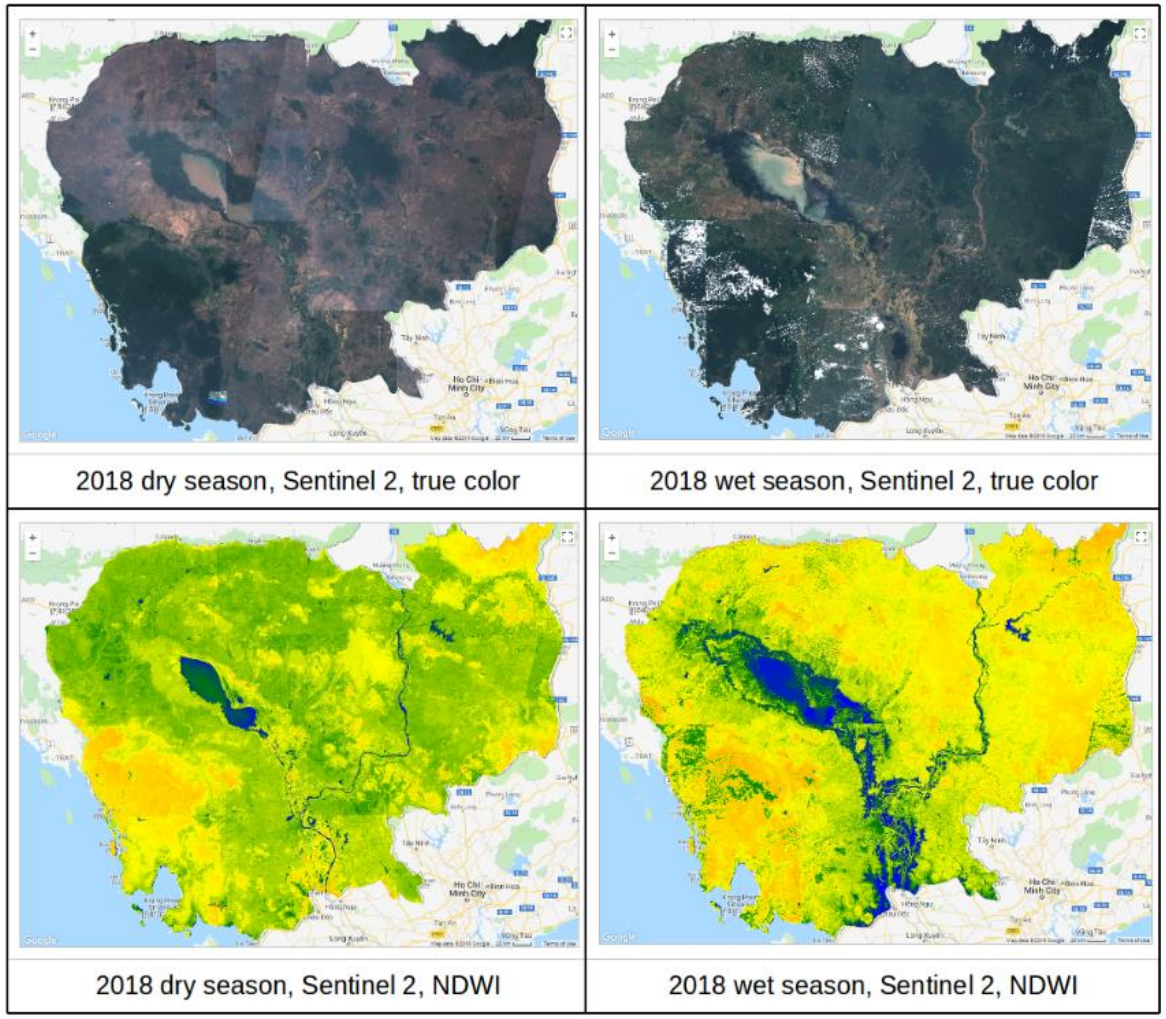


NDWI of Italy. Acquired on 2020-08-01.

