From leaves to ecosystems: what can we learn about fluxes using remote sensing?

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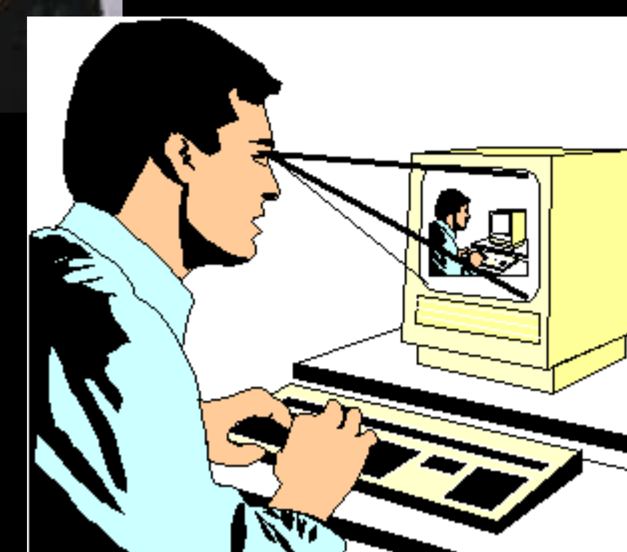
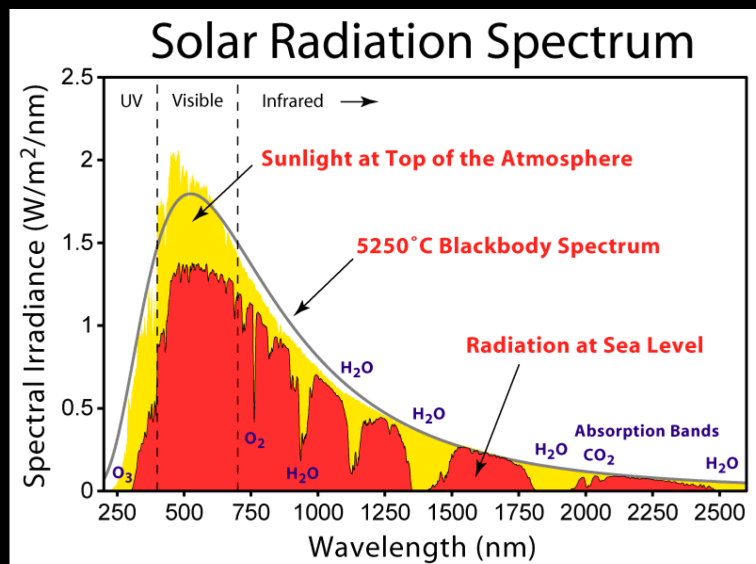
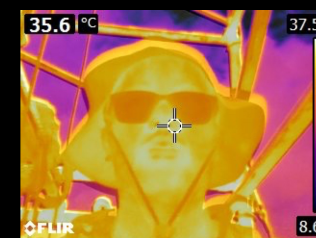
What is remote sensing?

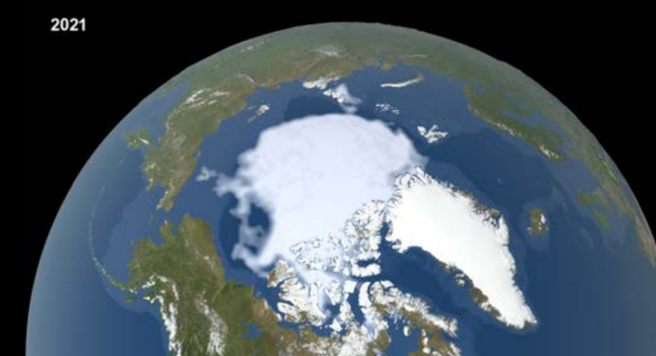
- Remote sensing: the acquisition of information about an object without making physical contact with the objects.



