Indices and their applications

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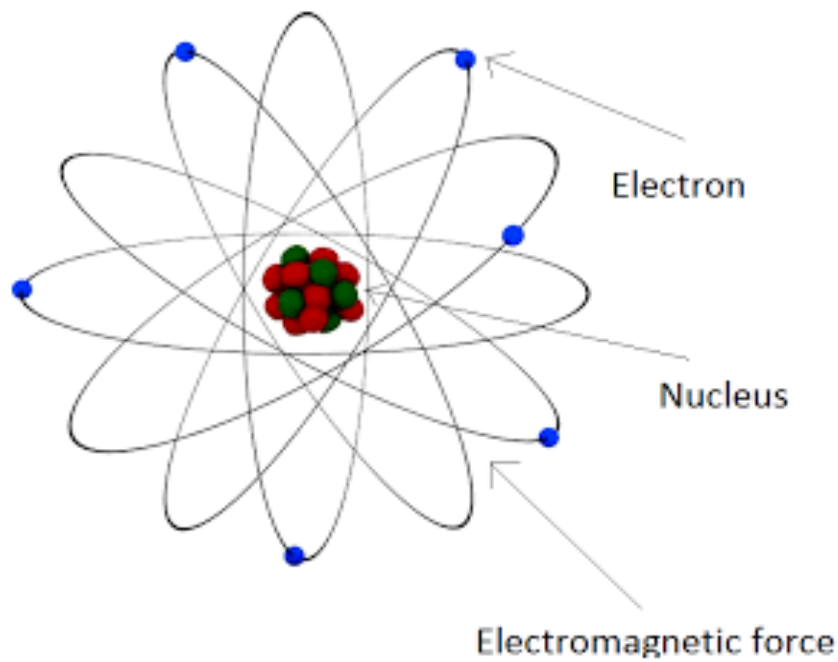
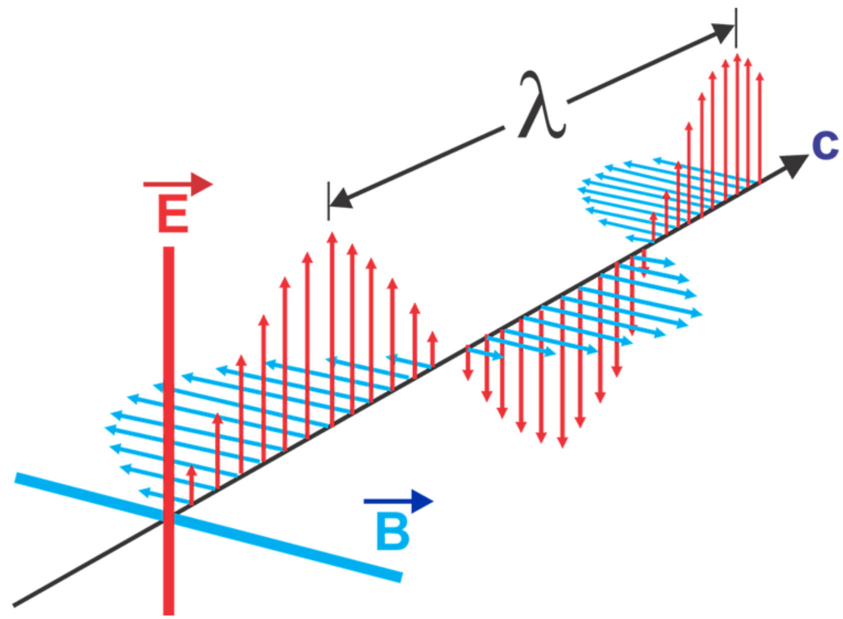
Electromagnetic waves

- Electromagnetic Energy
- Electromagnetic Field
- Electromagnetic Waves



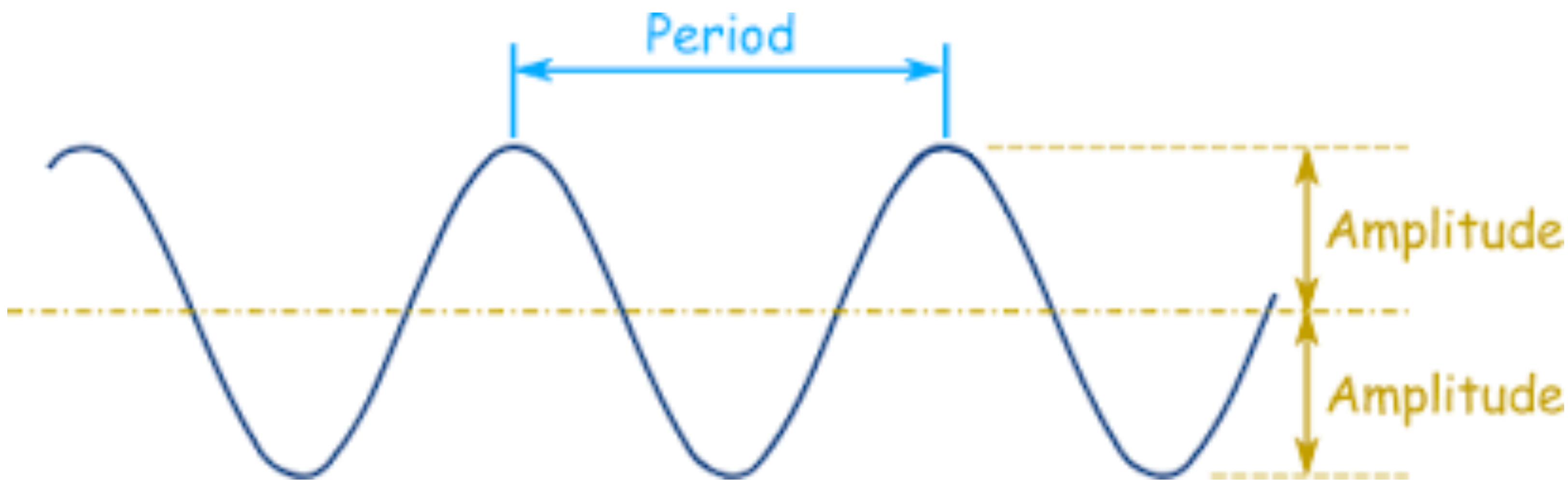
Electromagnetic waves

- Waves: disturbances that propagate periodically transmitting energy
- Electromagnetic waves:
  - *vertical vibration and horizontal propagation*
  - *$3x10^8$ m/s – vacuum speed*



