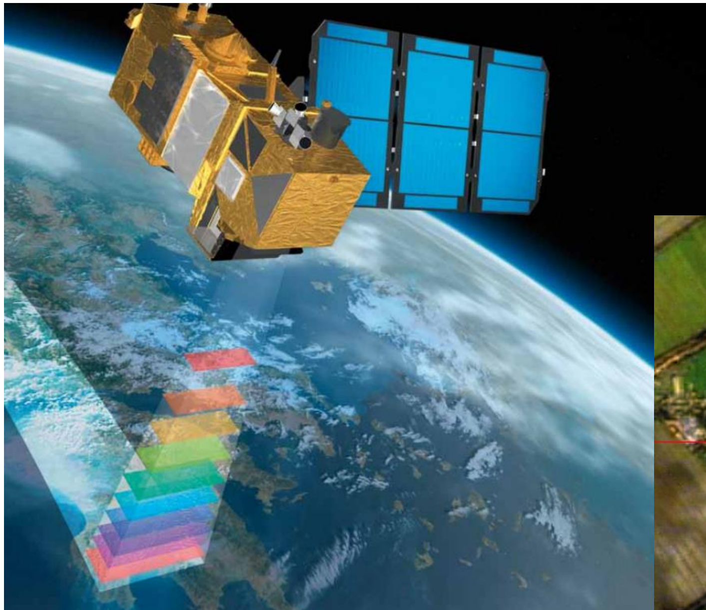

UNIVERSITÀ DEGLI STUDI DELLA TUSCIA
DIPARTIMENTO DI SCIENZE AGRARIE E FORESTALI

Introduction to Remote Sensing & Remote Sensing for Precision Agriculture

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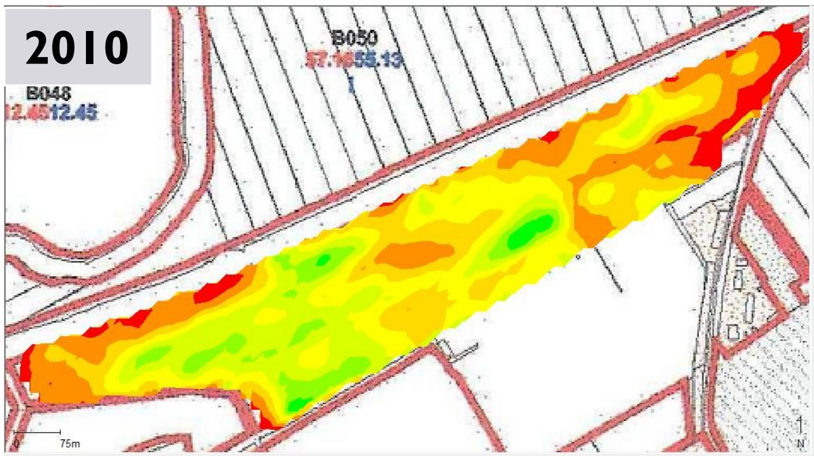
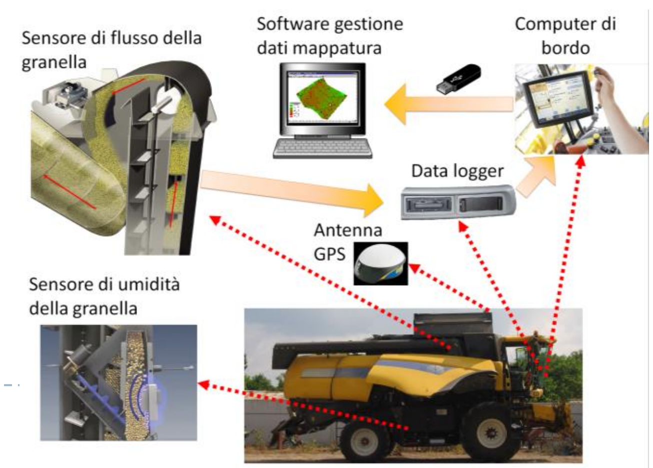
Managing spatial and temporal variability of soil and crop processses



Yield Mass (Dry)
(tonne/ha)

7.24 - 8.30
6.17 - 7.24
5.11 - 6.17
4.04 - 5.11
2.98 - 4.04
1.92 - 2.98
0.85 - 1.92



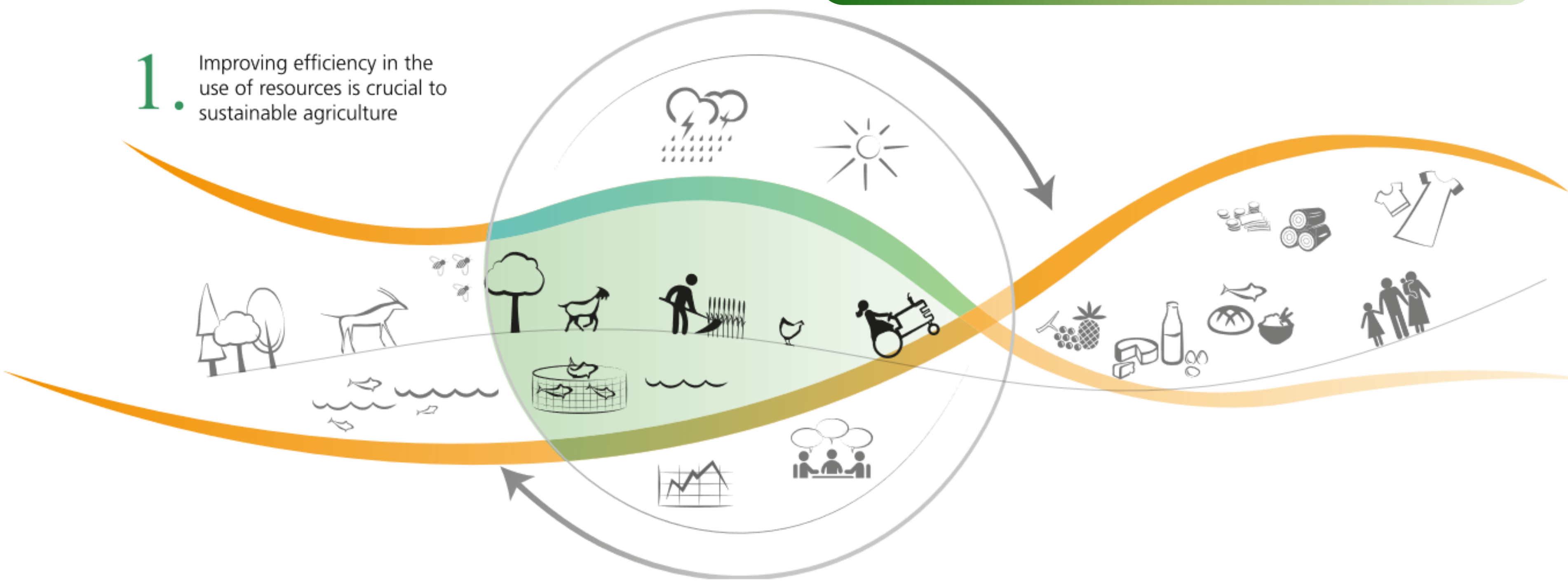
What is precision agriculture?

Take into account the variability in time and space of factors affecting the agricultural production process. to improve the efficiency of inputs in the management of this process

- Same results with lower input quantities (water. energy. phytochemicals. fertilizers. seeds...)
- Better results (quantity and quality) with equal use of input

Sustainable intensification

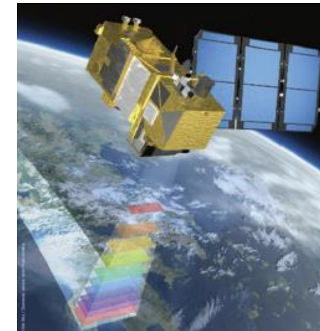
The 5 principles of Sustainable Food and Agriculture



Technological and agronomic aspects of precision agriculture

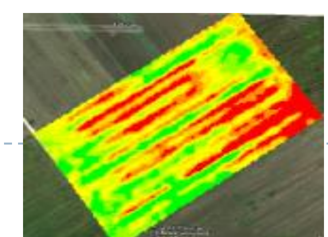
Engineering

- Use of the most recent technologies in the fields of ICT. electronics. sensors. robotics to drive and manage agricultural equipment :
  - **GNSS (GPS)**
  - **assisted guidance** and auto-steer of tractors
  - **Remote sensing from satellites**. airborne platforms. **UAVs**. **proximal sensors**. sensors on board **harvest machines. wireless sensor networks (WSN)**
  - Technologies to manage machinery & implements (spreaders. sprayers). **Variable rate technology (VRT)**

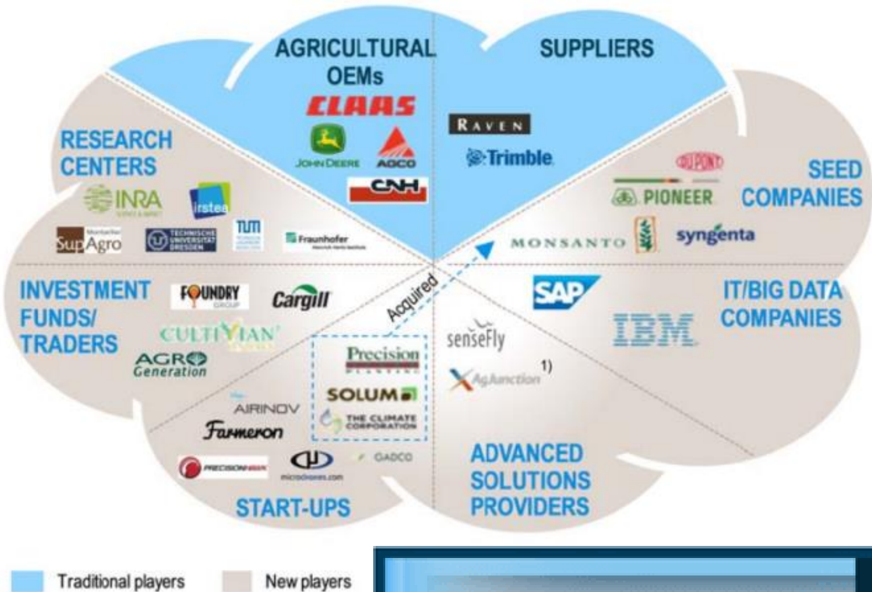


Agronomy

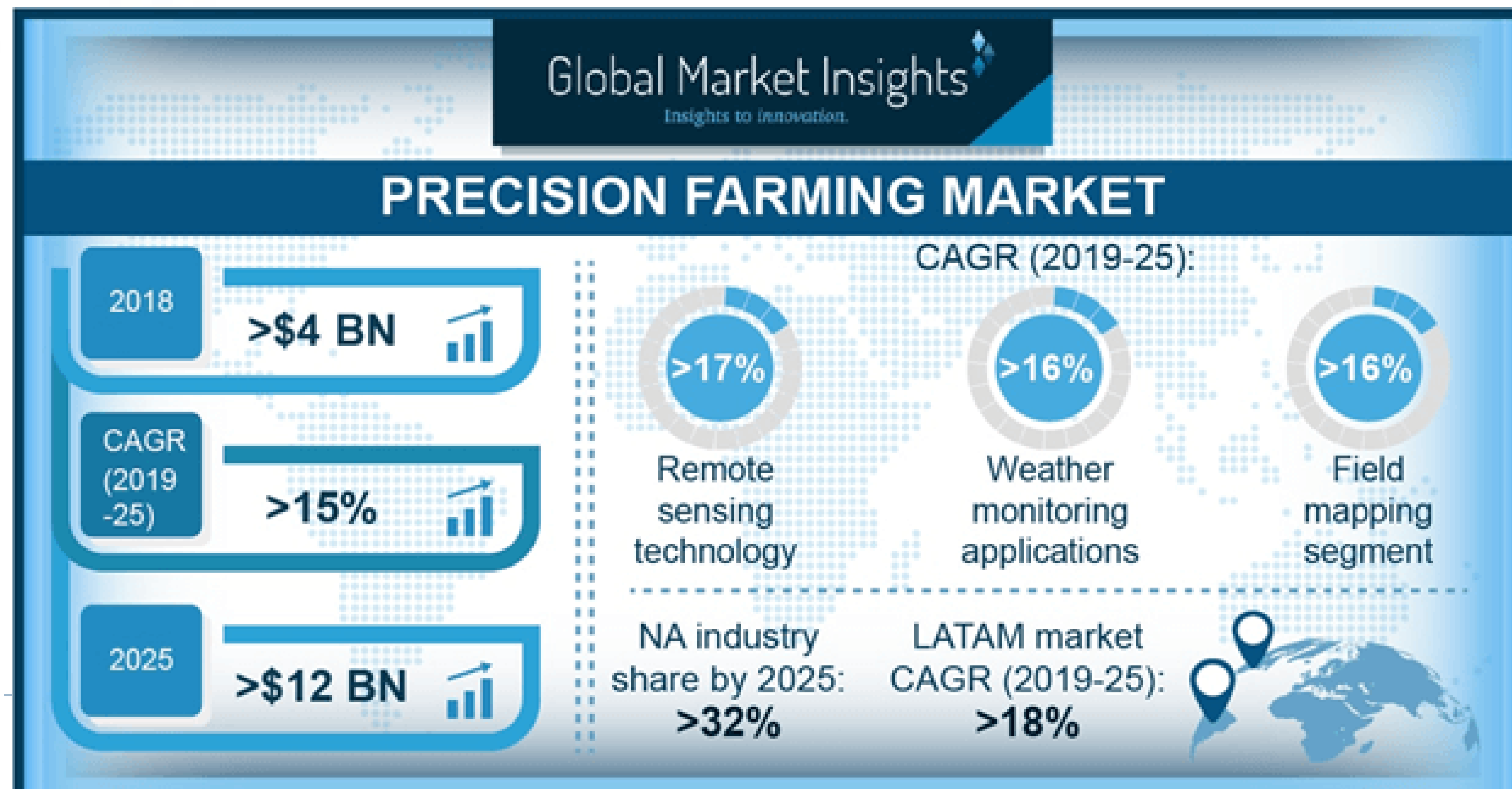
- Adapt agronomic management to the variability of soil and crop in space and time
  - ➢ **change of paradigm**
  - ➢ **site-specific management**




Dynamic market with high expectations

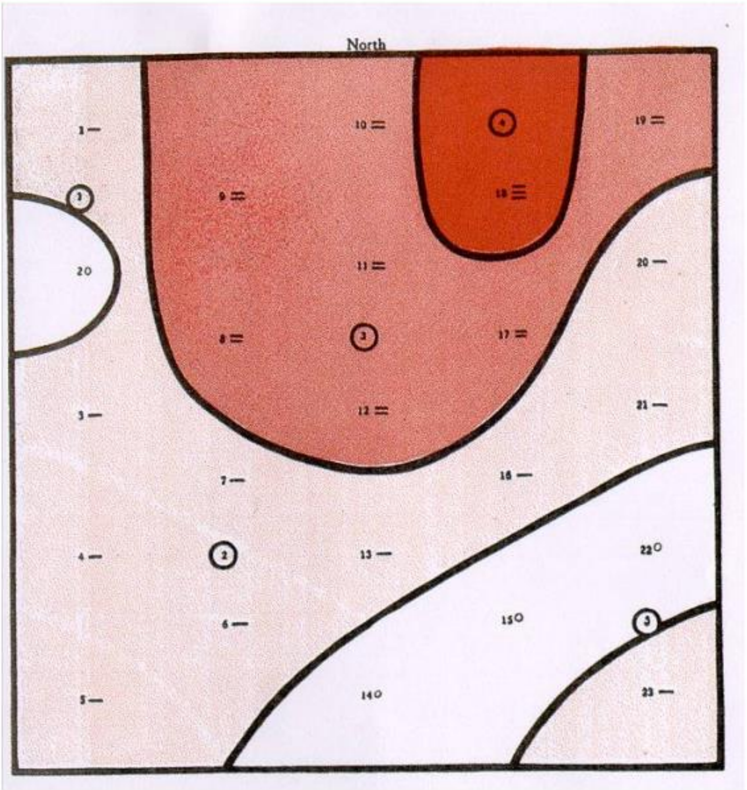


Market > 4 billion € in 2018 with annual compound growth rate (CAGR) of 15% [2019-2025]



Concepts of precision agriculture don’t require today’s technology

- In the **1920s** in the US, a University of Illinois extension bulletin showed how to grid sample for pH, map variability, and create management zones. *(Linsley and Bauer, 1929)*



But, PA as we know it today is technology-dependent

From monitoring to action

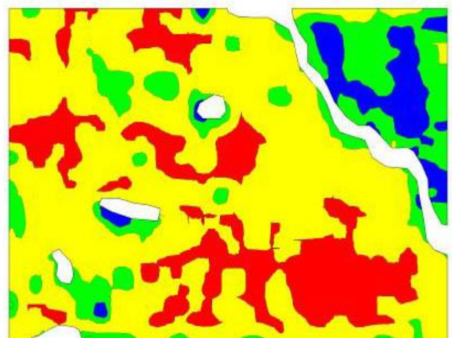
Data -> Information | **Interpretation** | **Application**

Satellites

UAVs

Proximal sensors

Prescription maps



Agronomic knowledge

Variable rate application (VRA)

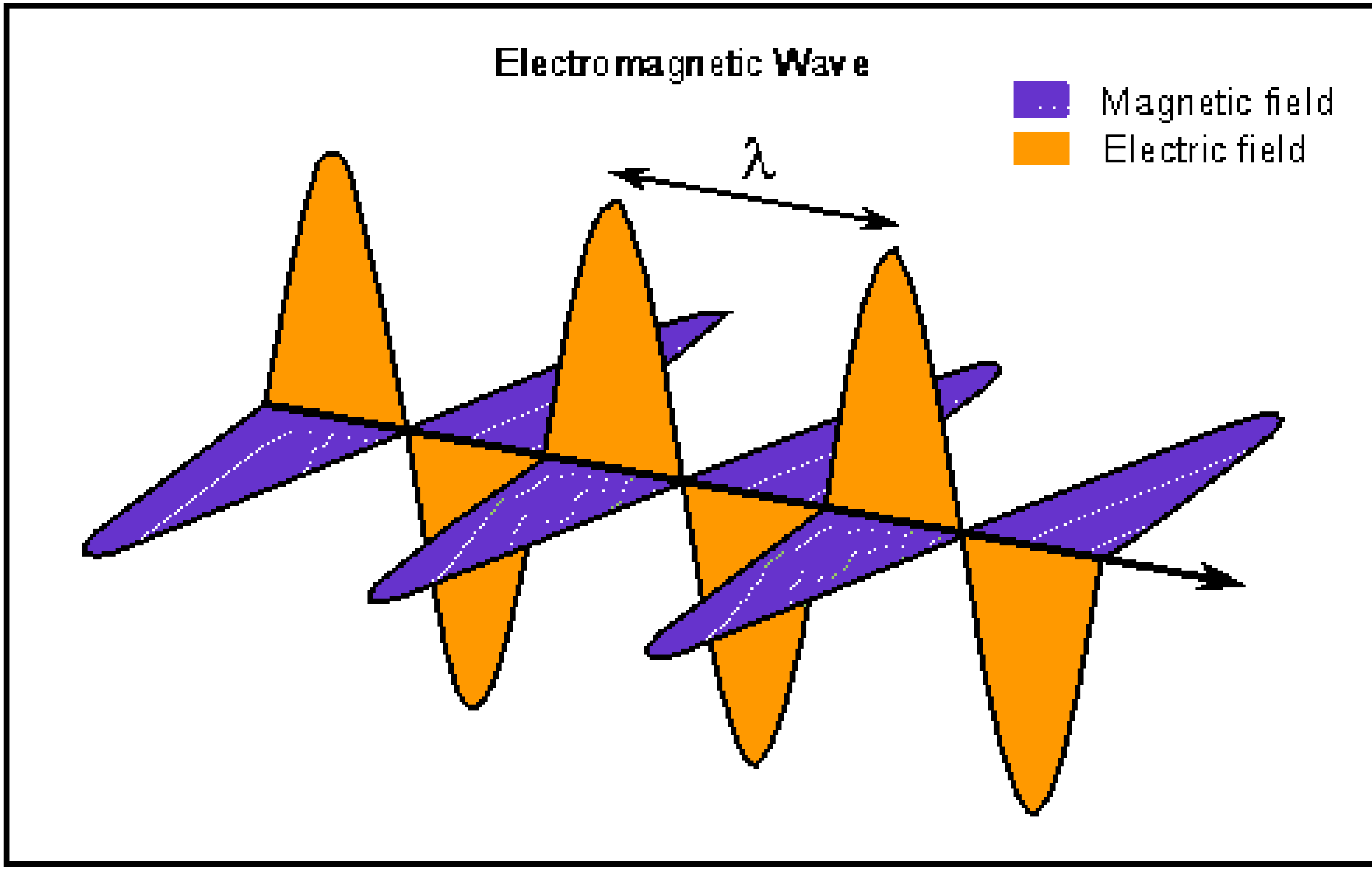
What is remote sensing?