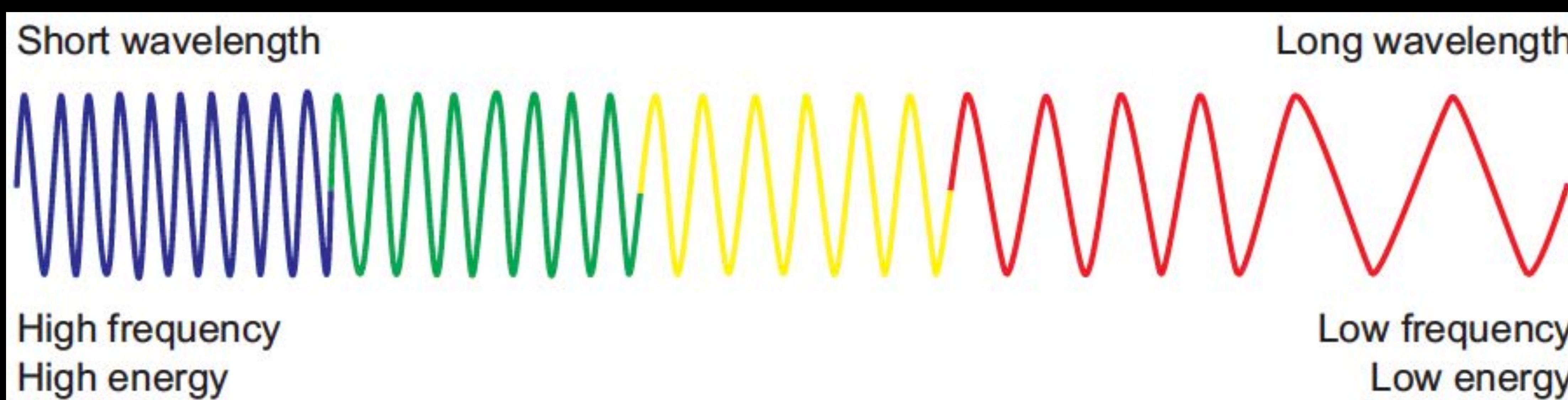
Remote sensing measures radiation







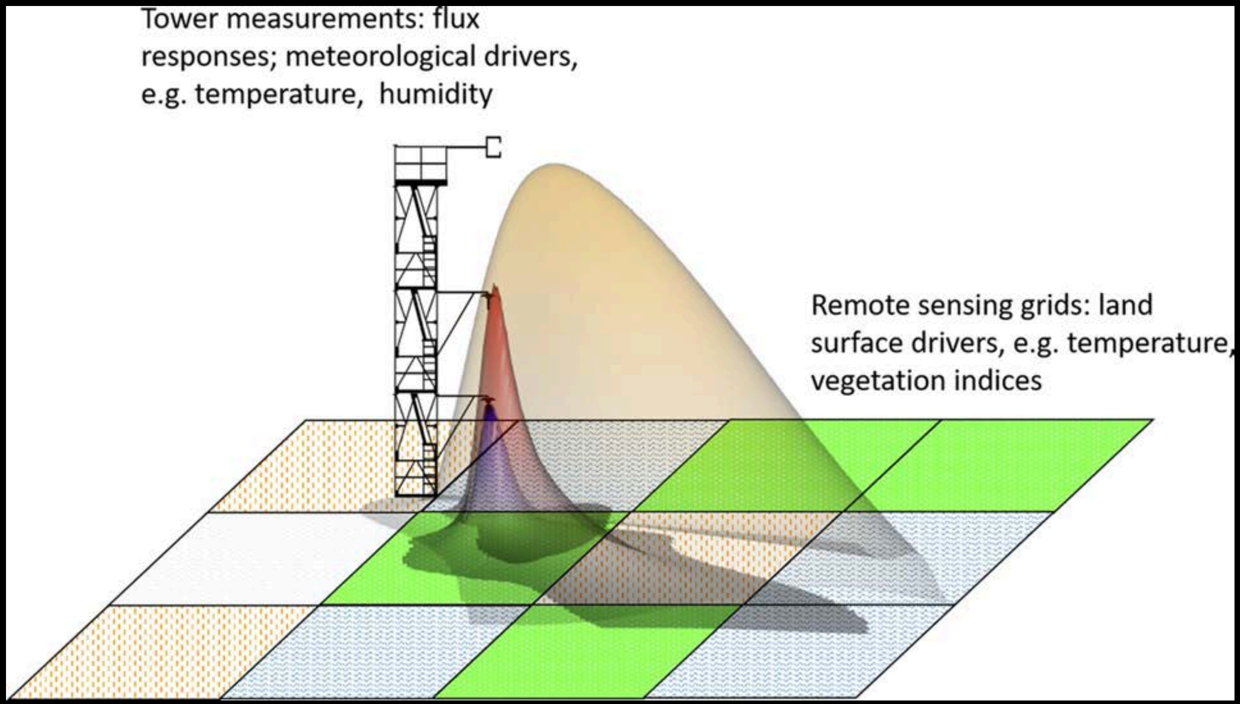
UV Visible NIR SWIR TIR FIR Microwave



Remote sensing ***products*** of fluxes (e.g., GPP and ET) are not ***measurements***, but rather modeling results using remote sensing measurements of radiation based on certain assumptions.

RS and Flux Tower complement each other

