Remote sensing of vegetation

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Using satellites to study vegetation

Advantages

- Can cover large areas quickly (especially remote or non-instrumented areas)
- Cheap
- Repeat observations
- Diverse and powerful and ever-evolving methods

Disadvantages

- Satellites don't observe many vegetation attributes directly (proxies and modelling)
- Need calibration and ground truthing to know accuracy
- Often misapplied and misinterpreted by casual users
- Data volumes

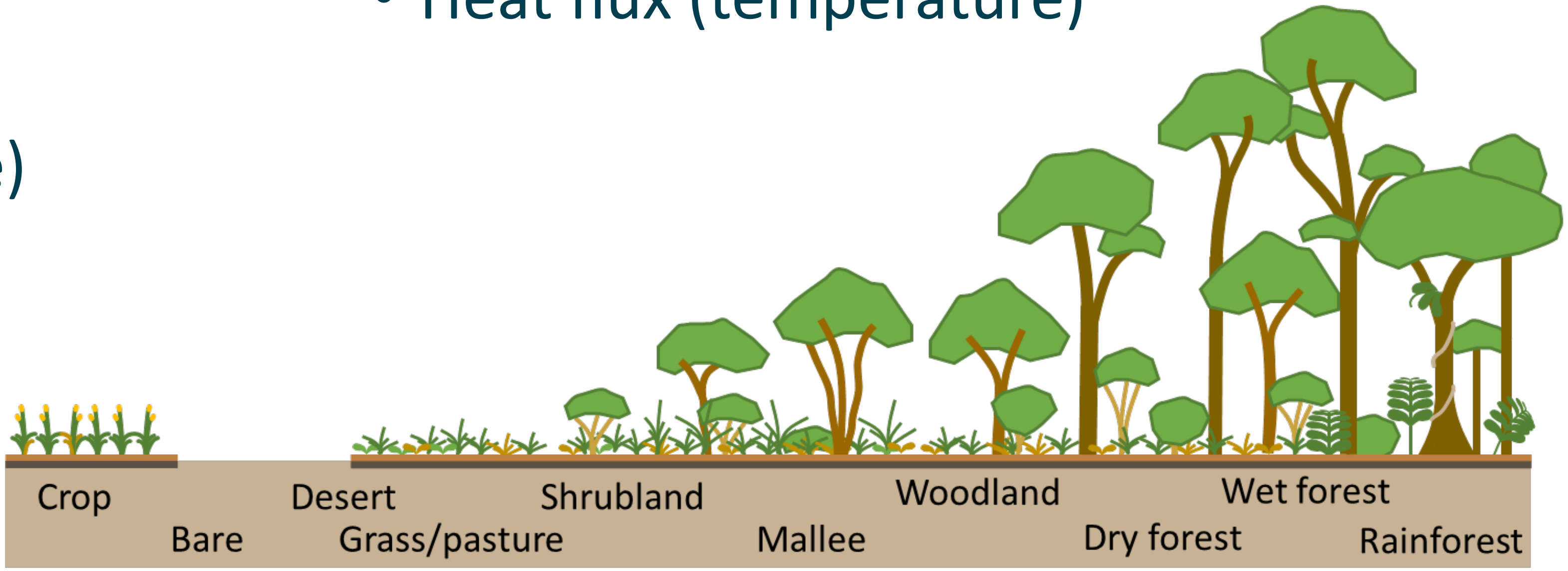
Vegetation attributes

Physical

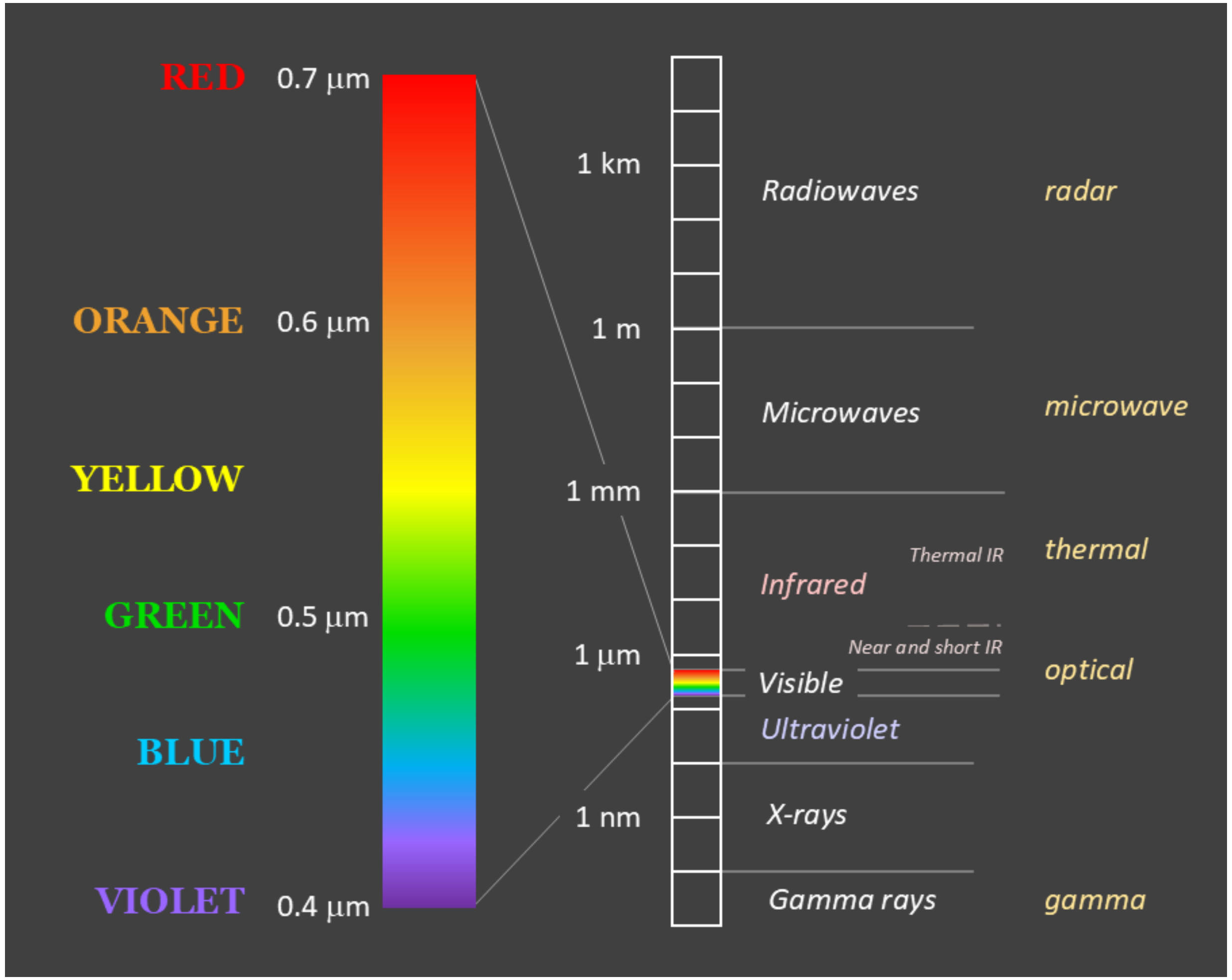
- Leaf/foliage area
- Albedo
- Vegetation/cover type
- Height and strata
- Biomass (woody and fine)
- Species/communities
- Health (disease, stress)
- Production (yield)
- Leaf chemistry

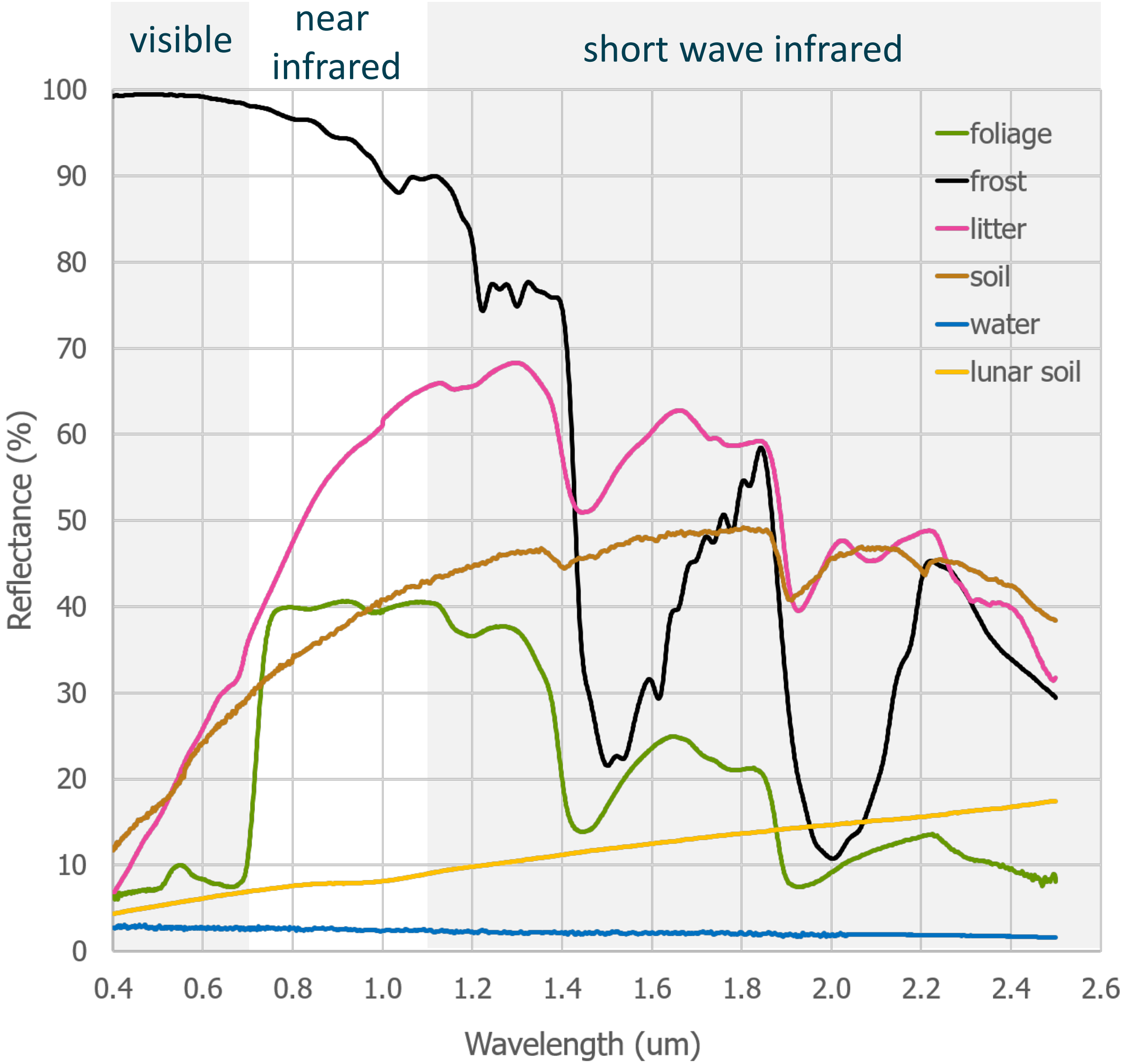
Functional

- Water flux (transpiration)
- Carbon flux (photosynthesis)
- Heat flux (temperature)



What can satellites 'see'?





What can satellites ‘see’?