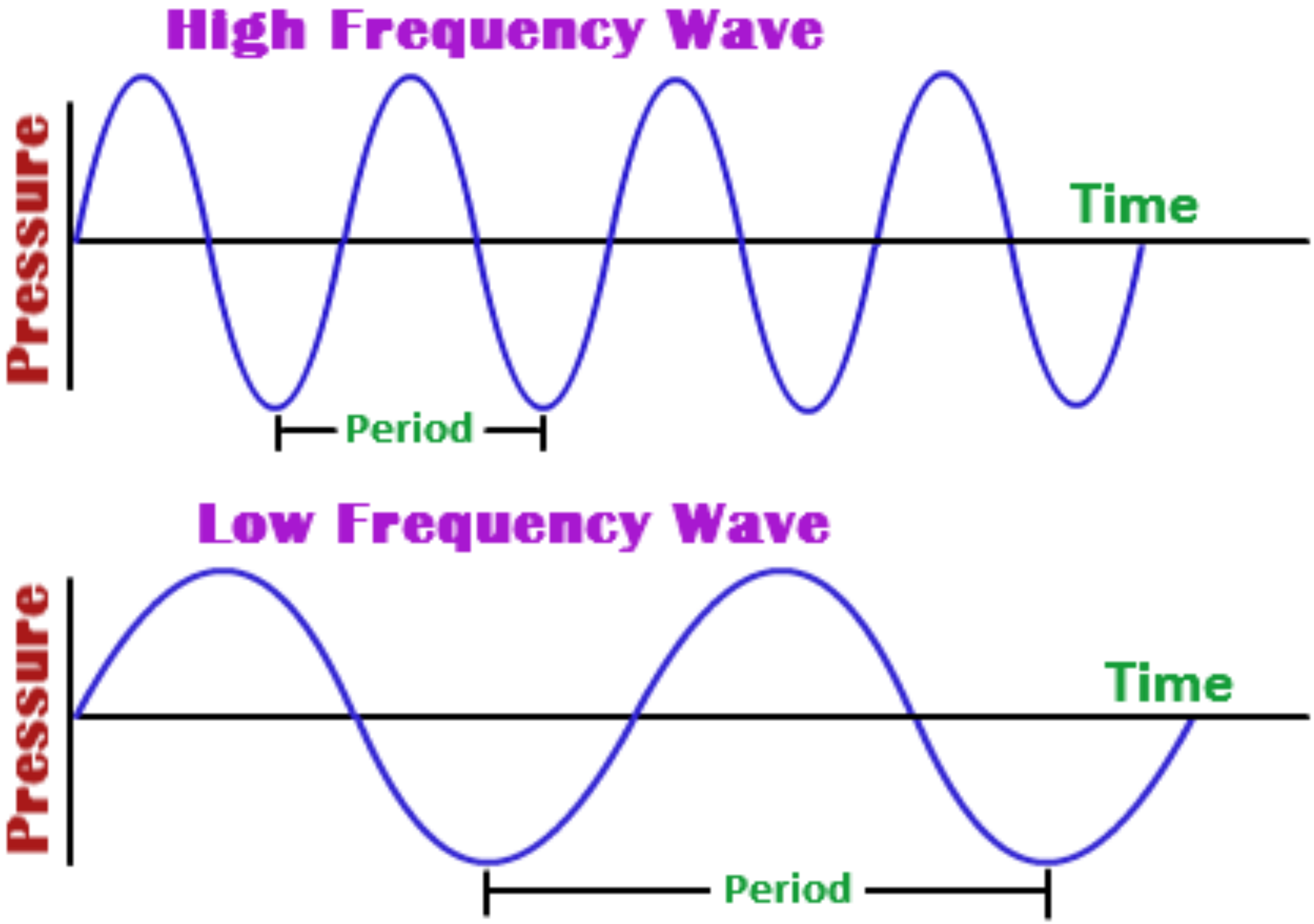
Electromagnetic waves

- Electromagnetic waves: frequency

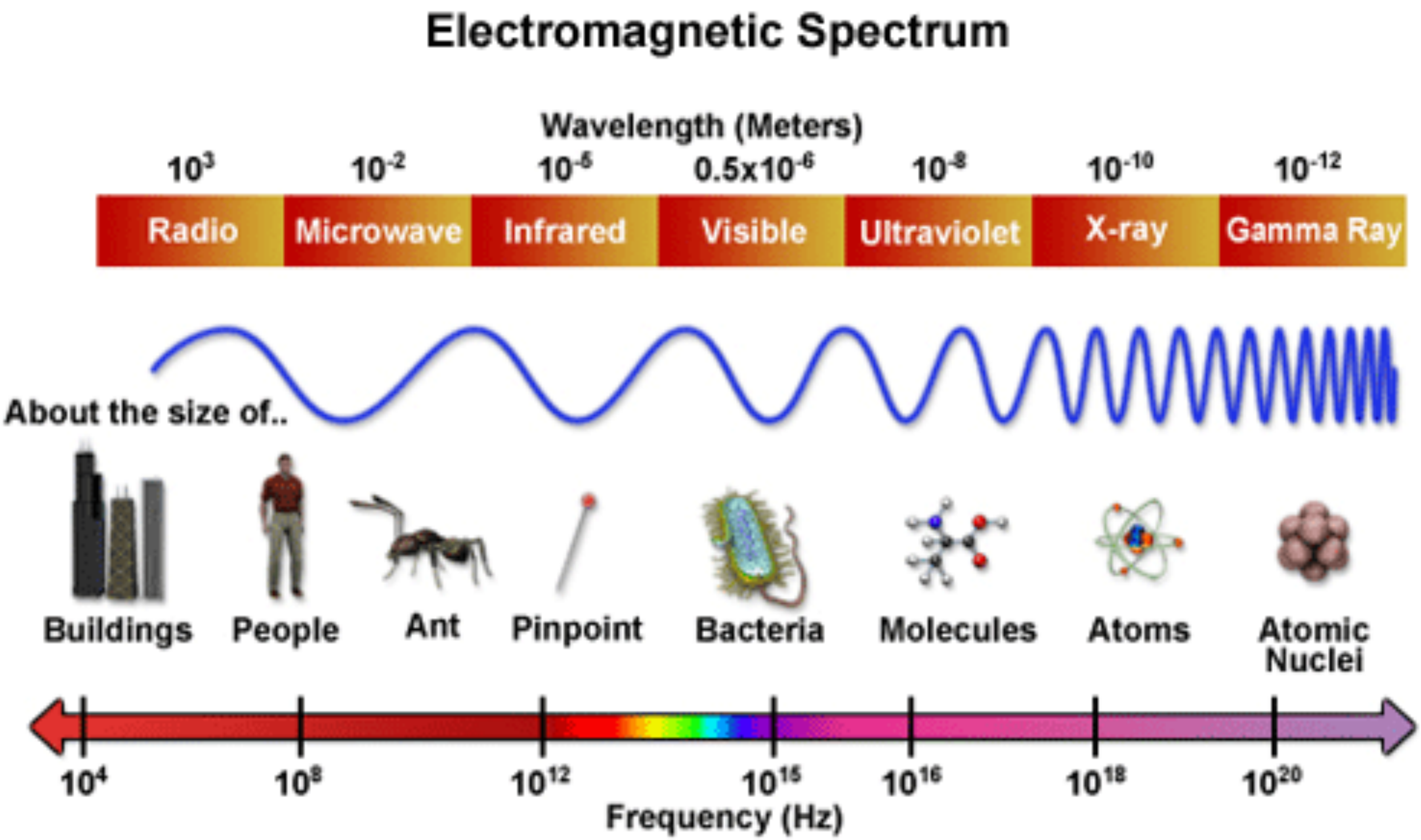


$$Frequency = \frac{n * cicles}{\Delta t} \Rightarrow Hz$$

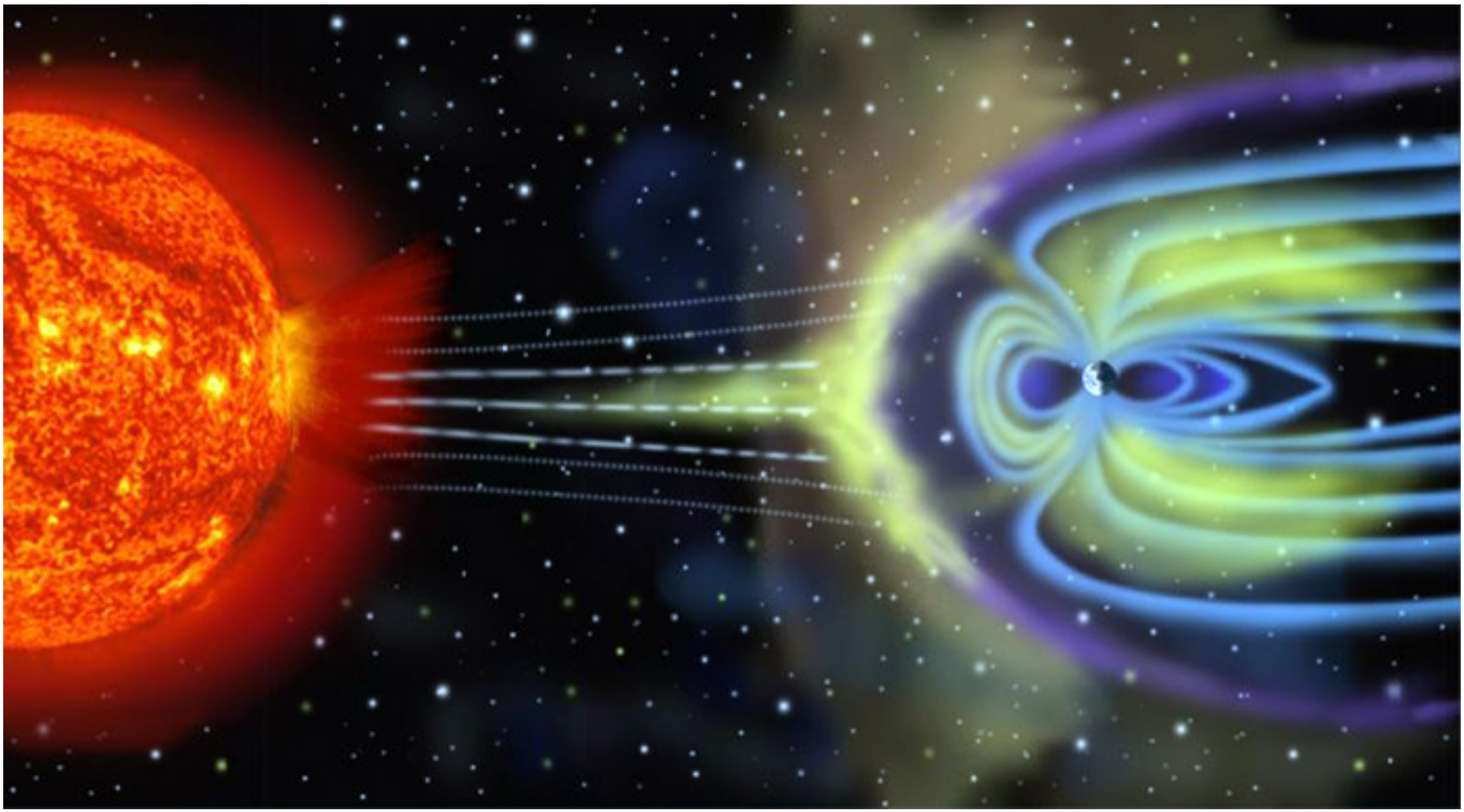
Electromagnetic waves



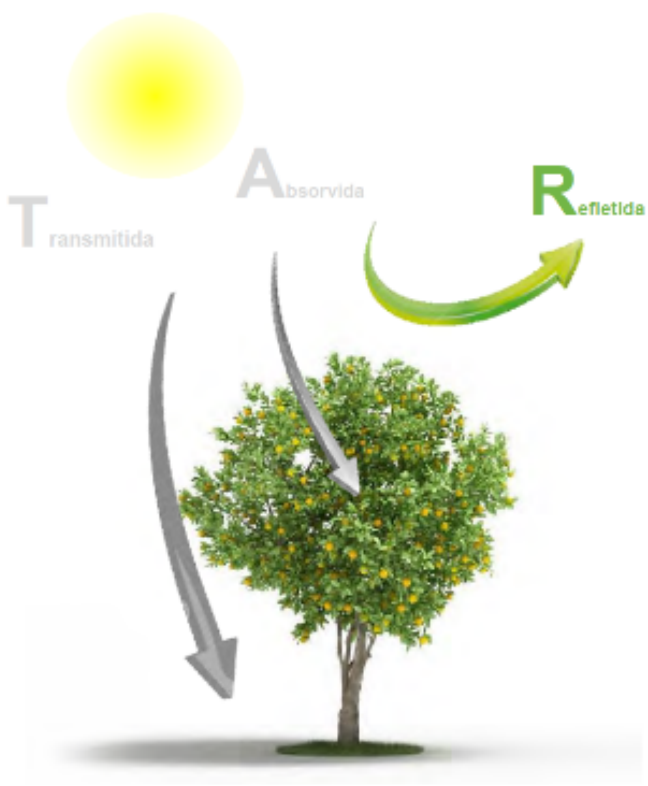
Electromagnetic waves



Electromagnetic waves



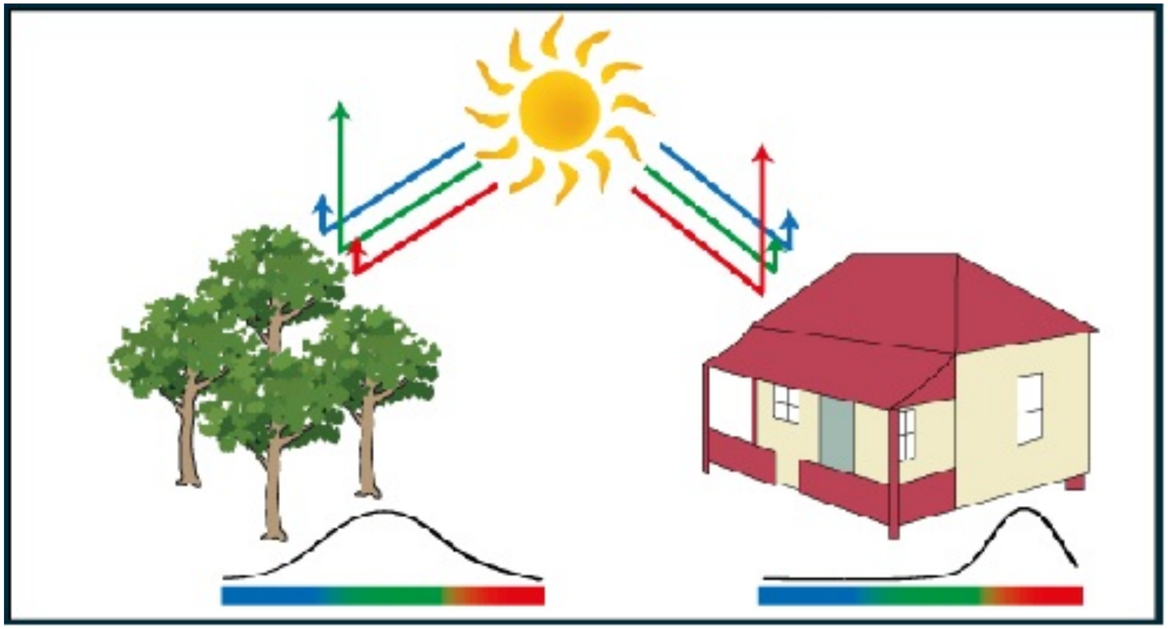
Electromagnetic waves



- Absorbed light: fotosynthesis reaction
- Transmitted light: vegetation cover