Satellite vs. Flux Tower

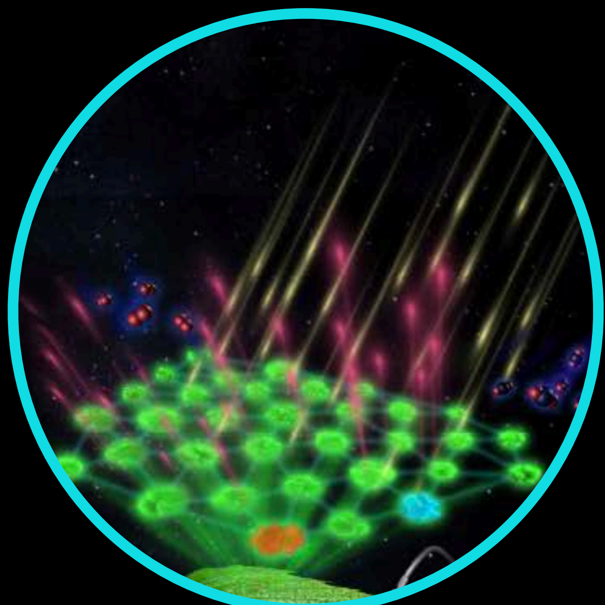


Metzger 2018

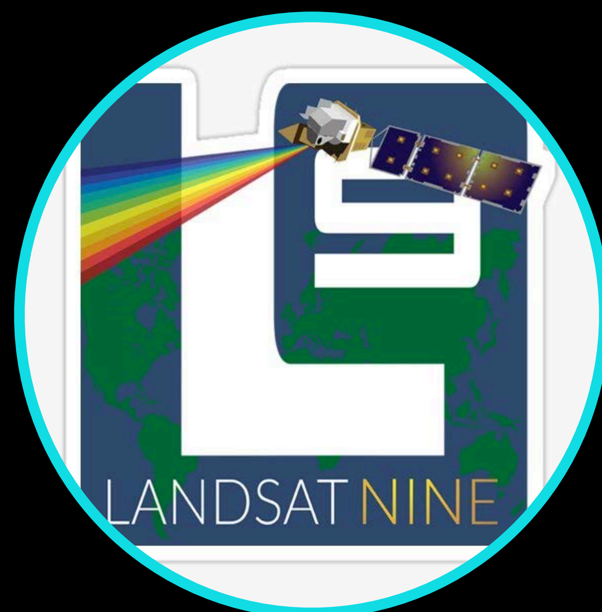
Optical tower-based instruments vs. Flux Tower

Source: Wayne Dawson

An exciting era for remote sensing

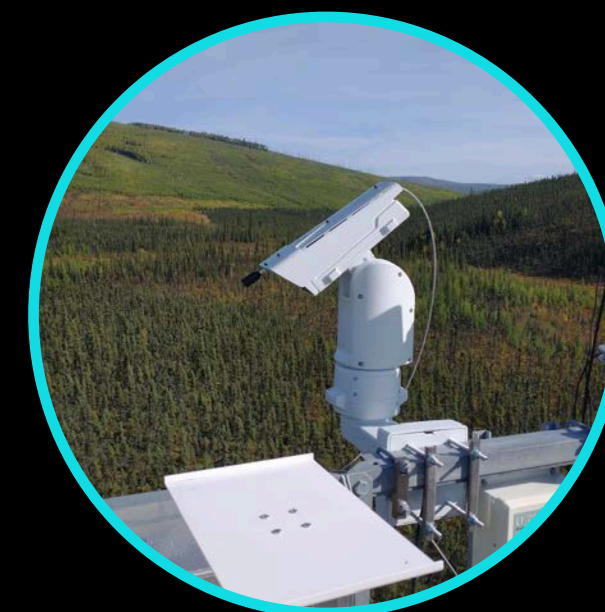


Novel technology and algorithms open new windows



The next generation satellite sensors

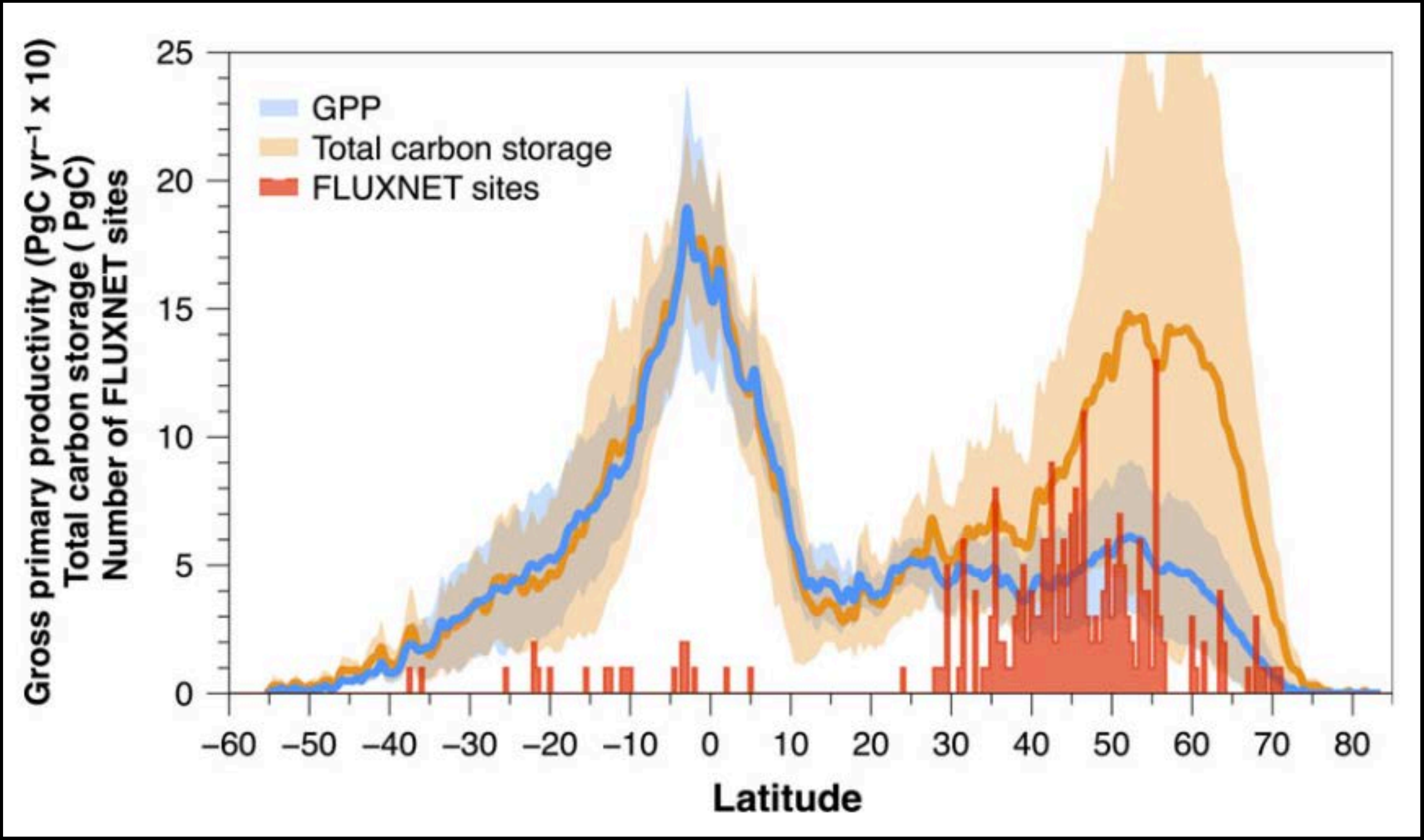
Drones!