Radio and microwaves

Measure strength, phase and timing of returned signal of emitted waves

Waves interact with objects with high dielectric properties (like rock, concrete, metal, water)

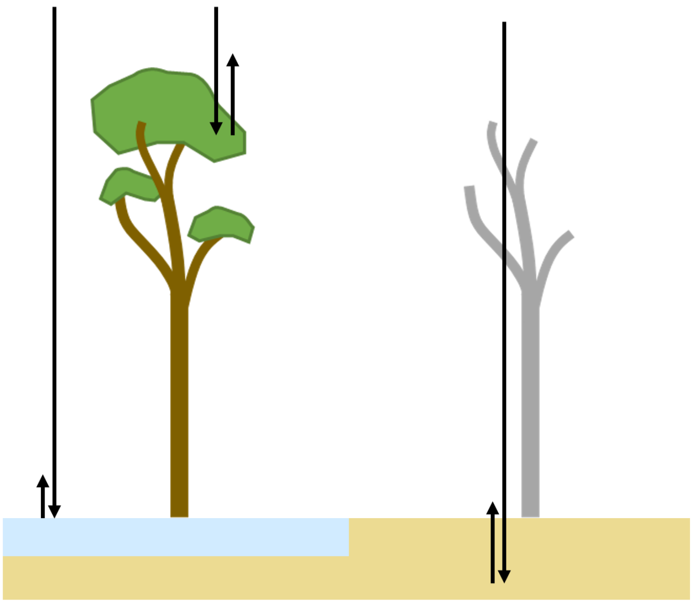
Can pass through smoke and cloud

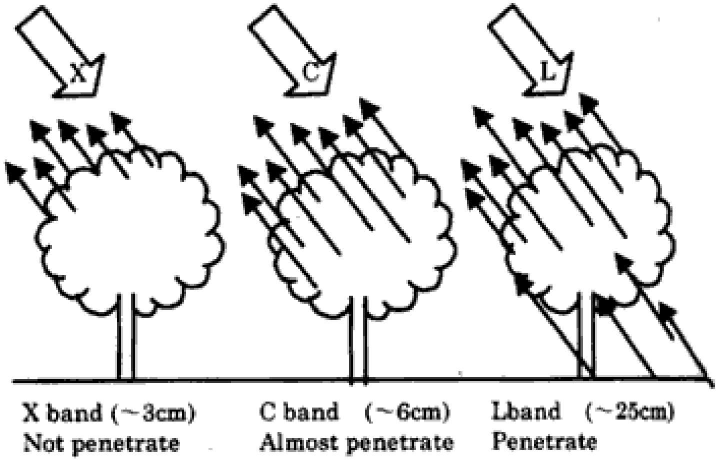
Wavelength determines the size of object detected

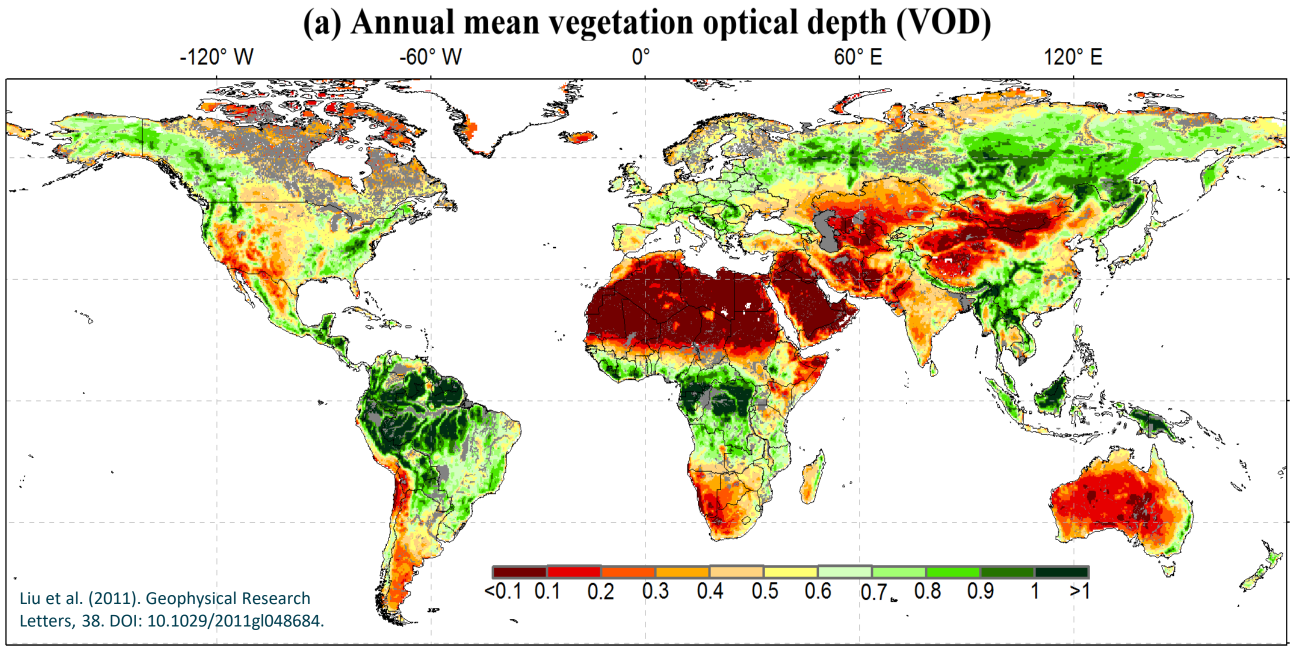
Used to detect surface features and their heights (ground, sea, waves, ice, floods, buildings)

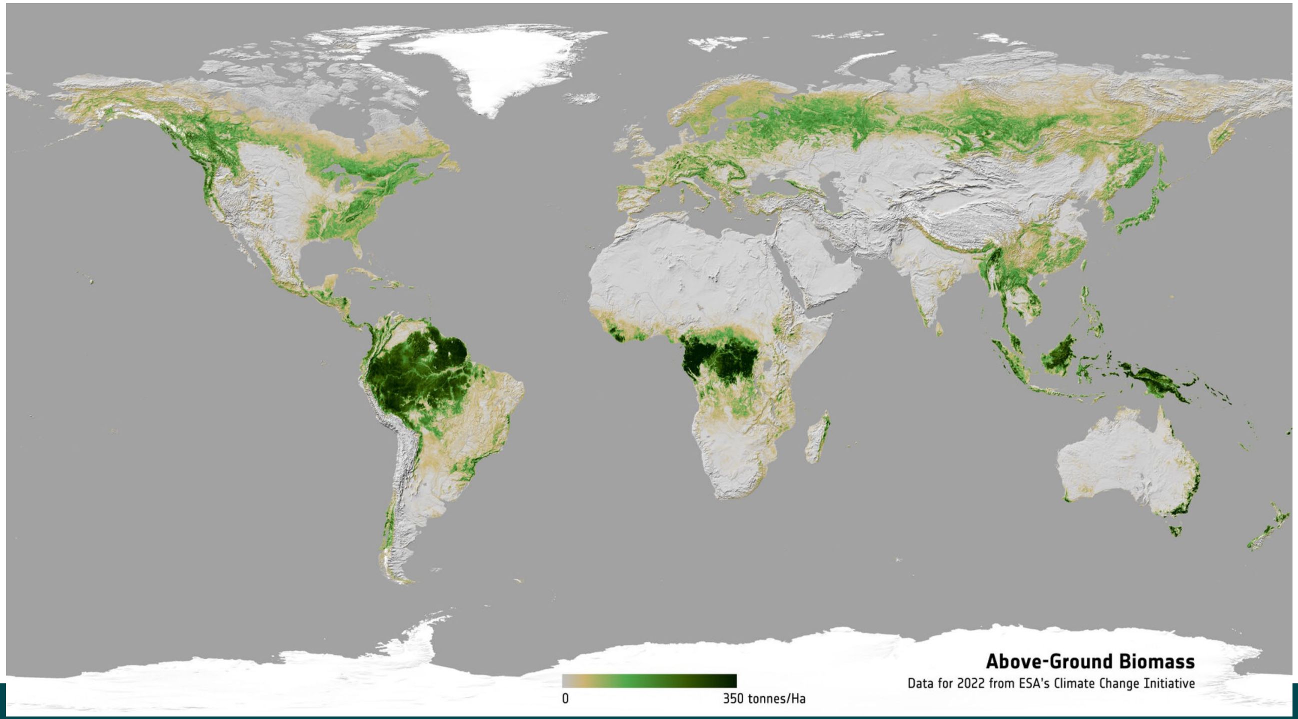
For vegetation, returns can be *correlated* to

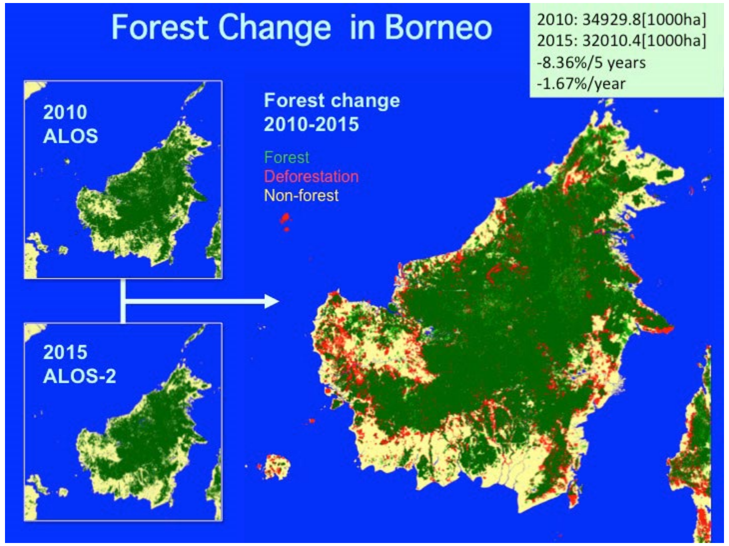
- biomass
- structure (height, horizontal and vertical density)
- *soil water*



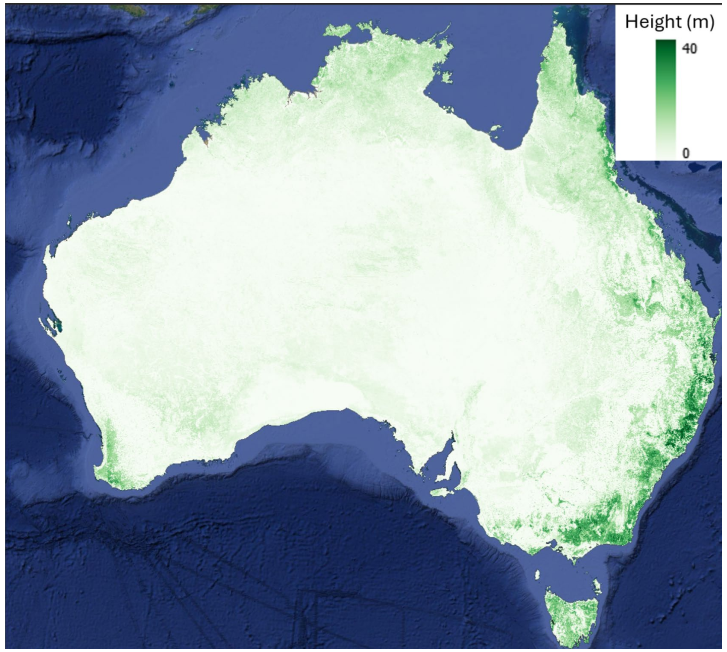








JAXA



Ticehurst *et al.* (submitted)

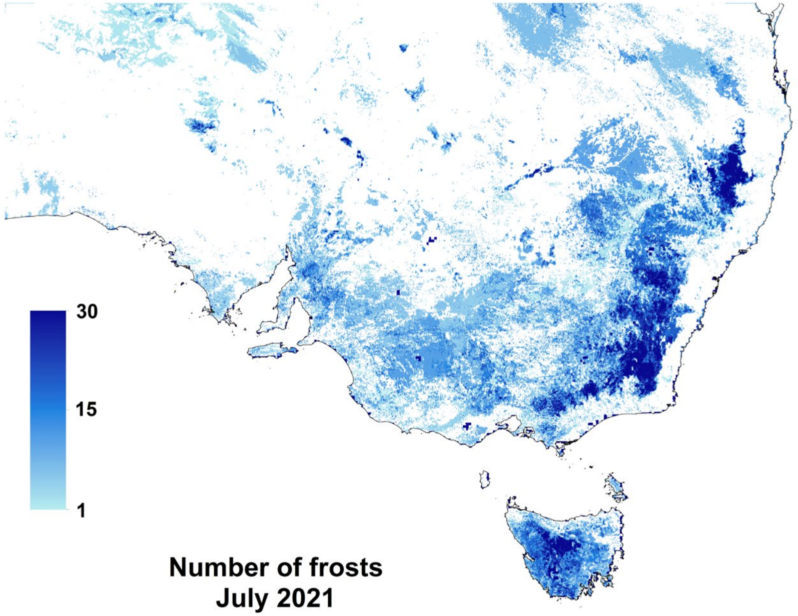
What can satellites 'see'?