- Reflected light: Vegetation Indices

What is a Spectral Signature?

- Different objects interact differently with electromagnetic energy (reflecting, absorbing or transmitting), this generates a spectral signature of each object;
- A target's spectral signature defines how the target interacts with different wavelenghts of the electromagnetic spectrum

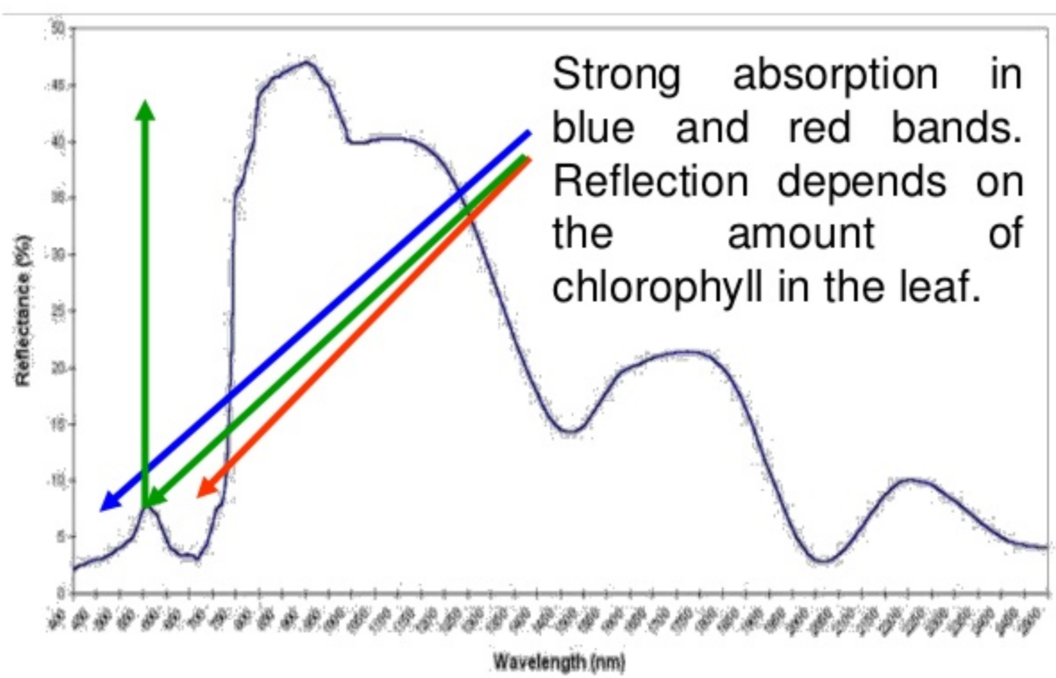


Spectral Signature

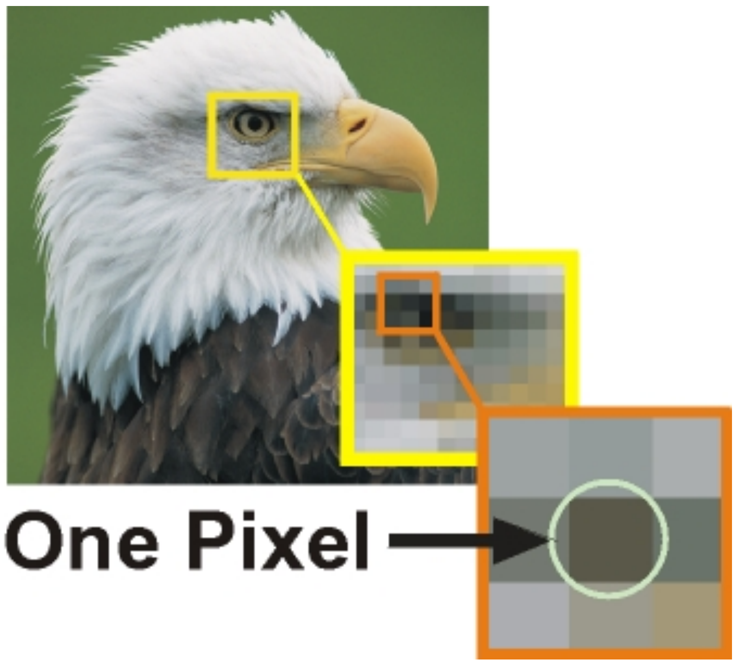
- Chlorophyll spectral signature;