Global networks of tower-based remote sensing

What can we learn about fluxes with remote sensing?

Remote sensing of global photosynthesis



Schimel et al., 2015

How is photosynthesis estimated? — leaf scale

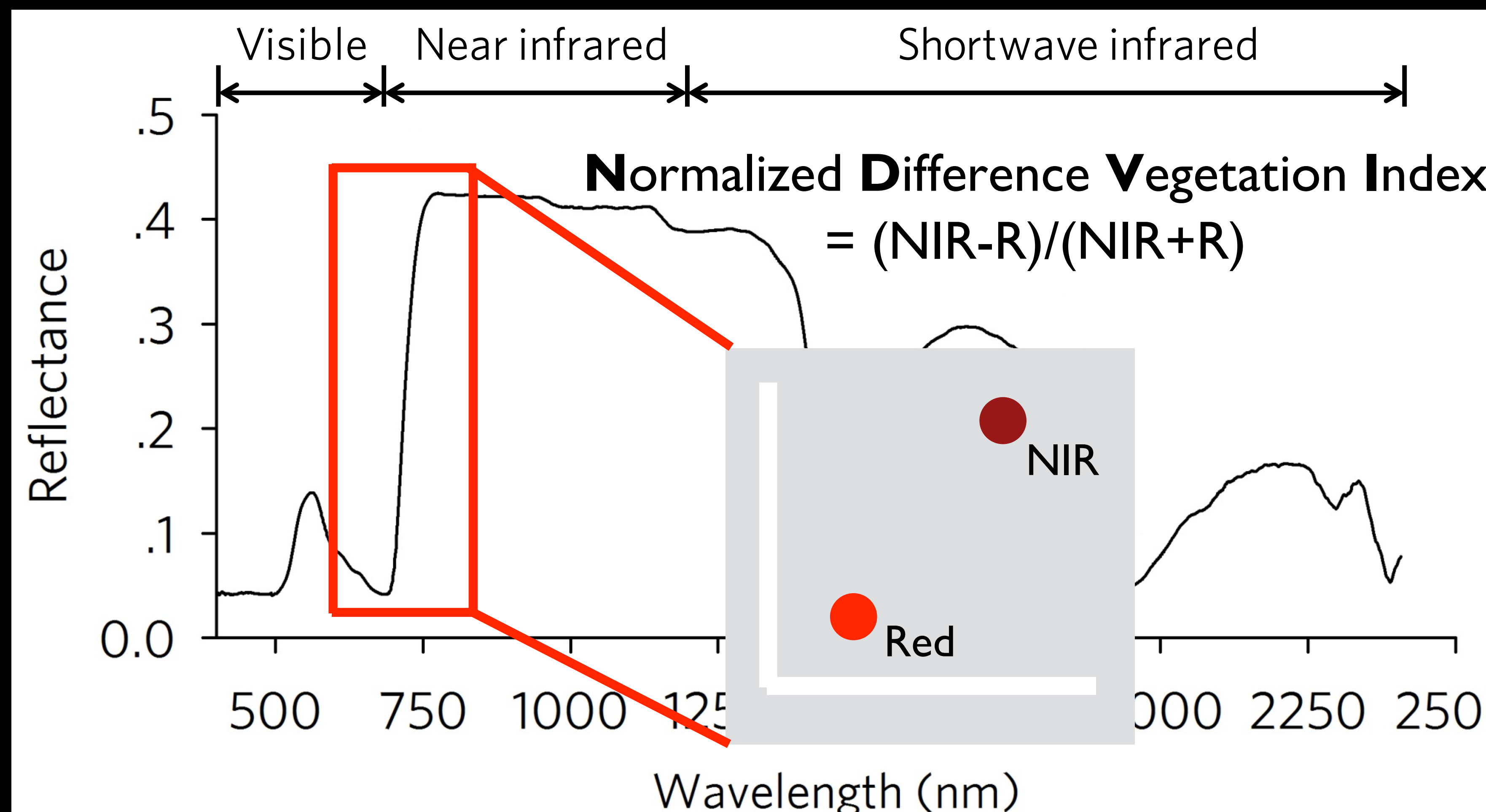
Portable
Photosynthesis System

Not-so-portable
Photosynthesis System

Source: Li-Cor; Joe Berry

Remote sensing of global photosynthesis

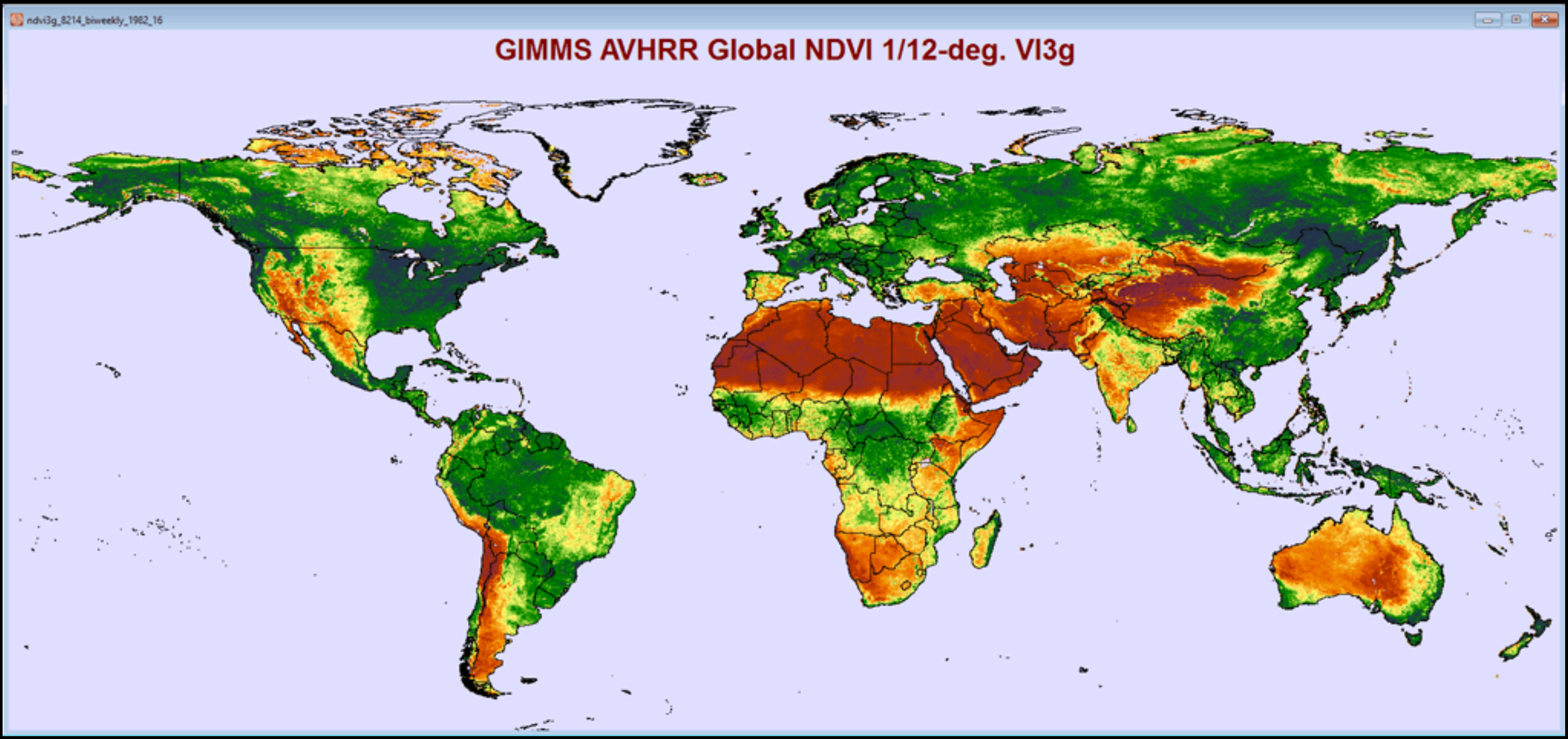
NDVI developed in the 1970s



Tucker 1979 RSE

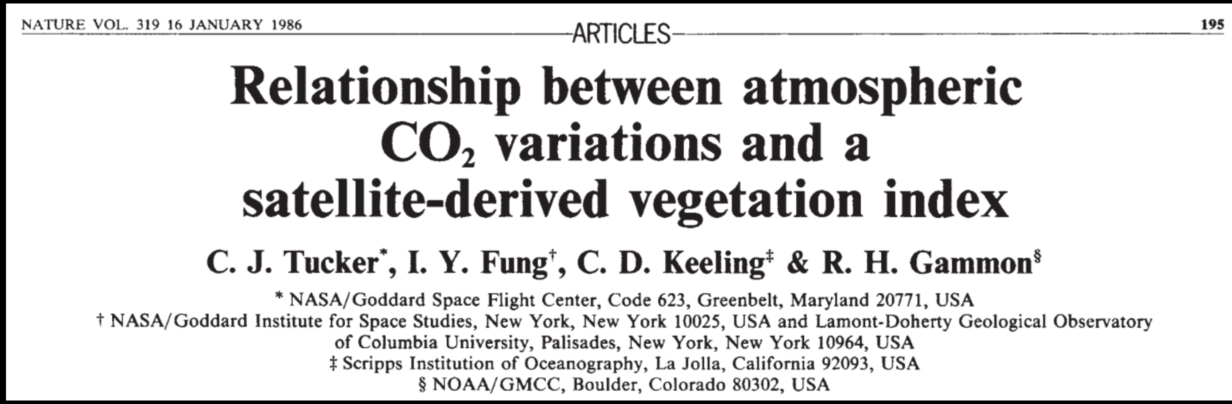
Remote sensing of global photosynthesis

Global mapping of vegetation in the 1980s



Remote sensing of global photosynthesis

Global mapping of vegetation in the 1980s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Relationship between atmospheric CO_2 variations and a satellite-derived vegetation index

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‡ Scripps Institution of Oceanography, La Jolla, California 92093, USA
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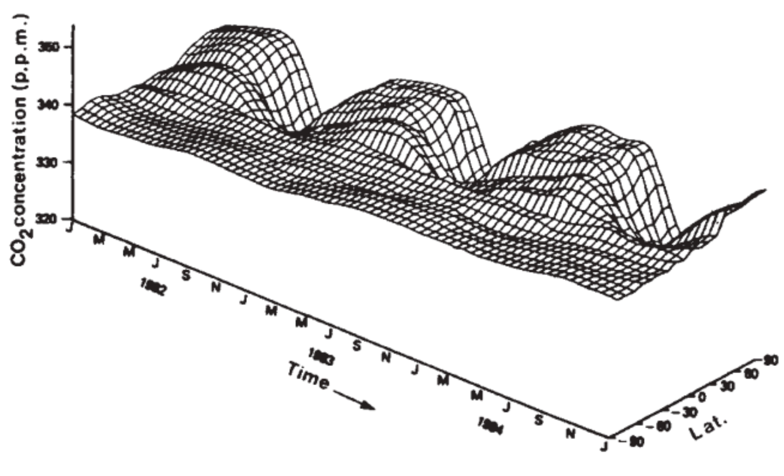
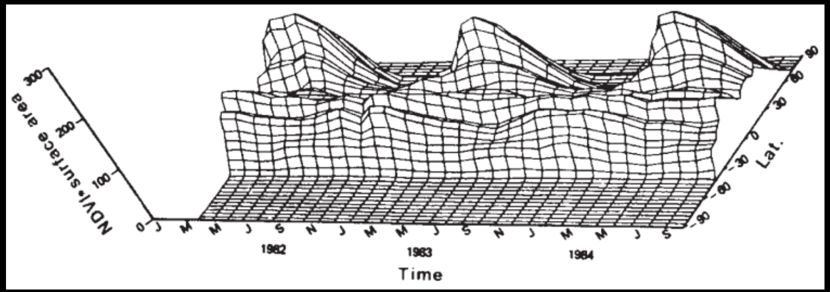


Fig. 1 Variation of global atmospheric CO_2 concentrations with latitude and time based on the NOAA/GMCC flask measurements for 1982–84.