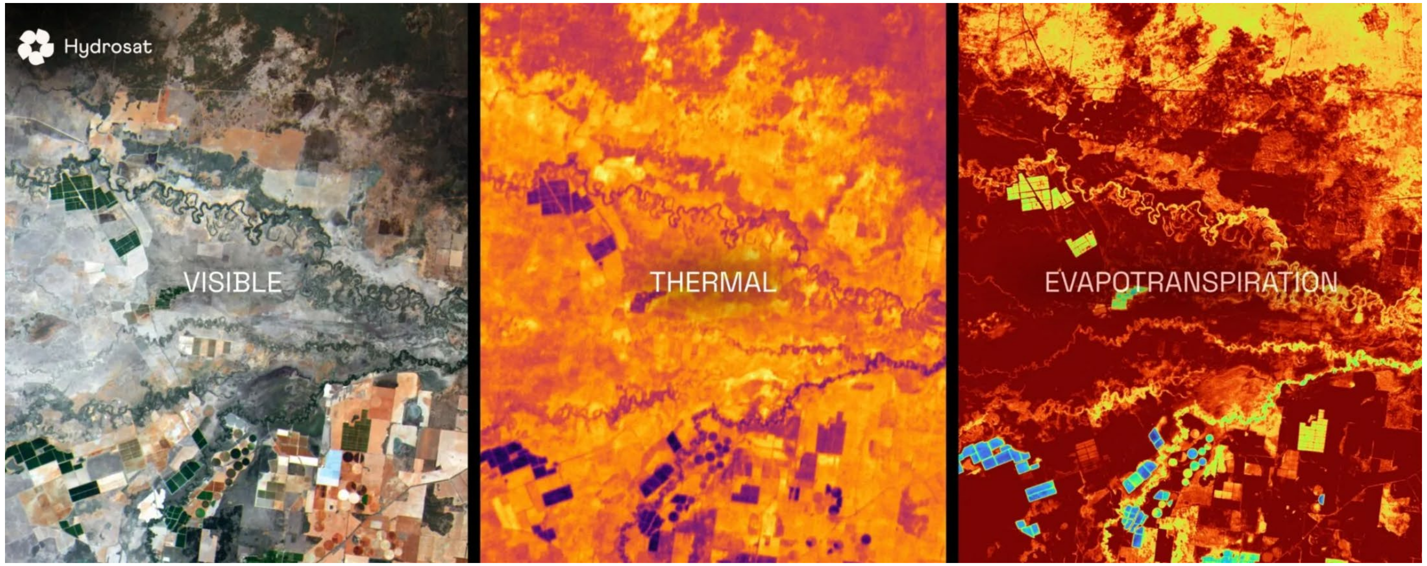
Thermal

Surface temperature (of the land surface or whatever is covering it)

Heat extremes

Evaporation and transpiration
- plant water stress
- irrigation rates
- productivity and yield
- disease
- fire risk





What can satellites ‘see’?

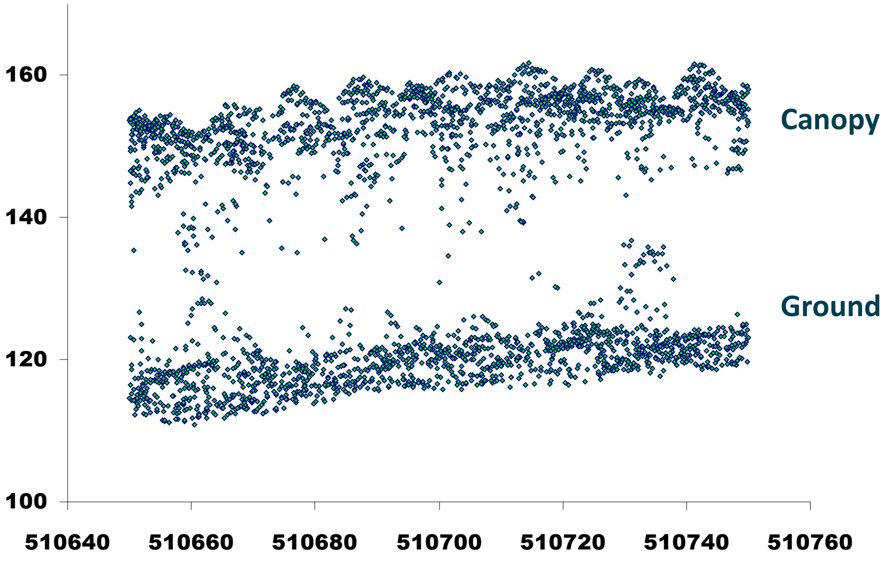
Active optical

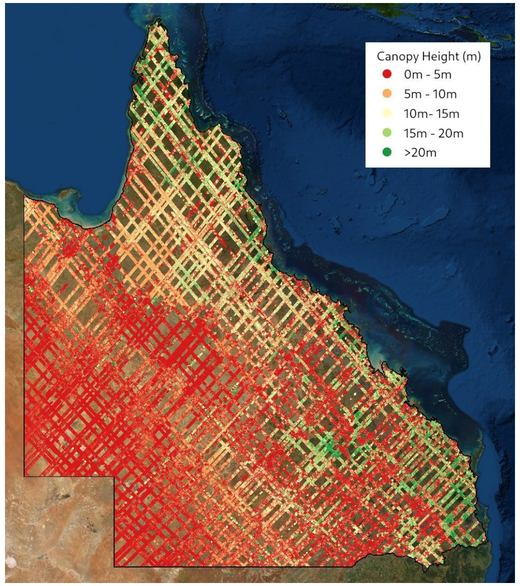
Active optical sensors are lidar systems that emit radiation from a laser (visible or infrared), and detect time of return (and hence distance)

Coverage from satellite-borne lidar sensors is patchy and low resolution (> 10 m laser footprint)

Processed and interpreted generally in the same way as airborne/drone and terrestrial lidar

Lidar is proving to be far more important for mapping vegetation structure and biomass in Australian compared to radio/microwave.





What can satellites 'see'?

Passive optical

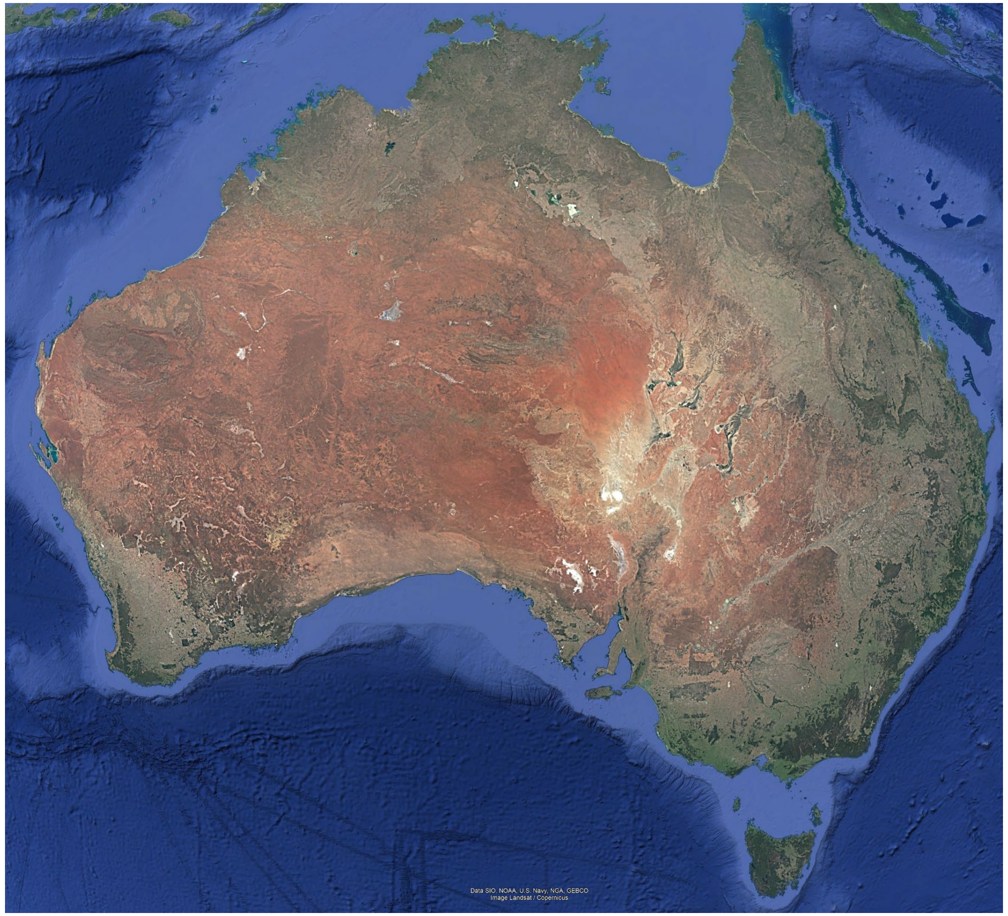
Passive optical sensors detect visible and near infrared radiation reflected from the land surface

These rely on solar radiation being reflected, and detect differences in reflectivity ('colour')

Day time only; sensitive to cloud, smoke, and other aerosols, and to sun angle

Interpretation relies on identifying differences in reflectance at specific wavelengths ('indices') and how these relate to surface object properties

That is, very few vegetation attributes can be directly observed from satellite – it's a game of proxies



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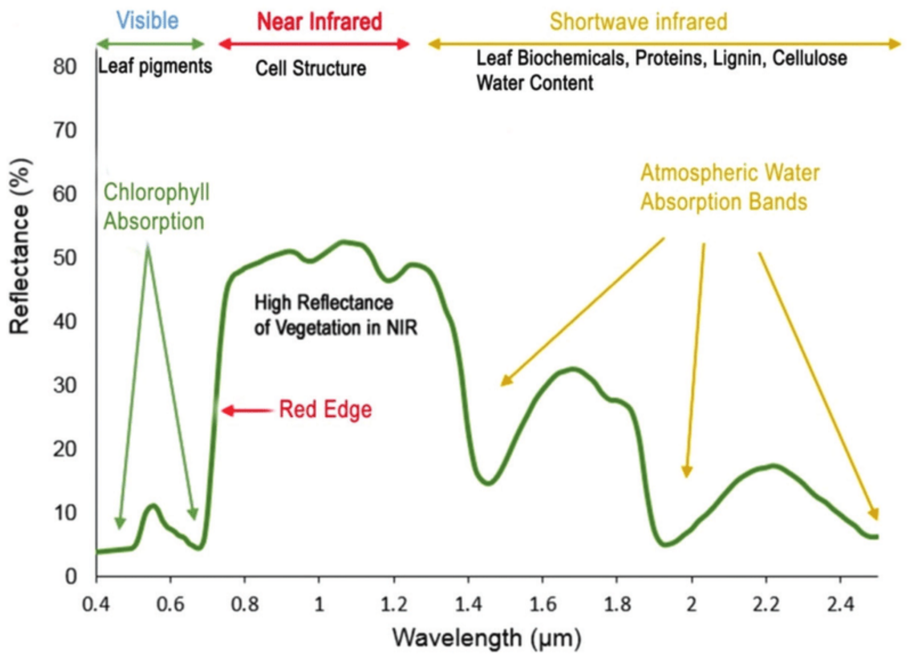
What can satellites ‘see’?