$$CO_2 + H_2O \rightarrow [light] \rightarrow C_6H_{12}O_6 + O_2$$

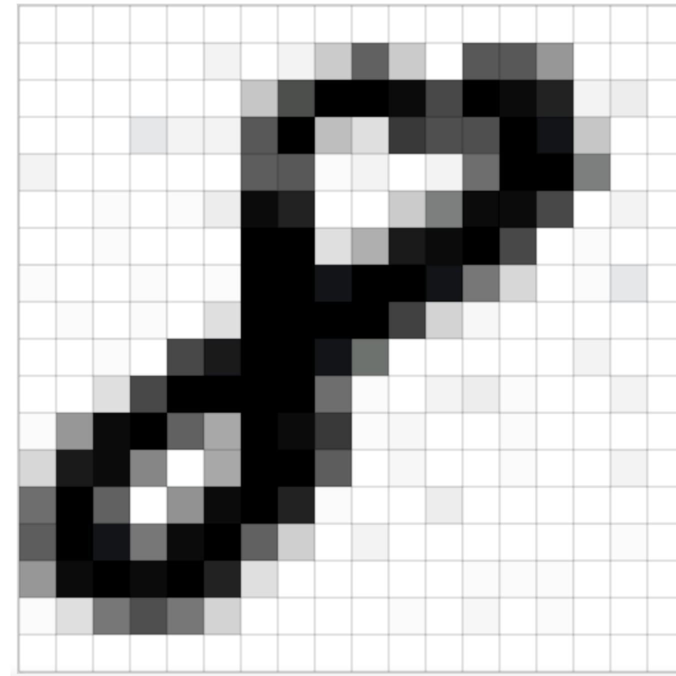
SPECTRAL REFLECTANCE OF VEGETATION



Pixels

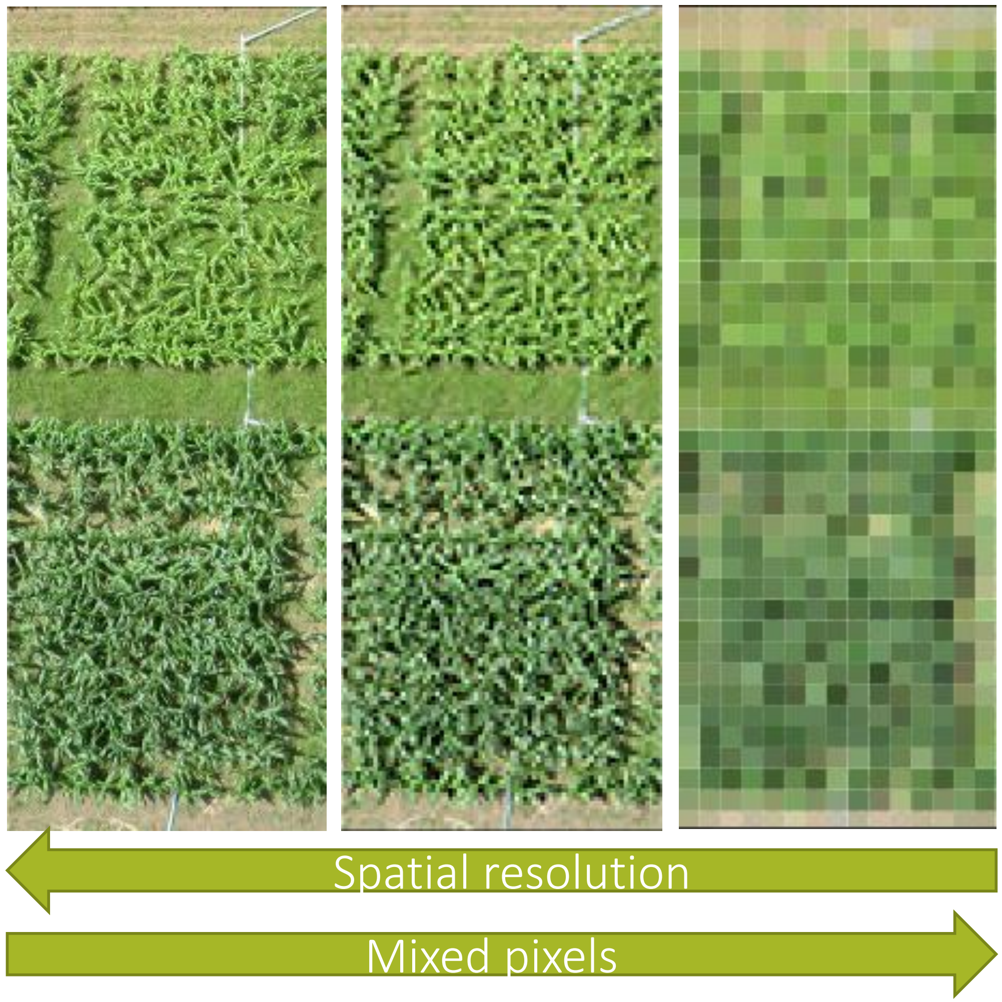


RGB from 0 to 255 range = 16 million;



0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	12	0	11	39	137	37	0	152	147	84	0	0	0
0	0	1	0	0	0	41	160	250	255	235	162	255	238	206	11	13	0
0	0	0	16	9	9	150	251	45	21	184	159	154	255	233	40	0	0
10	0	0	0	0	0	145	146	3	10	0	11	124	253	255	107	0	0
0	0	3	0	4	15	236	216	0	0	38	109	247	240	169	0	11	0
1	0	2	0	0	0	253	253	23	62	224	241	255	164	0	5	0	0
6	0	0	4	0	3	252	250	228	255	255	234	112	28	0	2	17	0
0	2	1	4	0	21	255	253	251	255	172	31	8	0	1	0	0	0
0	0	4	0	163	225	251	255	229	120	0	0	0	0	0	11	0	0
0	0	21	162	255	255	254	255	126	6	0	10	14	6	0	0	9	0
3	79	242	255	141	66	255	245	189	7	8	0	0	5	0	0	0	0
26	221	237	98	0	67	251	255	144	0	8	0	0	7	0	0	11	0
125	255	141	0	87	244	255	208	3	0	0	13	0	1	0	1	0	0
145	248	228	116	235	255	141	34	0	11	0	1	0	0	0	1	3	0
85	237	253	246	255	210	21	1	0	1	0	0	6	2	4	0	0	0
6	23	112	157	114	32	0	0	0	0	2	0	8	0	7	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Pixels



Spatial resolution :: Image quality
Image quality :: amount of information

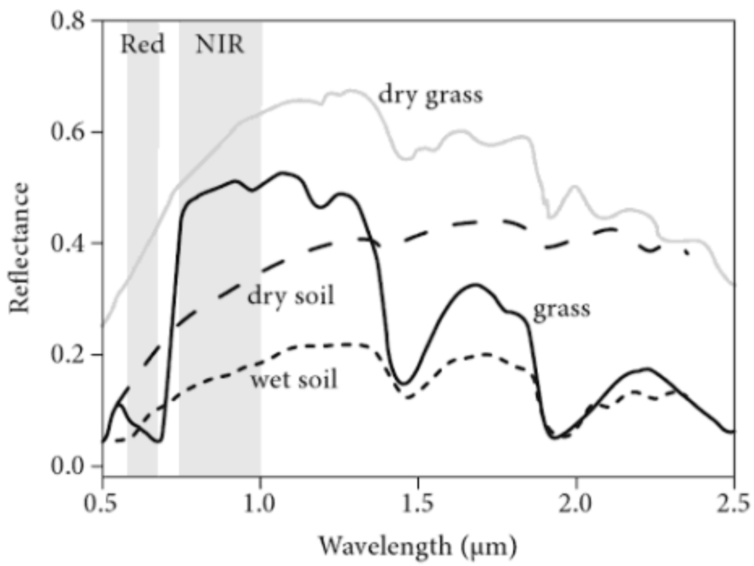
Spectral indices

They are new variables generated by the mathematical combination of two or more of the original spectral bands;

Can be used to correct for interfering structural features;

How to construct an index?

1. Factor of interest
2. Interfering factors



Example of indices

Examples of proximal sensing methods that show promise for field-based phenomics. IR = Infrared; NIR = near infrared.

Trait class	Target trait	Index or method	Applications or relevant traits	Point (P) or image-based (I)	Wavelengths	References
Pigment constituents	Chlorophyll	Normalized difference vegetation index (NDVI)		P	Red, NIR	Tucker (1979)
		Canopy chlorophyll content index (CCCI)			720 and 790 nm	Barnes et al. (2000)
	Carotenoids	Green atmospherically resistant vegetation index (GARI)	Chlorophyll concentration, rate of photosynthesis	P/I	550 and 860 nm	Gitelson et al. (2006)
Non-pigment constituents	Cellulose	Cellulose absorption index (CAI)	Bioenergy potential.	P	2100 nm	Daughtry (2001); Kokaly et al. (2009)
	Nitrogen	NDVI & CCCI	Plant nitrogen status, especially under stress	P	670, 720, 790 nm 670 and 770 nm; 590 and 880 nm	Tilling et al. (2007) Bronson et al. (2011)
	Lignin	Cellulose absorption bands	Stress responses. Bioenergy potential.	P		Kokaly et al. (2009)
Photosynthesis	Photosystem II activity	Photochemical reflectance index (PRI)	Diurnal radiation use efficiency	P	531 and 570 nm	Gamon et al. (1997)
	Photosystem II activity	Chlorophyll fluorescence	Stress effects on photosynthesis	P/I		Baker and Rosenqvist (2004)
Water relations	Transpiration or canopy conductance	Canopy temperature (CT) Crop water stress index (CWSI)	Instantaneous transpiration and hence crop water status.	P/I	Thermal IR	Jackson et al. (1981); Blum et al. (1982); Wanjura et al. (1984); Chaudhuri et al. (1986)
		Normalized water index (NWI)	Crop water status	P	850, 900 and 970 nm	Babar et al. (2006c); Gutierrez et al. (2010)
	Canopy water content	Normalized difference water index (NDWI)	Crop water status	P	860 and 1240 nm	Gao (1996)
	Water content	Leaf water thickness (LWT)		P	1300 nm and 1450 nm 1500–1700 nm	Seelig et al. (2008) Li et al. (2001)
Plant growth	Leaf area index	NDVI	Overall growth	P	Red, NIR	Babar et al. (2006a)
	Plant biomass	NDVI	Overall growth	P	590 and 880 nm; 670 and 770 nm	Bronson et al. (2011)
		NWI	Overall growth	P	850, 880, 920 and 970 nm	Prasad et al. (2009)
Plant architecture	Canopy height	Close-range photogrammetry	Light interception, overall growth, lodging resistance	I	Visible or NIR	Biskup et al. (2007); Frasson and Krajewski (2010)
		Ultrasonic	Canopy height and width	P	(Ultrasonic)	Ruixiu et al. (1989)
		Depth camera	Canopy height and width; leaf orientation and size	I	Infrared	Chéné et al. (2012)
Phenology	Maturity	Time series of index	Tracking leaf senescence	I	Green, red	Idso et al. (1980)
		Time series of fluorescence	Anthocyanin levels	P		Ghozlen et al. (2010)
	Flower number	Image analysis	Plant development	I	Visible	Adamsen et al. (2000); Thorp and Dierig (2011)
	Multiple stages	Analysis of time series of indices	Seedling emergence, onset of grain-filling, senescence	P + I	400–900 nm	Viña et al. (2004)