CO2 concentration



NDVI

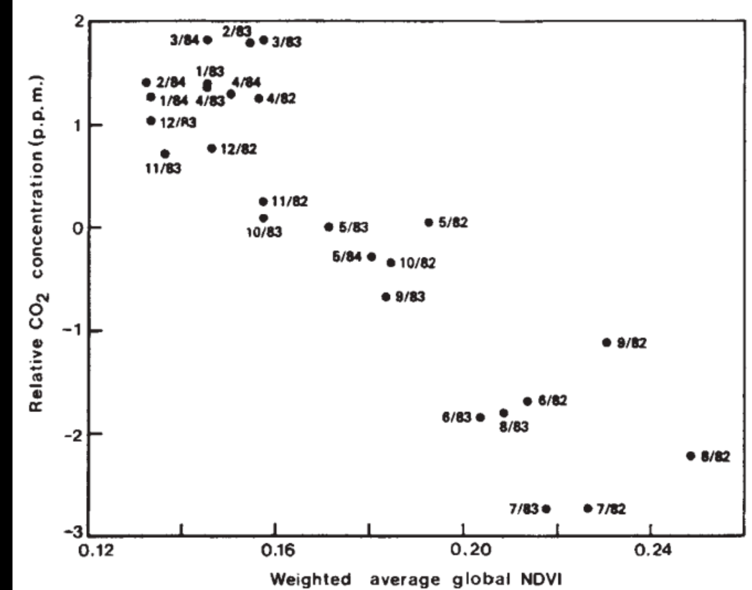
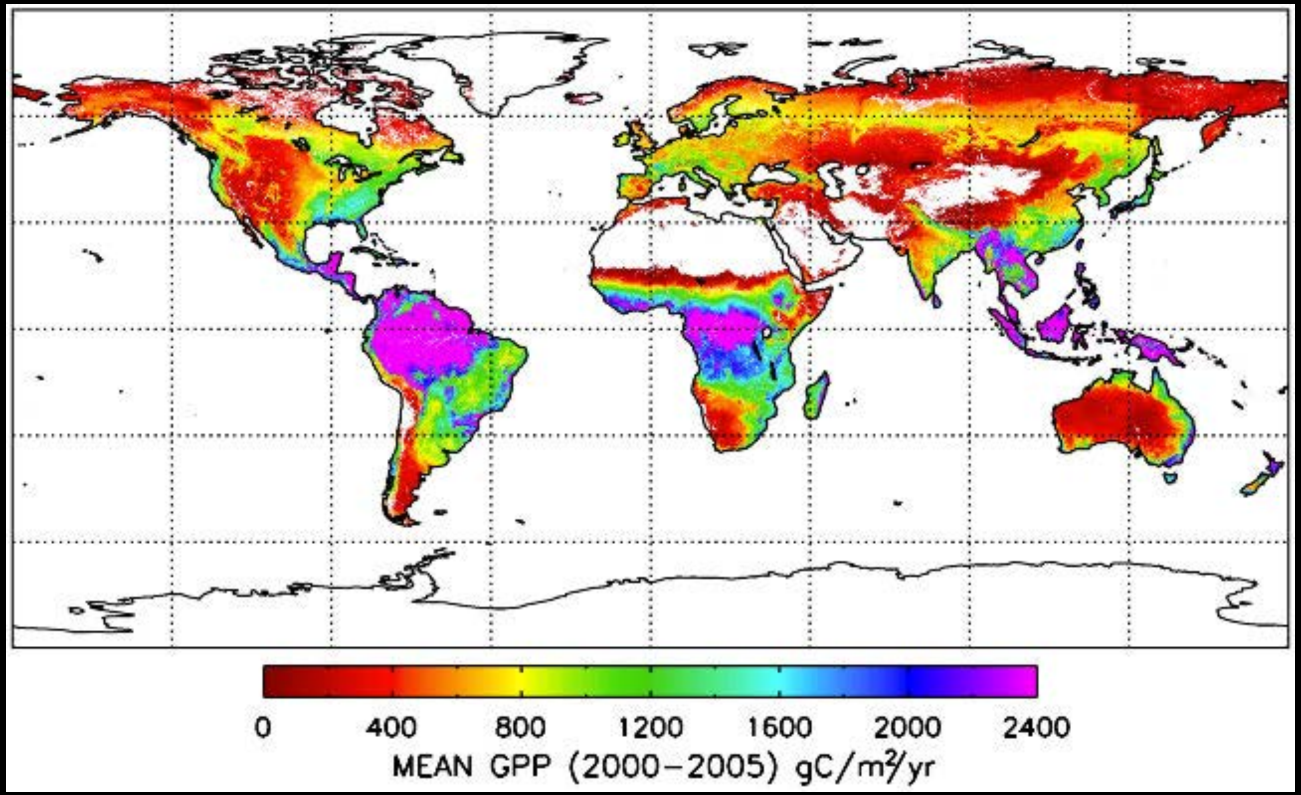


Fig. 4 The globally averaged atmospheric CO_2 concentration plotted against the globally averaged NDVI with a time lag of 1 month. The CO_2 data are from the global network of 20 NOAA/GMCC stations.