Vegetation indices (…deep sigh)

Primarily based on the contrast between high and low reflectance features, which (hopefully) relate to some real vegetation property, e.g.:

$$\text{Simple Ratio} = \frac{\rho_{red}}{\rho_{NIR}}$$

ρ is reflectance



Plethora of vegetation indices, most of which are variations of greenness indices, and most have no biophysical basis

Uncritical and uninformed use of VIs. Most analyses are data trawls (statistical or, worse, ML) looking for correlations with *something.*

The NDVI is the original and still the best greenness index (by far). More on the NDVI later.

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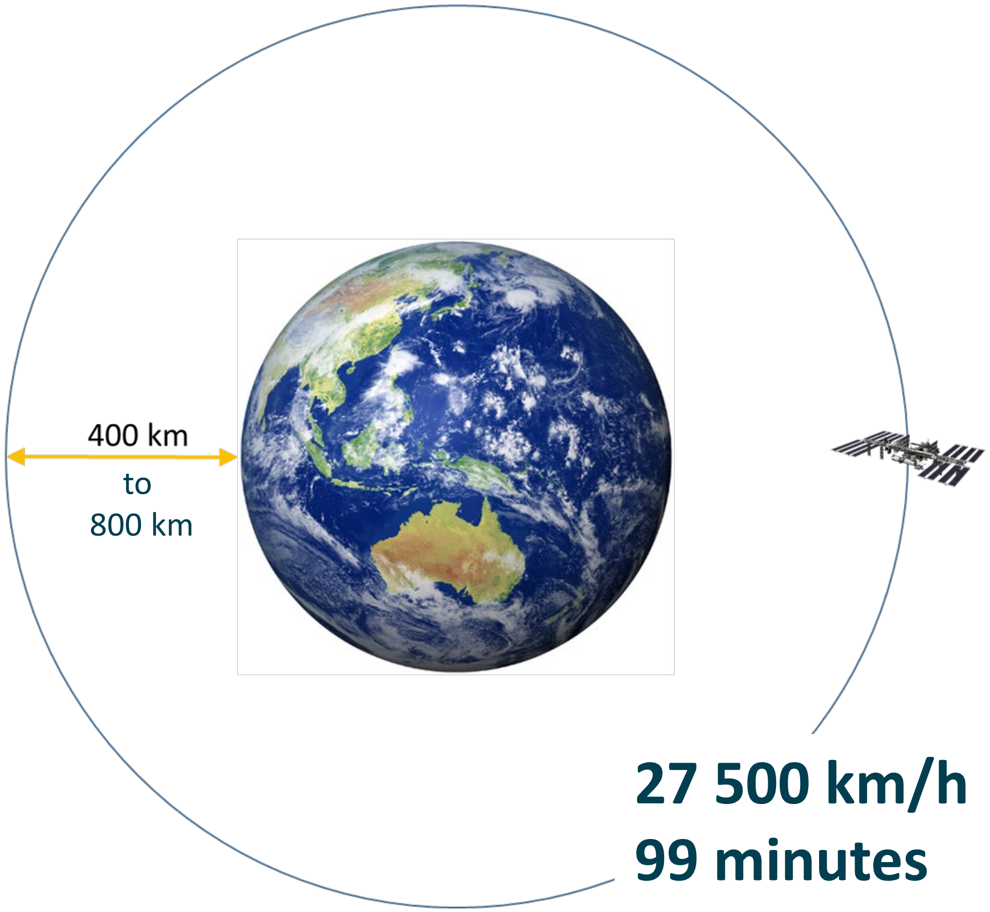
Satellite orbits and monitoring capability

Low Earth Orbit (LEO)

- Highest resolution (<1 – 1000 m)
- Narrow swathe (1 – 14 days for full Earth coverage)
- Variable overpass repeat times (daily – fortnightly)

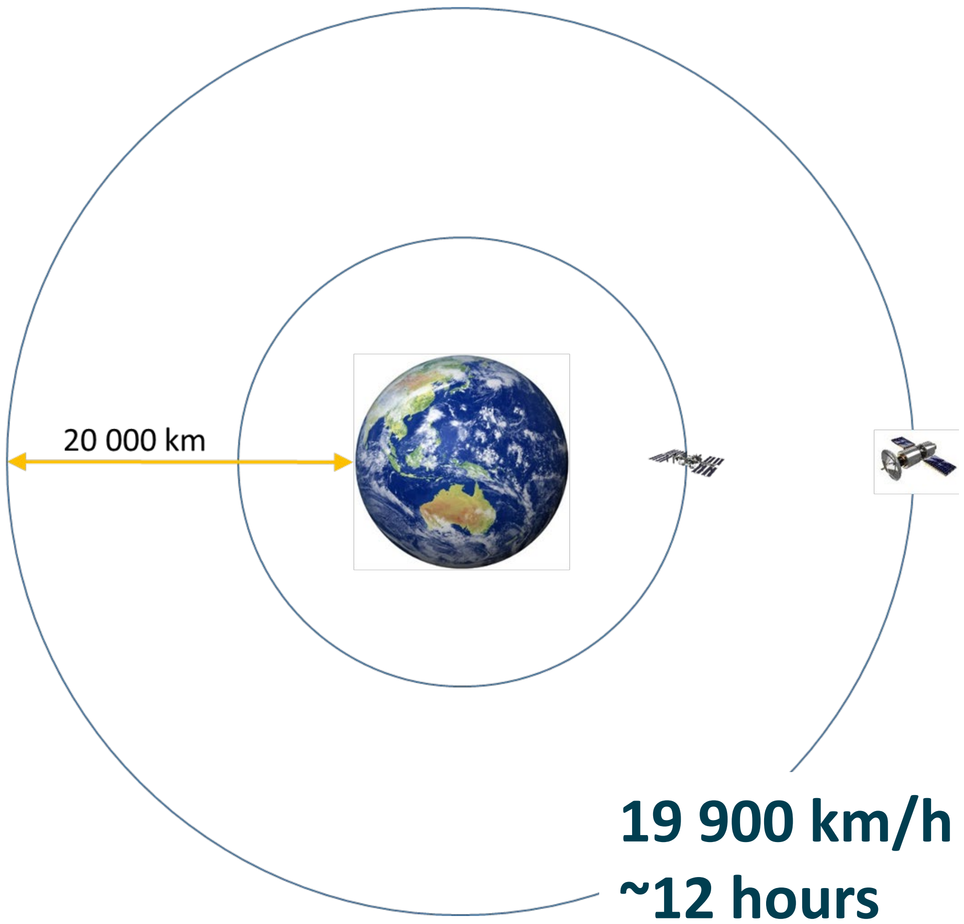


Unavoidable trade-off between resolution and repeat time:
Higher resolution → narrower swathe → slower repeat

Satellite orbits and monitoring capability

Mid Earth Orbit (MEO)

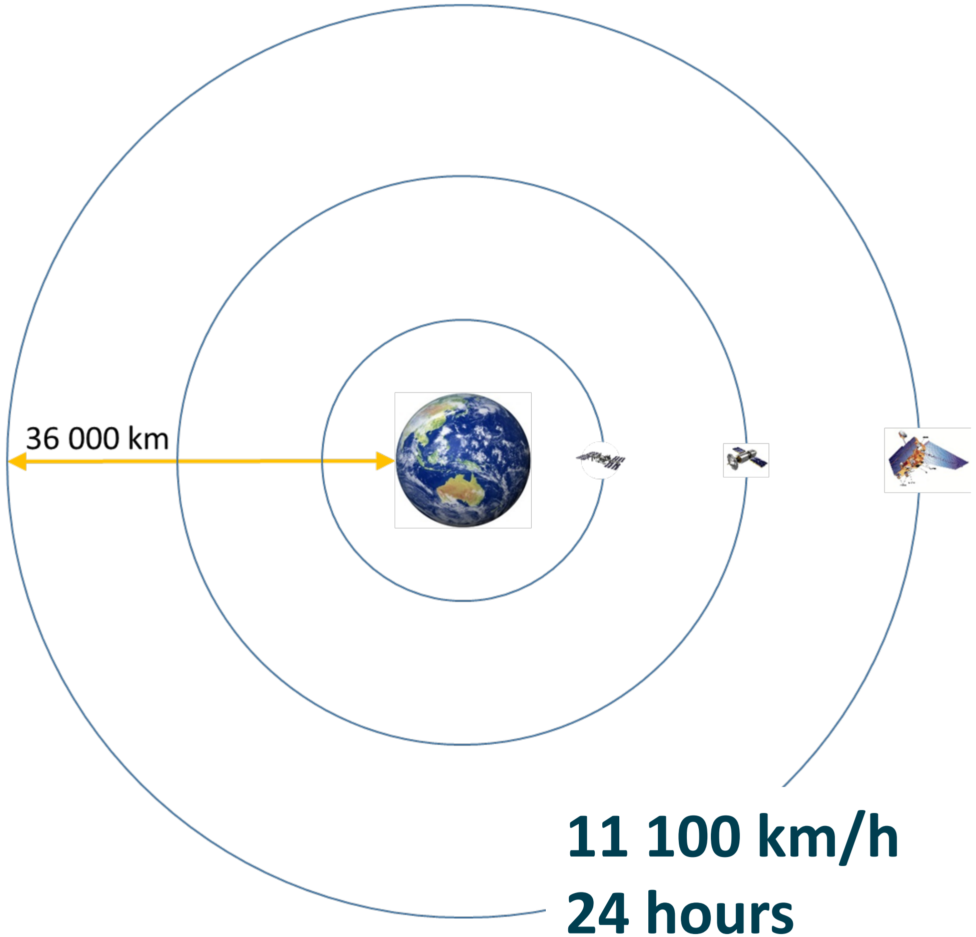
- GPS and communications satellites



Satellite orbits and monitoring capability

Geostationary Orbit (GEO)

- Low resolution (1 – 50 km)
- Full Earth disc
- Continuous acquisition
- e.g. weather satellites