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

# From EO signal to agriculture information content

## NORMALIZED DIFFERENCE WATER INDEX (NDWI)



2018 dry season, Sentinel 2, true color

2018 wet season, Sentinel 2, true color

2018 dry season, Sentinel 2, NDWI

2018 wet season, Sentinel 2, NDWI

# From EO signal to agriculture information content

## Biophysical variables estimation for agriculture applications

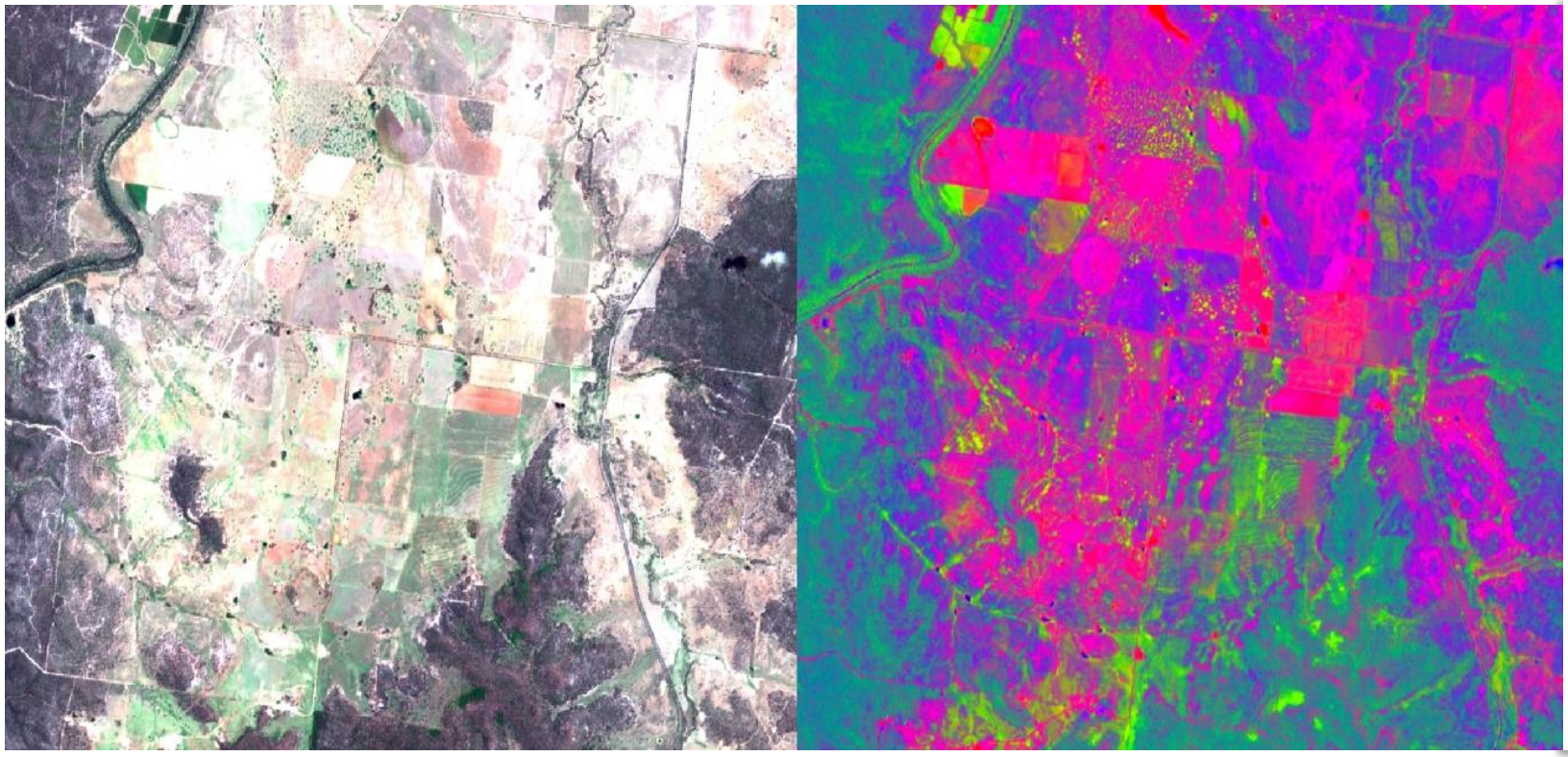
Biophysical variables are plant traits or characteristics of interest which can be measured on the ground and possibly estimate by remote sensing at various scales depending of the sensor spatial resolution

| 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 | | | | | | | | | |

# From EO signal to agriculture information content

## Fraction of green Vegetation Cover – FCover

- Corresponds to the fraction of ground covered by green vegetation
- Quantifies the spatial extent of the vegetation
- Independent of the geometry of illumination (unlike FAPAR)



The image on the left is a true-colour (red, green, blue) Sentinel-2 reflectance image. The darker areas are woodlands. The image on the right shows the same imagery, transformed using a model originally developed for Landsat which estimates fractional vegetation cover from the reflectance values. On each pixel, the proportions of red, green and blue represent the proportion of bare ground, live vegetation and dead vegetation respectively.

# From EO signal to agriculture information content

## Fraction of Absorbed Photosynthetically Active Radiation - FAPAR

- Quantifies the fraction of the solar radiation absorbed by live leaves for the photosynthesis activity.
- It refers only to the green and alive elements of the canopy
- Depends on the canopy structure, vegetation element optical properties, atmospheric conditions, and angular configuration

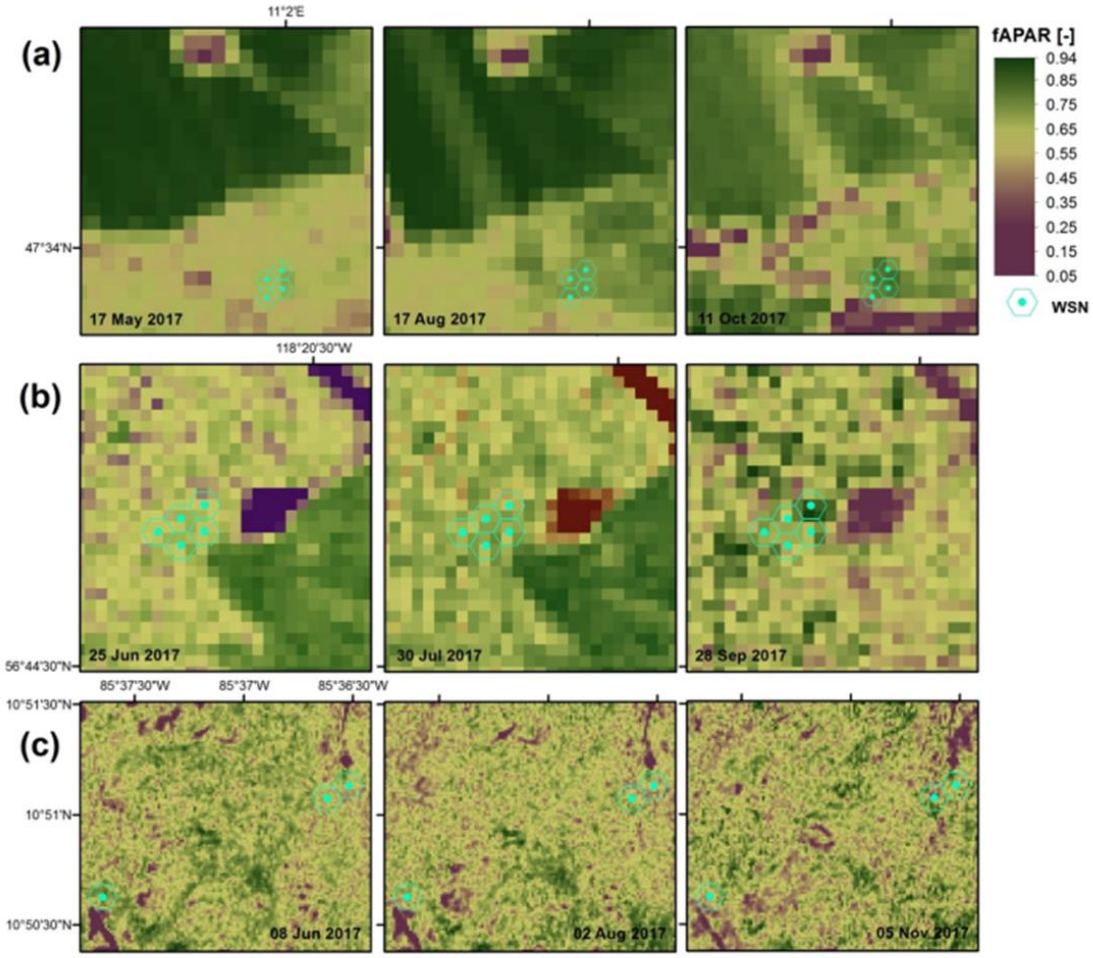



Fig. 7. The S2 fAPAR products at (a) Graswang, (b) Peace River and (c) Santa Rosa for several dates, representing early, peak and end of vegetation periods.