A negative relationship between CO2 concentration and NDVI

Remote sensing of global photosynthesis

MODIS in the 2000s



$$GPP = PAR \times fAPAR \times \varepsilon_p$$

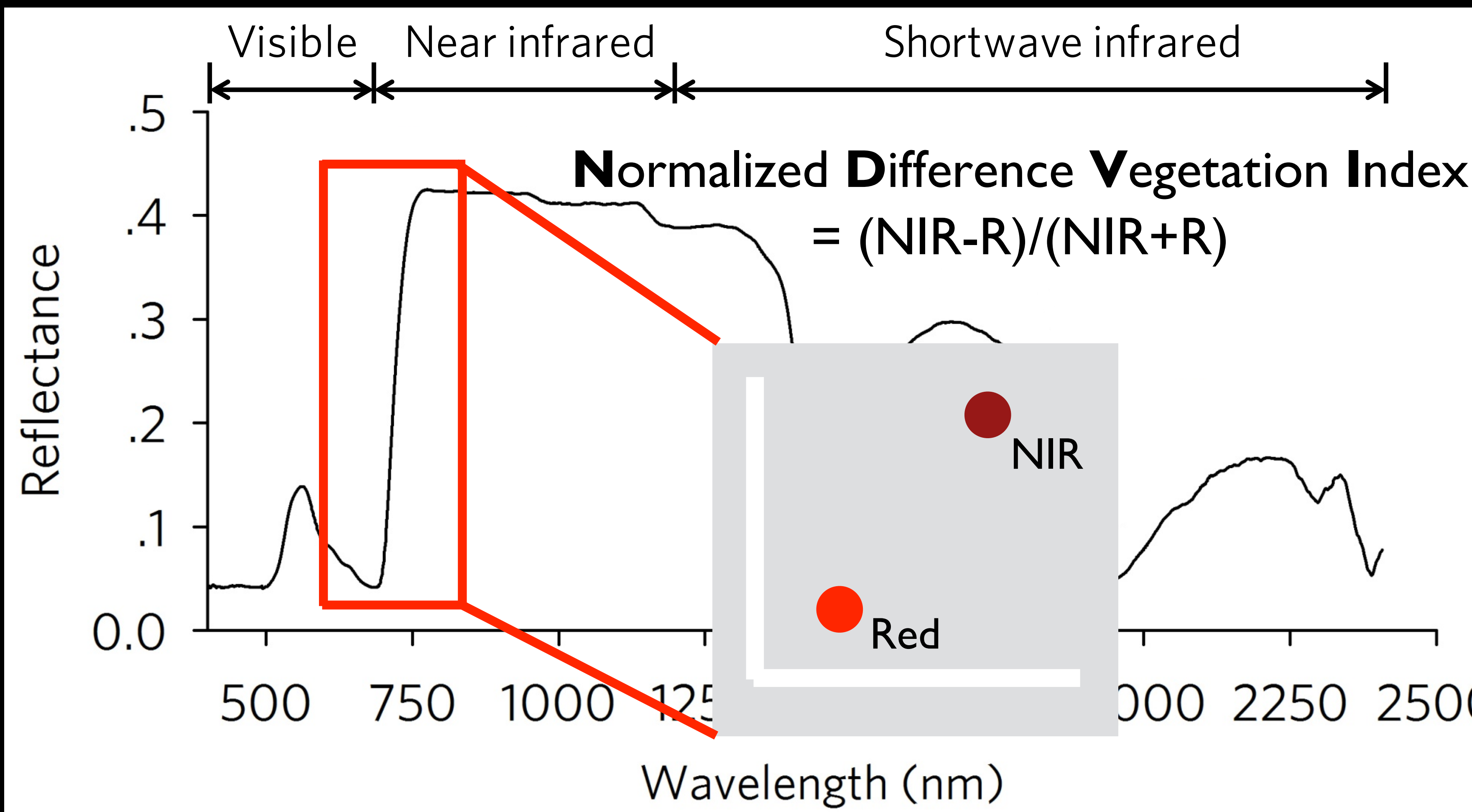
Absorbed PAR

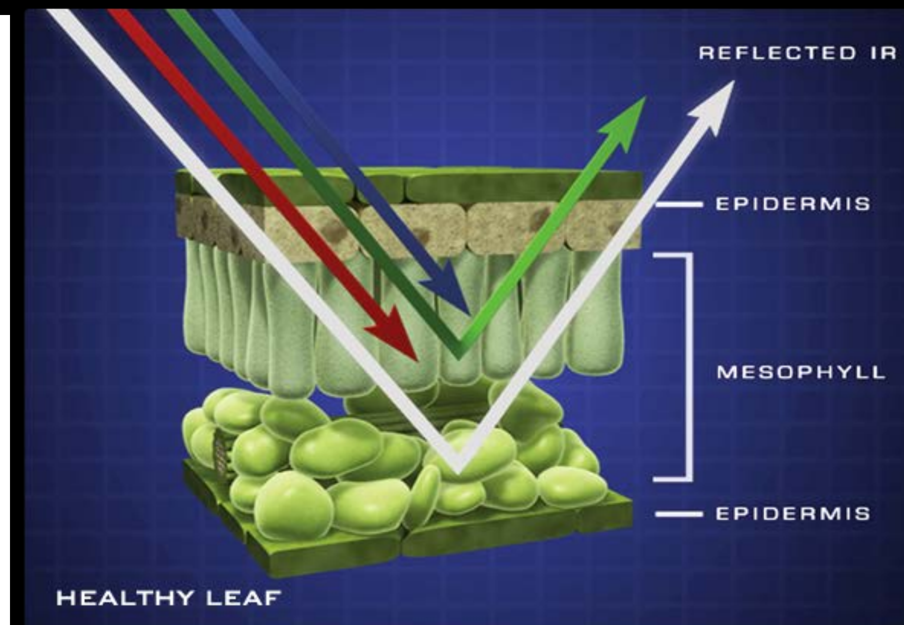
f(plant functional type, temperature, water availability)

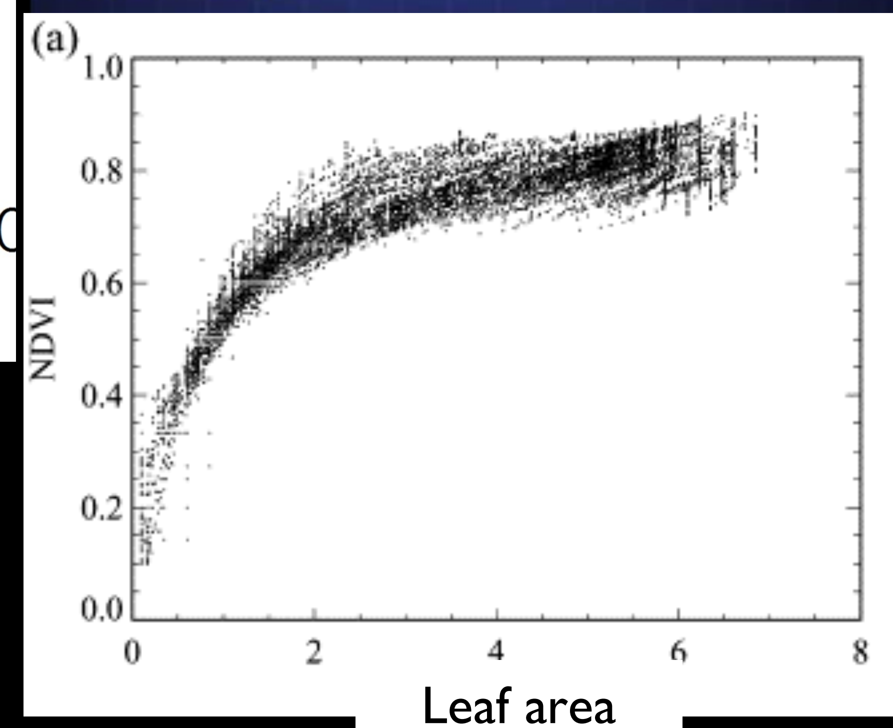
PAR: Photosynthetically Active Radiation

fAPAR: Fraction of PAR absorbed by leaves

The vegetation index is a measure of the "greenness" of tree canopy







Myneni et al. 2002

$GPP = PAR \times fAPAR \times \varepsilon_p$

Estimated in a similar way as Vegetation Index

f(plant functional type, temperature, water)

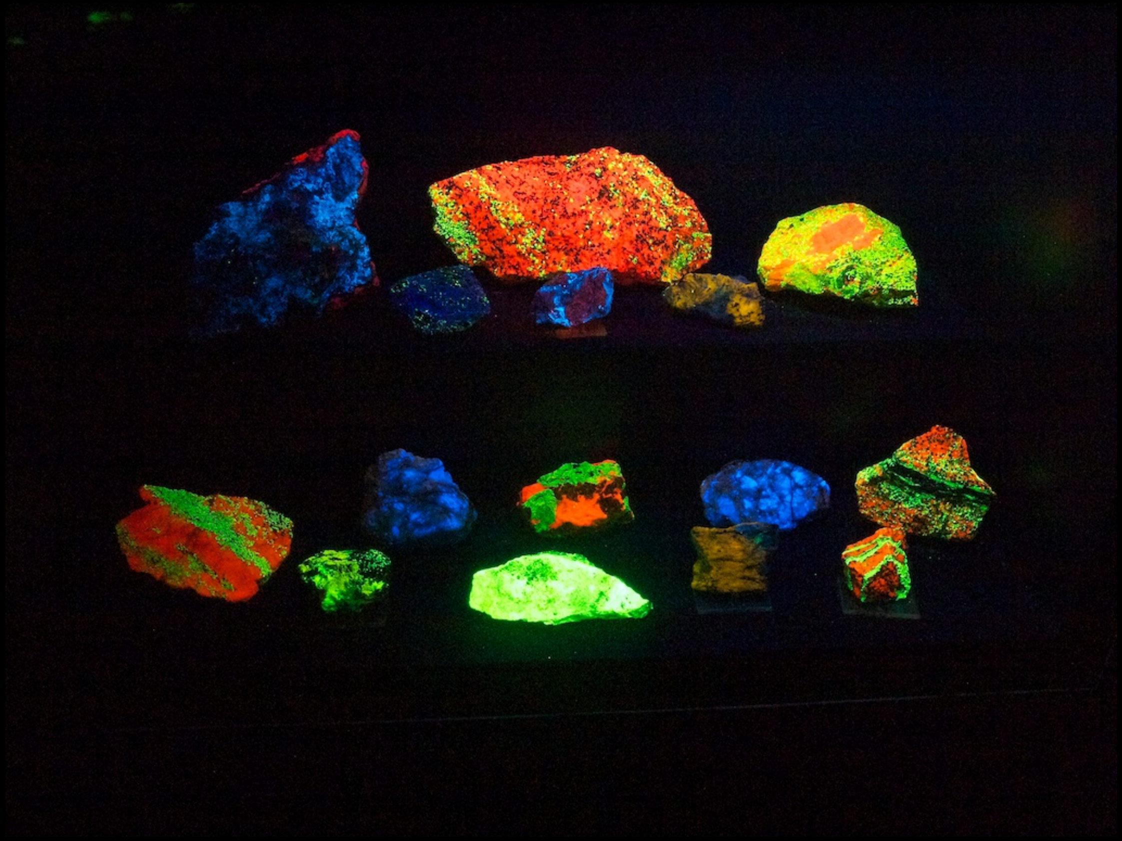
PAR: Photosynthetically Active Radiation