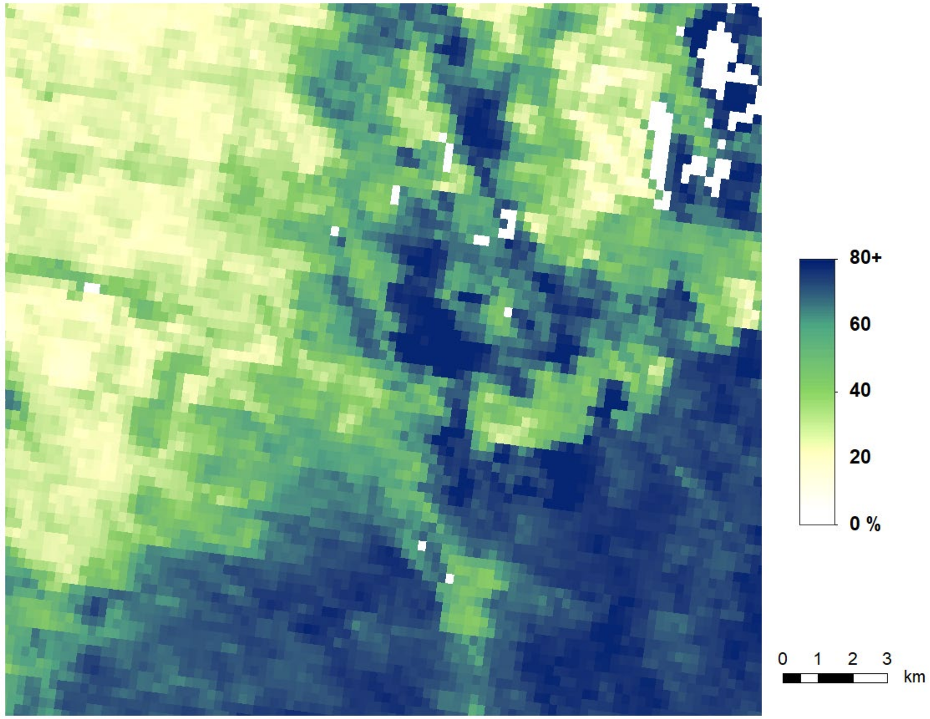


Coarse resolution but incredible temporal frequency (10 minutes)

11 100 km/h
24 hours

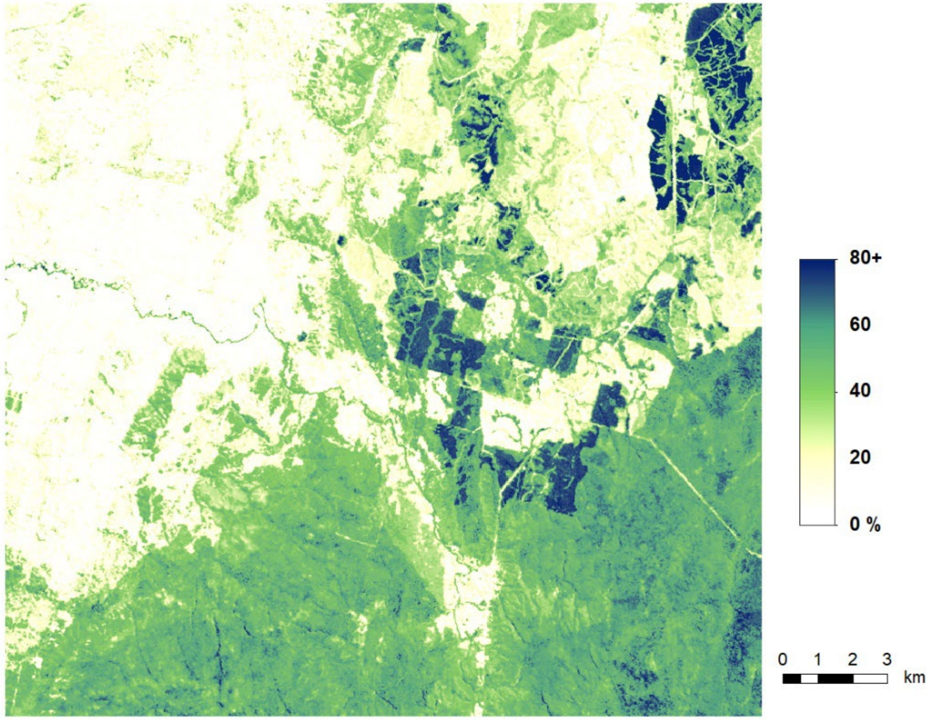
Which is more important for monitoring – resolution or repeat?

MODIS (daily, 250 m)



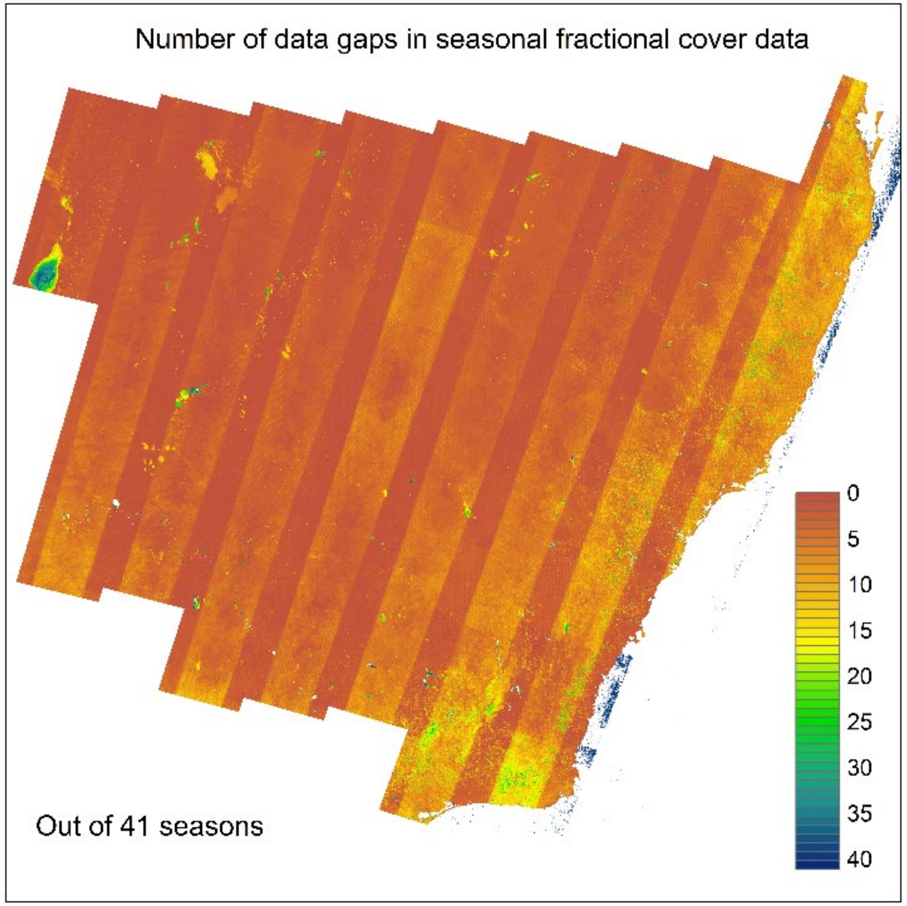
250 m tree foliage cover

Landsat (fortnightly, 25 m)



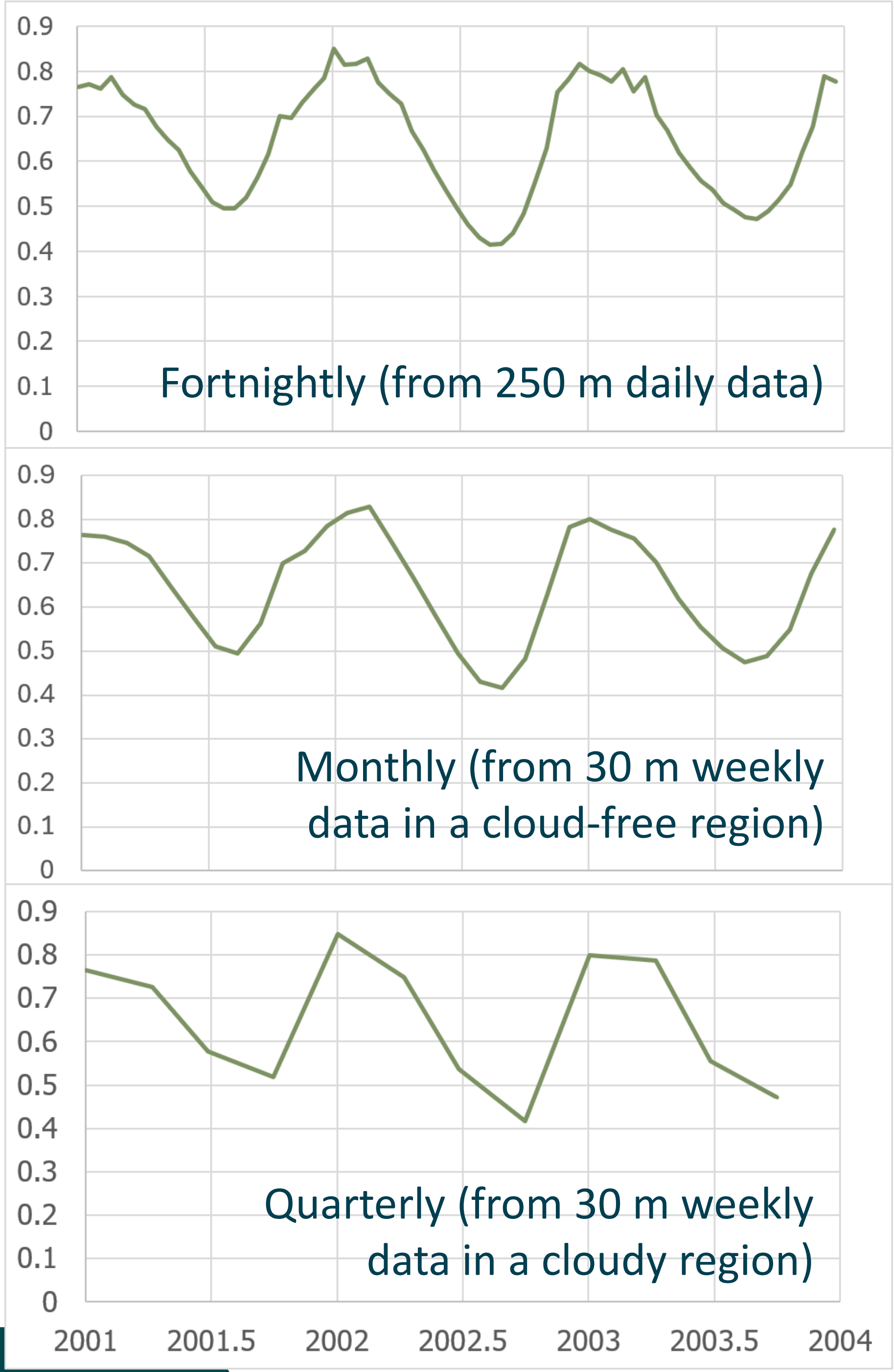
25 m tree foliage cover

Which is more important for monitoring – resolution or repeat?