Vegetation indices

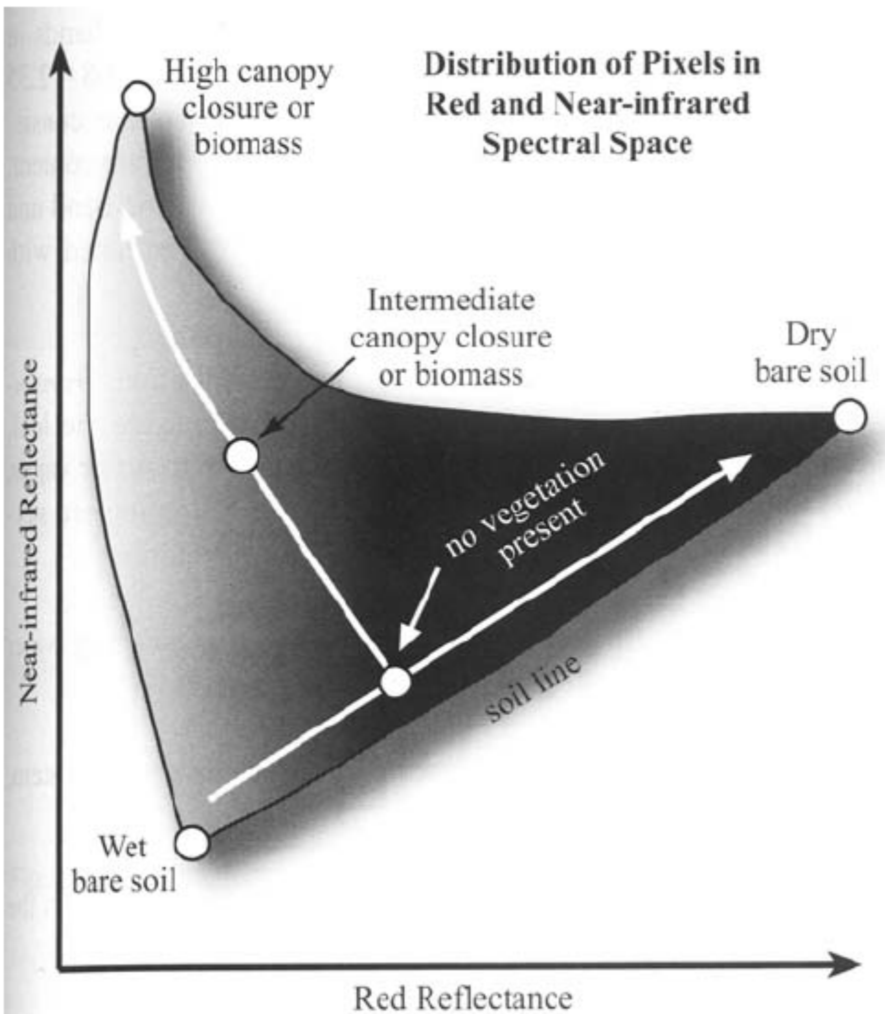
Vegetation Indices

- Dimensionless measures derived from radiometric data used to indicate amount of green vegetation in a field view;

- Are based on a variation reflectance in a 700nm wavelenghts, that is a characteristic of green vegetation;

- Other natural surfaces do not show as much reflection variation in this wavelength;

Vegetation Indices



Soil relation with NIR and R wavebands

$$\rho_{NIR} = a * \rho_R + b$$

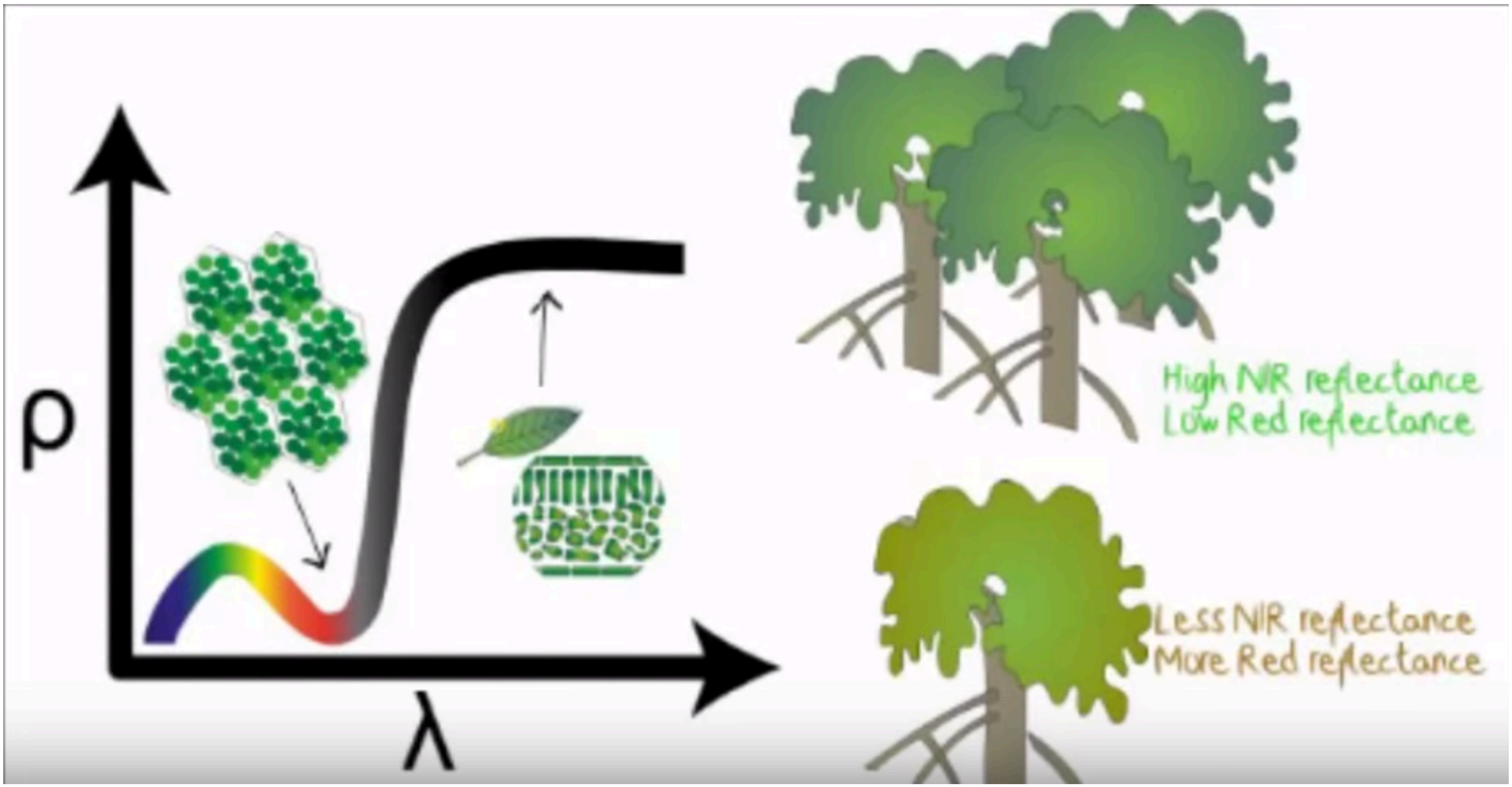
Broadband Indices

NDVI normalized difference vegetation index

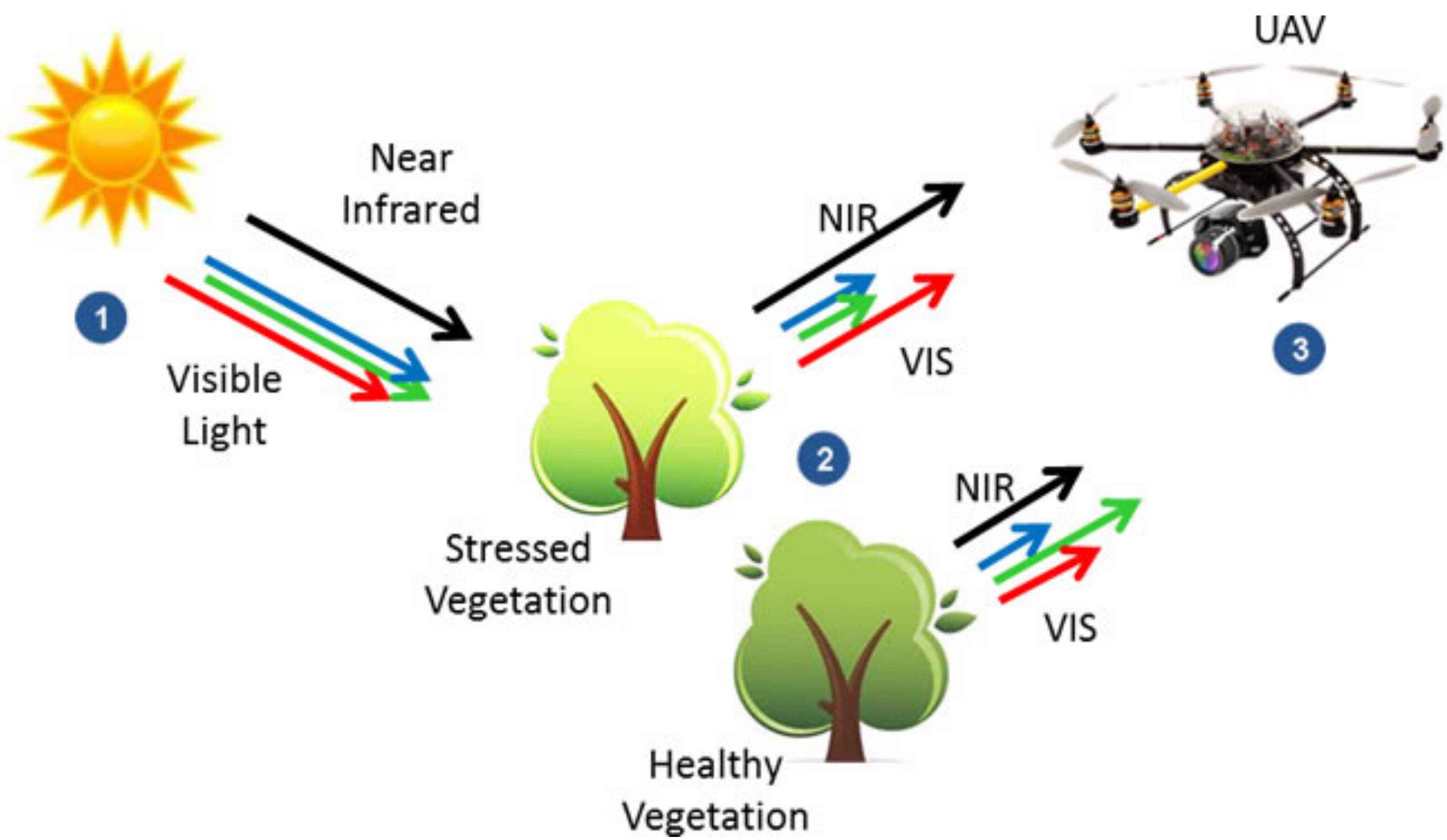
$$NDVI = \frac{(\rho_{NIR} - \rho_R)}{(\rho_{NIR} + \rho_R)}$$

- Numerator fraction represent vegetation quantity:
  - Lowe quantity = Less vegetation
  - Higher quantity = More vegetation
- The sum in denominador fraction represent:
  - Avarege reflectance in both wavelenghts;
  - Reduces the effect of non-uniform illumination;