A science that allows to obtain **qualitative** and **quantitative** information from an object. an area or a phenomenon through the analysis of data acquired from a **remote device (sensor)*** that is not in contact with the object. the area or the phenomenon investigated.

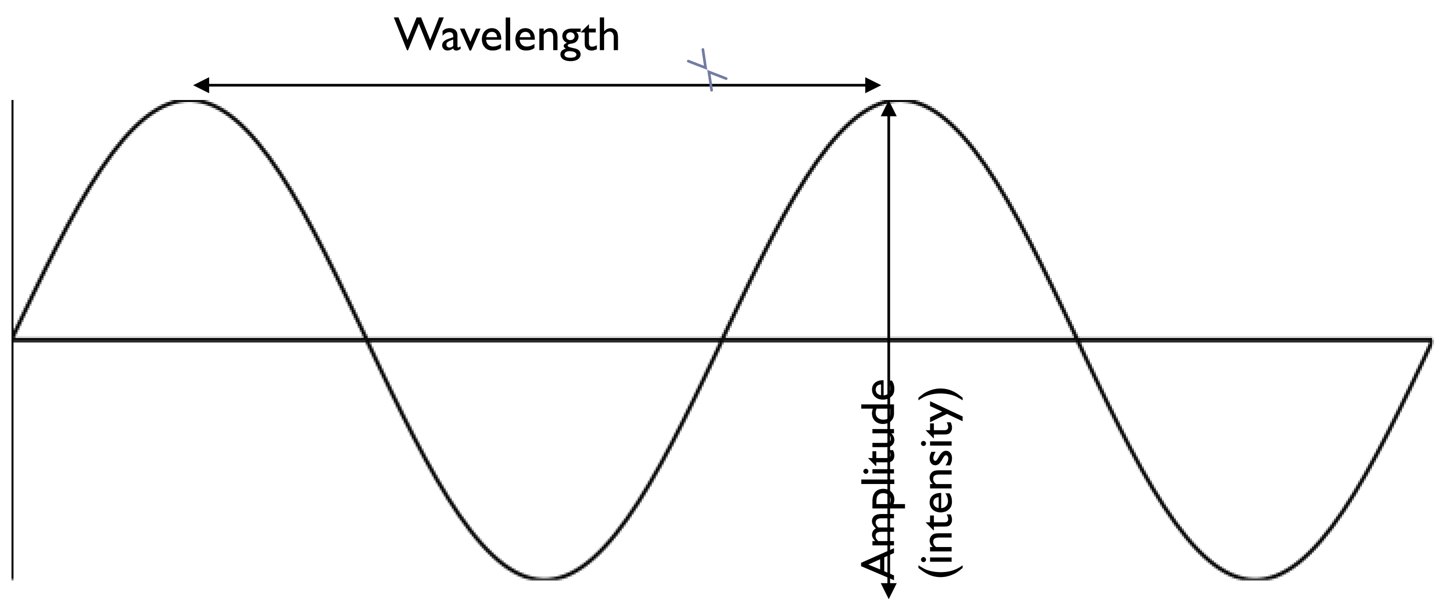
In precision agriculture is the **main technology** that allows us to have quickly and economically information to be used in agronomic management

* on board a **platform**: satellite. aricraft. drone. tractor (proximal sensing)

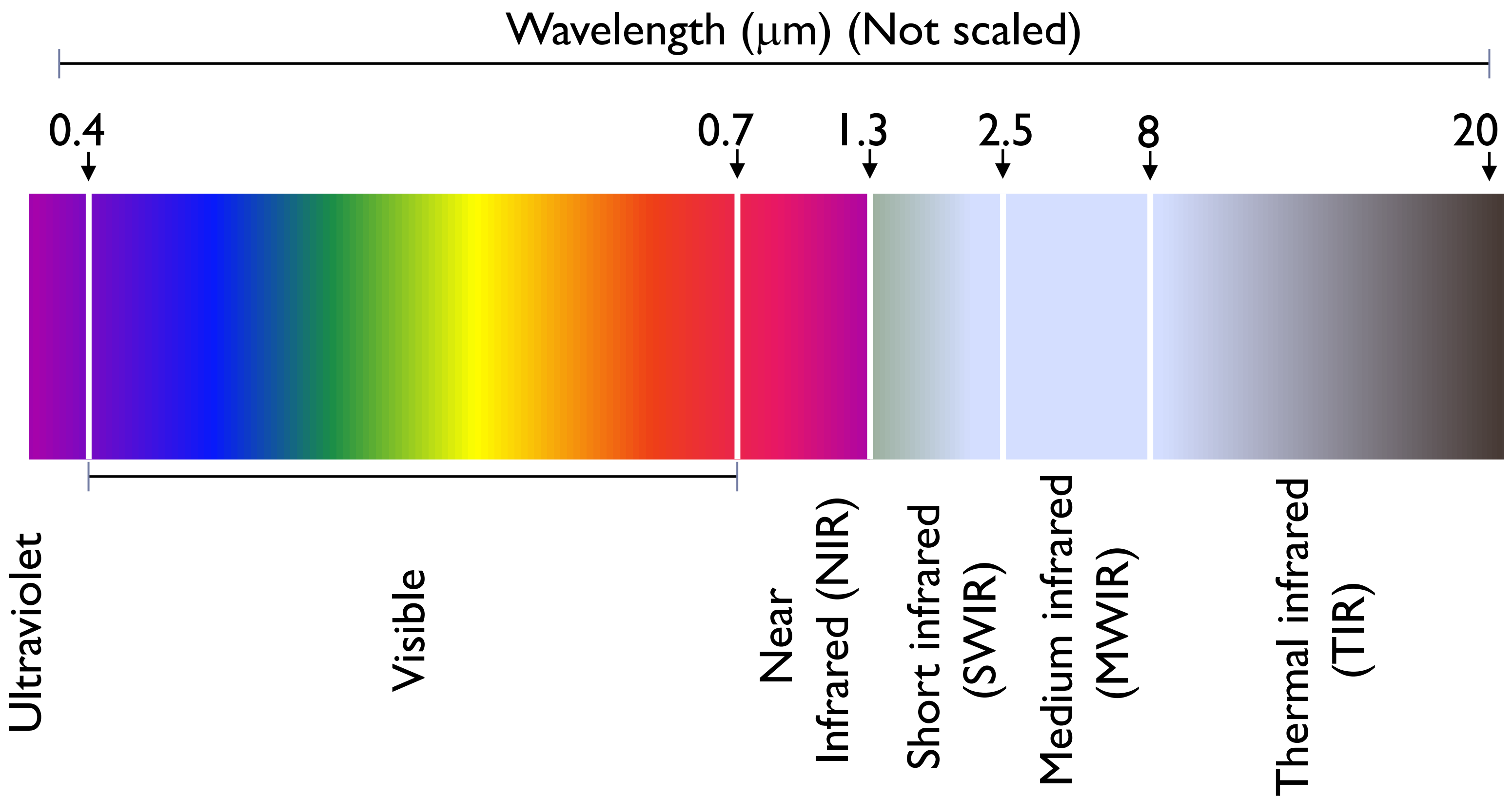
Electromagnetic radiation



Electromagnetic radiation propagates through waves characterized by a length that determines their behaviour when interacting with surfaces



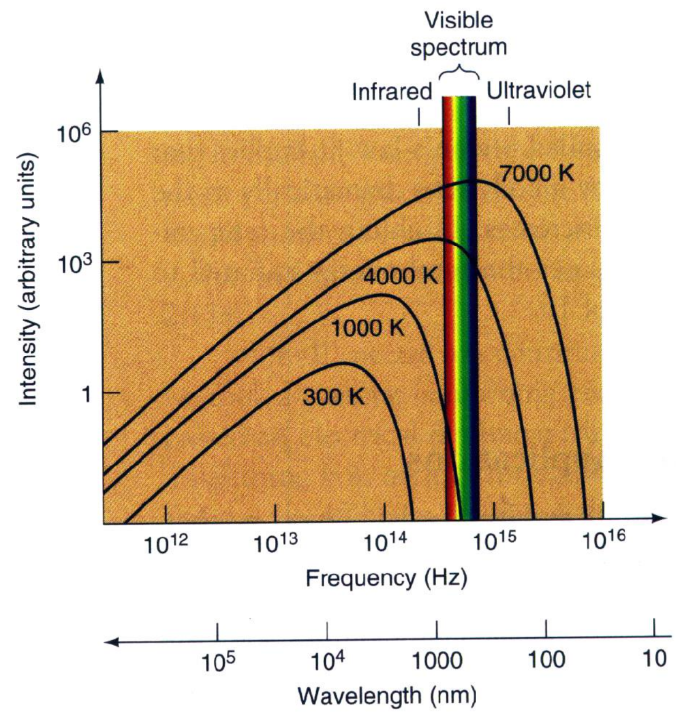
The different bands in the optical and infrared domain of electromagnetic radiation

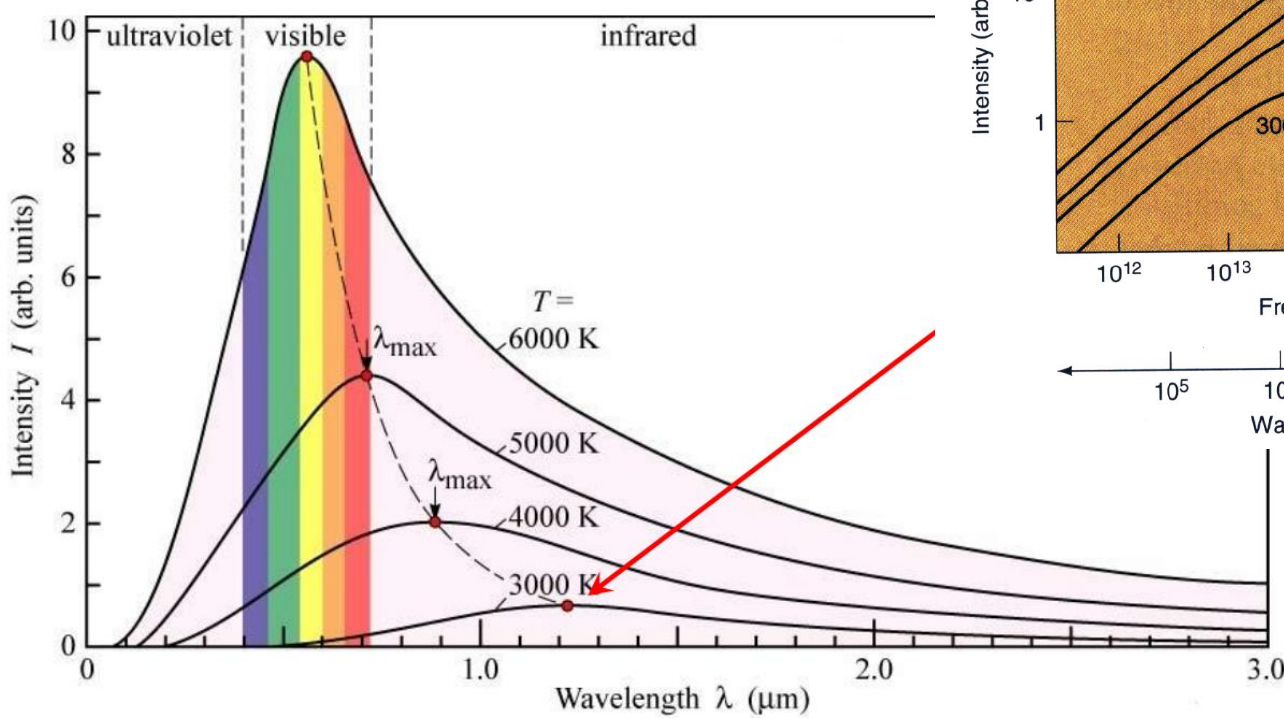


Sources of electromagnetic radiation

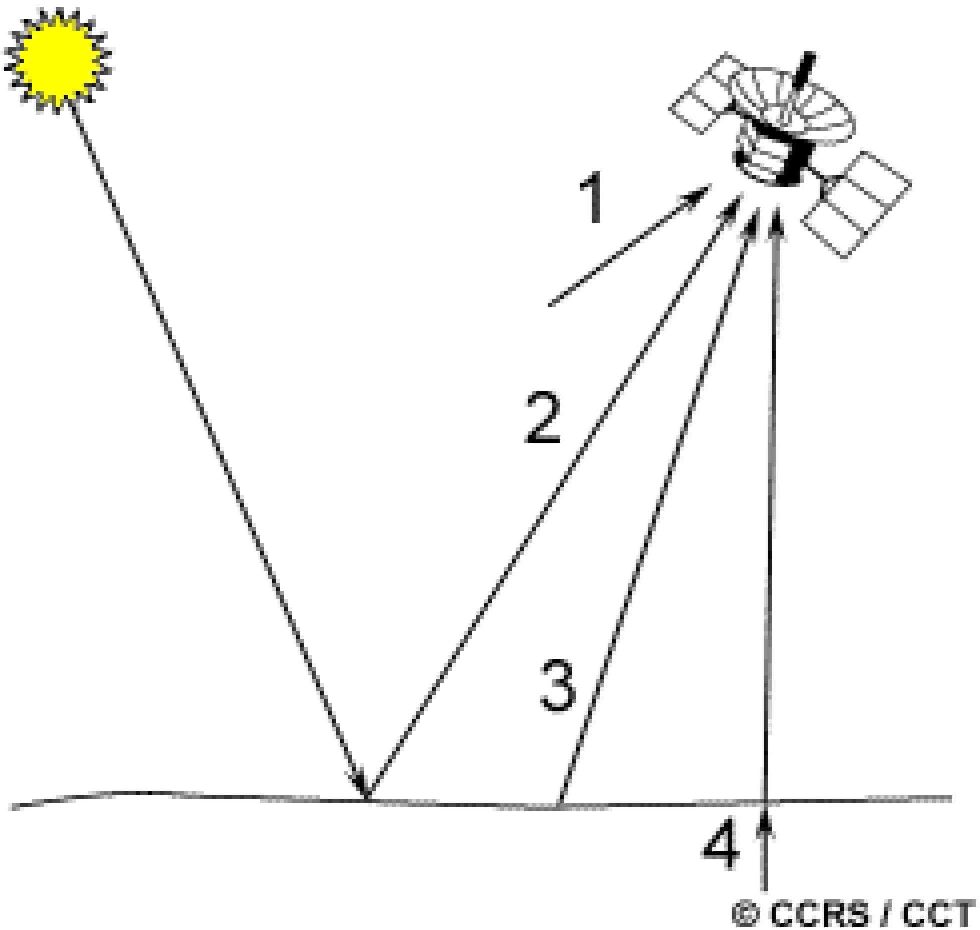
All bodies with a temperature above 0°K (-273.15°C) emit radiation that covers portions of the spectrum that vary according to their temperature.

As the temperature rises. the range of electromagnetic radiation emitted and the total amount of energy emitted increases.
while decreasing the wavelength relative to the peak of maximum energy emitted.





Components of a remote sensing system



Electromagnetic energy Source: The source of energy can be. the sun. the Earth or the sensor itself (active sensors)

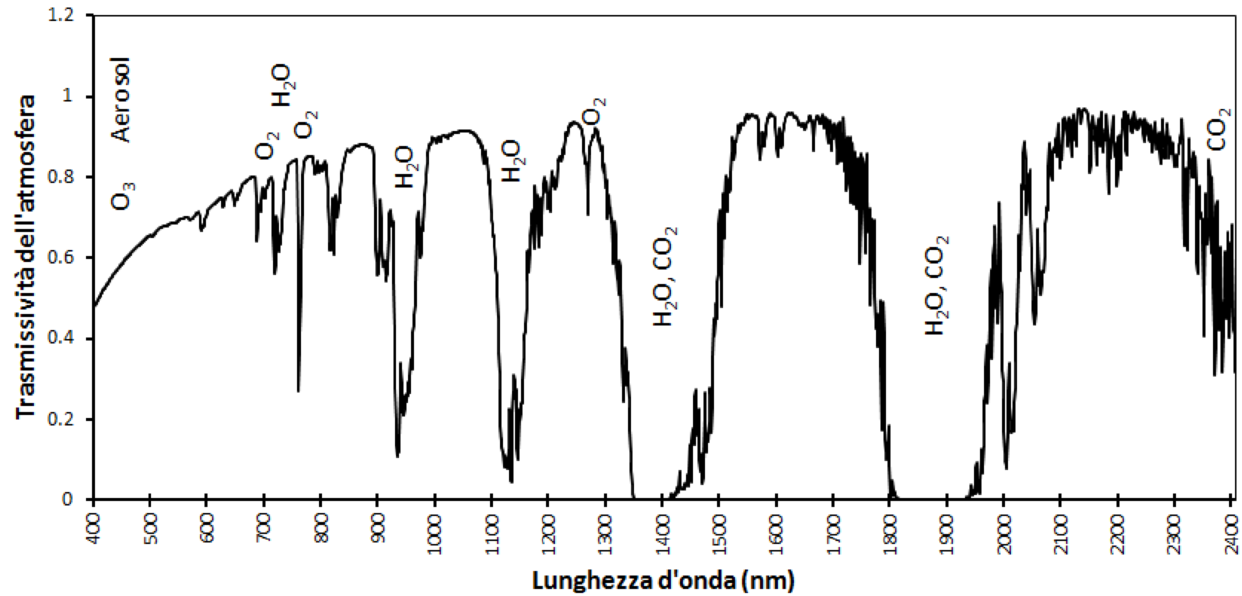
Interaction with the atmosphere: The atmosphere absorbs. diffuses and modifies both the incident and the radiation directed towards the sensor. The sensor also records radiation that comes directly from the atmosphere

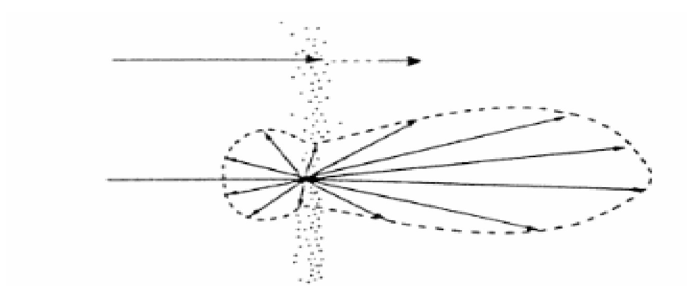
Interaction with the surface: The incident radiation on the surface is reflected. absorbed and transmitted in varying proportions according to the surface and wavelength characteristics. The surface also emits electromagnetic radiation.

The sensor: The energy reflected or emitted from the surface is recorded by the sensor

The influence of the atmosphere

Atmospheric gases, aerosols and vapors help absorb, diffuse and refract solar radiation directed and reflected from the Earth's surface.