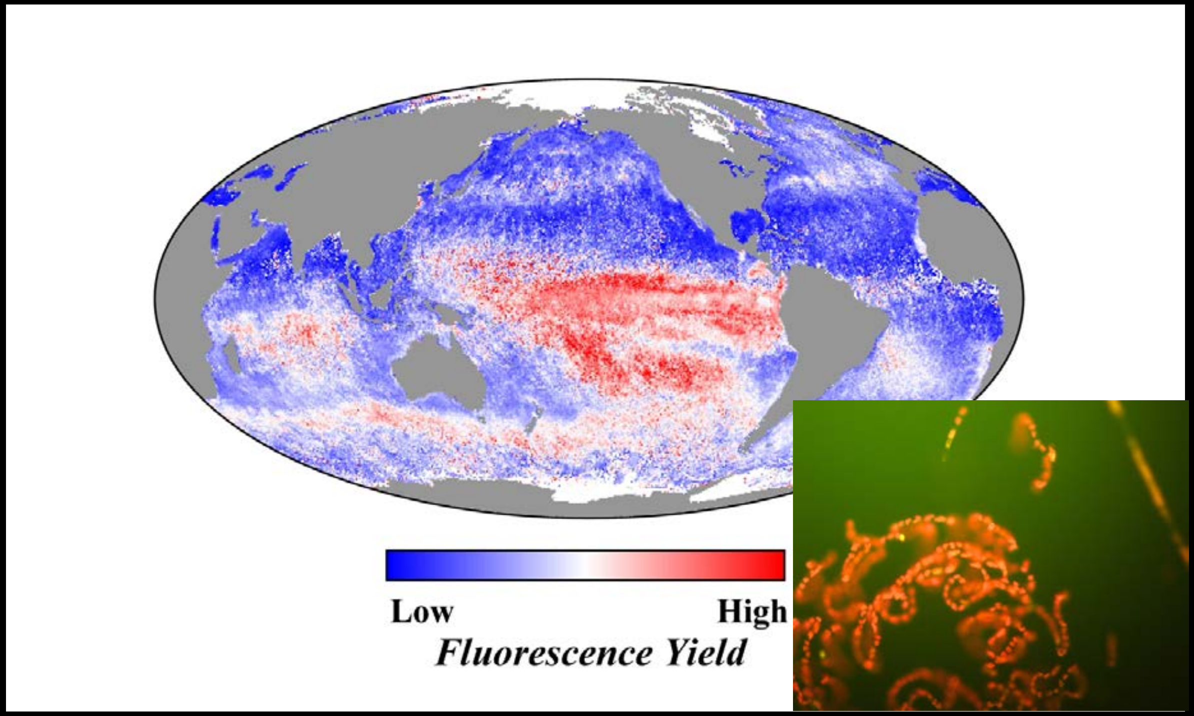
fAPAR: Fraction of PAR absorbed by leaves

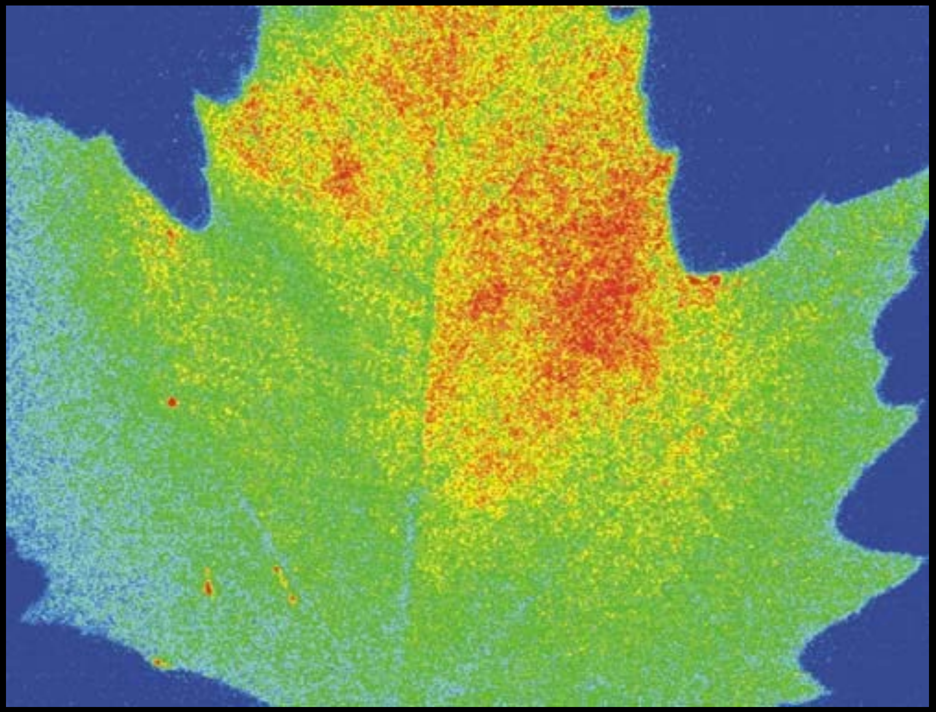
Vegetation index is about potential photosynthesis

Is there a tool that can help us to tell the real-time photosynthesis of plants globally?