NDVI normalized difference vegetation index



NDVI normalized difference vegetation index



NDVI normalized difference vegetation index

- Scale index: 0 to 1;
- There is negative numbers with clouds, snow or water surfaces image: -1 to 1;

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

$$\rho_R \geq \rho_{NIR}$$

NDVI normalized difference vegetation index

NDVI is correlated with:

- canopy density;
- vigor;
- chlorophyll content;
- leaf nitrogen;
- biomass;
- photosynthesis;
- productivity;
- leaf area index (LAI);
- fraction vegetation cover (fVEG);
- fraction of absorbed photosynthetically active radiation (fAPAR);

NDVI normalized difference vegetation index

NDVI variation by the mechanisms:

i) distinction between what is vegetation and what is soil in the index;

ii) chlorophyll concentration and other biochemical compounds that may affect the leaf spectral reflectance;

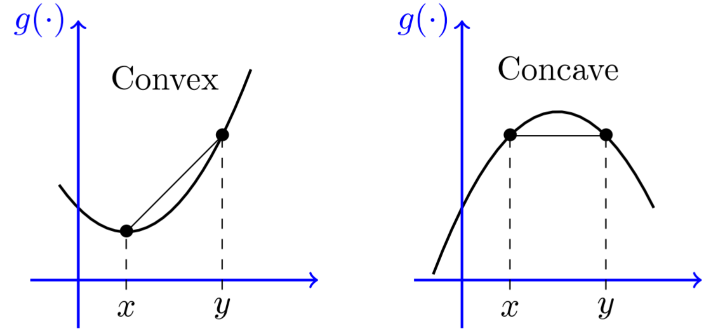
iii) variation between the R and NIR reflectance of the radiation as a function of the illumination angle and shading variation of the visible area;

NDVI normalized difference vegetation index

- The shadows response effects and ilumination angle can be correct with a proportion of fVEG;
- The response can be:

1 – convex -> $\left(\rho_{NIR-plant} - \rho_{NIR-soil}\right) \geq \left(\rho_{R-soil} - \rho_{R-plant}\right)$

2 – concave -> $\left(\rho_{NIR-plant} - \rho_{NIR-soil}\right) \leq \left(\rho_{R-soil} - \rho_{R-plant}\right)$



NDVI normalized difference vegetation index

- fraction vegetation cover: fVEG

$$\rho_R = f_{VEG} * \rho_{R-vegetation} + \left(1 - f_{VEG}\right) * \rho_{R-soil}$$

$$f_{VEG} \cong \frac{\left(VI - VI_{soil}\right)}{\left(VI_{vegetation} - VI_{soil}\right)}$$

$$VI = \left(\rho_{NIR} - \rho_R\right)$$

NDVI normalized difference vegetation index

- To correct for chlorofill concentration can be used fAPAR
- fAPAR = fraction absorbed of photosynthetic active radiation

$$\rho_R = f_{APAR} * \rho_{R-veg} + \left(1 - f_{APAR}\right) * \rho_{R-soil}$$

$$f_{APAR} = f_{VEG} * \alpha_{VEG}$$

GNDVI green NDVI

- Improved sensitivety for dense vegetation with high LAI and increases over a much wide range of chlorofill than NDVI;
- Range: -1 to 1;

$$GNDVI = \frac{(\rho_{NIR} - \rho_G)}{(\rho_{NIR} + \rho_G)}$$

SAVI soil-adjusted vegetation index

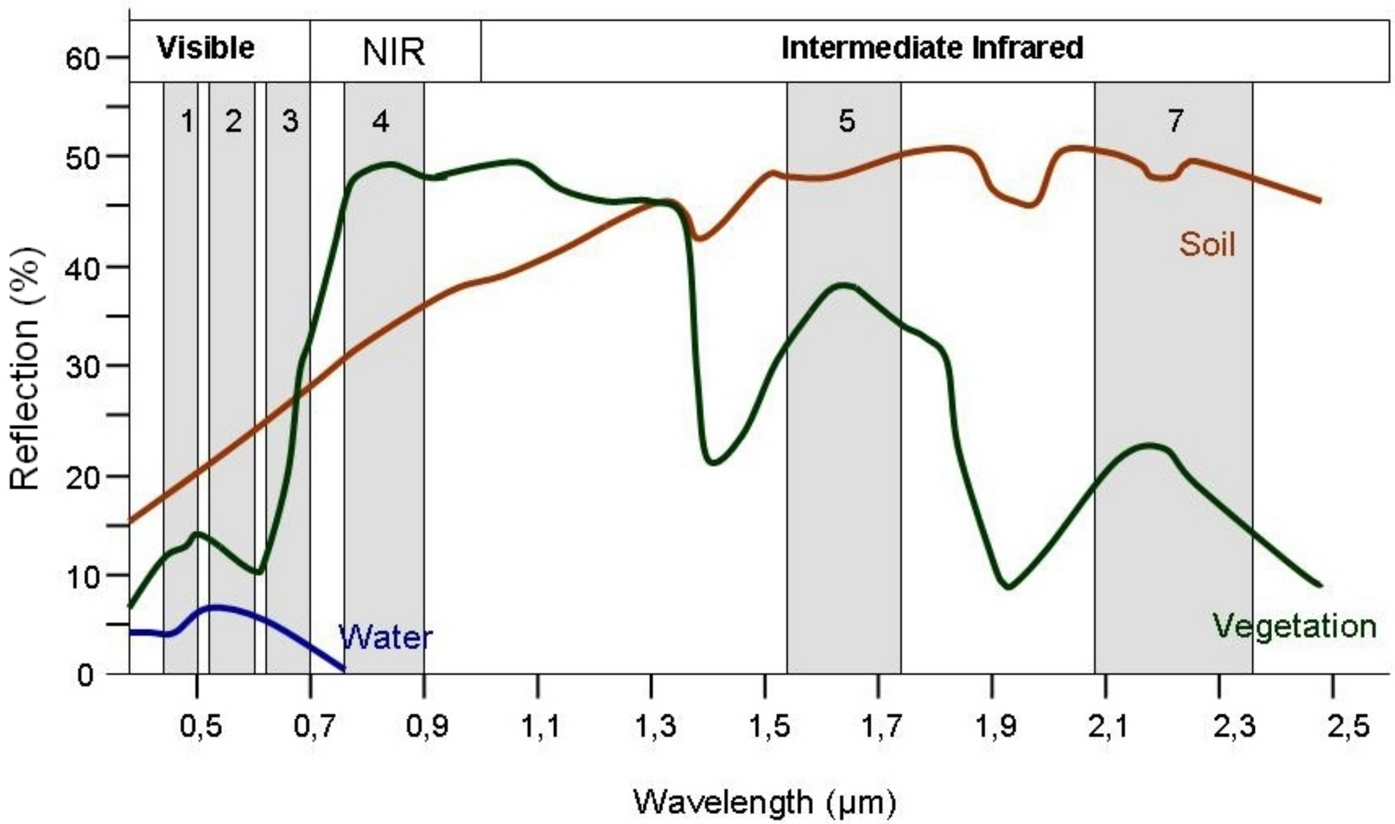
- Corrects for varying soil reflectances(brightness), with “L” as an empirical correction factor to account for the fact that with increasing canopy density a greater proportion of NIR reaches the soil. The L coefficient varies from 0 at high LAI to 1 at low LAI and often assumed to be 0.5.

$$SAVI = \frac{(\rho_{NIR} - \rho_{RED})}{(\rho_{NIR} + \rho_{RED}) + L} * (1 + L)$$

$$MSAVI = \frac{2\rho_{NIR} + 1 - \sqrt{(2\rho_{NIR} + 1)^2 - 8(\rho_{NIR} - \rho_{RED})}}{2}$$

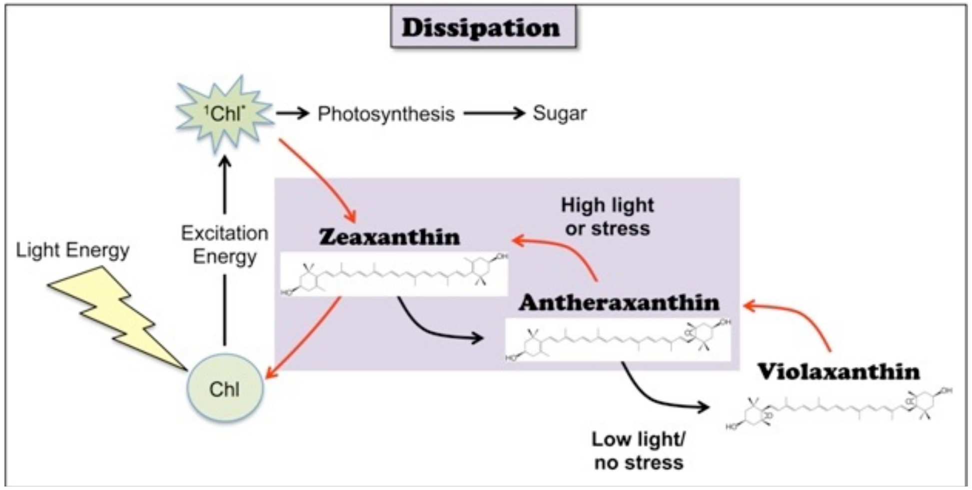
SAVI soil-adjusted vegetation index

- Soil reflectance spectrum



Narrowband indices

PRI photochemical reflectance index



Xanthophyll adjust the energy distribution at the photosynthetic apparatus:
light-use efficiency (ϵ) and hence **photosynthesis rate.**

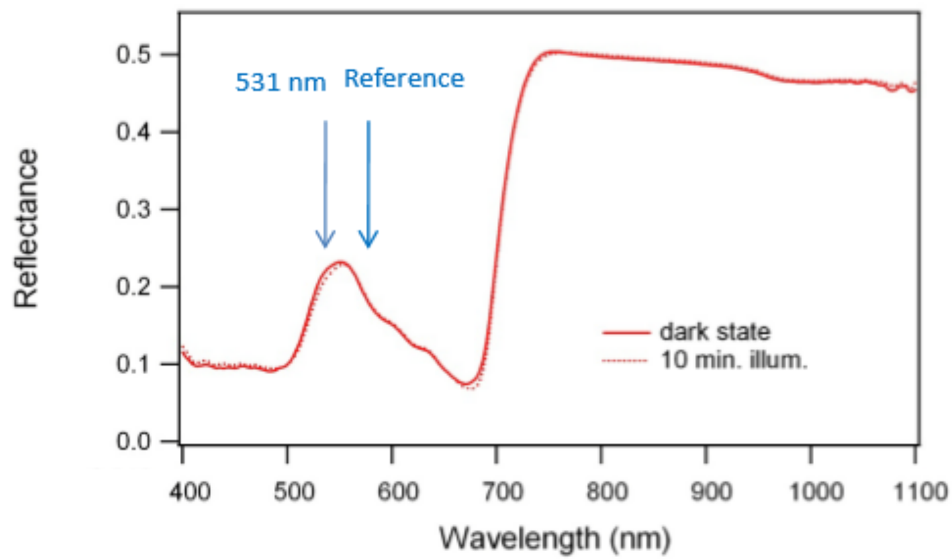
PRI photochemical reflectance index

Is it possible to measure energy flux remotely?