ABSORPTION

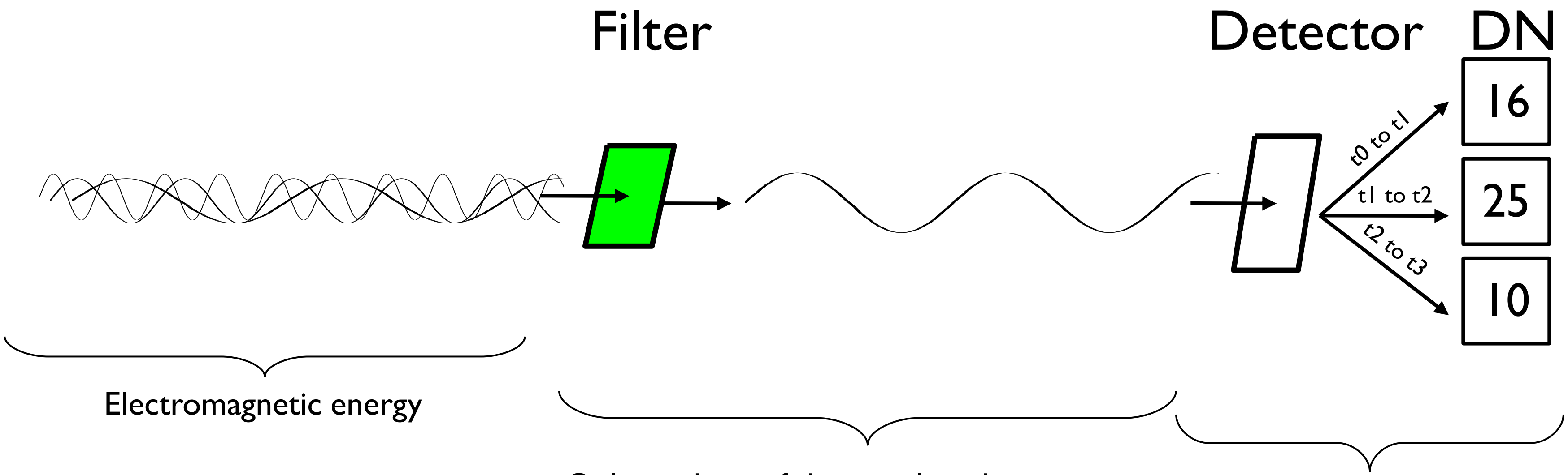
DIFFUSION (SCATTERING)

Raleigh

Mie

Function of wavelength and diameter of particles/molecules

How a RS system works



Electromagnetic energy

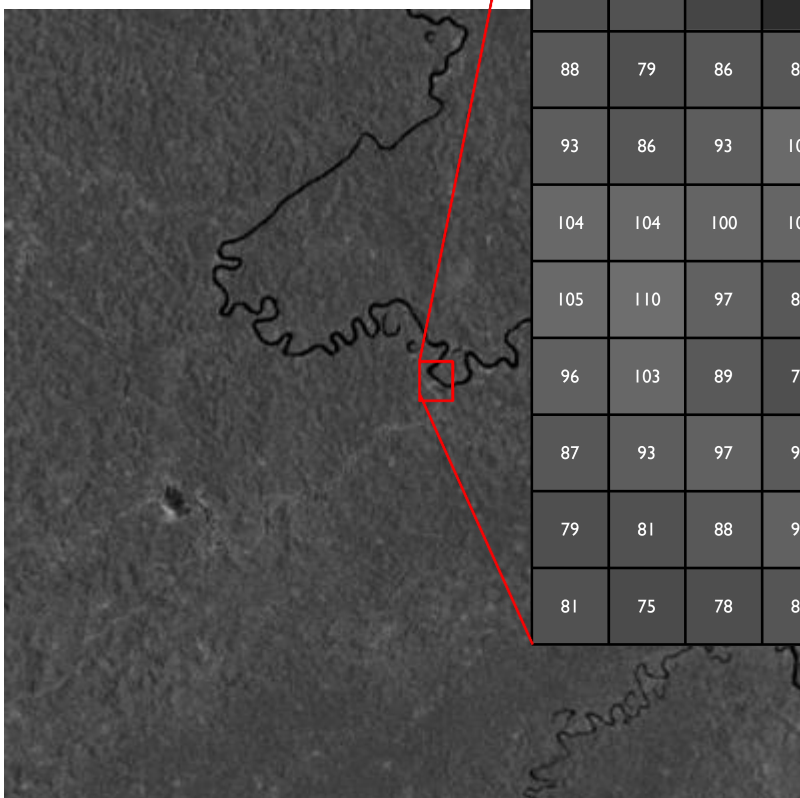
Only a subset of the wavelengths passes the filter and reaches the detector. Their whole is our spectral band.

The radiation that arrives at the detector generates an electrical signal. This signal is sampled for a certain time interval (DT) and then quantised and recorded as a digital number (DN).

What is a digital image?

Digital Number (DN) →

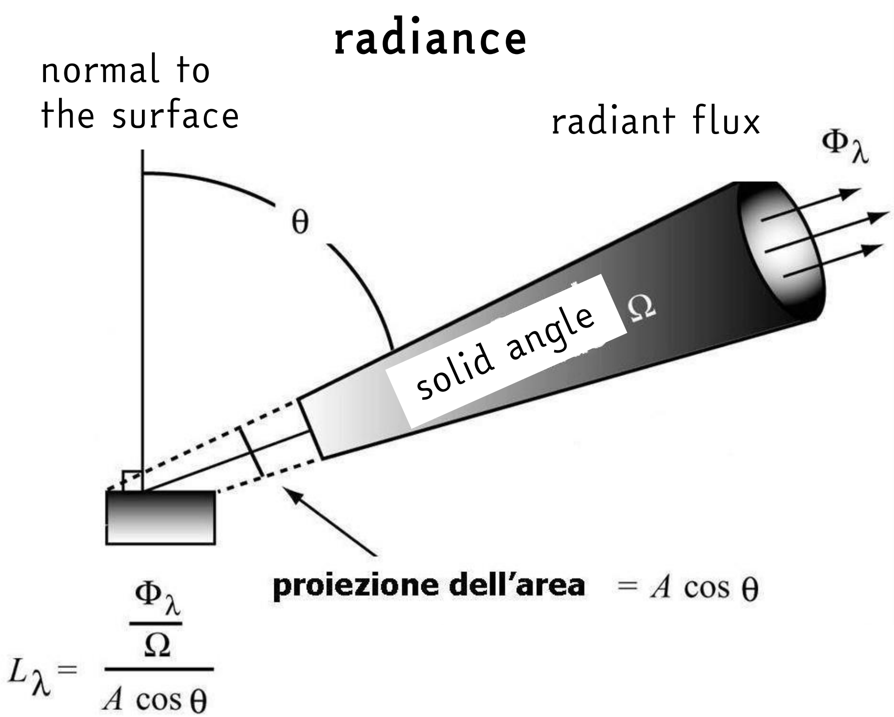
70	53	41	64	84	85	81	88	91	87
79	77	45	38	59	77	84	86	85	85
80	82	69	44	32	45	72	86	82	78
88	79	86	87	65	40	41	75	79	78
93	86	93	106	106	84	56	43	58	75
104	104	100	101	95	91	83	51	39	56
105	110	97	88	84	85	87	77	59	44
96	103	89	79	79	75	77	79	74	72
87	93	97	90	82	76	70	67	61	71
79	81	88	97	93	85	78	74	70	72
81	75	78	85	94	97	92	84	80	72



Digital numbers (DNs) typically vary in range 0- 255; 0 - 511; 0 - 1023. etc. These ranges derive from powers of 2 (binary Num.): 2^8=256; 2^9=512; 2^{10}=1024.

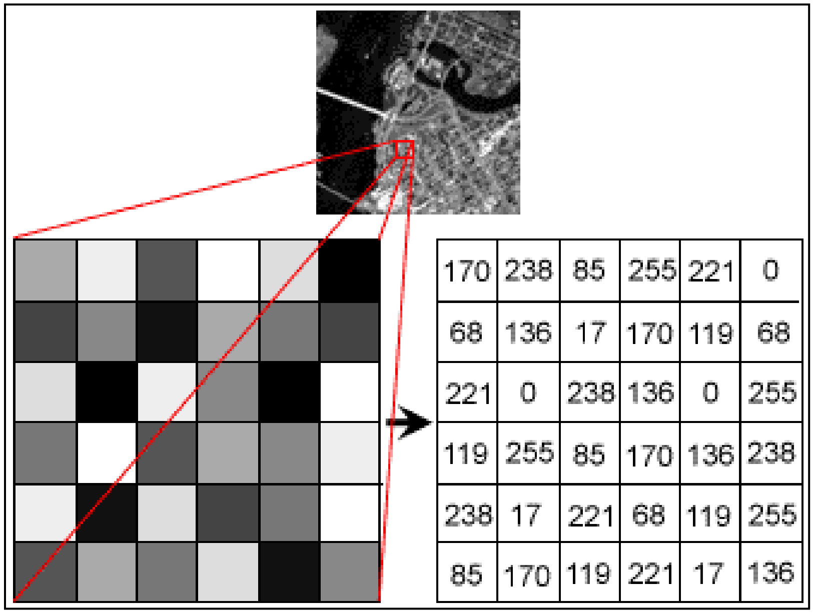
What the computer sees...

A sensor measures radiance



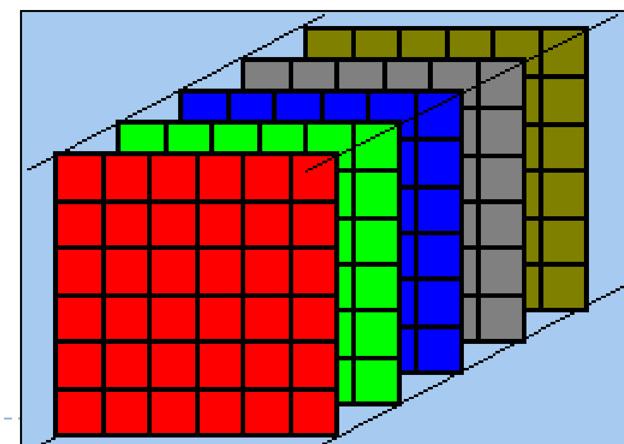
The physical quantity measured by the sensors is the **radiance** (L) [$Wm^{-2}sr^{-1}$]. defined as the **radiant flux** [Watt] coming out of a surface per unit area [m^{-2}] and per **unit of solid angle** [for steradian. sr^{-1}. the unitary solid angle that underlies a spherical cap of area equal to the square of the radius]. measured on a plane perpendicular to the direction considered.

Characters in a raster digital image

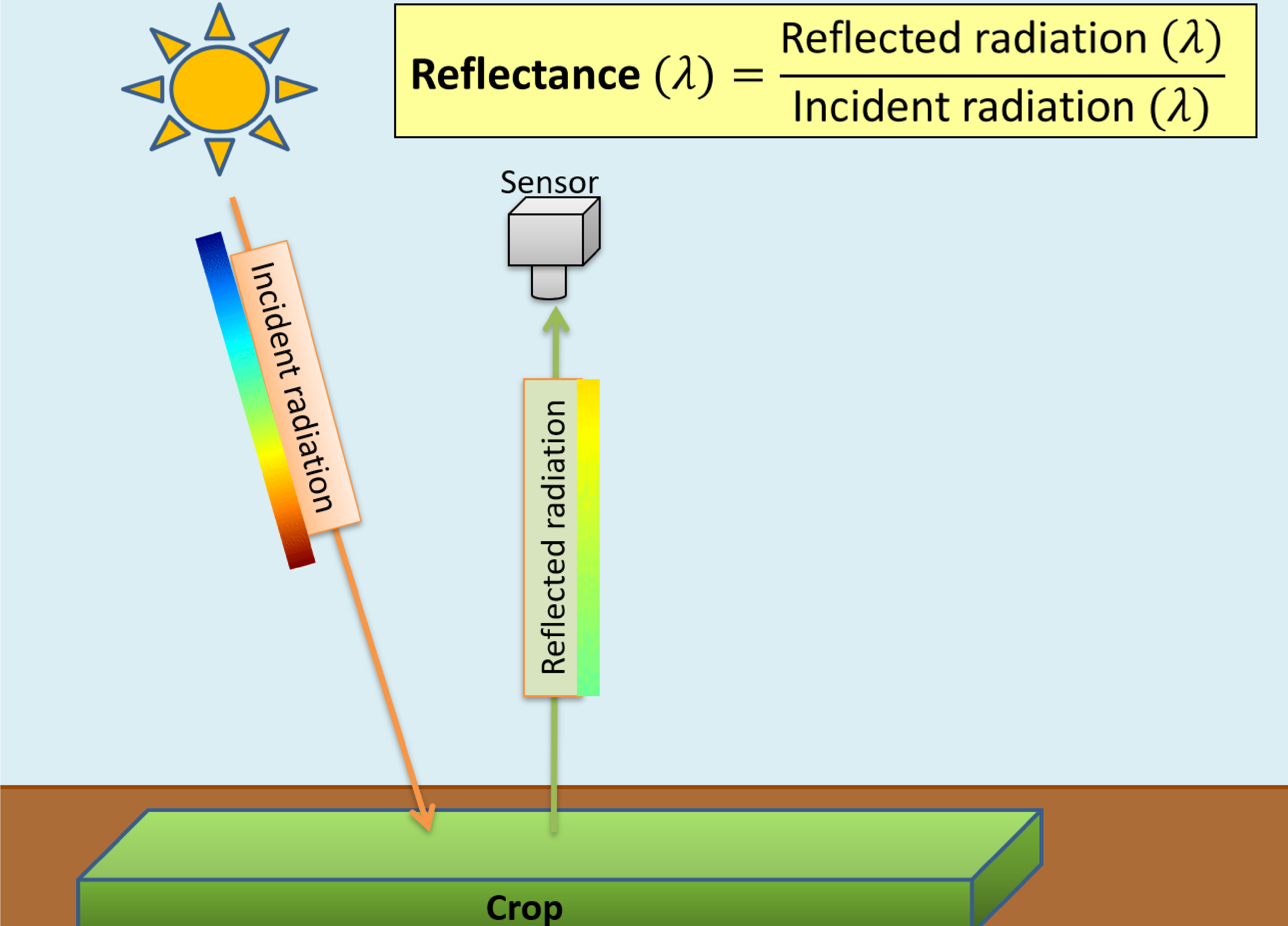


The values for each pixel (DN = Digital Number) indicate the average radiance that comes from the sensor and from the ground surface that falls into the pixel.

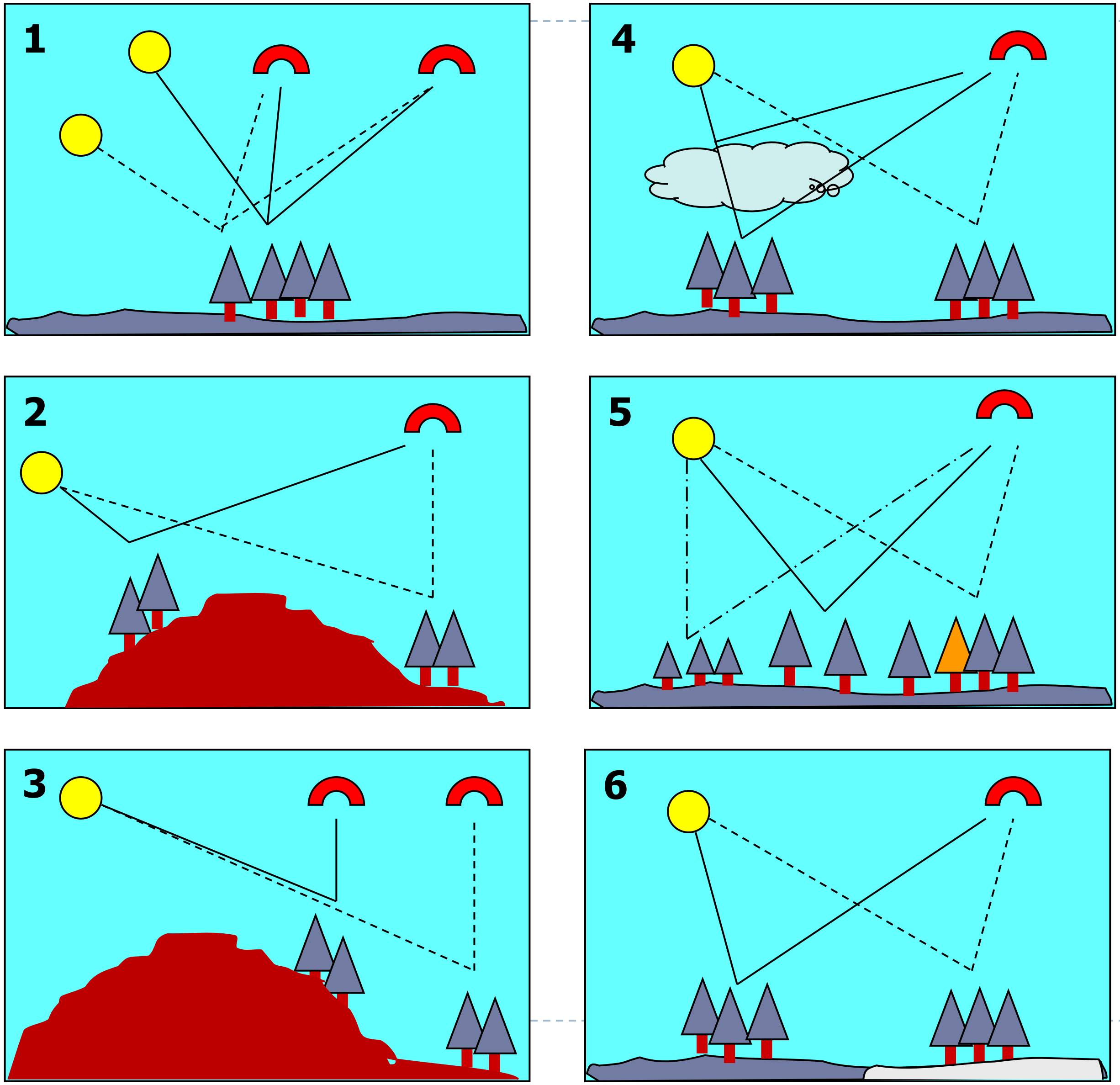
In a multispectral image the radiance is measured in multiple ranges of the electromagnetic spectrum and for each of these the matrix of DN is created.



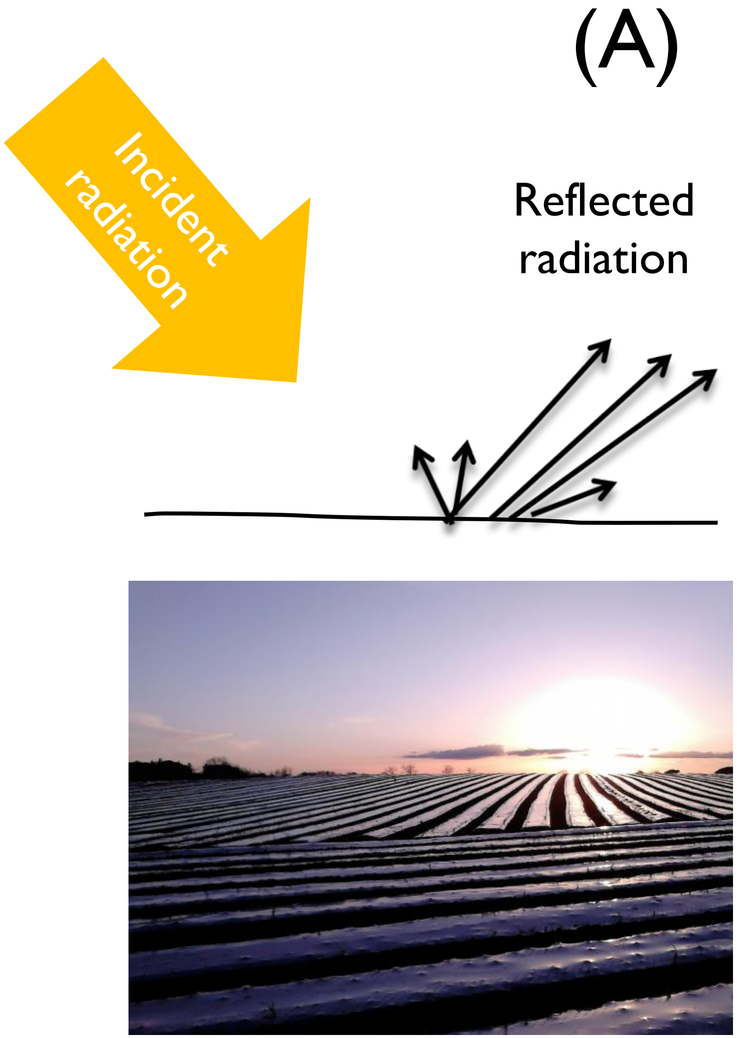
$$\textbf{Reflectance}\ (\lambda) = \frac{\text{Reflected radiation}\ (\lambda)}{\text{Incident radiation}\ (\lambda)}$$

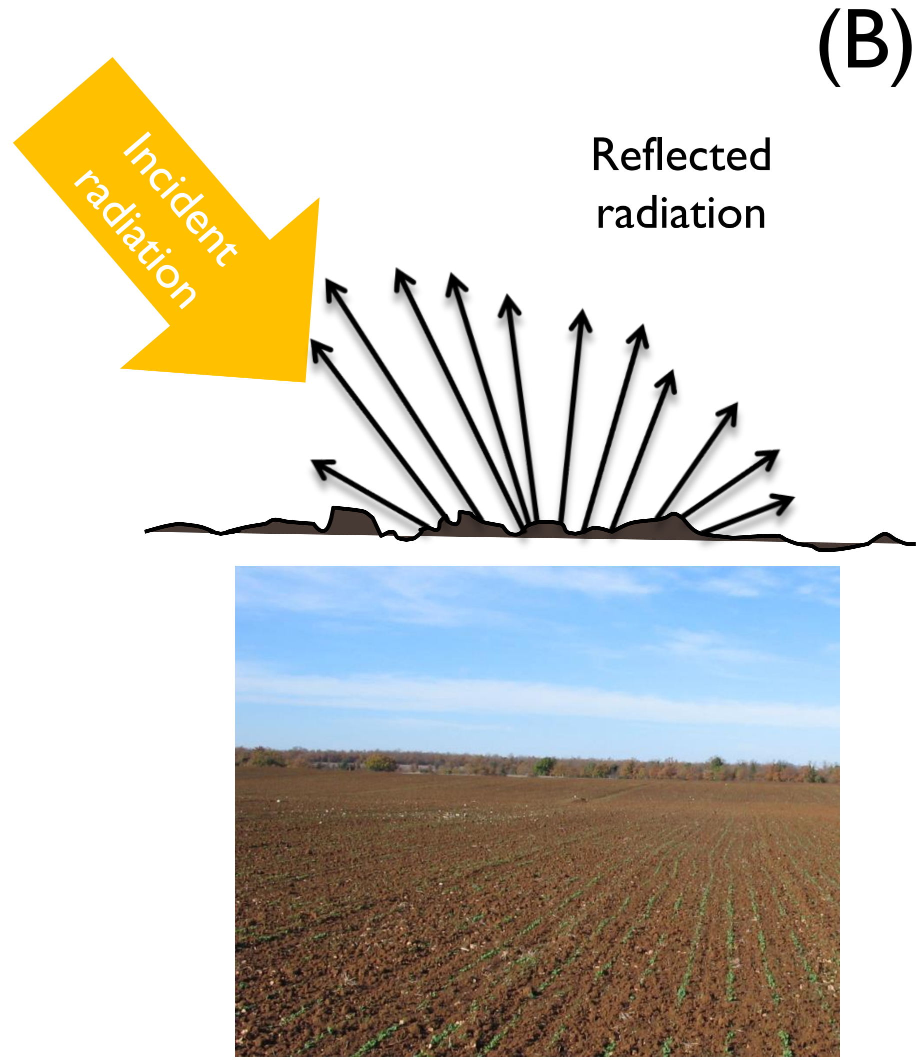


Factors influencing reflectance



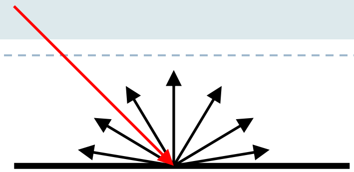
1. Sun-Sensor geometry
2. Exposure
3. Slope
4. Atmosphere
5. Object Features
6. Substrate



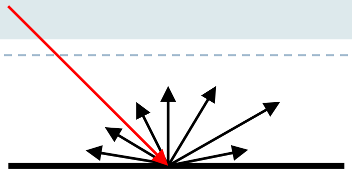


The specular Reflection (A) which prevails in the case of "smooth" surfaces occurs mainly in the opposite direction of the angle of incidence. while the diffuse reflection (B) is distributed in all directions. but often in a non-uniform manner. with a greater Intensity in the direction of the incident radiation (hotspot). The variation of the reflectance according to the angle of illumination and observation is called BDRF.