# From EO signal to agriculture information content

## Canopy Chlorophyll Content (CCC)

The **total amount of chlorophyll a and b pigments** in a contiguous group of plants per unit ground area (in g/m²)

- Closely related to the plant nitrogen content (fertilization)
- Absorption at 675 nm very sensitive to changes in chlorophyll content but only for low CCC values
- Lower chlorophyll absorption at 550 nm, sensitive to a greater range of CCC , not easily saturated but less sensitive to chlorophyll changes

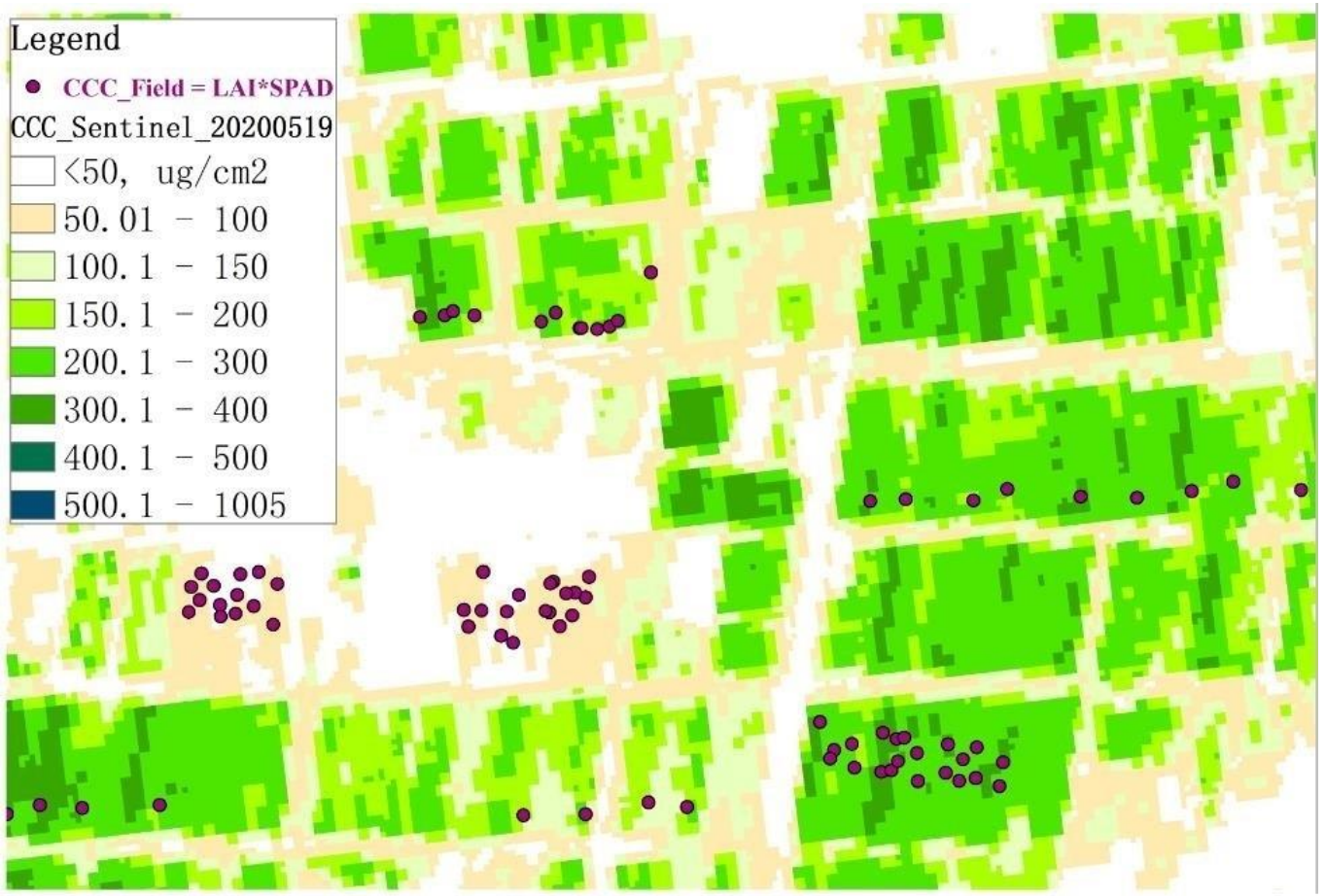
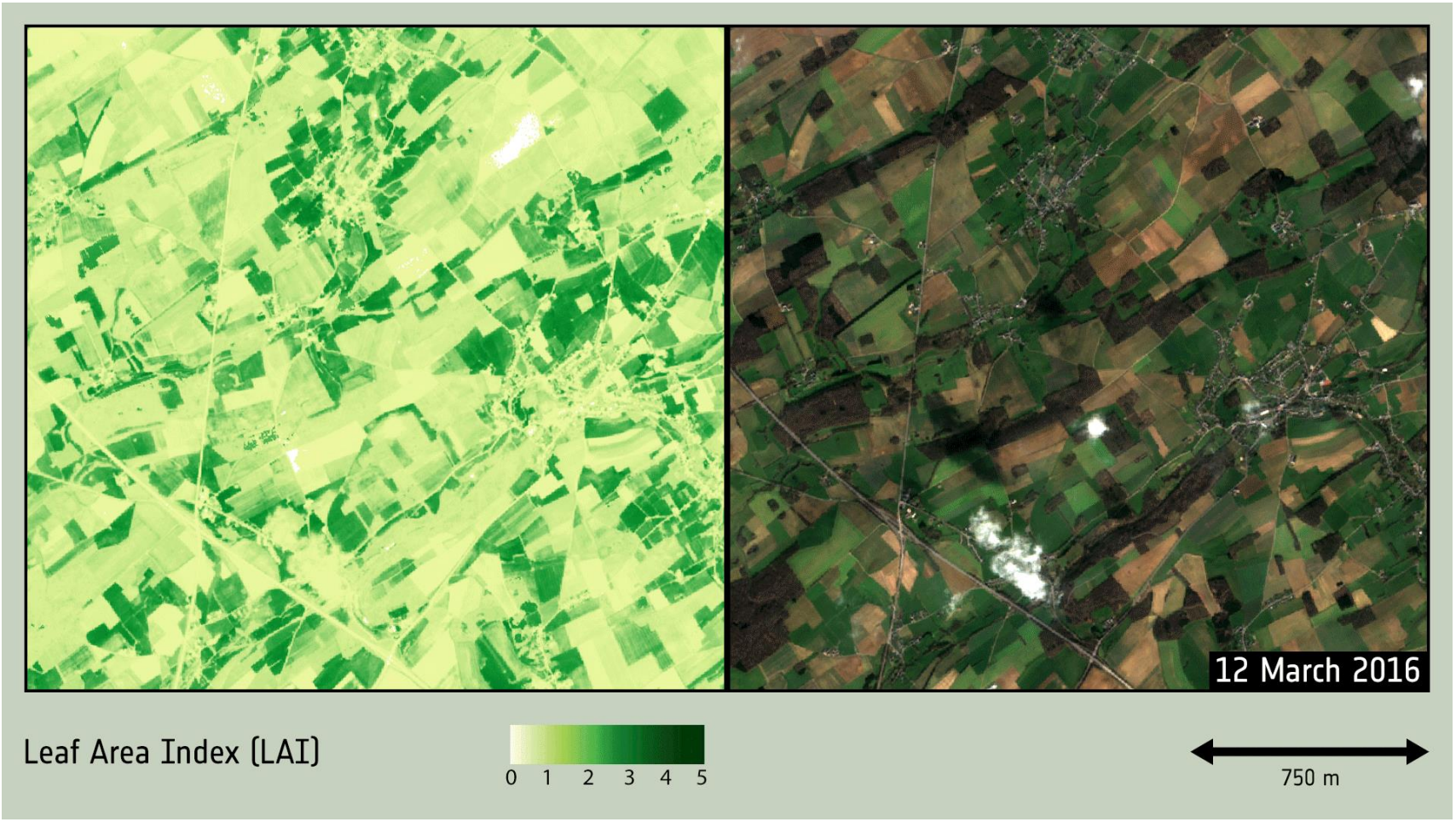