High resolution imagery (< 100 m) is great for monitoring phenomena with low temporal dynamics (≥ year)

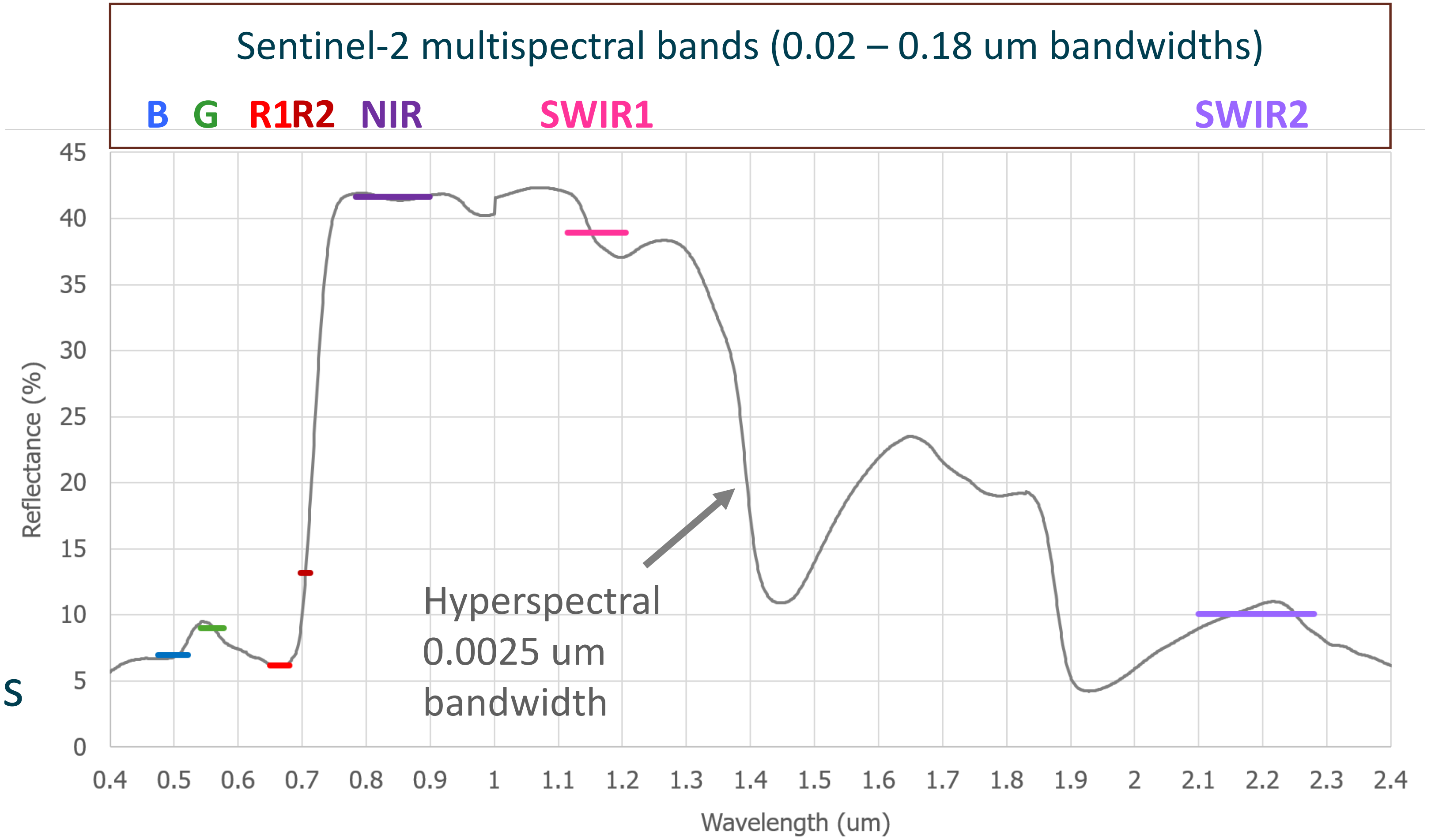
But it is truly horrible for monitoring phenomena with high temporal (≤ seasonal) dynamics ……(depending on cloudiness)



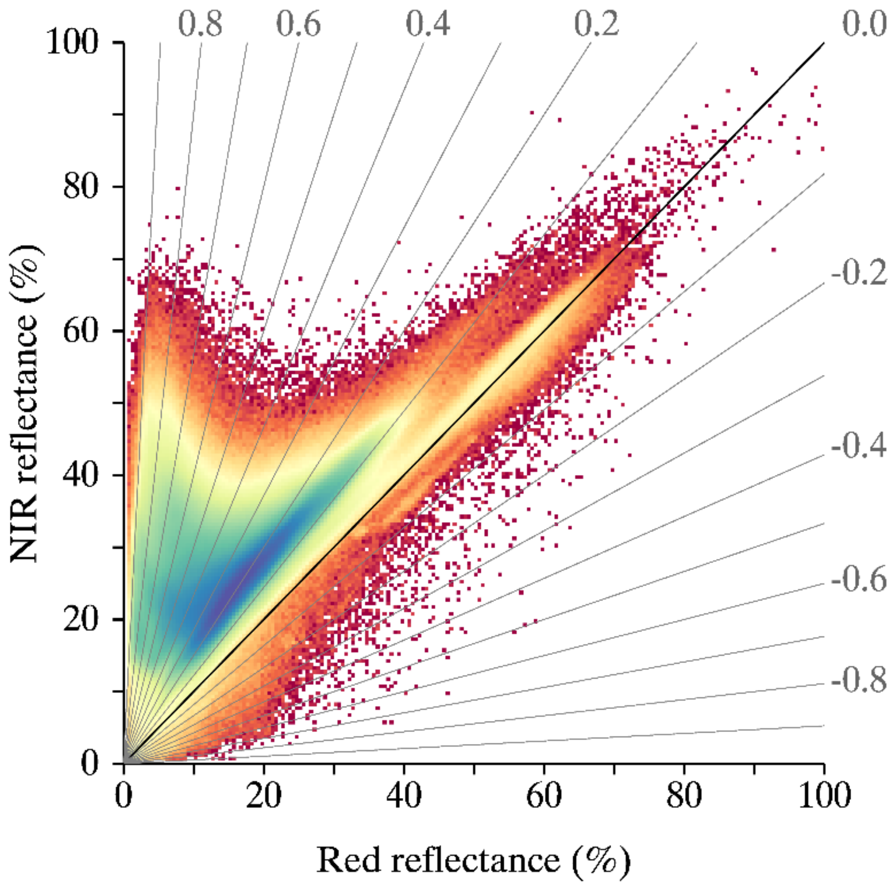
Hyperspectral vs multispectral

Hyperspectral imagery provides amazing *spectral* detail (good for identifying species, chlorophyl concentration etc)

But the data volumes are HUGE and limit imagery acquisition to small areas and/or infrequent repeat times