Bidirectionality of reflectance



Lambertian surface



Non-Lambertian surface

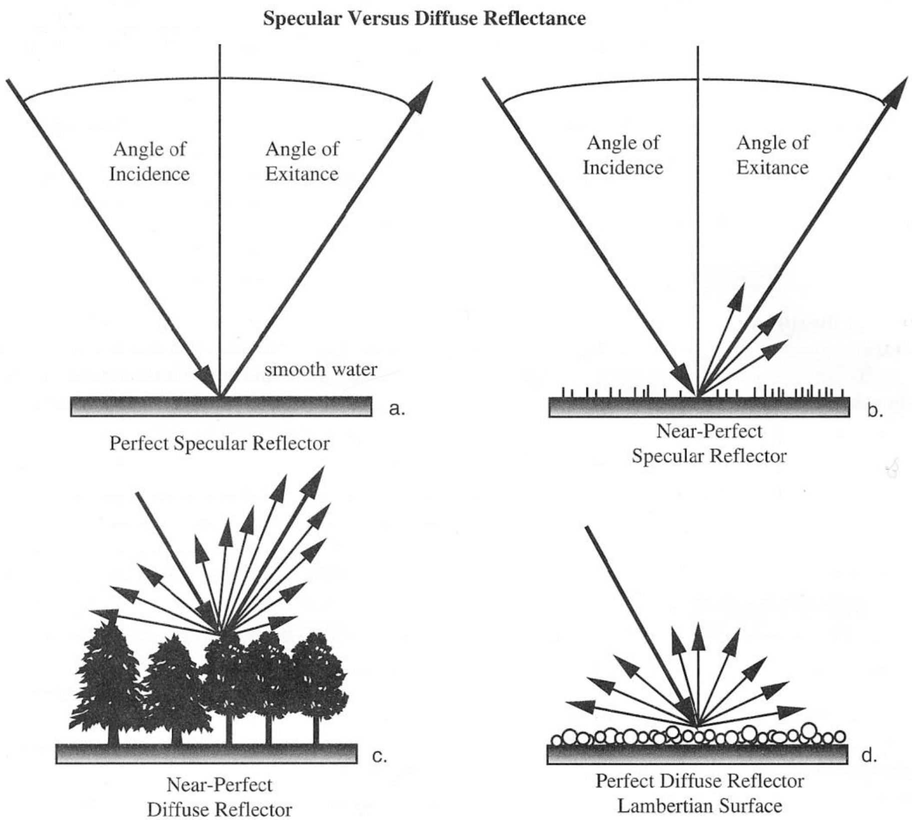


Figure 2-16 The nature of specular and diffuse reflectance.

BRDF

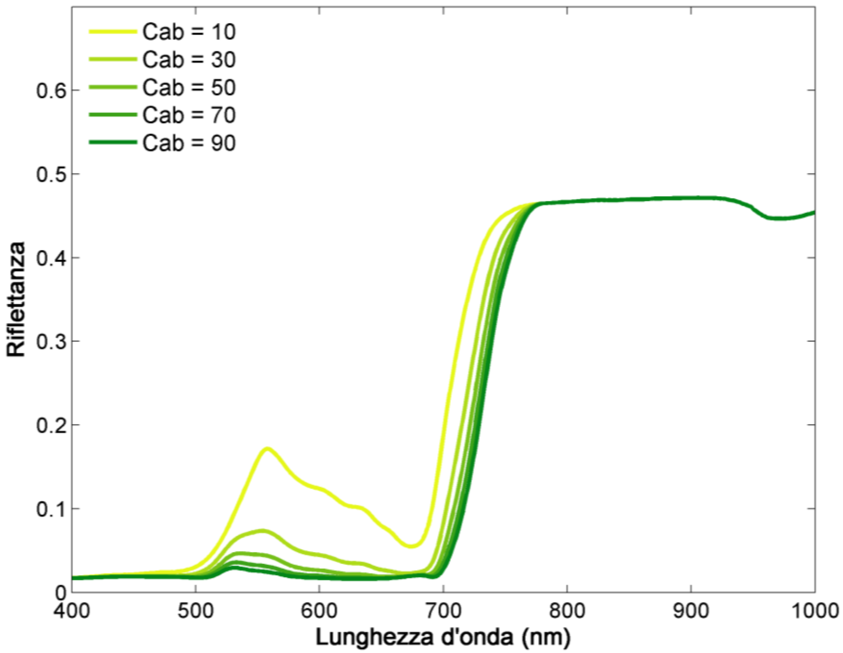
Sun behind the Observer

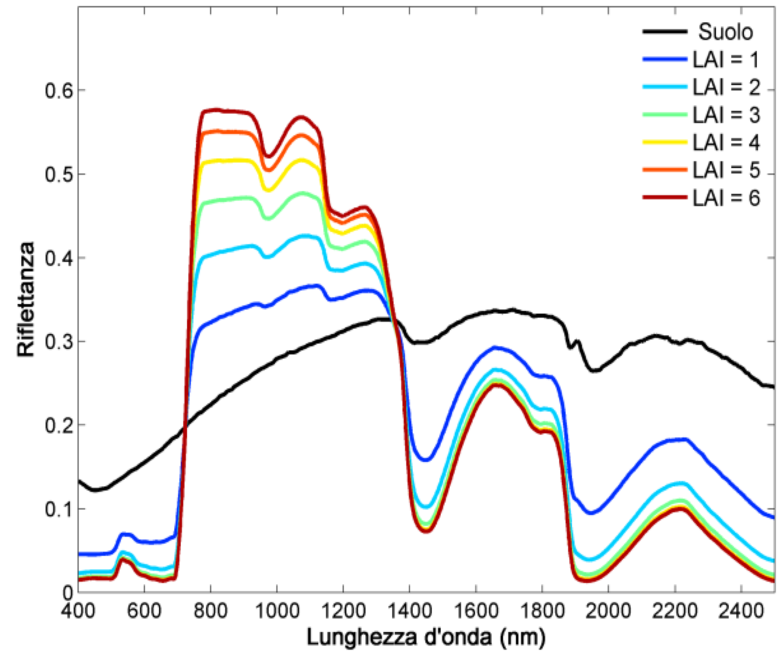
Sun in front of the Observer

BRDF

Sun behind the Observer   Sun in front of the Observer

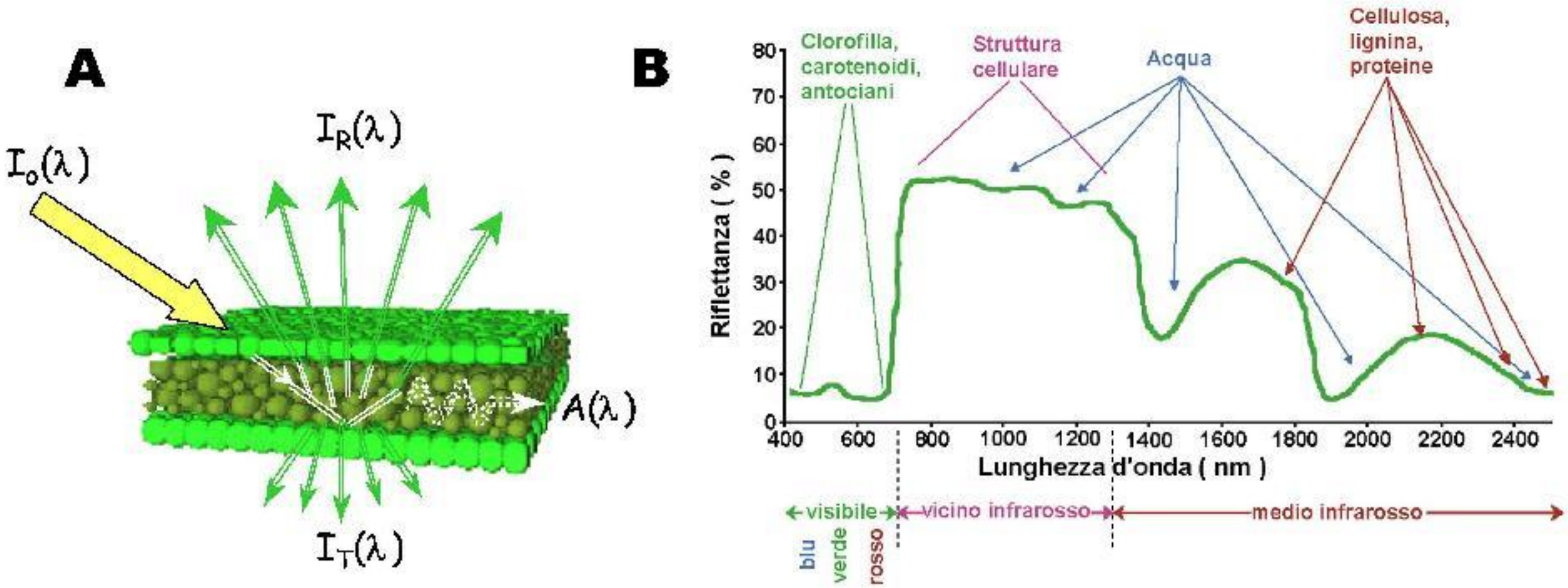
Leaf and canopy reflectance spectra





Behaviour of reflectance spectra with changes of leaf chlorophyll a+b (Cab) from 10 to 90 $\mu g/cm^2$ of leaf (left) and of canopy reflectance spectra with changes of leaf area index (LAI) (right)

Leaf reflectance spectrum



depends on mesophyll structure. water. pigments   etc...

The resolutions

- **Spectral**: indicates the number of capturing bands and their amplitude.
- **Radiometric**: Detector sensitivity of a certain sensor in perceiving and coding in signal the differences of radiant flux. In practice. the radiometric resolution represents the number of levels in which the original signal can be decomposed.
- **Geometric**: Size of elementary ground area of which electromagnetic energy is detected (pixel).
- **Temporal**: Period of time between two successive acquisitions of the same area.

Spatial resolution of a sensor

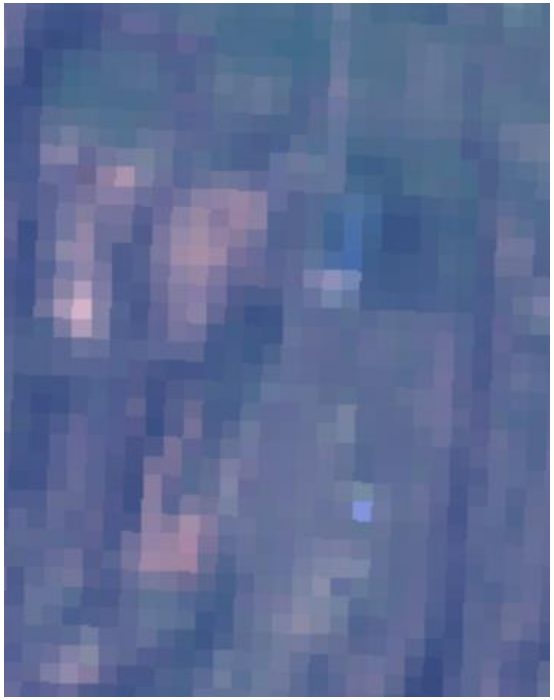
Quickbird 70 cm (Google Earth)