Figure 1 Winter wheat Crown Chlorophyll Content and sample sites in Yucheng, Shandong Province

# From EO signal to agriculture information content

## LEAF AREA INDEX (LAI)

LAI is a dimensionless index measuring the one-sided green leaf area over a unit of land (m^2 / m^2).

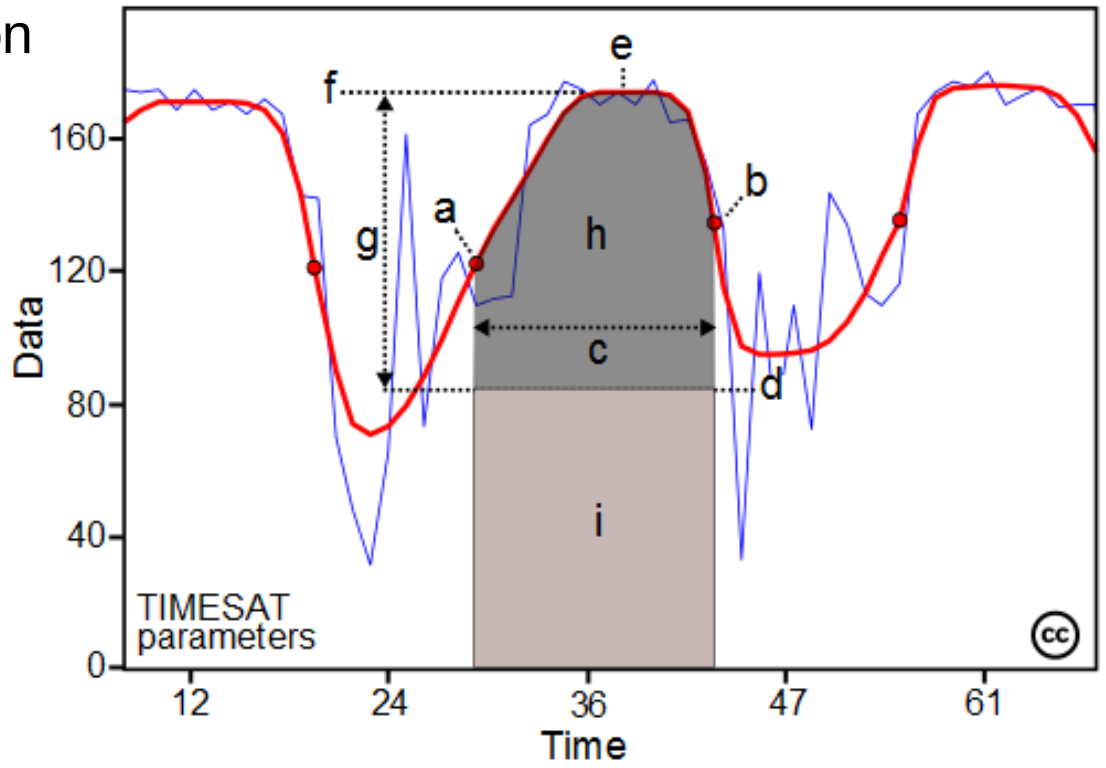


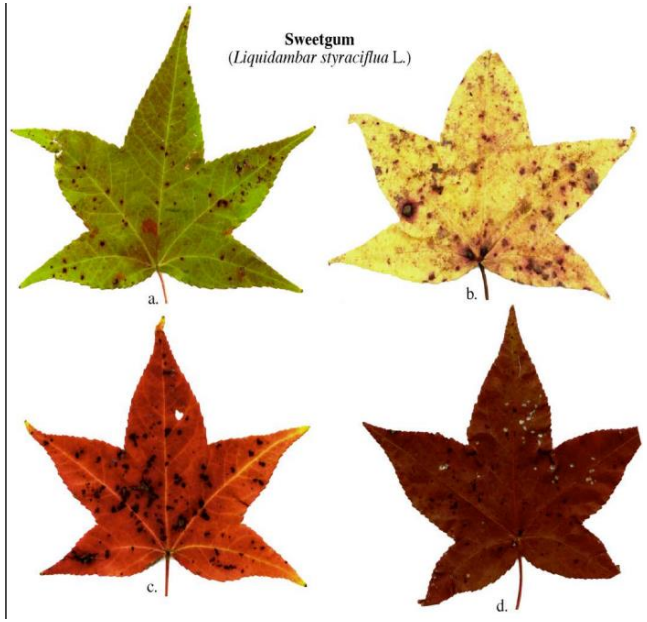

Data from the Copernicus Sentinel-2 mission can be used to measure the 'leaf area index' of vegetation (left). This information can, in turn, be used to monitor crop growth and agricultural practices like harvesting. The animation shows the development of crop fields in Belgium between March and October 2016.