How to associate cycle and spectrum?

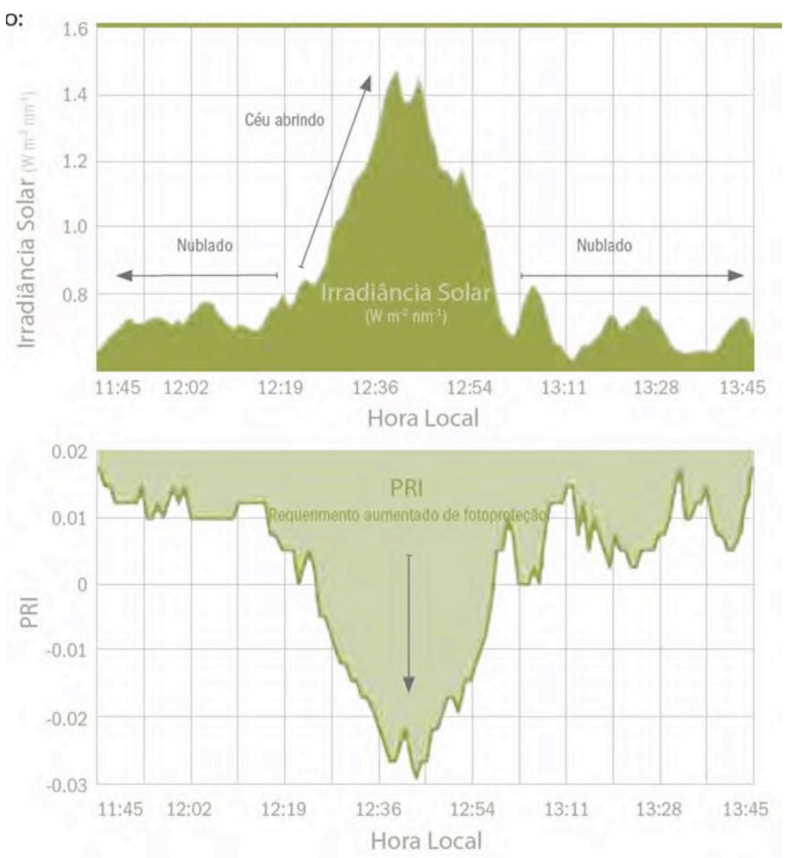
Absorption of zea and violaxanthin;

$$PRI = (p_{531} - p_{570})/(p_{531} + p_{570})$$

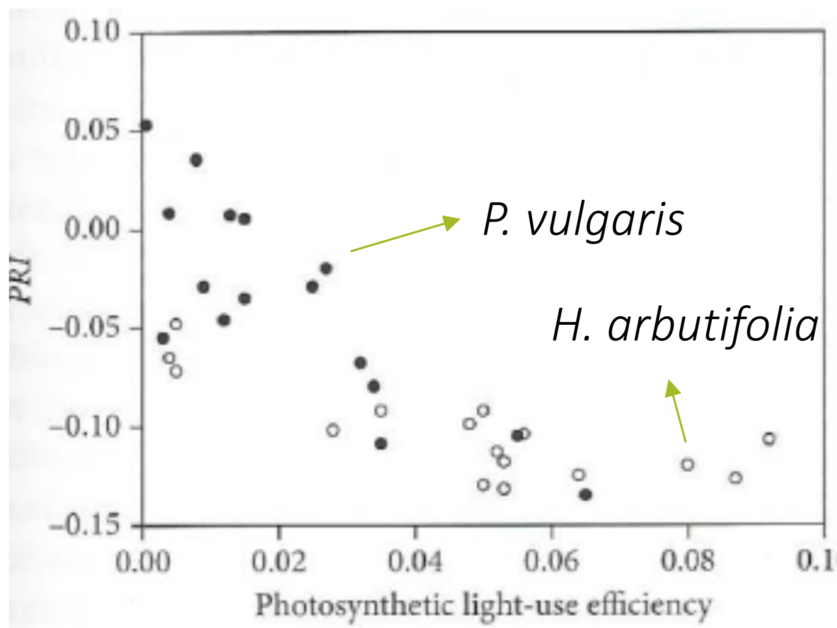


PRI photochemical reflectance index

Temporal behaviour



Association to light use efficiency



PRI photochemical reflectance index

$$NPP = f(APAR) \times \epsilon$$

NPP: net primary productivity;
$f(APAR)$: fraction of absorbed photosynthetically active radiation;
ϵ: light use-efficiency.

Aproximation:

$$NPP = NDVI \times PRI$$

Determination of ϵ remains a primary challenge

Water indices

Water indices

Relative Water Content (RWC) = $(fresh\ mass - dry\ mass)/(turgid\ mass - dry\ mass)$

RWC range: 60 ~ 98%

Conventional procedures:
Difficult to measure;
Sometimes destructive;
Restricted number of samples;

Remote sensing:
Ease;
Sample size.

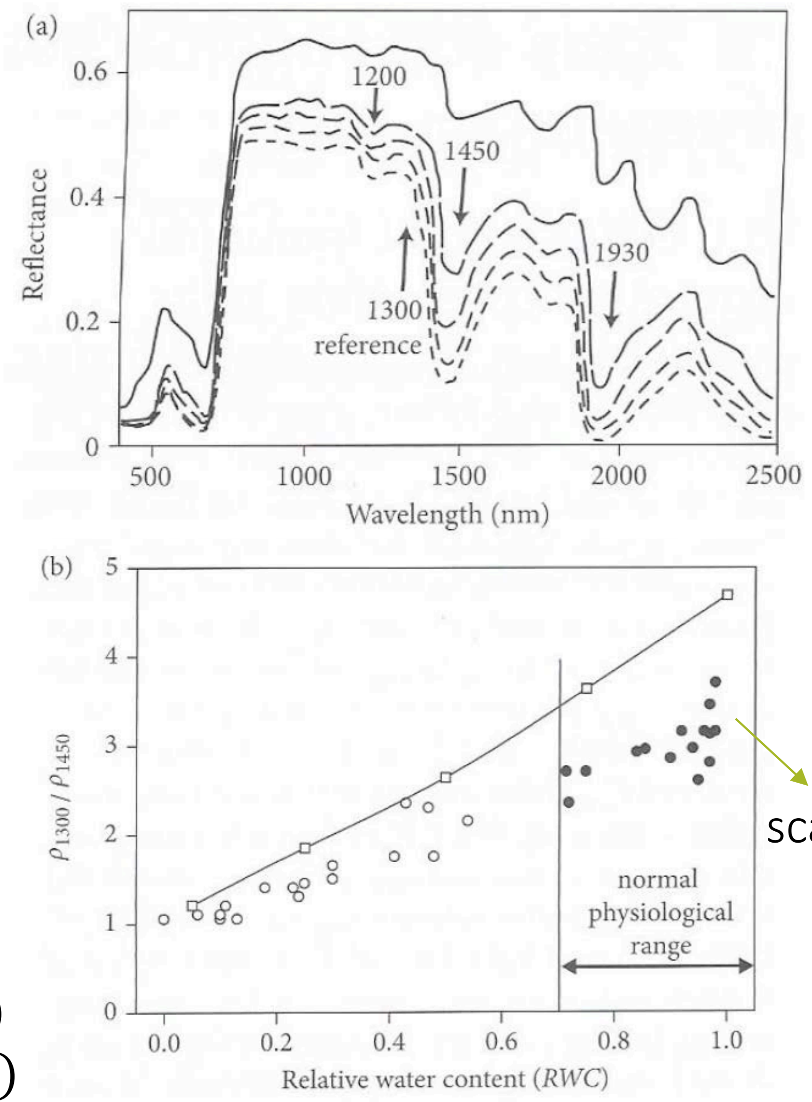
Canopy water content::crop water status (deficit-stress)

Water indices

How find the appropriate band?