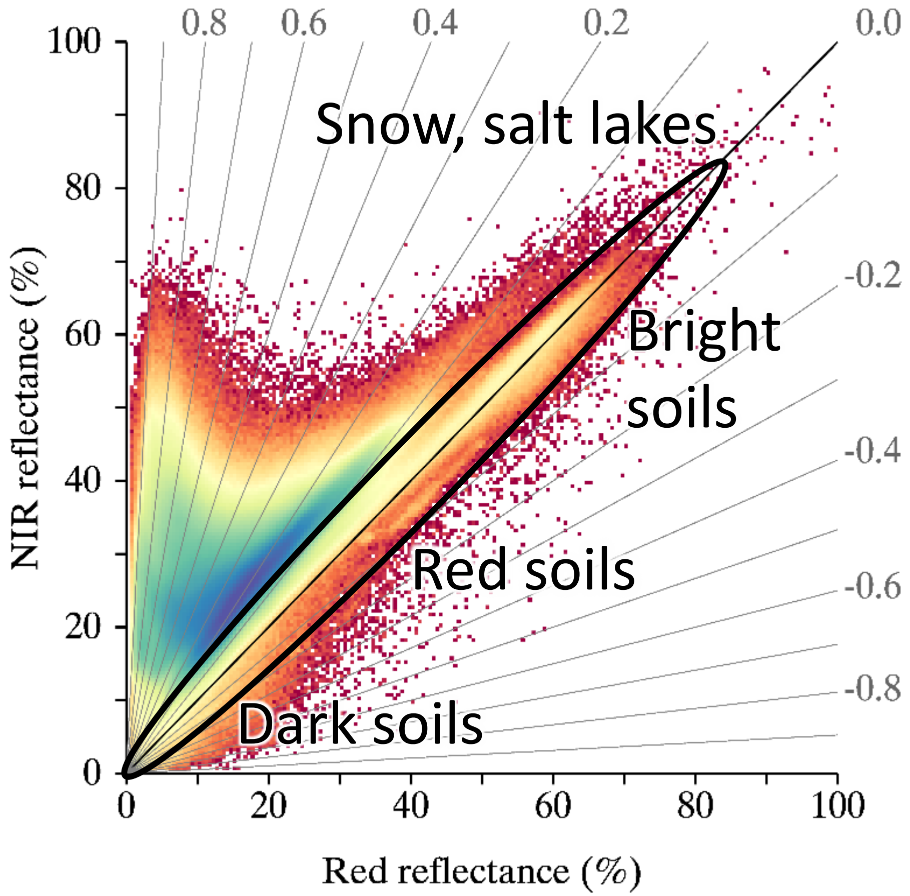
Greenness indices



Frequency plot of Australian R and NIR reflectance

The classic 'cover triangle' first noted in the 1970s

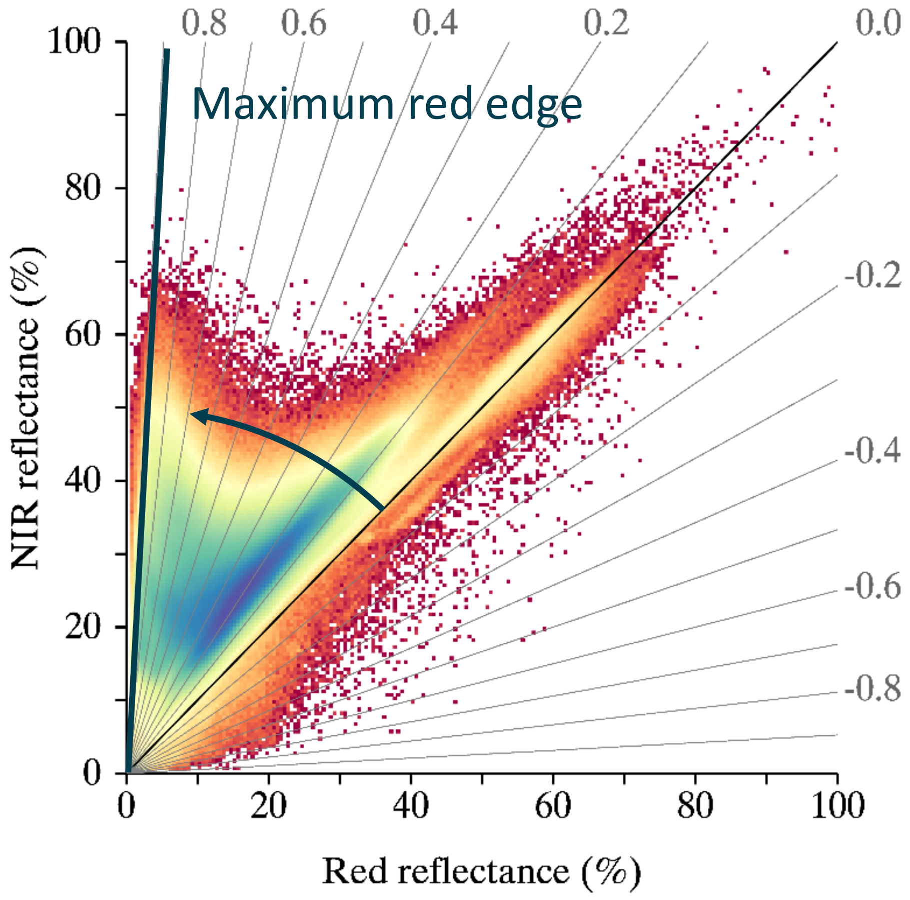
Greenness indices



Bare soils reflect approximately equal R and NIR reflectance

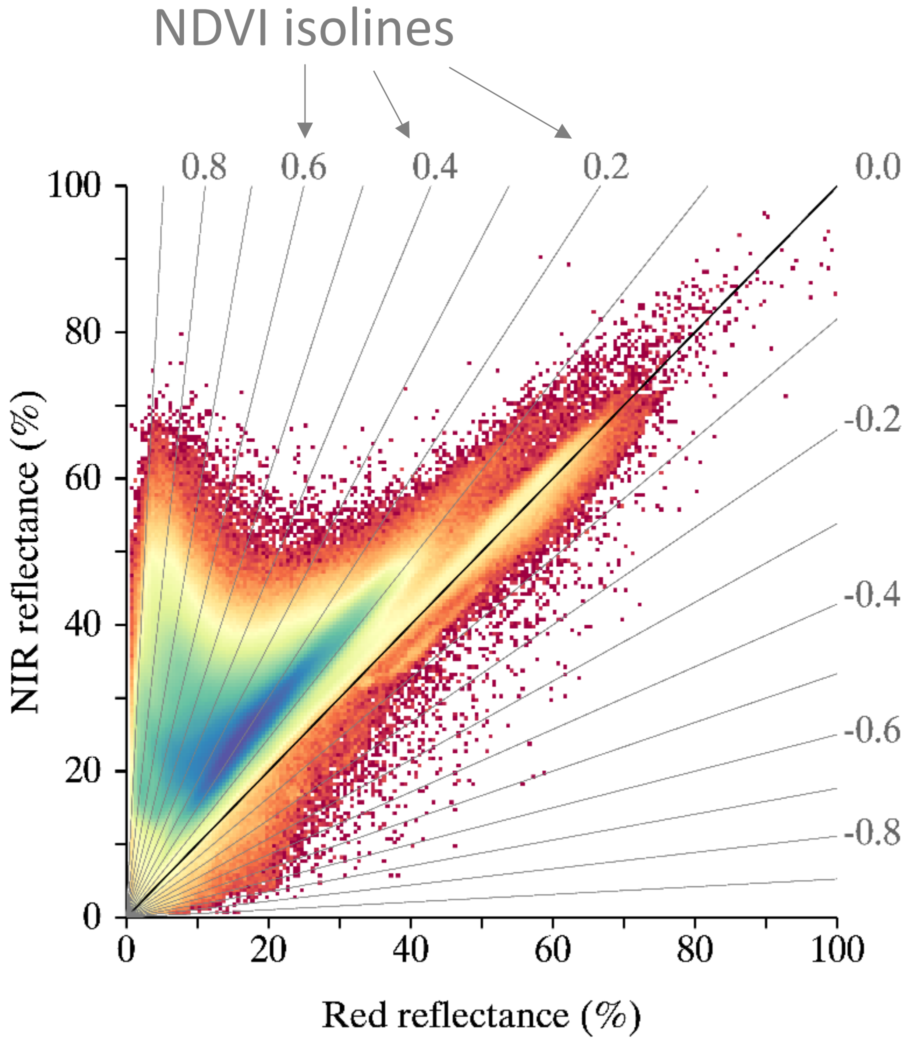
This is the 'soil line', which theoretically represents bare soil

Greenness indices



The more leaves that cover the ground, the relatively more R is absorbed

There's a maximum red edge that represents a full canopy (100% foliage cover)



Normalised Difference Vegetation Index (NDVI)

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

Data space is -1 to 1
Land surfaces range from ~0 to 1
That this is a *difference ratio* is important,
 because this minimises numerous errors
 (viewing angle, shadow etc)
Is a relative index (not biophysical)…but is
 linearly related to foliage cover

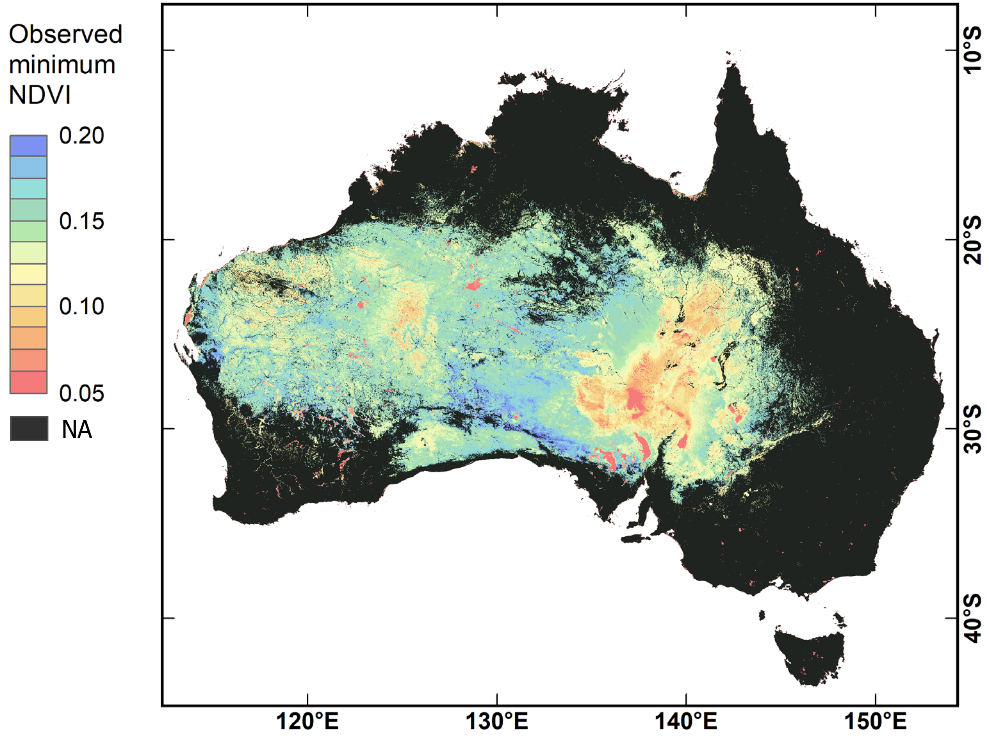
Rouse *et al.* (1974) *Monitoring the vernal advancement and retrogradation (greenwave effect) of natural vegetation. Report number NASA/GSFC Type III Final Report, Greenbelt.*
Tucker (1979) Red and photographic infrared linear combinations for monitoring vegetation. *RSE 8(2), 127-150.*

Foliage cover

NDVI can be approximately converted to foliage cover according to

$$F = \frac{\mathrm{NDVI} - \mathrm{NDVI}_{\mathrm{min}}}{\mathrm{NDVI}_{\mathrm{max}} - \mathrm{NDVI}_{\mathrm{min}}}$$

F = foliage cover (fraction)
$NDVI_{min}$ = minimum (soil) NDVI
$NDVI_{max}$ = maximum NDVI (dense, full canopy)



Soil NDVI ($\mathrm{NDVI}_{\mathrm{min}}$) is very difficult to know without field measurements. Lab measurements show it varies between 0.05 and 0.4 but averages 0.2

Maximum NDVI ($\mathrm{NDVI}_{\mathrm{max}}$) can be derived by interrogating your NDVI image stack to see the maximum value in locations known to have full, dense canopies

Asrar et al. (1984) Estimating absorbed photosynthetic radiation and leaf-area index from spectral reflectance in wheat. *Agronomy Journal* **76**, 300-306.
Carlson and Ripley (1997) On the relation between NDVI, fractional vegetation cover, and leaf area index. *Remote Sensing of Environment* **62**, 241-252.
Montandon and Small (2008). The impact of soil reflectance on the quantification of the green vegetation fraction from NDVI. Remote Sensing of Environment, 112, 1835-1845.

Greenness and leaf cover

Foliage cover fraction

Is the fraction of ground that is covered (from vertically above) by green foliage. Ranges between 0 and 1.

Fraction of absorbed PAR (fPAR)

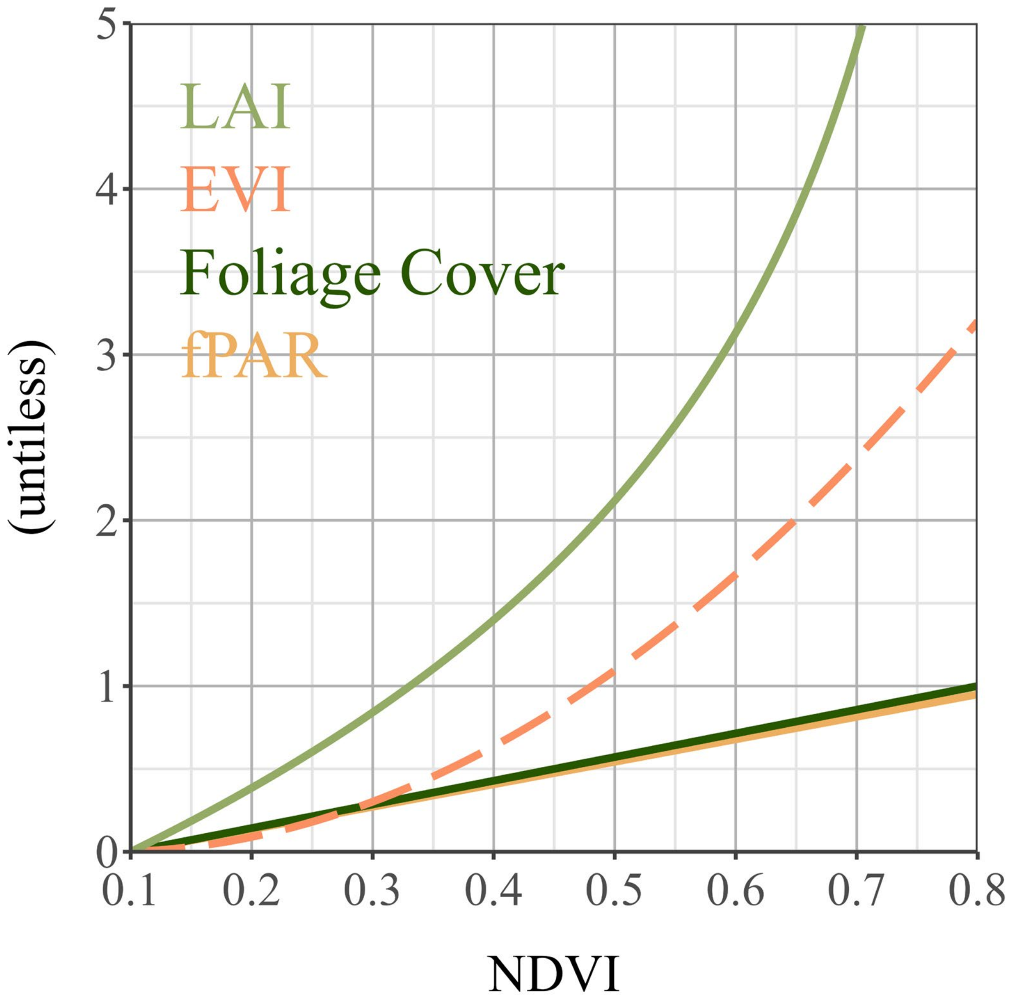
Is the fraction of incoming photosynthetically active radiation (PAR; that is, visible light) absorbed by foliage. ≈ foliage cover x 0.95 (leaves reflect ~ 5% PAR).