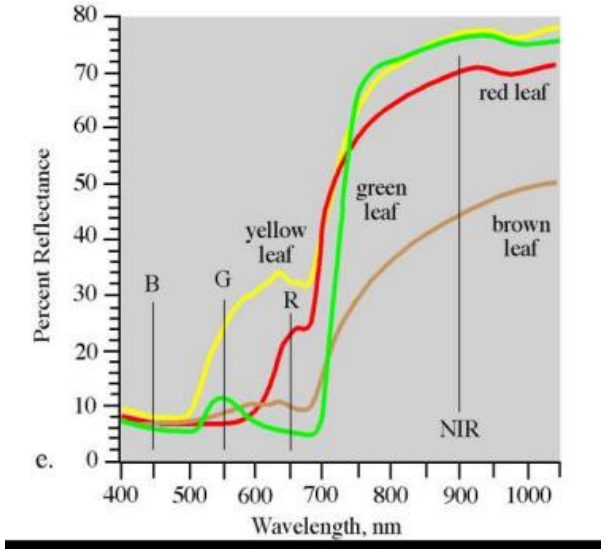
# From EO signal to agriculture information content

## 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



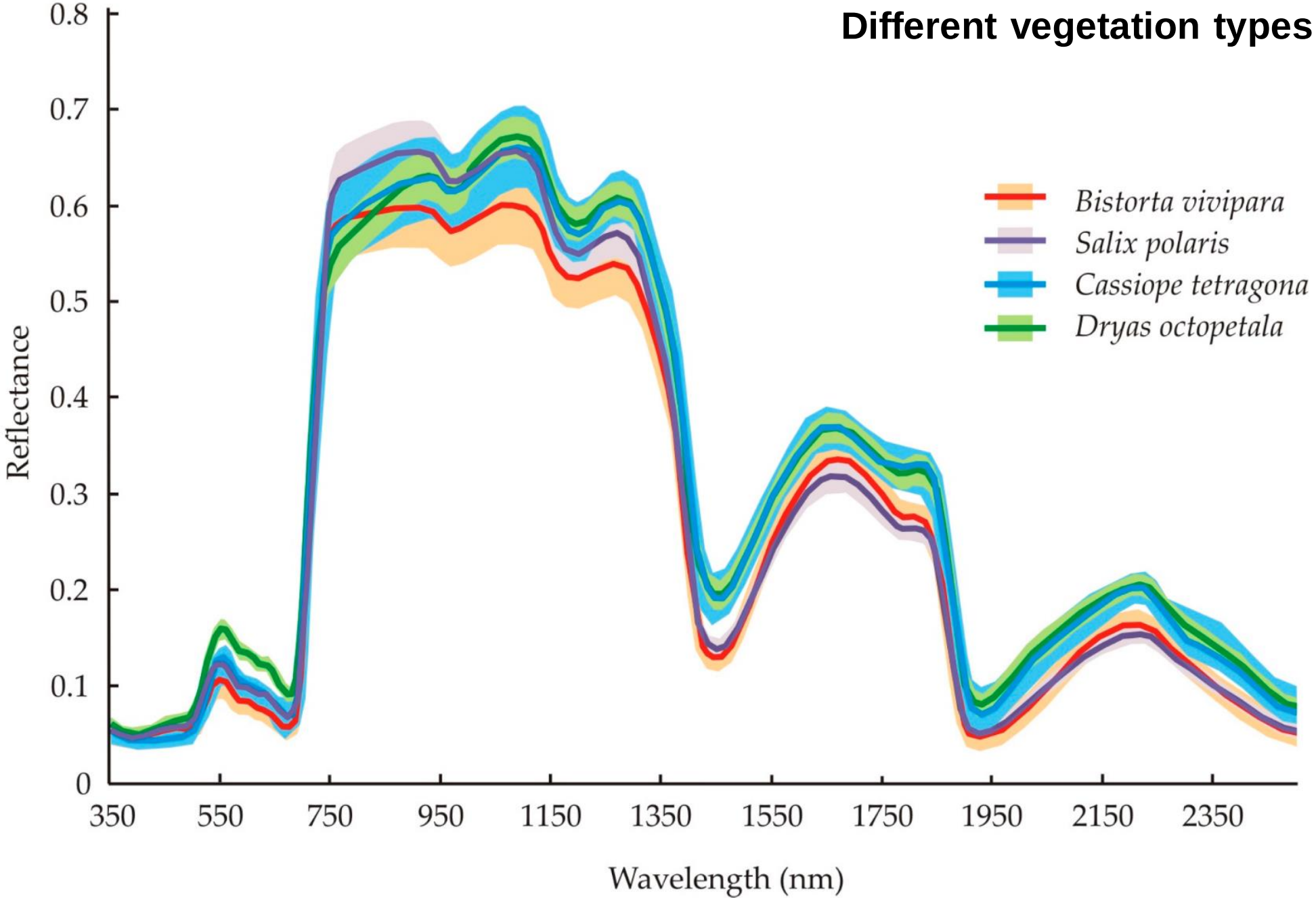

Bistoria vivipara


Salix polaris


Cassiope tetragona


Dryas octopetala

## Different vegetation types



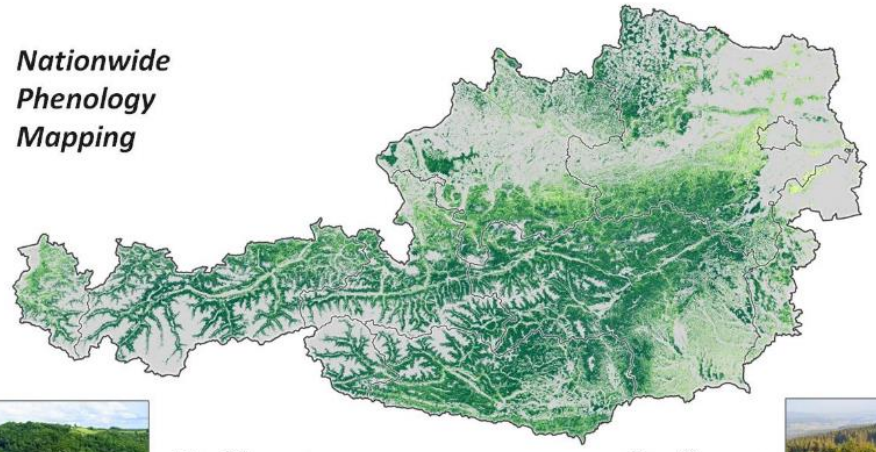
# Phenology and disturbances

## Data Download & Preprocessing

NAS → Corrections → Stack → Multi-core

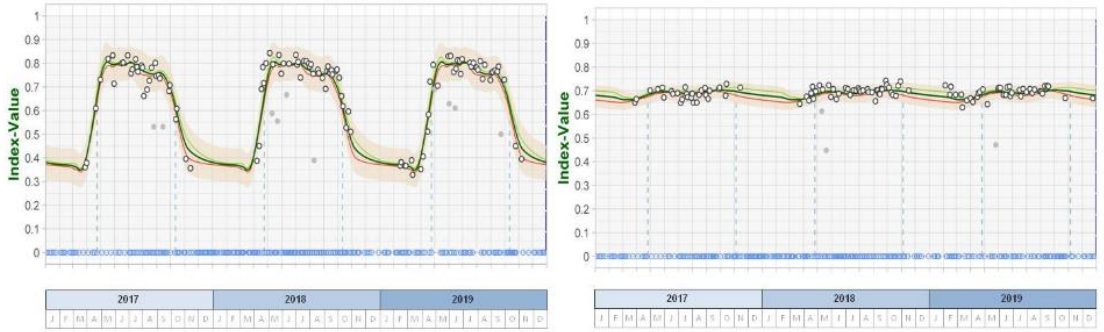
## Phenology Modelling

*Nationwide Phenology Mapping*