Sensor accuracy *vs* absorption depth;

$$LeafWaterIndex = \frac{p_{1300}}{p_{1450}}$$



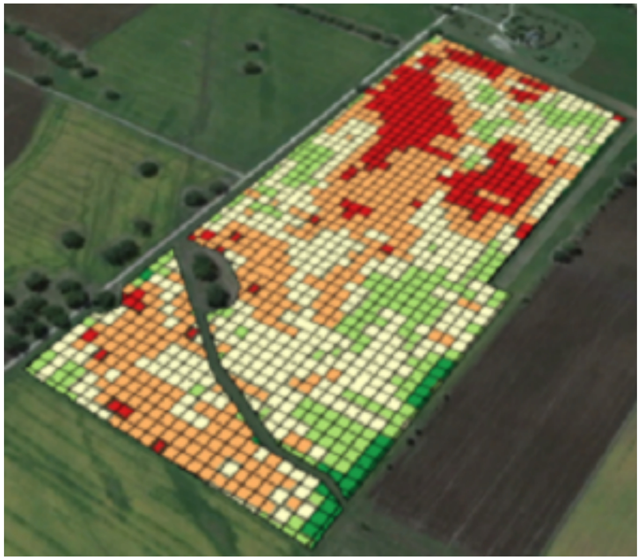
scattering

$$NDWI_{1240} = (p_{980} - p_{1240})/(p_{980} + p_{1240})$$
$$NDWI_{1640} = (p_{858} - p_{1640})\ /(p_{858} + p_{1640})$$

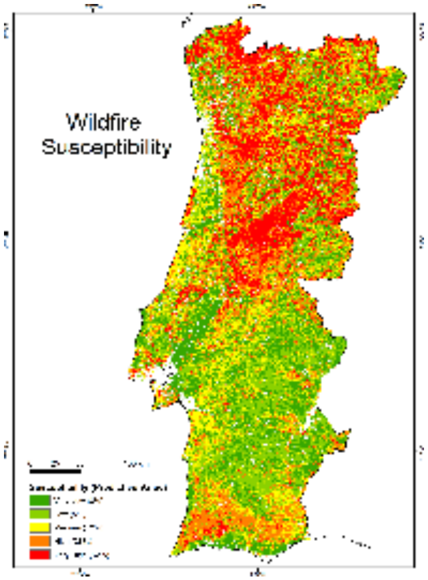
Water indices

Remote sensing:
Instantaneous, non-destructive & large scale

water stress detection



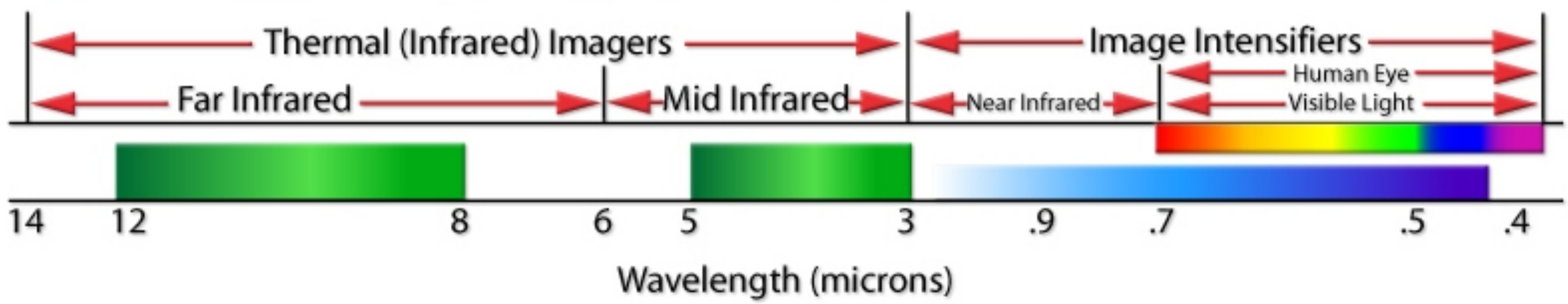
fire risk assessment



efficient irrigation scheduling

Thermal indices

Thermal



Canopy temperature::transpiration::stomatal conductance;

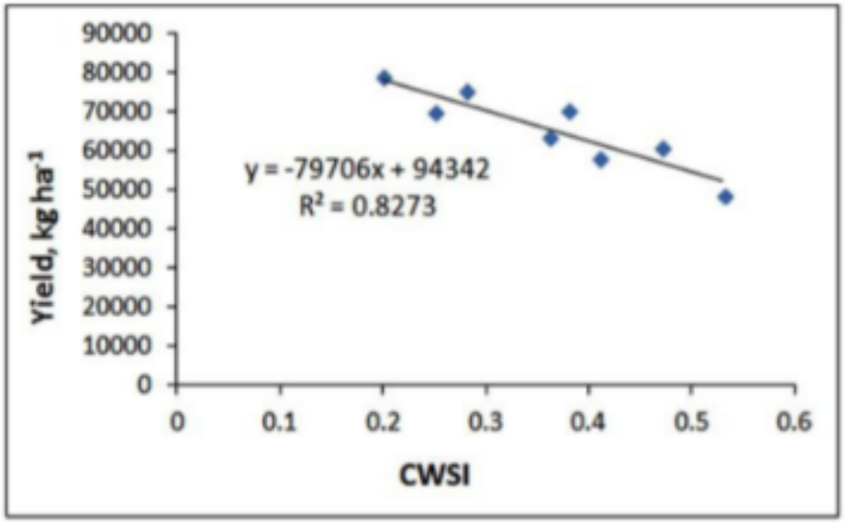
Stressing conditions (drought):: canopy temperature is affected;

Stomatal conductance *vs* photosynthesis;

OBS.: Conductance depends mainly on stomatal closure.

Thermal

Crop water stress index $(CWSI) = (T_{canopy} - T_{nwsb}/T_{upper} - T_{nwsb})$



Çolaka et al., 2015

Advantages:

Calibration eliminates significant amount of error;

Disadvantages:

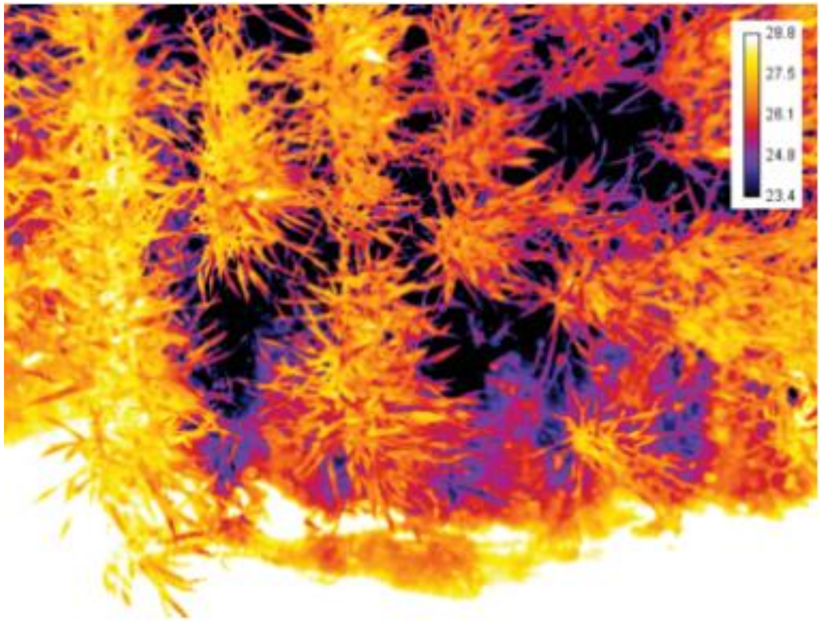
Baselines must be determined;

Environmental conditions must be similar.

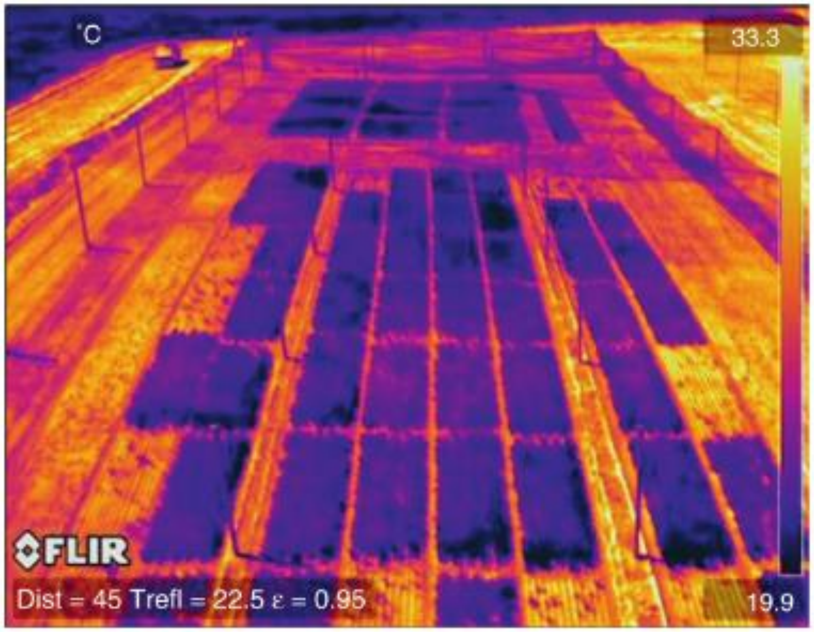
Single leaf or full canopies (no soil):
soil visible *vs* stomatal closure;

Thermal

Plant level



Plot level



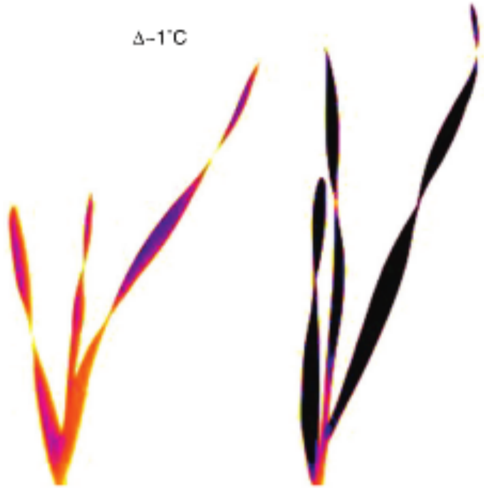
Thermal

Staygreen

Animal health

Irrigation systems

Nutrient effect



FINAL REMARKS

Indices can be useful when correctly utilized;

Plant breeding – field based phenomics;

Indices have been around for decades – but it is just the beginning.

Thank You!

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