https://goo.gl/maps/zrcV6LBd4PUyfQ6S8

Sentinel-2 10 m

https://sentinelshare.page.link/ikYf

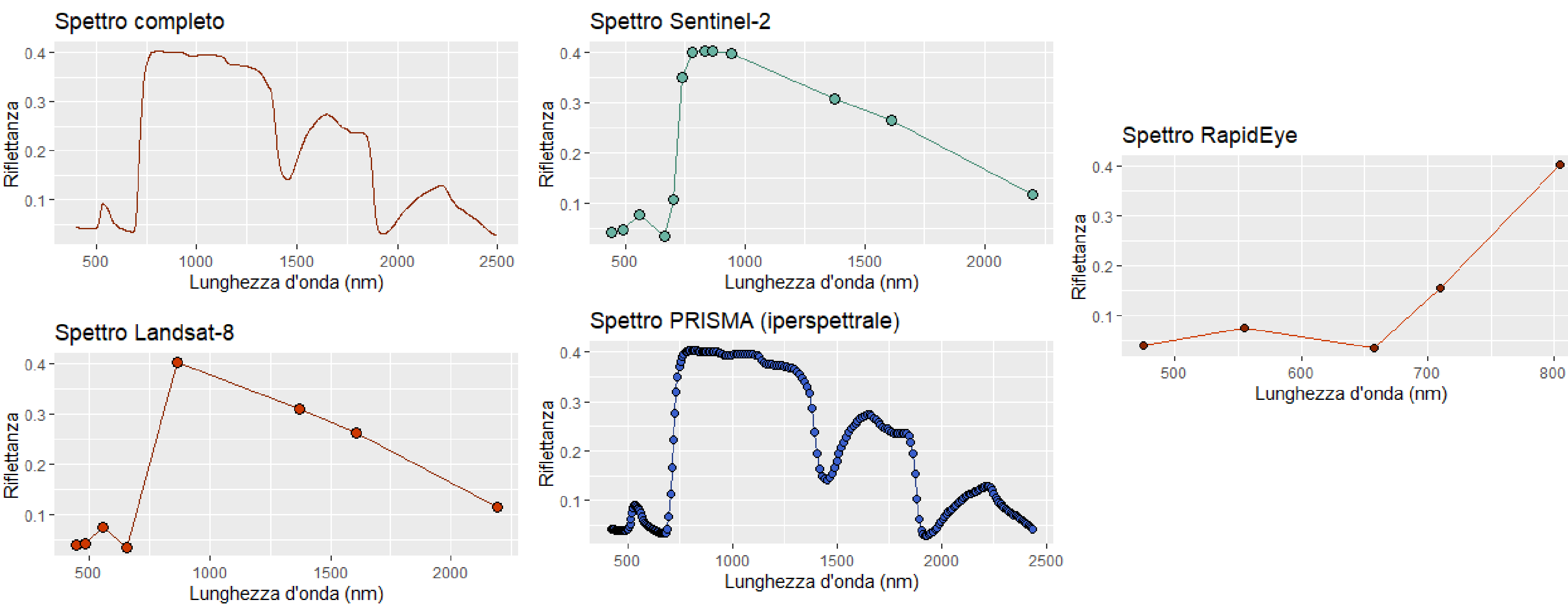
Landsat 30 m



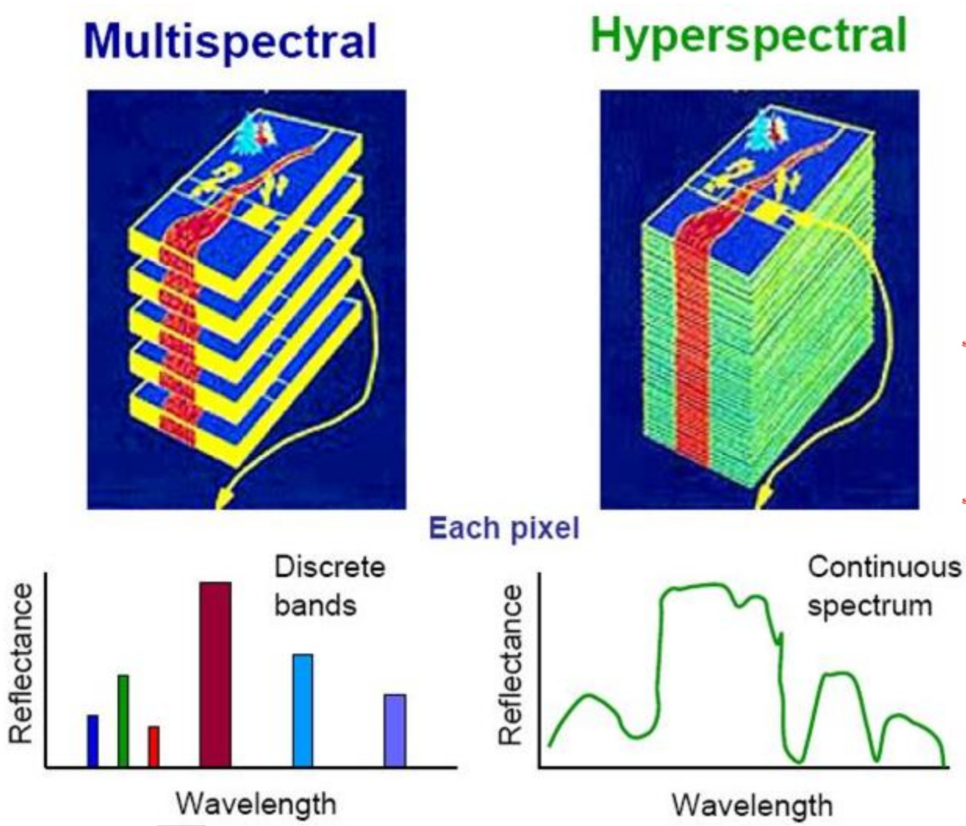
https://sentinelshare.page.link/y3r6

Spectral resolution of a sensor

The same spectrum "seen" by different satellites



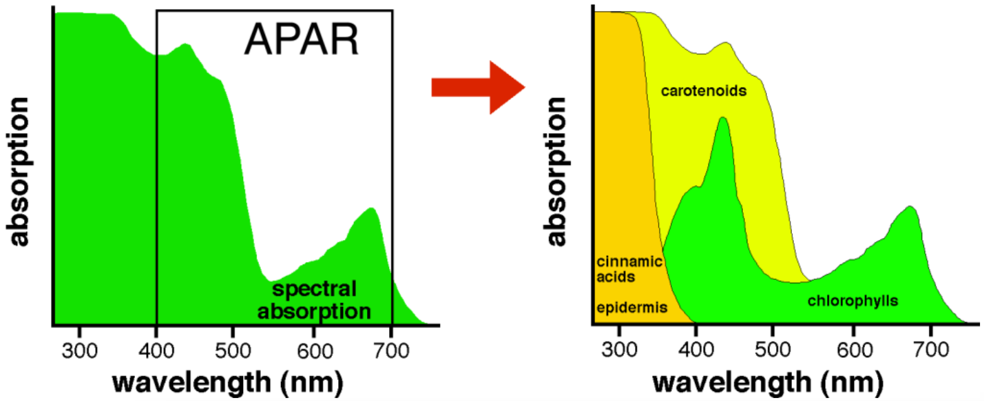
Spectral resolution

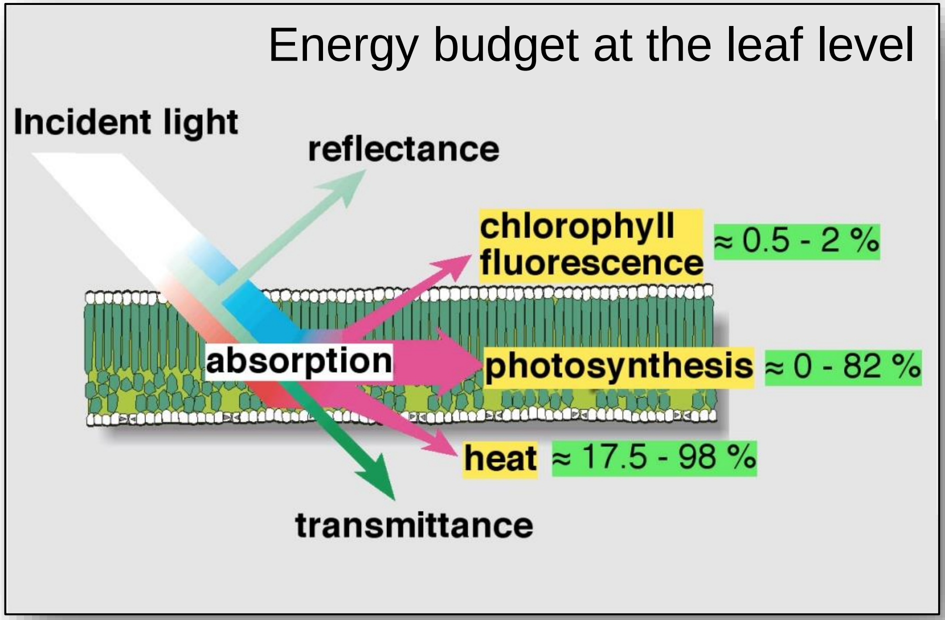


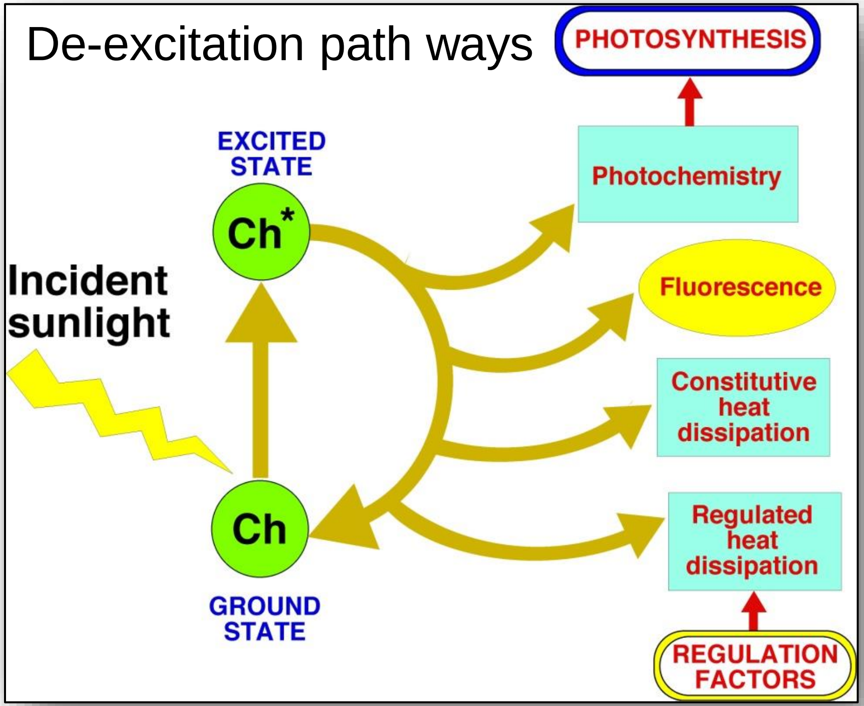
- By spectral resolution we mean the number of bands detected and their width: the greater the number of bands. and consequently the smaller their width. the greater the ability to identify the objects taken according to their reflectance characteristics.
- With multispectral sensors. images are acquired in a limited number of distinct. wide and usually non-contiguous bands.
- Hyperspectral sensors. on the contrary. are able to detect numerous intervals of wavelengths very narrow and close to each other. as if to carry out the analysis of the entire electromagnetic spectrum.

Beyond reflectance there is also fluorescence …..

Chlorophyll fluorescence as an indicator of usage of the absorbed light by vegetation





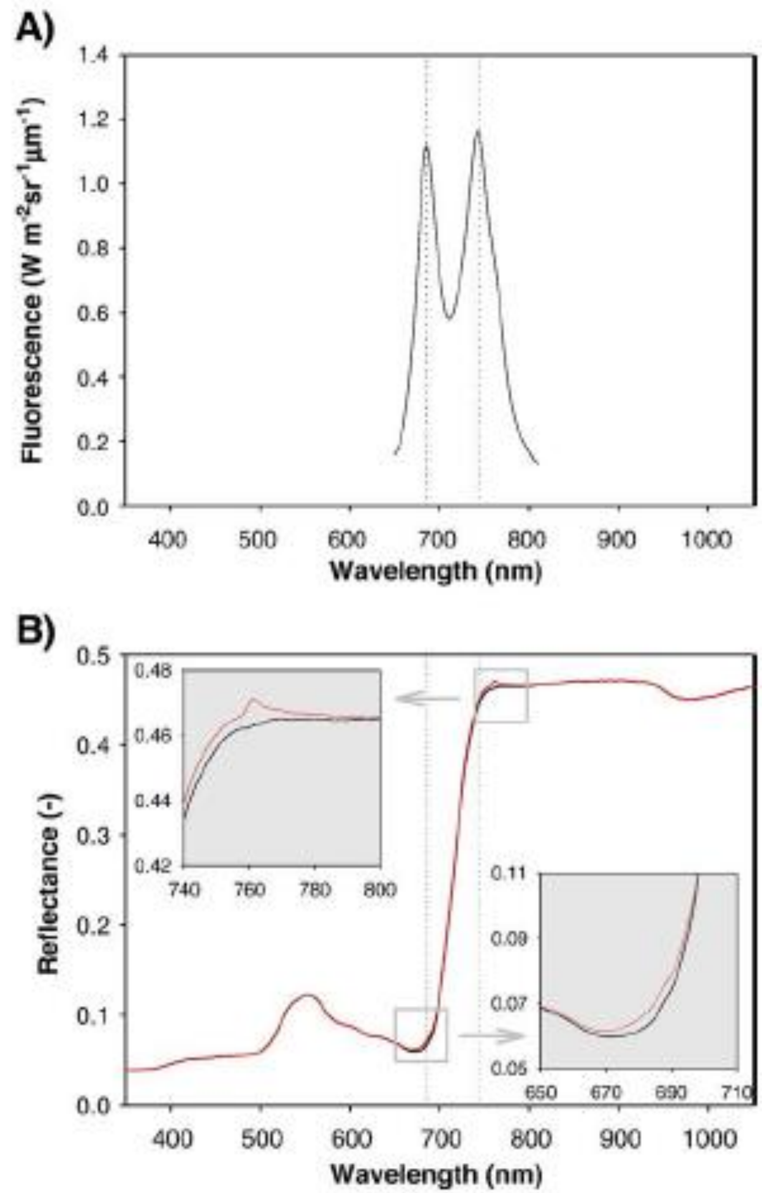


Fluorescence

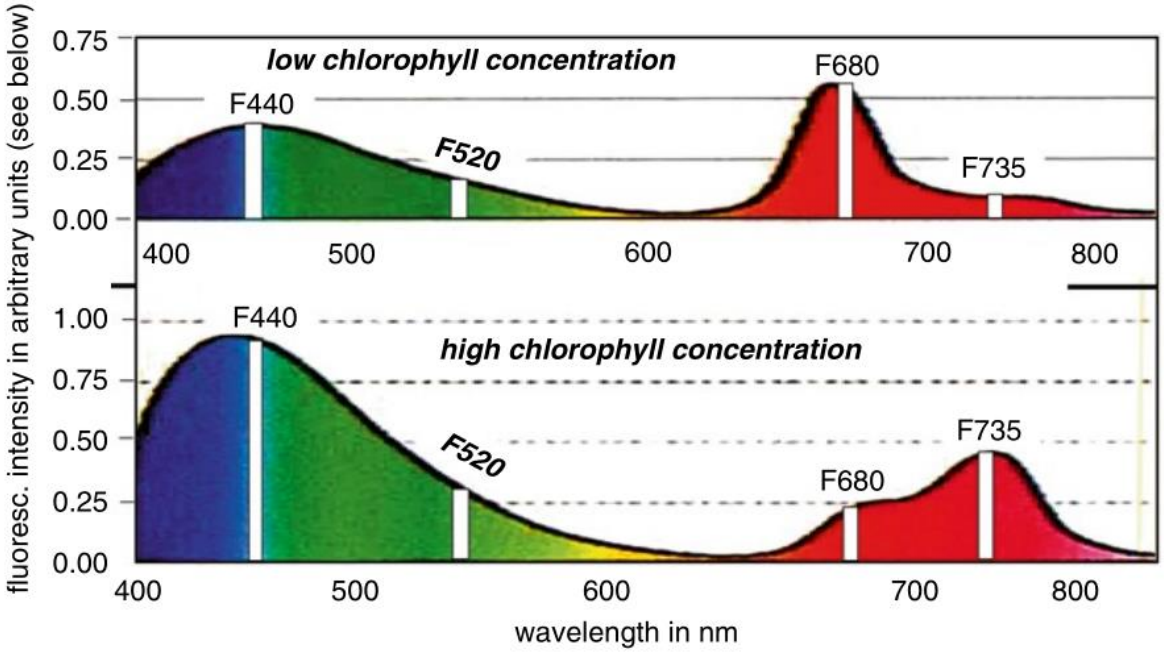
Luminous excess dissipation by chlorophyll fluorescence (re-emission of light energy absorbed at greater wavelengths)

Like heat dissipation. it competes with photosynthesis

The fluorescence peaks are at about 685 e 730 nm.

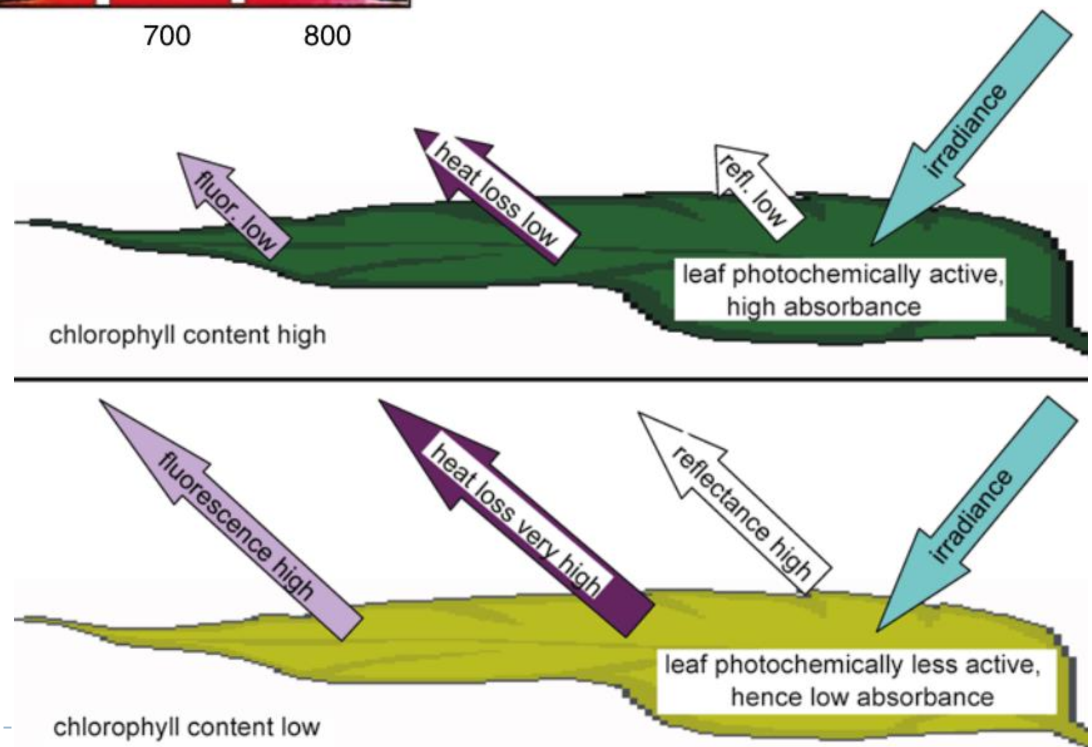


Meroni et al. 2009



Fluorescence after excitation with UV light

Fluorescence is related to the chlorophyll content



Sun induced fluorescence (SIF)

We are able to measure the fluorescence in a passive way only in narrow spectral bands where the solar irradiance is strongly reduced (Fraunhofer lines). In NIR there are two bands at 687 and 760.4 nm due to oxygen

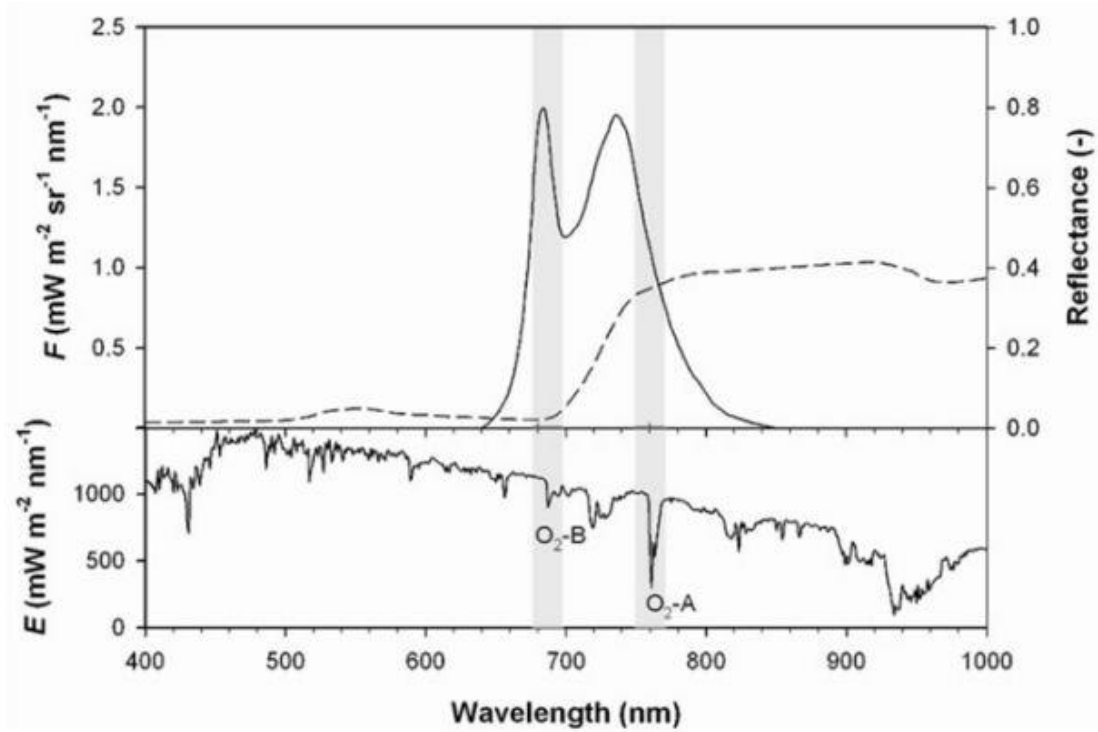
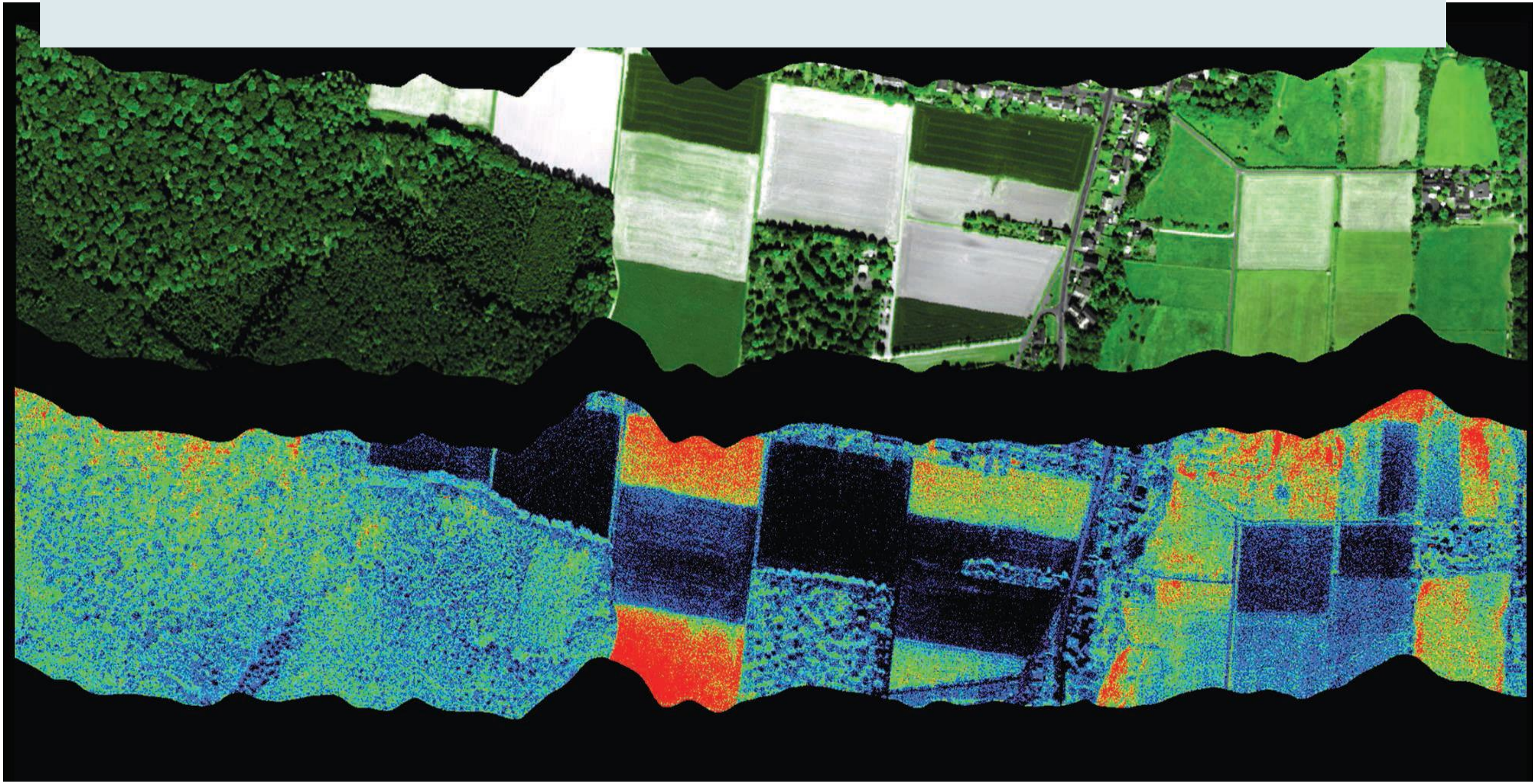


Figura 2 Sopra: la linea continua è l'emissione in fluorescenza (SIF) mentre quella tratteggiata è la riflettanza di una foglia verde. Sotto: irradianza incidente a livello della superficie terrestre. Le aree ombreggiate segnalano la posizione delle due linee di assorbimento dell'ossigeno atmosferico utilizzate per la stima di SIF, bande B ed A posizionate a 687 e 760 nm, rispettivamente.