Enhanced vegetation index (EVI)

Absolutely no idea

Leaf Area Index (LAI)

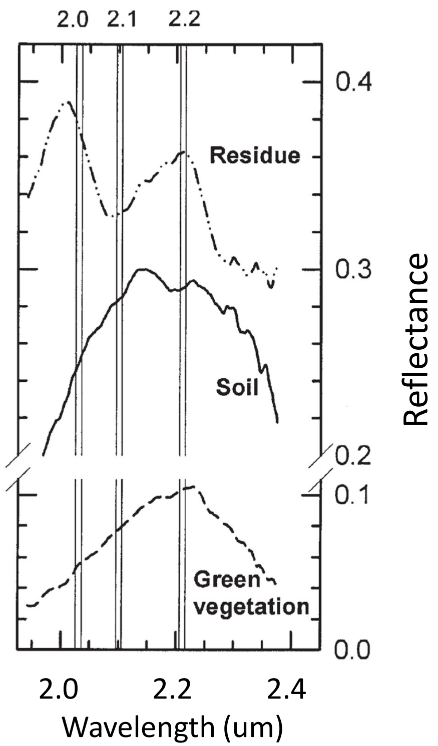
Is the ratio of (one-sided) green leaf area to the underlying ground area. Units are m^2/m^2 (i.e. unitless) and values range between 0 and 15 (and above).



Honourable mention VIs

Cellulose absorption index (CAI)

Cellulose has an absorption feature at 2.1 um



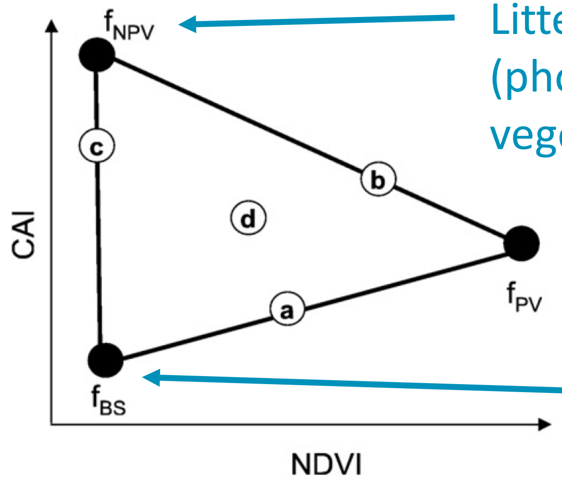
Daughtry *et al.* (2005) RemSens

$$CAI = \frac{\rho_{2.0} + \rho_{2.2}}{2} - \rho_{2.1}$$

Describes the relative abundance of dead foliage (no chlorophyll) and other litter, and how dry it is

Fractional cover from NDVI & CAI

Green cover fraction + litter cover fraction + bare ground fraction = 1



Guerschman *et al.* (2009)

Applications

- Bare ground (erosion, dust potential)
- Grass curing
- Land condition/disturbance
- Vegetation ‘nativeness’

Honourable mention VIs

Solar-induce fluorescence (SIF)

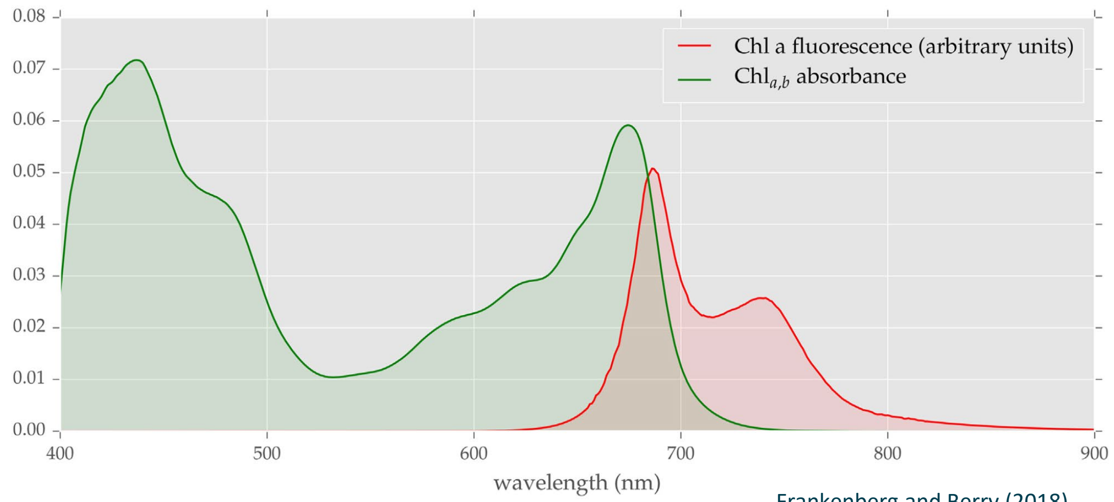
When photosynthesising, leaves *emit* a little bit of red & NIR light

It is very small (0.5%) compared to the red & NIR reflected (hence, we can't see it)

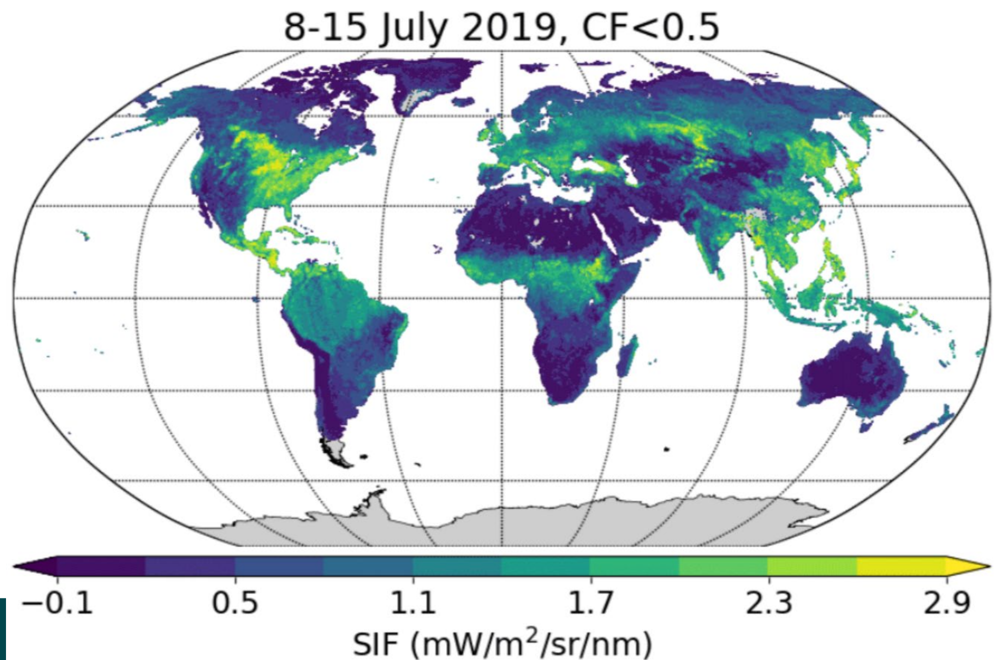
There are very narrow bands in the red spectrum where sunlight is absent. Reflectance from plant surfaces *should be* zero here, and any light detected is from fluorescence.

Satellites with very specific, narrow red bands can therefore detect SIF, which is proportional to photosynthetic rate.

SIF imagery is very coarse-scale



Frankenberg and Berry (2018)



Gaunter *et al.* (2021) ESSD

Honourable mention VIs

Photochemical reflectance index (PRI)

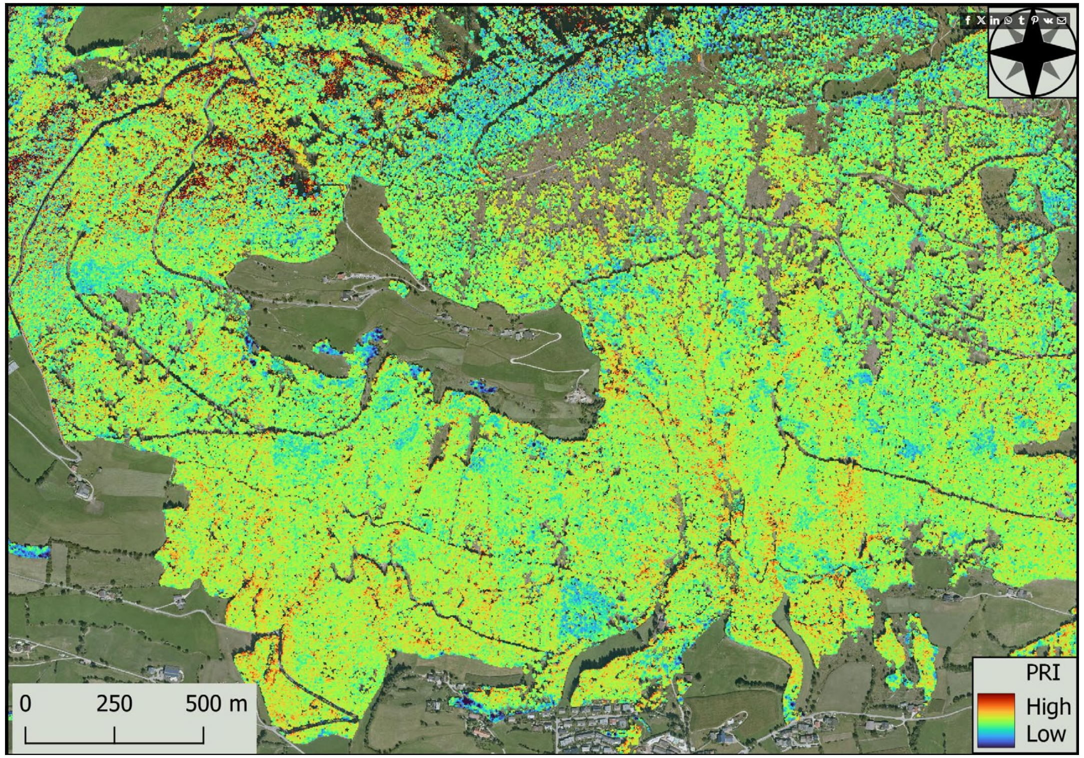
For a given amount of sunlight, photosynthesis is determined by the leaf area and the efficiency with which light can be used to capture CO_2 (= 'light use efficiency', or LUE):

$$\text{photosynthesis} = \text{sunlight} \times \text{leaf area} \times \text{LUE}$$

Under stress, leaves produce more carotenoids (yellow-brown pigments) for a given amount of chlorophyl, which lowers the LUE. Carotenoids also absorb more blue-green light (at 0.53 um)…

The PRI measures the abundance of carotenoids relative to chlorophyl:

$$\mathrm{PRI} = \frac{\rho_{0.53} - \rho_{0.57}}{\rho_{0.53} + \rho_{0.57}}$$



AVT Airborne Sensing

Applications

- LUE and photosynthesis
- Disease and plant health
- Plant stress (water, nutrients, heat etc)