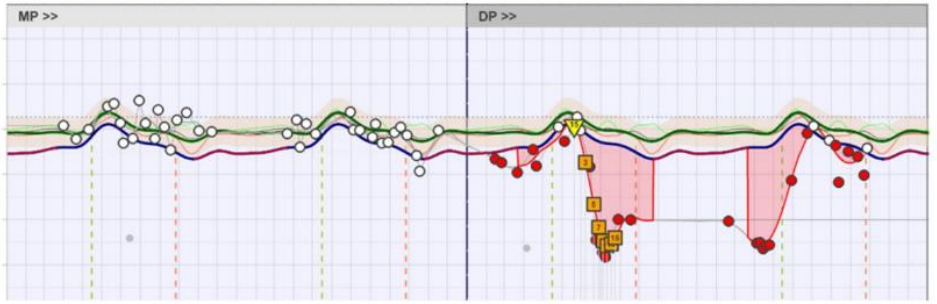
*Deciduous*

*Coniferous*

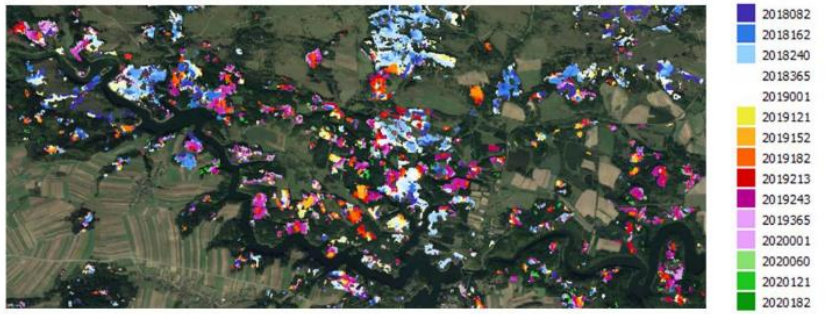



## Forest Disturbance Mapping

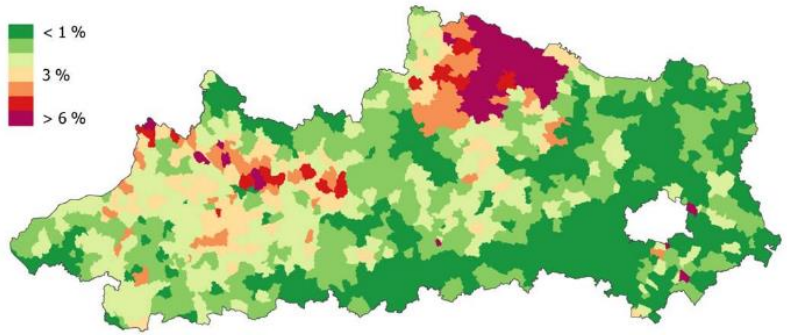
*Detected Phenological Anomalies*




*Reconstructed Forest Disturbance Date*

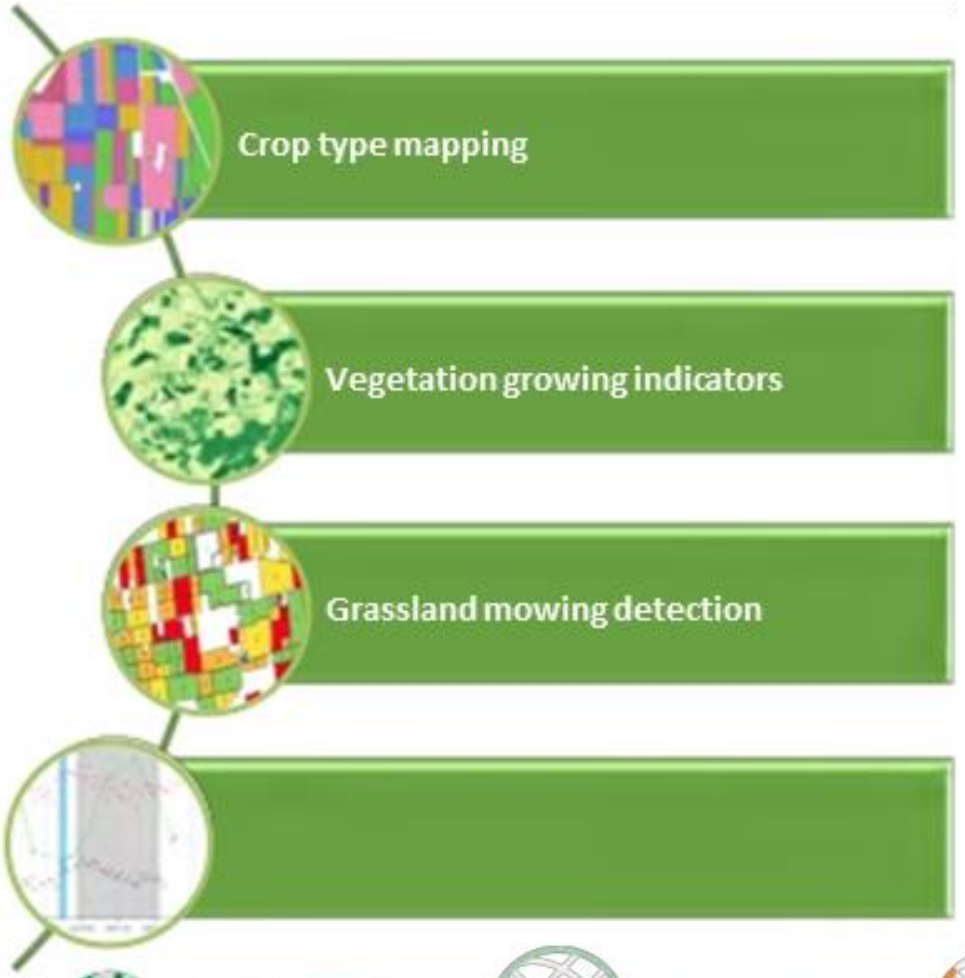



*Disturbed Area aggregated at Municipality Level*

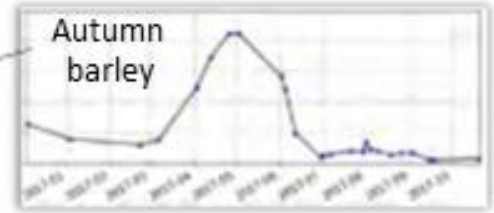


# Sentinel-based markers for CAP Monitoring

https://dataspace.copernicus.eu/news/2023-10-19-cap-monitoring-national-scale-slovenia-based-copernicus-data