Meroni et al. 2010

You can measure fluorescence from aerial sensors (And in the future by satellite: FLEX)



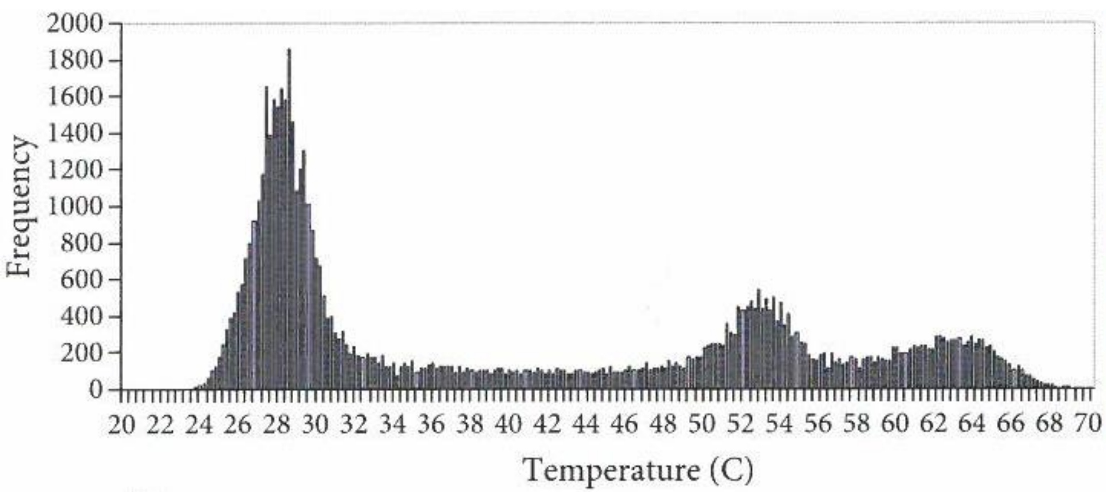
Chlorophyll fluorescence map from HyPlant

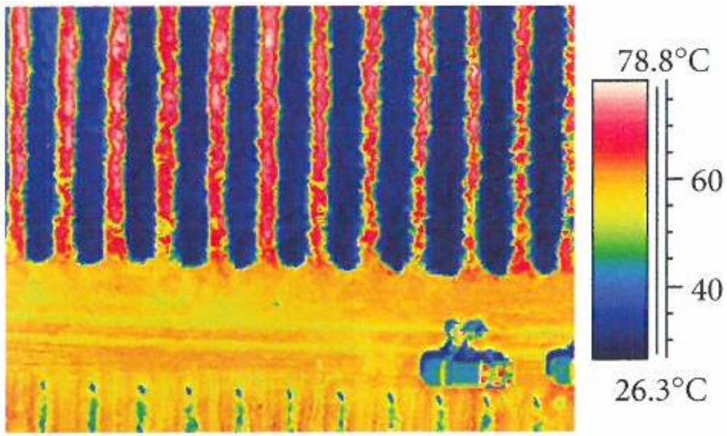
Thermal infrared Remote Sensing

According to Stefan-Boltzmann's law. all bodies with a temperature higher than absolute zero emit radiation. At terrestrial temperatures the radiation is emitted between 3 and 15 μm. **both day and night**

$$E = \varepsilon\sigma T^4$$

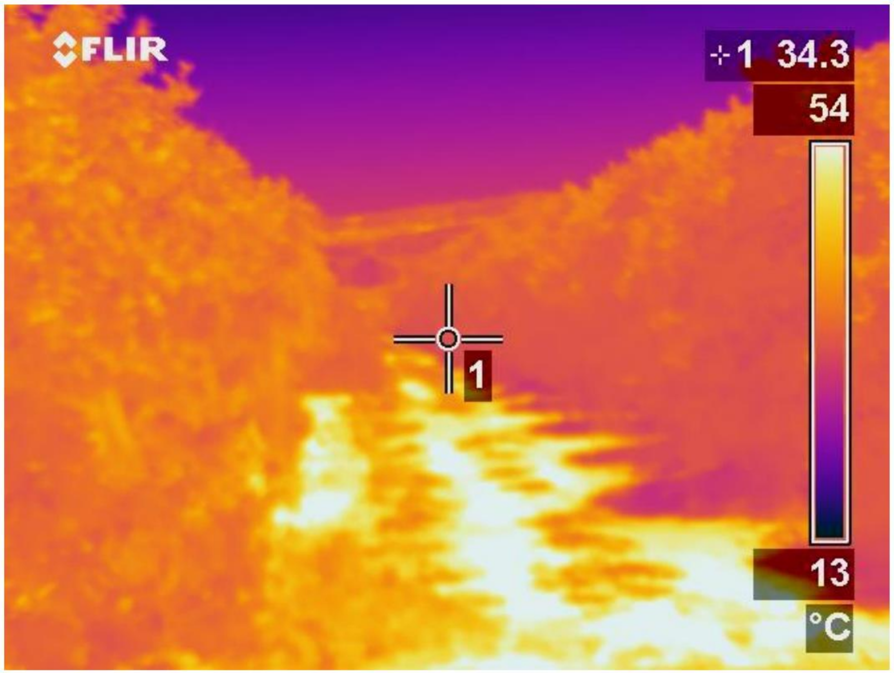
E is the radiation flow emitted by the body (W m^{-2}). ε **the emissivity**. *s* a constant and T the body temperature



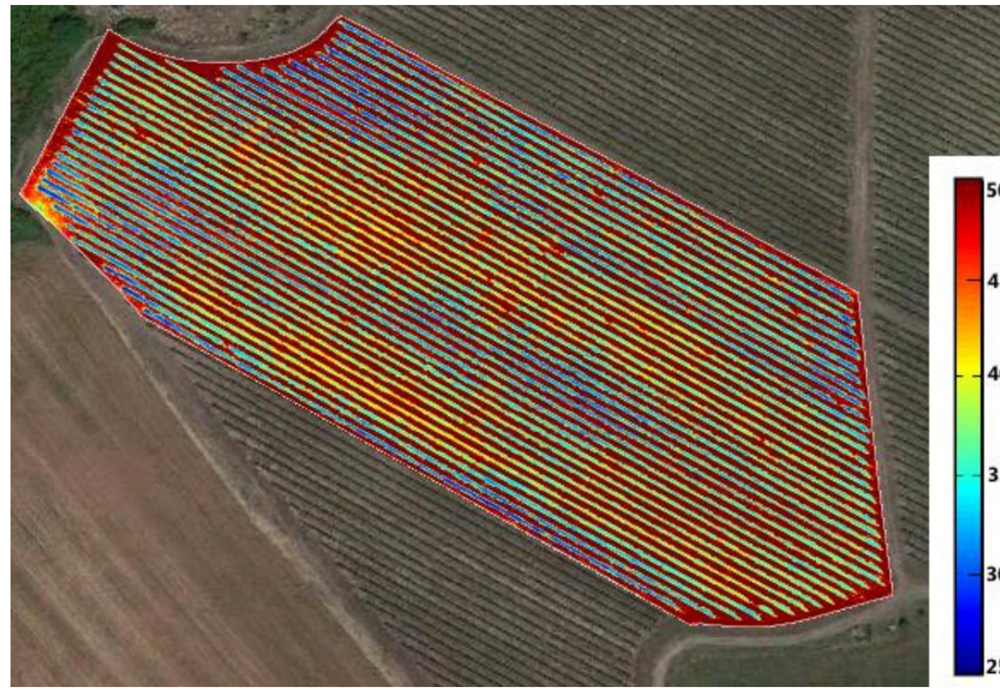


Thermal infrared remote sensing

From the ground (proximal sensing)

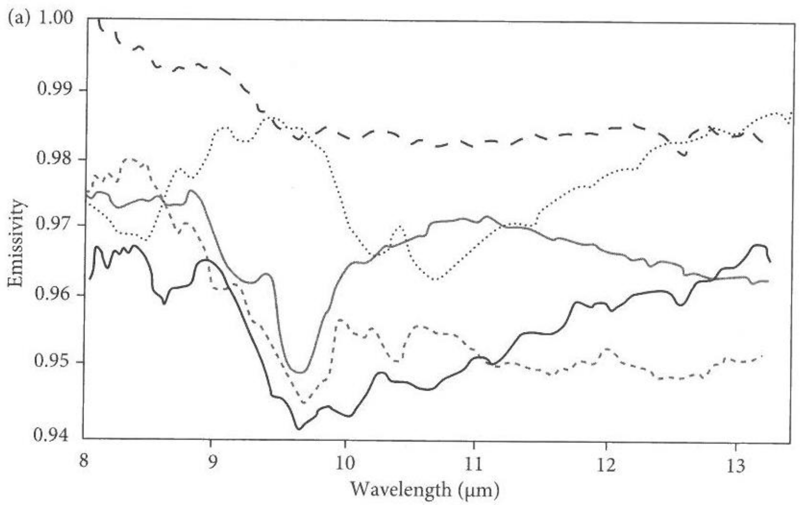


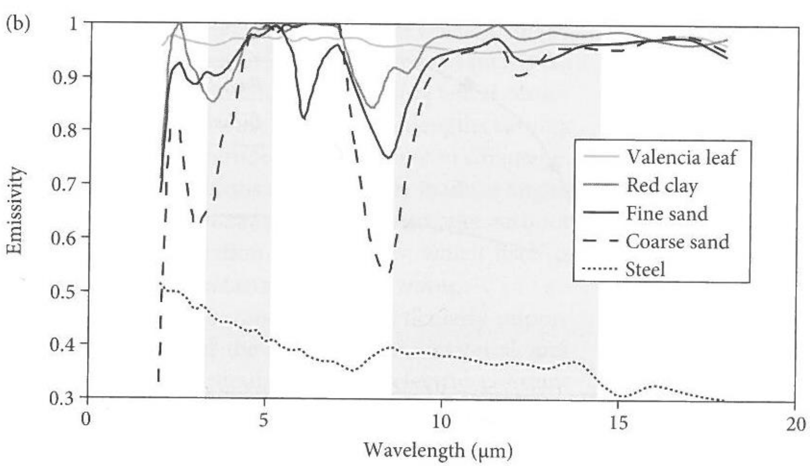
From UAV (drone)



Thermal infrared Remote Sensing

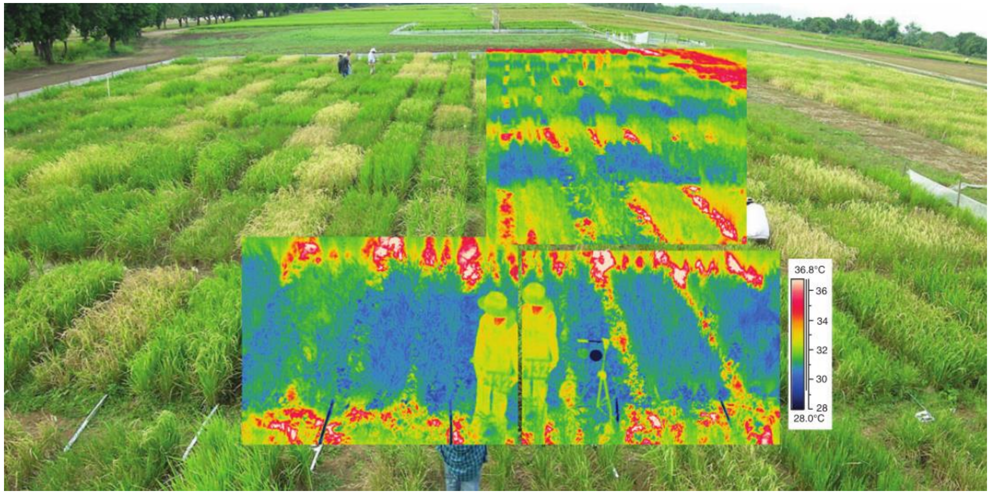
The emissivity changes with the material and with the wavelength



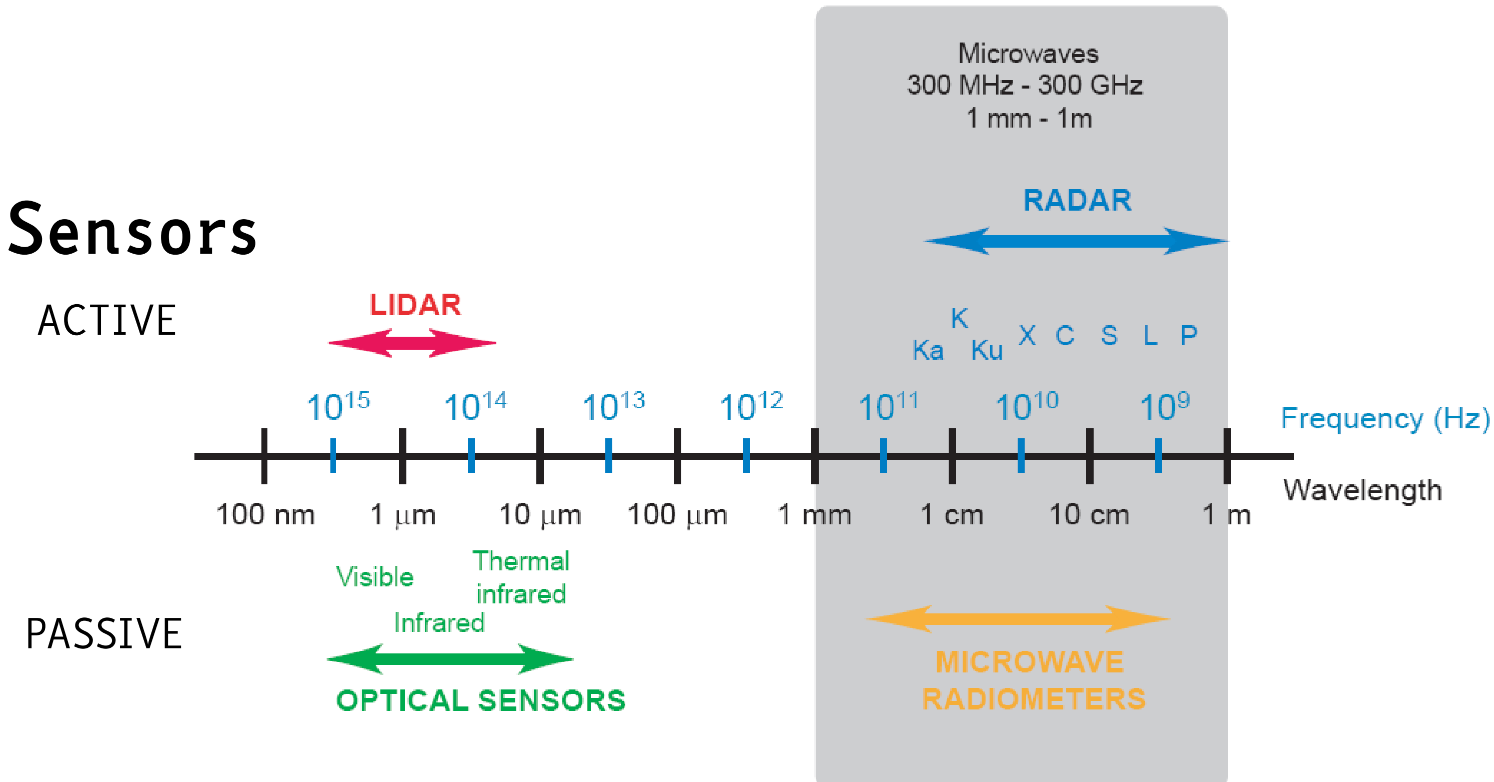


Error if you consider ε constant

Sample	ε (8-14 μm)	ΔT (ε=1)
Sand	0.8-0.9	15-6
Clay	0.94-0.98	4-1
Water, Vegetation	0.97-0.99	2-0.6
Snow	0.99	0.6



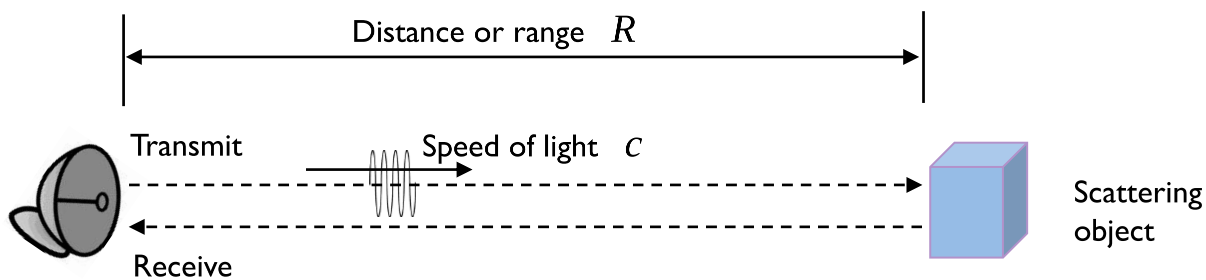
Remote sensing in the microwave domain



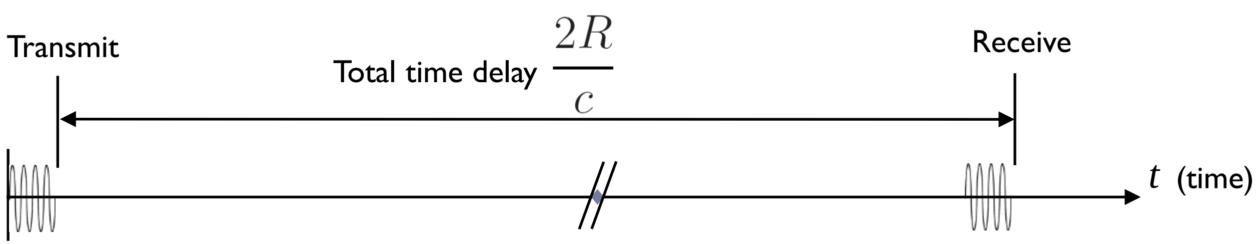
The bands in the microwave domain used in remote sensing (radar)

Band name	Frequency (GHz)	Wavelength (cm)	Characteristics and possible uses
P	0.3-1	30-100	penetrates the clouds; forest biomass estimation (e.g. satellite ESA Biomass)
L	1-2	15-30	penetrates into crops and soils
S	2-4	7.5-15	useful to detect the rain in progress
C	4-8	3.8-7.5	monitoring of soil moisture to 2-3 cm; information on crop biomass (e.g. satellite ESA **Sentinel-1**)
X	8-12.5	2.4-3.8	information on the geometric structure (roughness) of vegetation
Ku	12.5-18	1.7-2.4	sensitive to rain; interacts with the surface of crops; roughness; phenology
K	18-26.5	1.1-1.7	sensitive to forest surfaces; strong attenuation in the atmosphere
Ka	26.5-40	0.75-1.1	strongly absorbed by water. useful for monitoring water in the leaves

Radar Measurements: time and distance

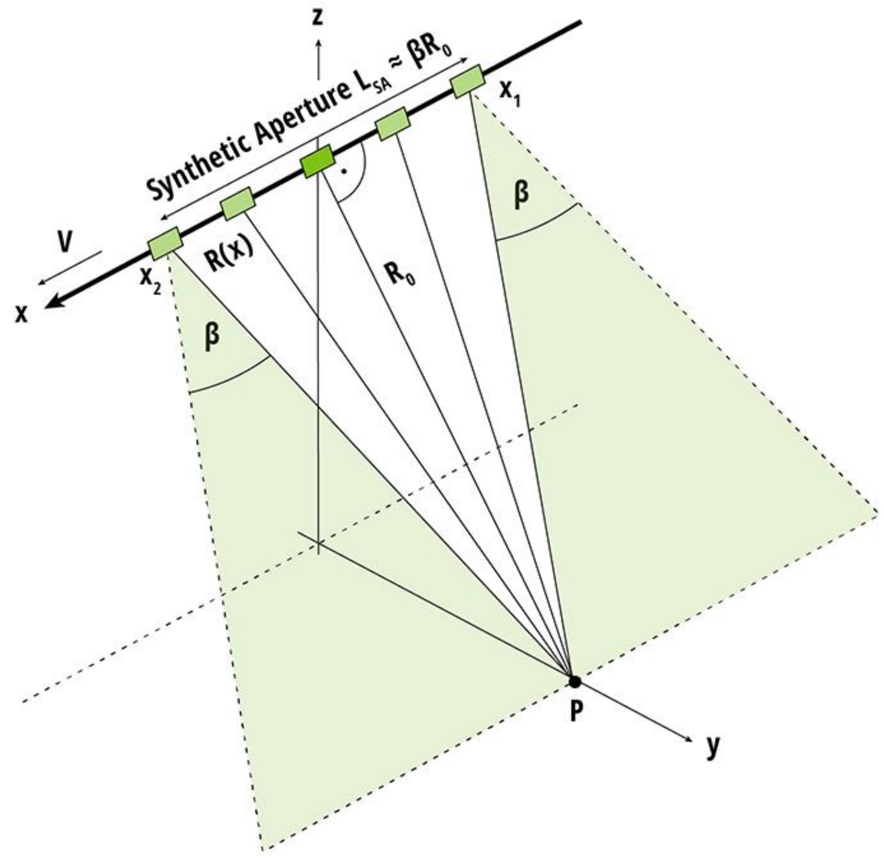


Received echo (backscatter from the object)



SAR: Synthetic Aperture Radar

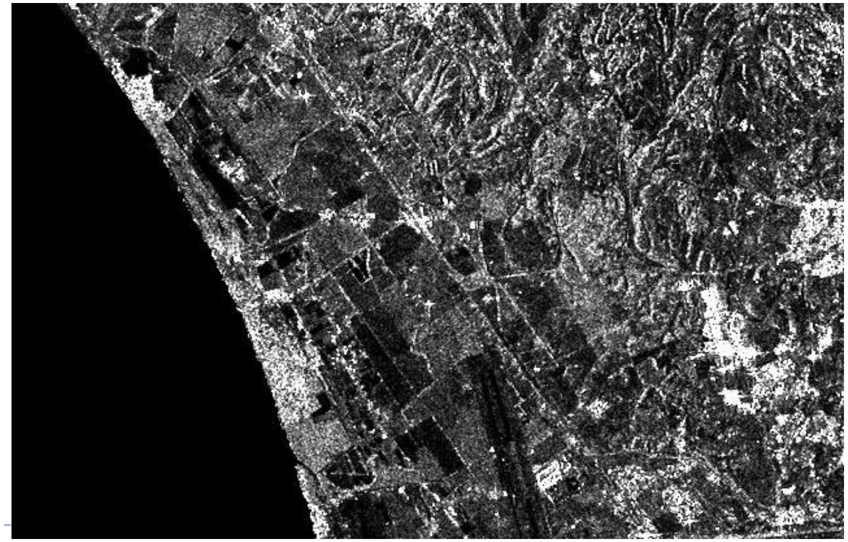
The spatial resolution of radar data is directly related to the ratio of sensor wavelength to sensor antenna length. The longer the antenna. the higher the spatial resolution. A satellite operating at a wavelength of about 5 cm (C-band radar). to achieve a spatial resolution of 10 m. should have an antenna about 4.250 m long.
An antenna of this size is not practical for a satellite.
Therefore. scientists and engineers have come up with a smart solution - synthetic opening. In this concept. a sequence of acquisitions from a shorter antenna are combined to simulate a much larger antenna. thus providing higher resolution data.