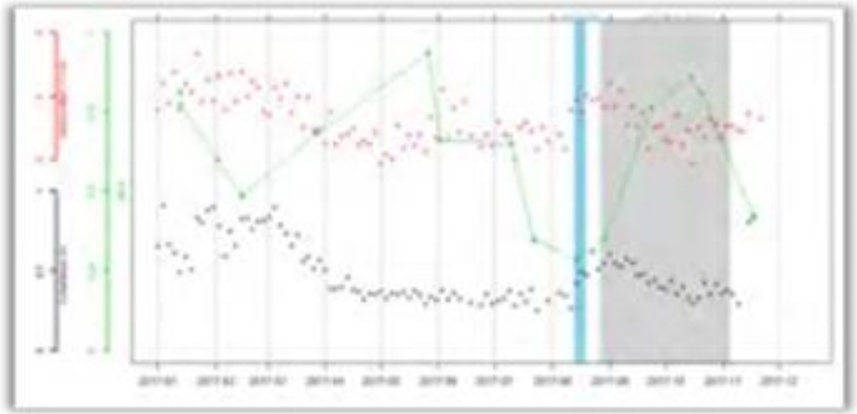



Crop type information & vegetation growing indicators





Number of detected mowing events



sen4cap common agricultural policy

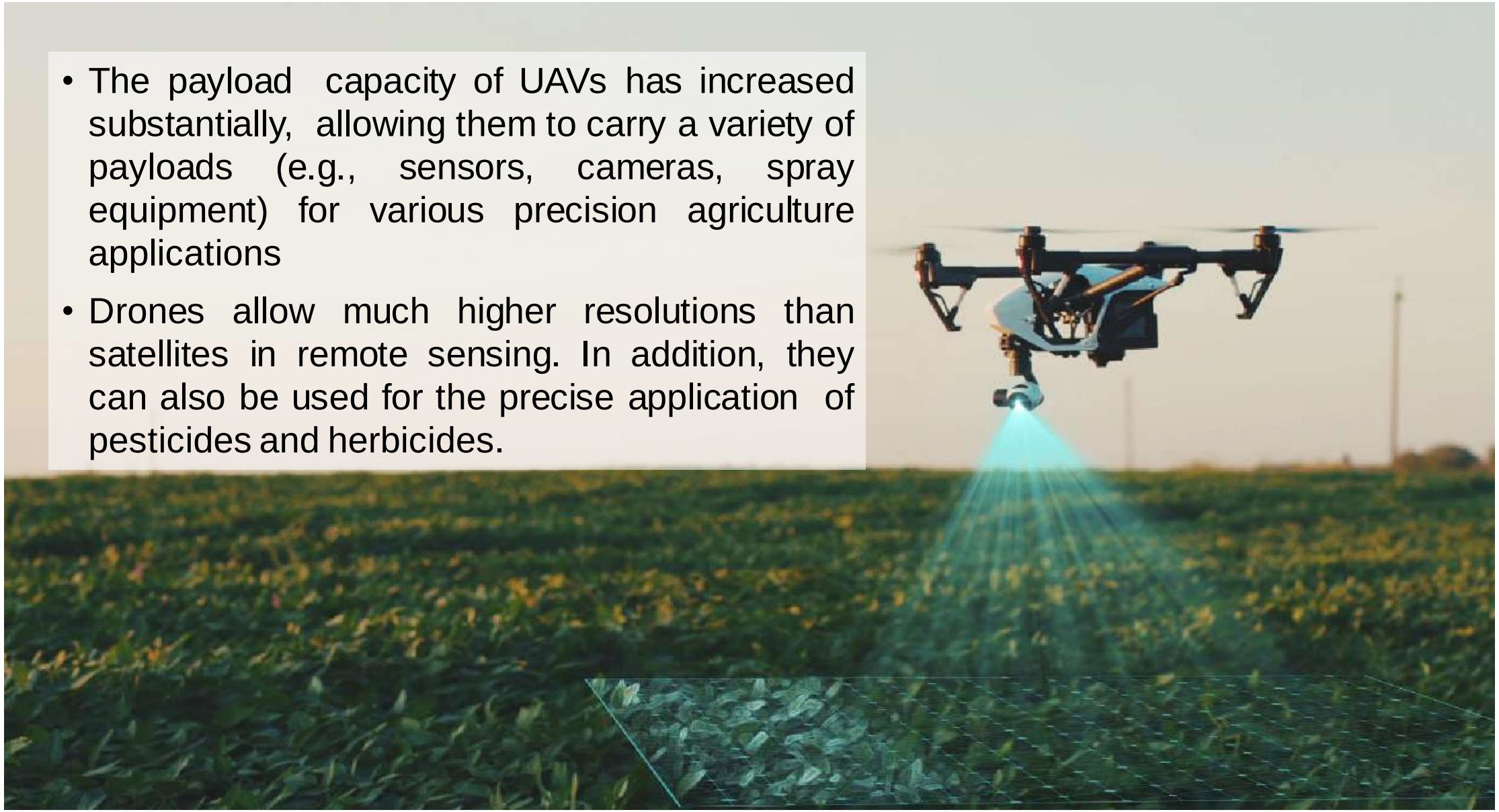
Sen2-Agri Sentinel-2 for Agriculture

Sen4Stat Sentinels for Agricultural Statistics


Other sensors and platforms

# Unmanned Aerial Vehicles (UAVs)

- The payload capacity of UAVs has increased substantially, allowing them to carry a variety of payloads (e.g., sensors, cameras, spray equipment) for various precision agriculture applications
- Drones allow much higher resolutions than satellites in remote sensing. In addition, they can also be used for the precise application of pesticides and herbicides.



# Various Drone Payloads and Their Applications[69]

## RGB Camera

Only able to capture the wavelengths of the visible spectrum.

- Monitoring plants outer defects, greenness and growth
- Calculating a range of vegetation indices
- Creating high-resolution digital elevation models (DEMs)
- Mapping vegetation height

## Lidar (Light Detection and Ranging)

Uses laser beams to create a 3D representation of the surveyed environment

- Creating high-resolution digital surface models of terrain and elevation
- Measuring canopy heights, coverage, tree density, location and height of individual trees

## Position Sensors

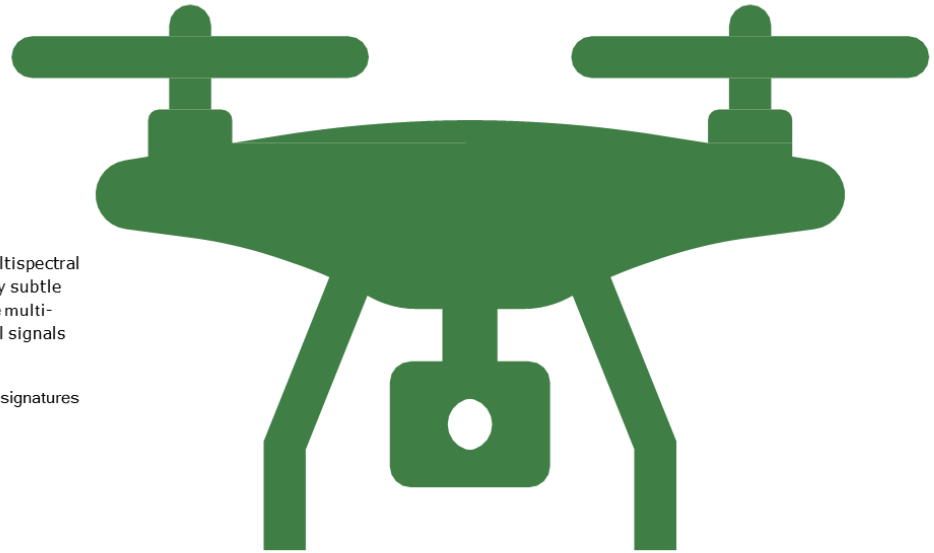
Includes inertial navigation systems, GPS, magnetometer

- Finding the physical location of the UAV

## Multispectral Camera

Able to capture wavelengths beyond the visible spectral range, usually through 3-15 bands.[70]

- Monitoring and mapping crop diseases and weeds
- Estimating the vegetation state
- Detecting nutrient deficiency
- Mapping vegetation height



## Chemical Sensors

- Measuring and detecting quantities of various chemical agents