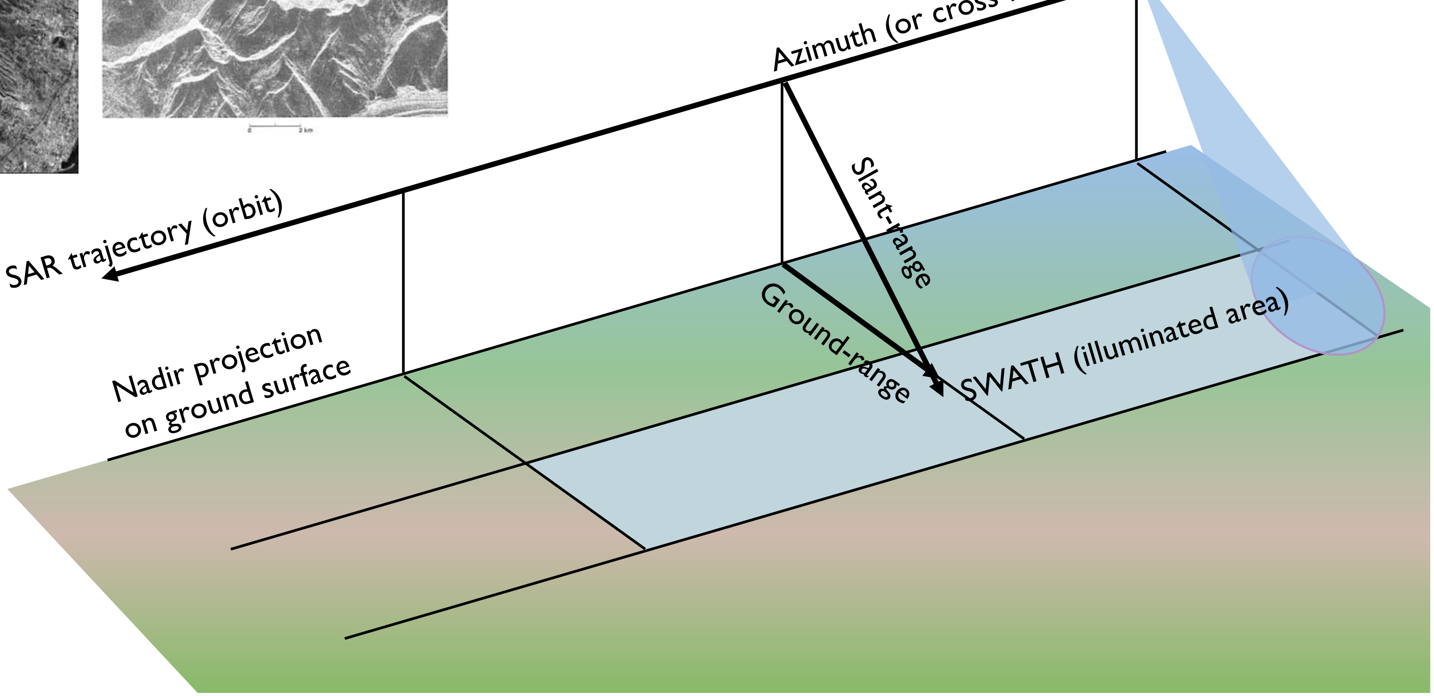
Advantages and disadvantages of SAR

- Ability to capture data both day and night
- Almost independent of weather conditions (not affected by clouds)
- Microwave penetration (depending on the band):
- Vegetation
- Soil

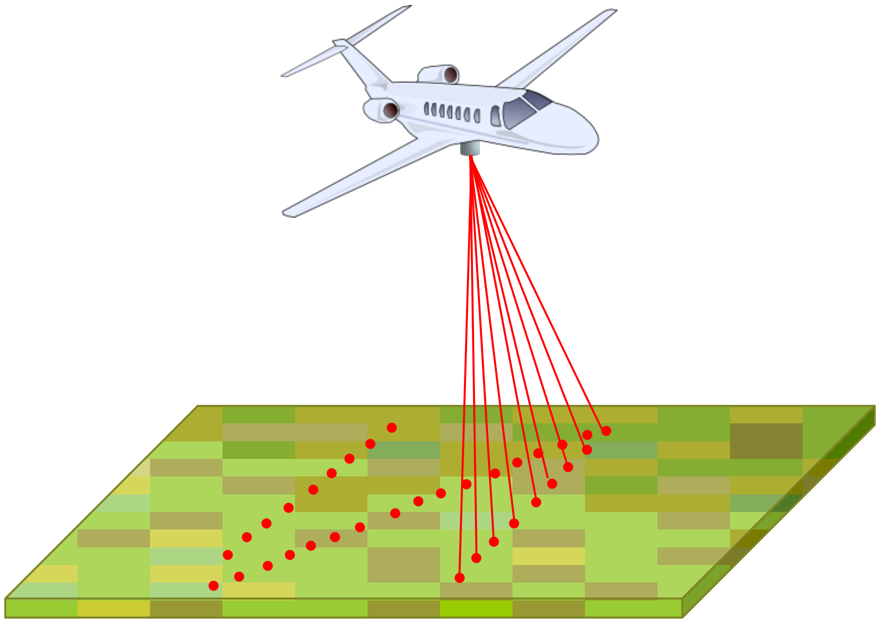
Information on physical properties (roughness. humidity) but not chemical properties of surfaces



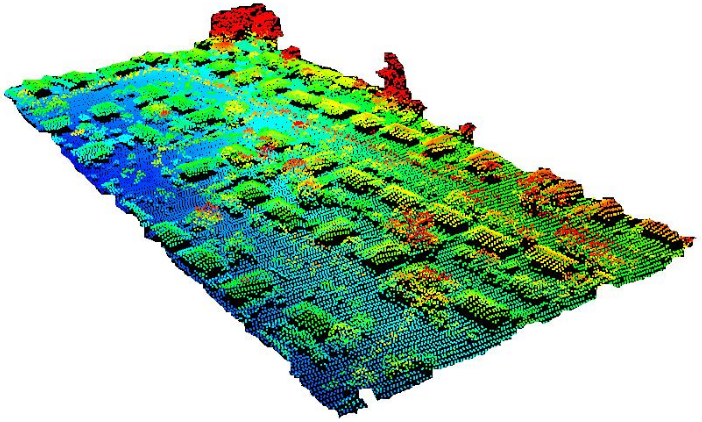
SAR: side looking geometry



LIDAR (light detection and ranging)



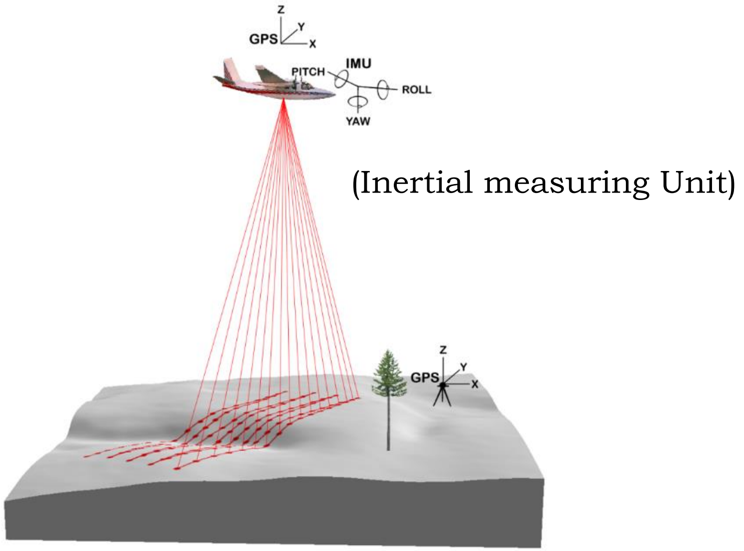
The active-type sensor sends light pulses (lasers) to the target and through a detector. detects impulse return after it has been reflected



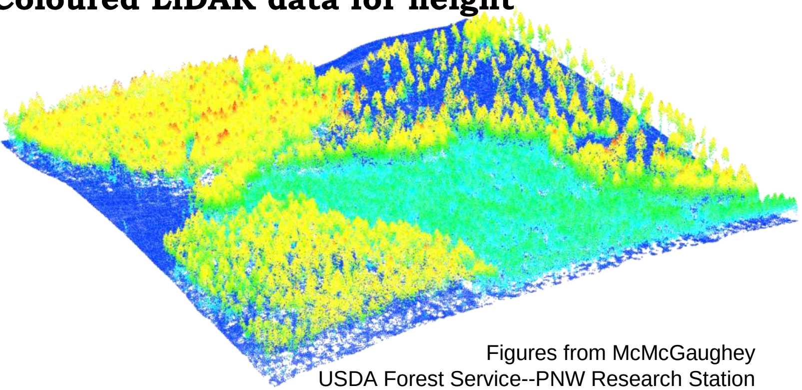
By recording the time it takes the luminous impulse to go and return from the target (with an accuracy of the order of nanoseconds). and knowing the speed of light (constant). the LiDAR is able to accurately detect the distance between the sensor and the Target. Knowing in a precise way the coordinates of the sensor in the three-dimensional space (from GPS and inertial navigation system). it is possible to derive the coordinates of the points where the luminous impulse hit the objects (e.g. the plants).

Lidar

Laser Scanner with transmitting-receiver unit



Coloured LiDAR data for height

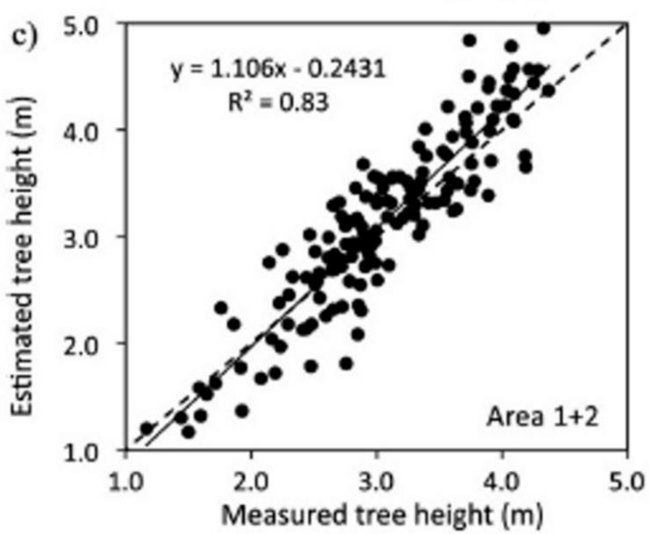


Figures from McMcGaughey
USDA Forest Service--PNW Research Station

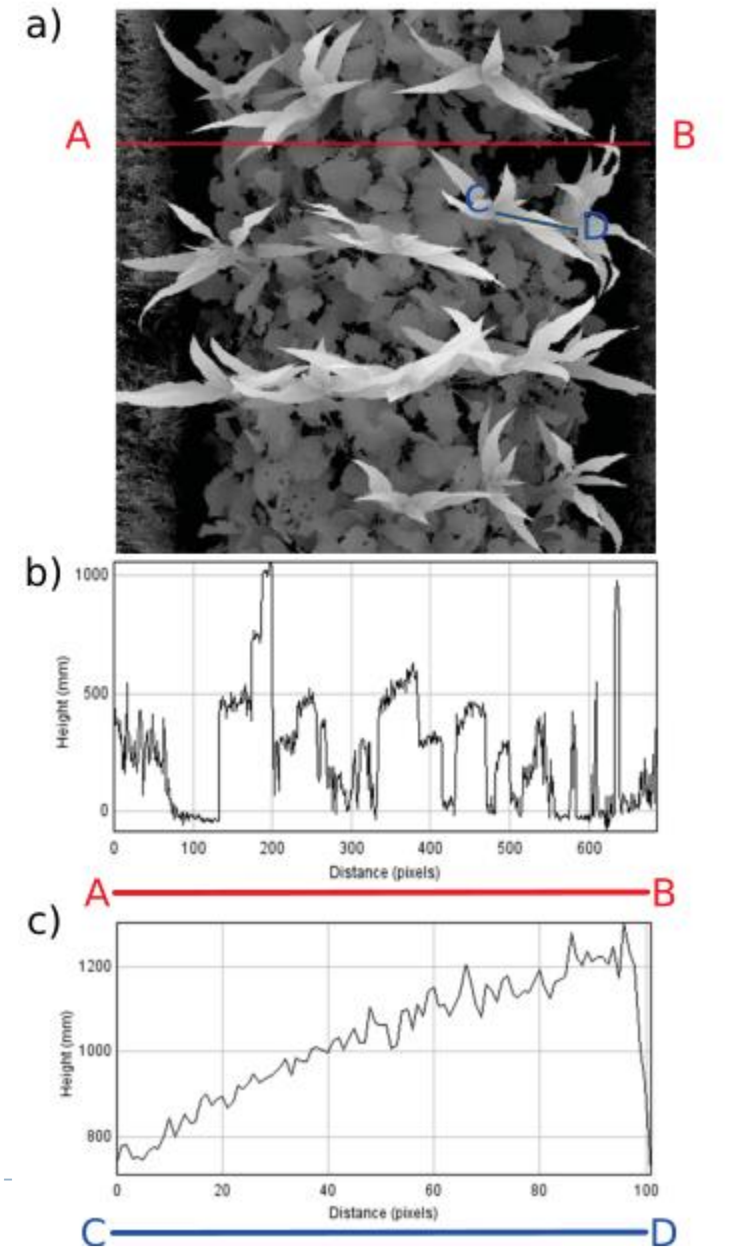
- Whenever the laser is emitted
- The laser generates an optical impulse
- The impulse is reflected by an object and returns to the receiving system
- A high-speed meter measures the time it takes for the impulse to go and return
- The measured time is converted to distance (the distance from the lens and the position of the aircraft is then used to determine the elevation and position)
- Multiple return pulses can be measured for each pulse emitted
- Up to 200.000 pulses per second
- By tracing the angle at which the laser pulse is launched. you can calculate the X. Y. and Z coordinates of each "return"
- Direct acquisition of 3d data

Estimation of plant height by LiDAR data

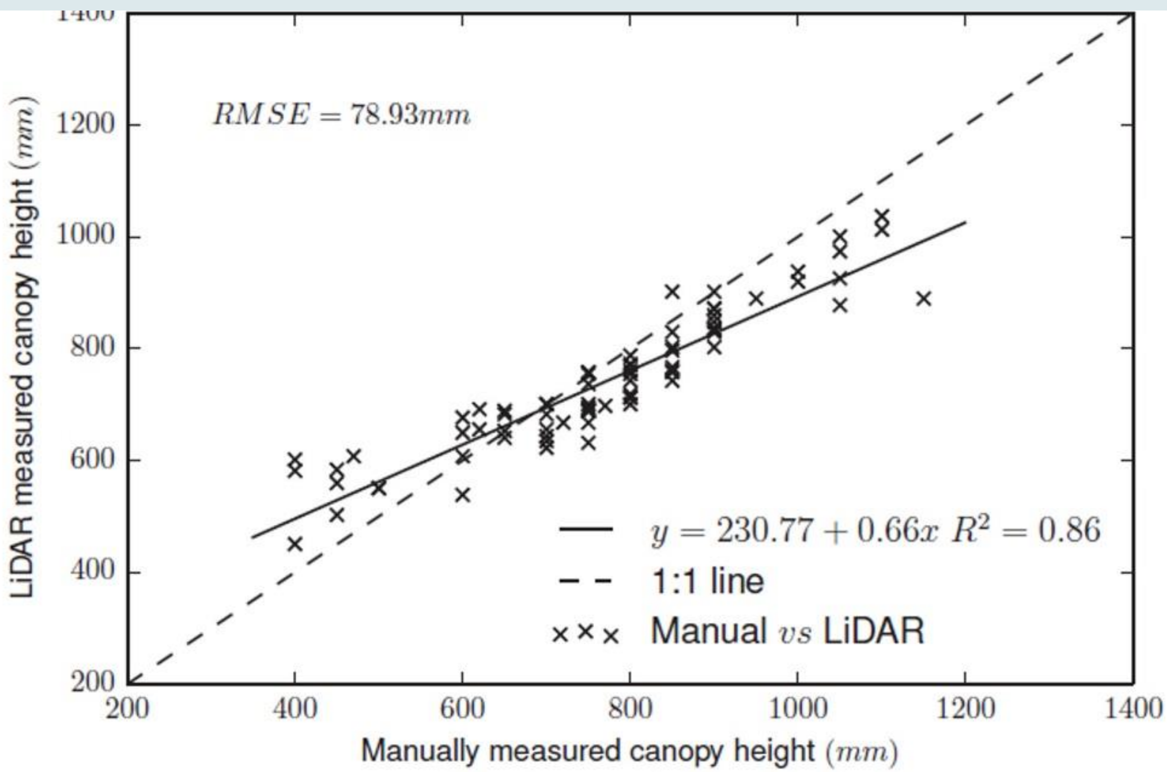
Very high resolution imagery (5 cm pixel^{-1}) to generate ortho-mosaics and digital surface models (DSMs) through automatic 3D reconstruction methods.



Results of the validation assessment comparing field-measured olive tree height and DSM-retrieved height. The dashed line represents the 1:1 line. and the solid line represents the fitted linear function.

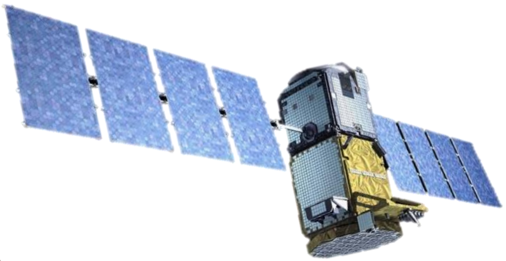


LiDAR data validation for plant height estimation



The comparisons that are made between the actual measurements of the height of the grain plants and those made by the LiDAR technology show that we can estimate with good accuracy the height of the plants quickly and at a distance by the technology transported by drones.
(**Deery et al.. 2014**).

Remote sensing platforms for precision agriculture



"Free" — esa — sentinel-2

~0.01 €/ha* — BlackBridge (a Planet Labs Company) — RAPIDEYE

~0.3 €/ha* — DigitalGlobe — WorldView-2

~60 €/ha

S110 NIR

TETRACAM INC

~70-120 €/ha

MULTISPEC 4C

~4-15 €/ha*

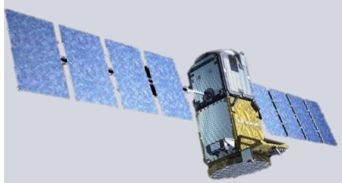
YARA — N-Sensor

Trimble — GreenSeeker

Holland Scientific — Crop Circle

TOPCON Precision Agriculture — CropSpec

Information

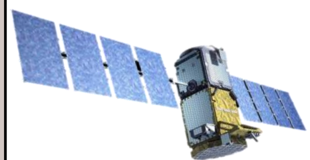
Platform	Spatial resolution	Frequency & timeliness	Spectral resolution	Data processing needs
	sentinel-2 10-20 m RAPIDEYE 5 m WorldView-2 2 m	1 – 30 days (depends on cluds) delivery: ~1-10 days	4-10 bands bandwidth 15-70 nm	+/- atmosph. corr. Vegetation inidices…. …. biophysical products
	0.05 – 0.15 m	On demand delivery ~2 -7 days	2-4 bands bandwidth 50- 200 nm	+mosaiking +geom.registration + radiometric corr. +atmosph. corr. +Vegetation inidices….
	0.5 – 5 m	On demand Delivery immediate	2-4 bands bandwidth 3- 20 nm	none if on-the-gosystem +filtering if map based

Data requirements for precision agriculture

Management technique	Frequency and timeliness required	Spatial resolution required	Spectral resolution required
Fertilization	High. especially for N management	Medium (10-20 m depending on the fertilizer spreader)	Medium-high
Disease and pest management	High	High(cm)	High
Weeding	High	High(cm)	High
Irrigation	High	Medium (depending on irrigation methods)	Medium (Thermal IR)
Sowing	low	Medium (depends on sowing machine)	Medium-high
Tillage	low	Medium (depends on implements)	Medium-high

Compatibility between platforms and agronomic management requirements

Not feasible
experimental
operational

Management technique	Satellite 	UAV 	Proximal sensor 
Fertilization	Nitrogen fertilization		Nitrogen fertilization
Disease and pests management			
Weed management		Pre-sowing Post-emergence	✓pre-sowing
Irrigation		???	
Sowing		???	
Tillage		???	