## Hyperspectral Camera

Has more and narrower spectral bands compared to multispectral (They are most suitable when there is a need to identify subtle differences in signal along a continuous spectrum. Since multi-spectral cameras sample larger wavebands, these small signals may not be detected)[71]

- Distinguishing different plant species with similar spectral signatures
- Identifying plant biochemical composition
- Quantifying soil vegetation
- Calculating chemical attributes

## Biological Sensors

- Identifying various forms of microorganisms

## Meteorological Sensors

- Measuring weather-related indicators such as wind speed, temperature and humidity

## Thermal Camera

Infrared radiation to form a heat zone image, operating at wavelengths of ~14,000 nm

- Evaluating water stress and assessing irrigation uniformity
- Calculating vegetation indices
- Calculating chemical attributes

## Spraying System or Similarpayloads

- System consisting of pumps and sprinklers for spraying chemical inputs

# On-site sensors

On-site sensors measure field and crop characteristics with high accuracy, which growers can use to make farming decisions. Sensors are used in pest monitoring, soil monitoring, smart irrigation, yield monitoring, weather monitoring, and precision planting and spraying applications. The most commonly used sensors are listed in the table below.

Table 4: Types of on-site sensors for precision agriculture

| Group | Sensors |
|---|---|
| Soil | Moisture, temperature, nitrogen, phosphorous, potassium, carbon, pH |
| Plants | NDVI, chlorophyll, plant health, plant water demands, sugar content |
| Atmospheric | Temperature, humidity, wind speed, rainfall, pressure, precipitation |
| Water | pH, temperature, turbidity, water depth, conductivity, dissolved $O_2$ |

For more information, see the tutorial:

6. Precision agriculture mapping – digital image analyses using Sentinel-2 multispectral data, image classification, comparison with UAV multispectral data, using SNAP software

Thank you for the attention