Useful satellites for precision agriculture

Space Agencies (public bodies = free data):

[vedi https://earth.esa.int/eogateway/]

European Space Agency (ESA):

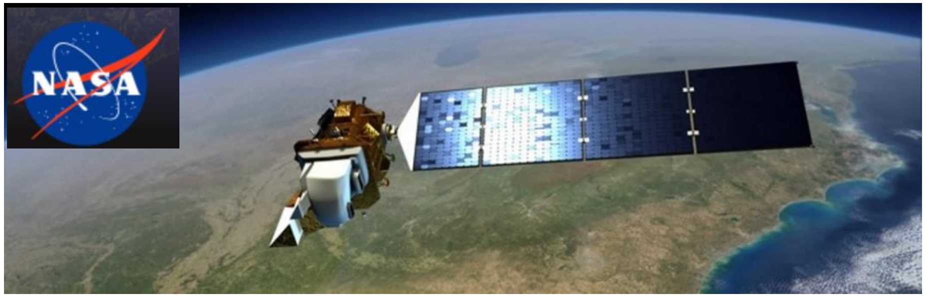
Copernicus programme (co-funded by the European Commission)

Sentinel-1: C-band radar (5-20 m). Time revisits 6 days (2 satellites)

Sentinel-2: multispectral 12 bands (10-20-60 m). Time revisits 5 days (2 satellites)

NASA :

Landsat-8: multispectral 8 bands (30 m) and thermal infrared (100 m). Revisit time 16 days



Useful satellites for precision agriculture

Private companies (very high spatial/temporal resolution. for a fee):

Airbus + Spot Images (CNES) (France)

SPOT-6 and 7: multispectral 4 bands (6 m). Ability to revisit 1-3 days

Pleiades-1 e 2: multispettrale 4 bande (2 m). Capacità di rivisita 1 day

Planet (USA/Germania)

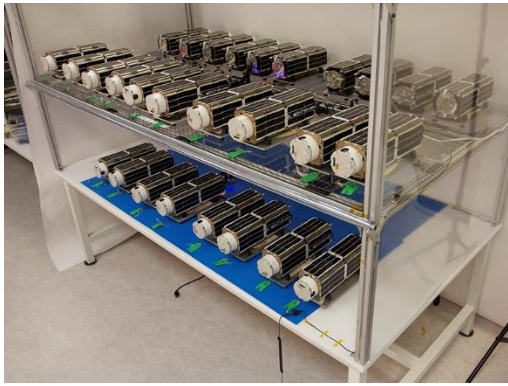
PlanetScope (>130 DOVE Cubesat): multispectral 5 bands (3.9 m). Daily revisit capacity

SkySat (21 satellites): multispectral 4 bands (0.75 m). Daily revisit capacity (+ times)

Maxar (USA) (<- DigitalGlobe)

WorldView 2: multispectral 8 bands (1.8 m). Almost daily revisiting capacity

WorldView 3: multispectral 8 VNIR bands (1.2 m)+ 8 SWIR (3.7 m) + CAVIS (30 m). Daily revisit capacity



DOVE Cubesat

DEIMOS (Spagna)

Deimos-2: multispectral 4 bands (4 m. 0.75 m pan-sharpened). Ability to revisit 2 days

Correction levels of satellite **products** supplied

The level of correction of the **product** provided (image plus additional information on the acquisition etc.: metadata). can be of different types

- Products called level zero (**L0**) correspond to raw data
- Level 1 Products(**L1**) to which a correction has been applied:
  - Radiometric (**L1A**). the radiance recorded to the sensor is provided
  - Geometric (**L1B**). with ortho-rectification of the image
  - Co-recording of the ortho-rectified image on global reference systems (L1C) with sub-pixel accuracy (1-2 m);
- Products of level 2 (es. **L2A**) an atmospheric correction is applied to the products L1
- Next-level products (**L3** and **L4**) include further processing. to provide products suitable for specific needs (e.g. vegetation indices or biophysical variables: LAI. Chl...)

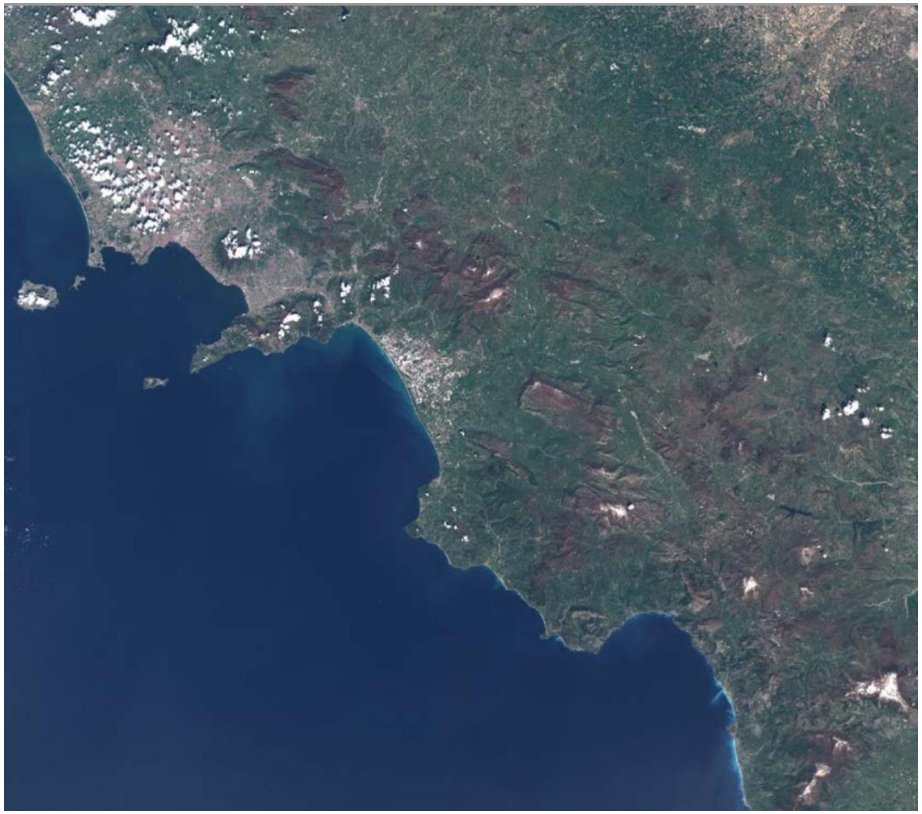
For Sentinel-2 ESA currently provides L1C and L2A level products for download online (free):

Livello-1C: includes a radiometrically calibrated and geometrically corrected image with sub-pixel accuracy (approximately 8-10 m)

Livello-2A: the main output is an ortho-rectified reflectance image (after atmospheric correction). multiple classifications. clouds etc....

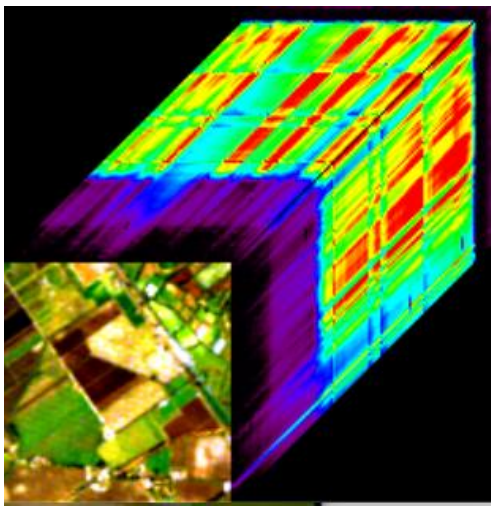
Sentinel-2 Products

Level-1C



Level-2A

On the 22 March 2019 the Italian Space Agency (ASI) launched the hyperspectral PRISMA scientific mission. having onboard an imager covering the 400-2500 nm range with 234 spectral bands and about 10 nm of bandwidth.



Spatial resolution	
Hyperspectral:	30 m
PAN:	5 m
VNIR:	400 - 1010 nm (66 spectral bands)
SWIR:	920 - 2505 nm (174 spectral bands)

Spectral Accuracy: ±0.1 nm
Absolute Radiometric Accuracy: 5%
with 12 bits quantized data

SNR

VNIR (400-1010 nm): >160:1 (>450:1 at 650nm)
SWIR (920-2505 nm): > 100:1 (>360:1 at 1550nm)
PAN (400-700 nm): > 240:1

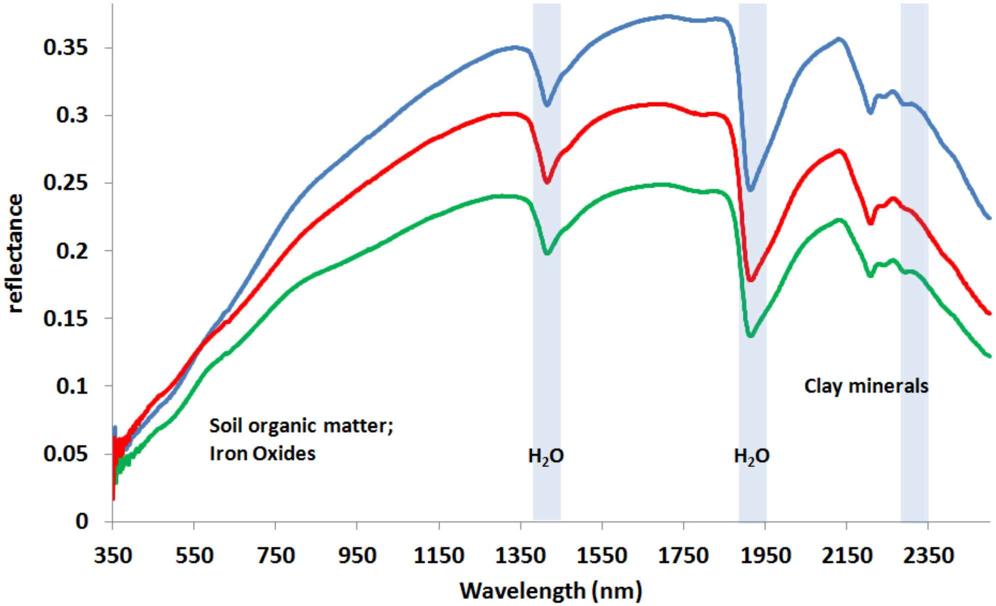
ASI L2d product:
Geolocated & geocoded at surface reflectance
(Hyperspectral / PAN).
It includes:
- Aerosol Characterization Product (VNIR);
- Water Vapour Map - Cloud Characterization

Estimation of soil properties from hyperspectral remote sensing

Bare soils are typically observed in arable croplands

Can we retrieve quantitative information from optical remote sensing data of bare soils ?

Soil chromophores

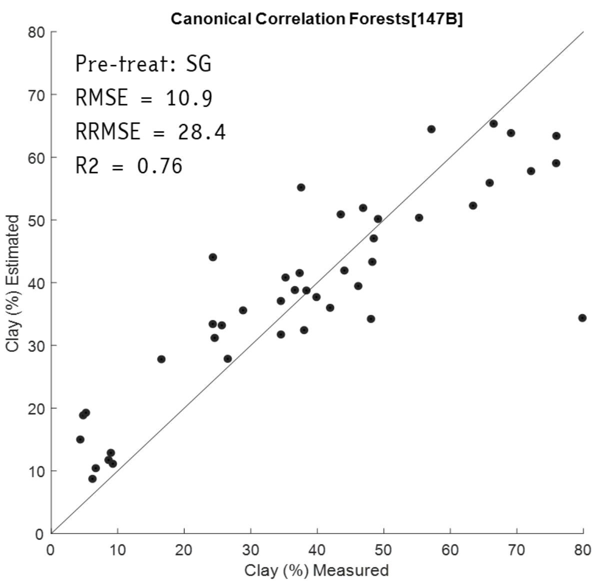


….soil reflectance conveys information from the topsoil surface only

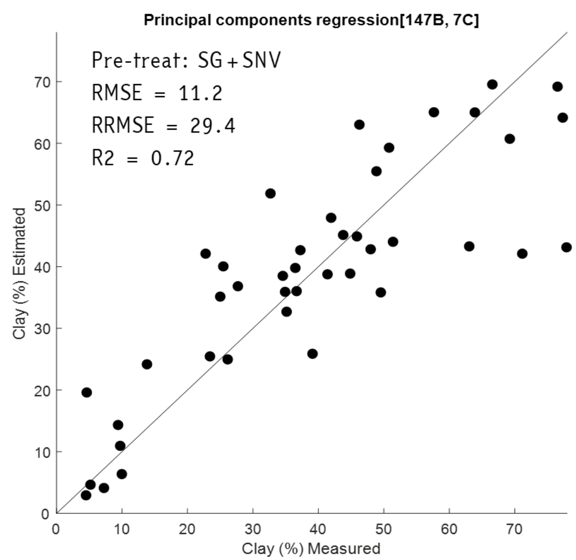
Results: CLAY

ESU 4-fold cross validation results: **CLAY**

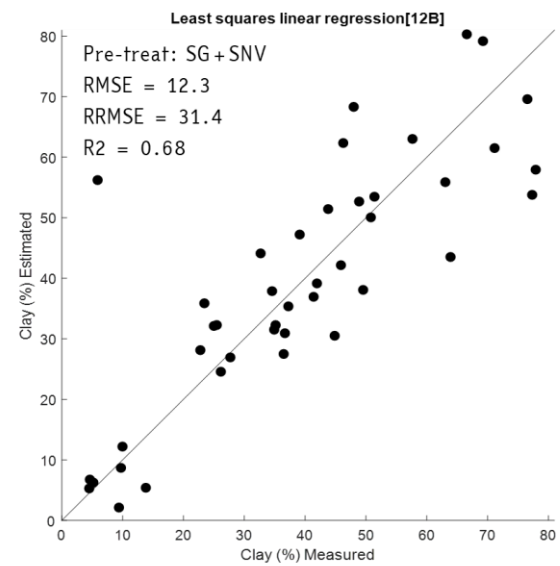
PRISMA Hyperspectral 30 m



PRISMA pan-sharpened 5 m

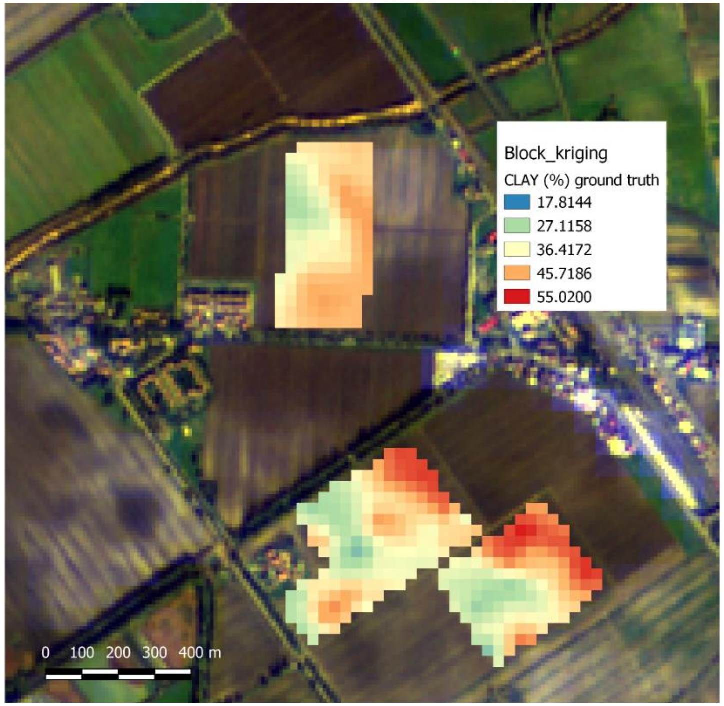


Sentinel-2 10 m

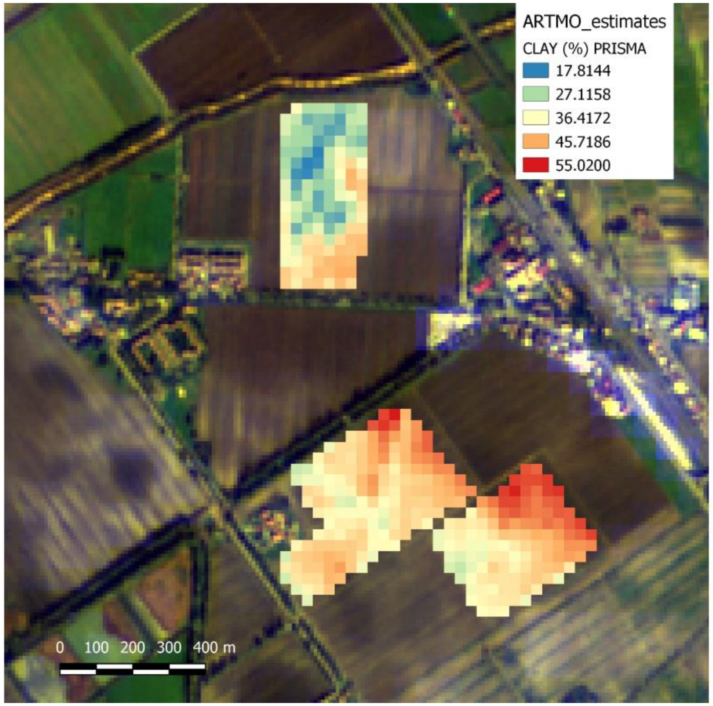


CLAY estimated vs measured intensive sampling

Measured CLAY BK 30m

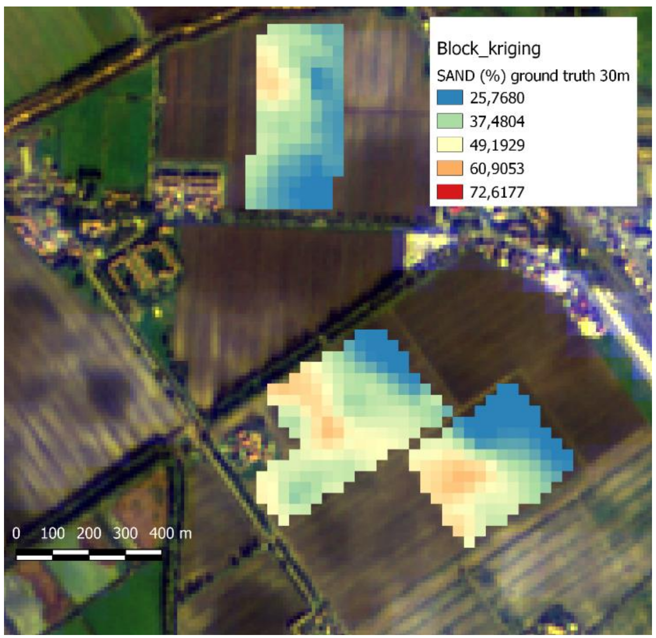


PRISMA Hyperspectral 30 m

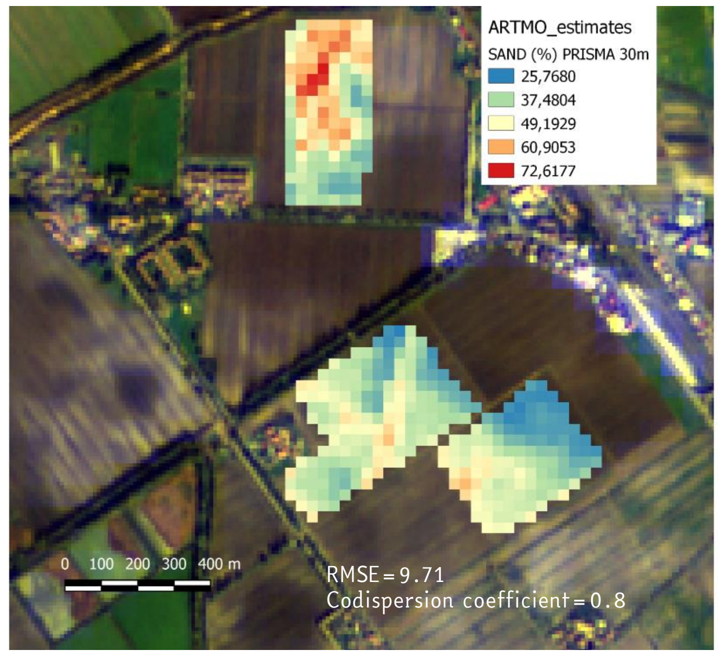


SAND estimated vs measured intensive sampling

Measured SAND BK 30m



PRISMA Hyperspectral 30 m SAND



Conclusions

- Remote sensing from different platforms (satellite. drone. tractor) is an essential enabling technology for precision agriculture
- It can be used to monitor and map crop and soil properties
- E.g. Hyperspectral PRISMA satellite shows a spectral (VNIR and SWIR domain) quality that allows the retrieval of the textural and compositional topsoil characteristics;
- Lots of data are available for free
- Processing is becoming easier: no longer powerful computers required (-> cloud computing platforms)