Fluorescence in nature

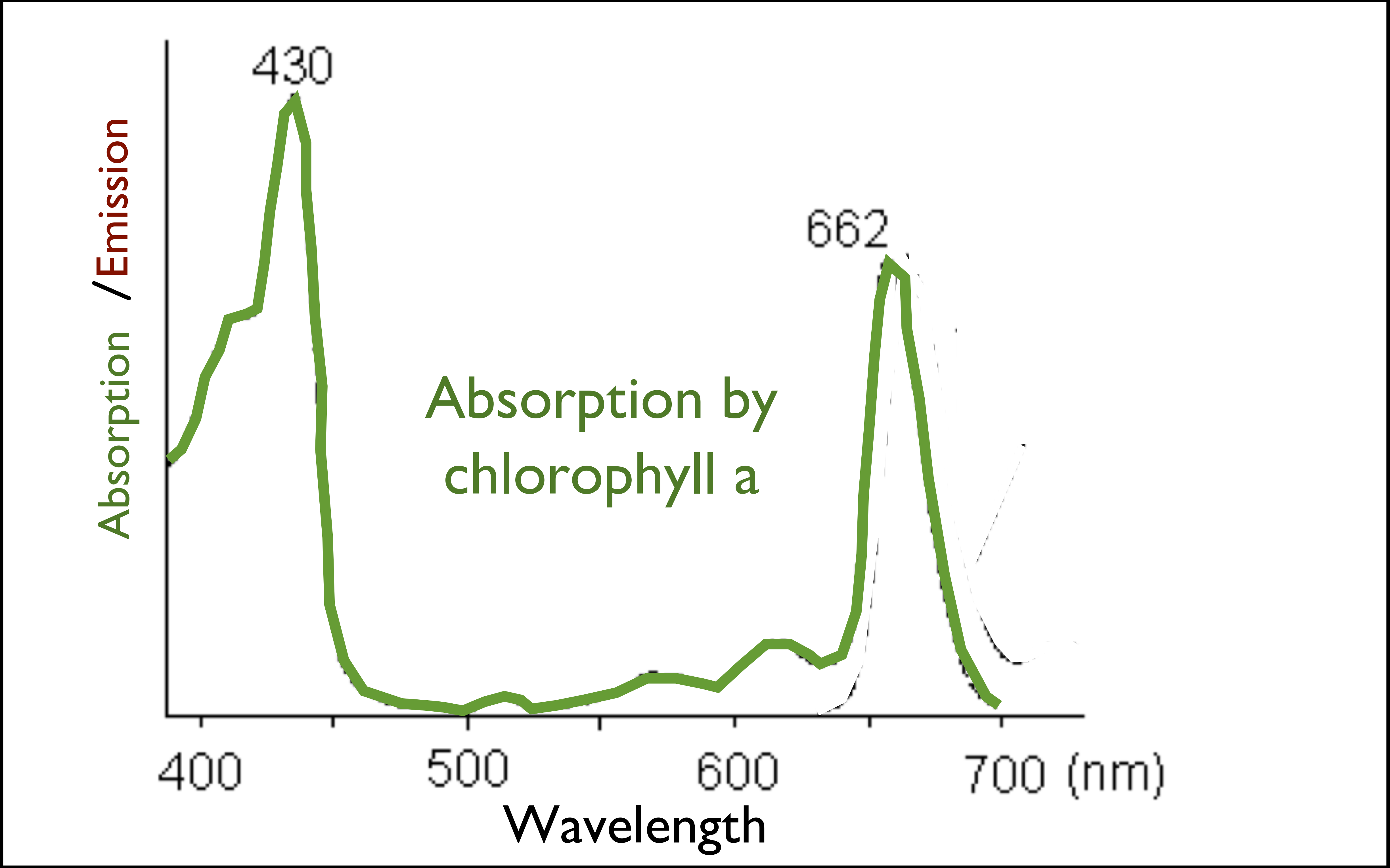




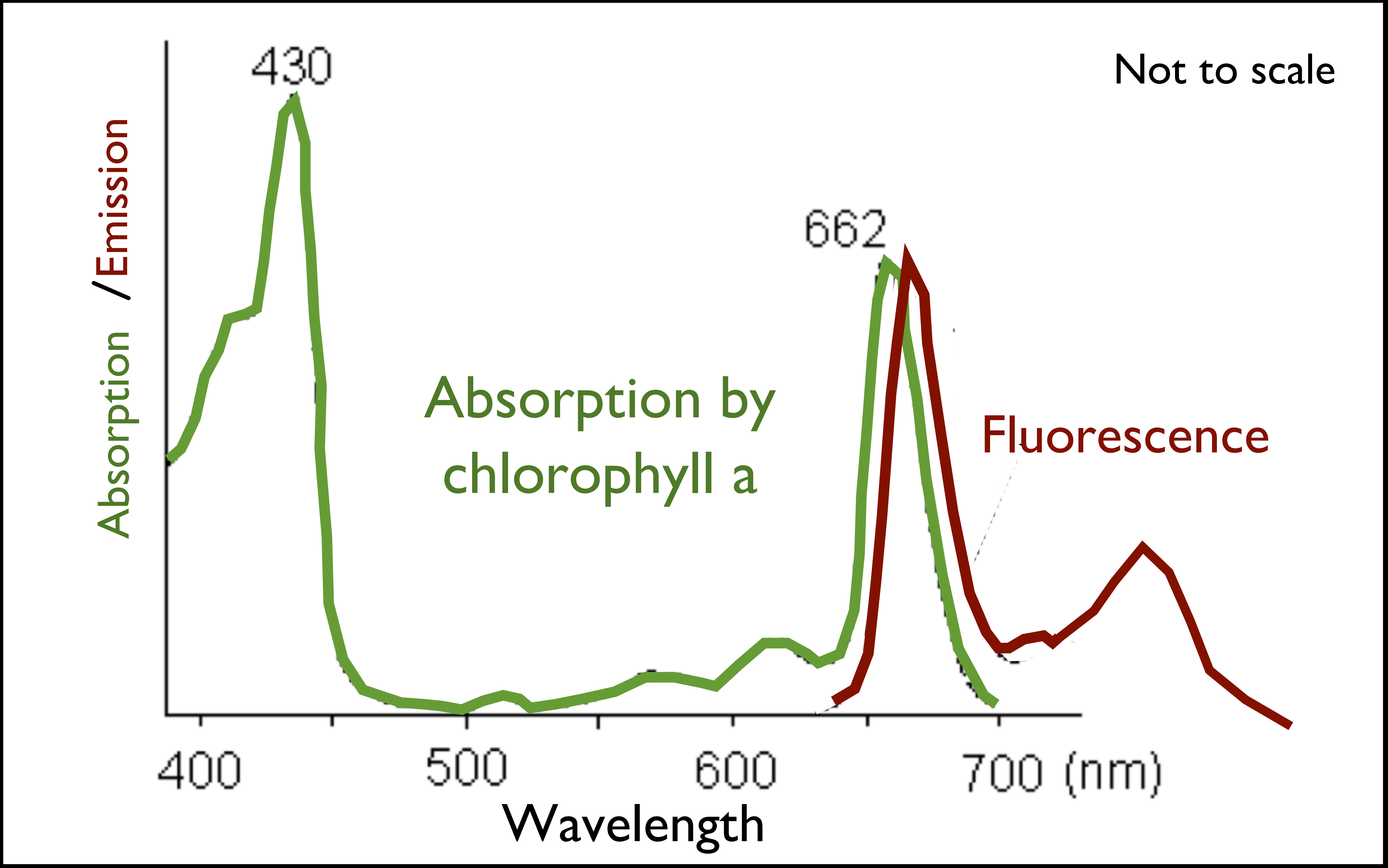


Source:Matt Reinbold; Wikipedia; NASA

Chlorophyll absorb mainly blue and red photons

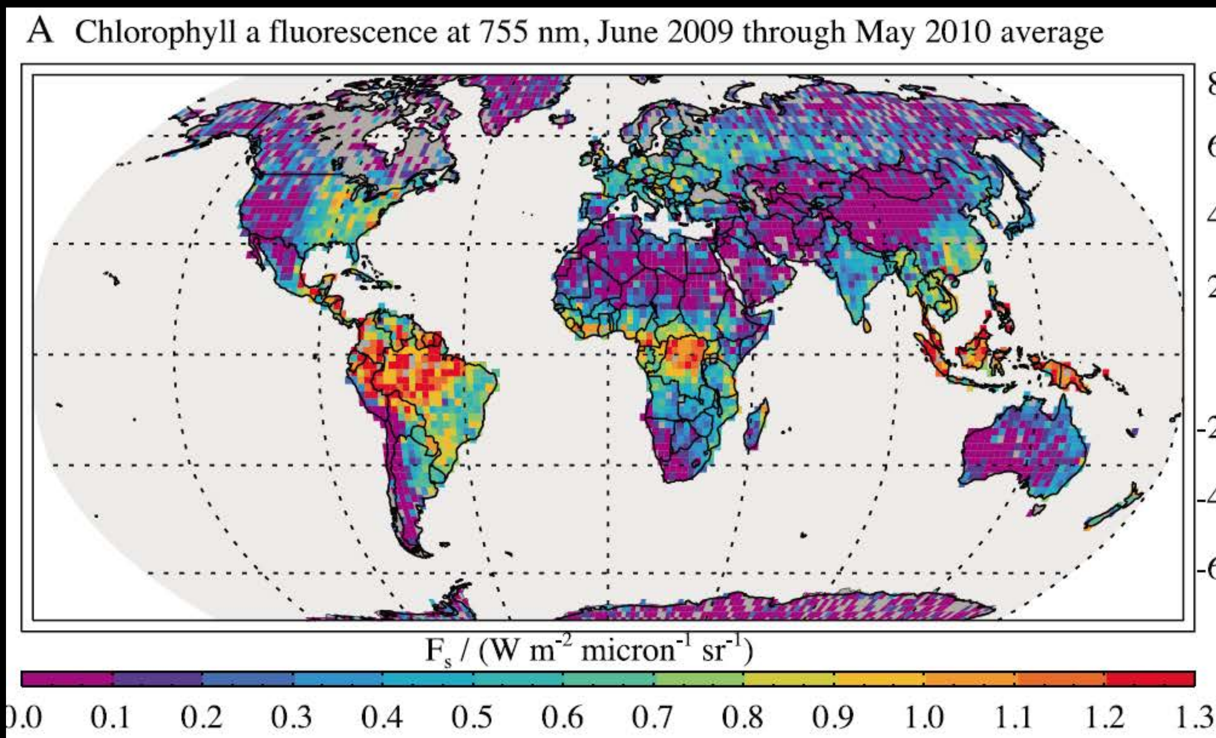


SIF is emitted in a longer wavelength



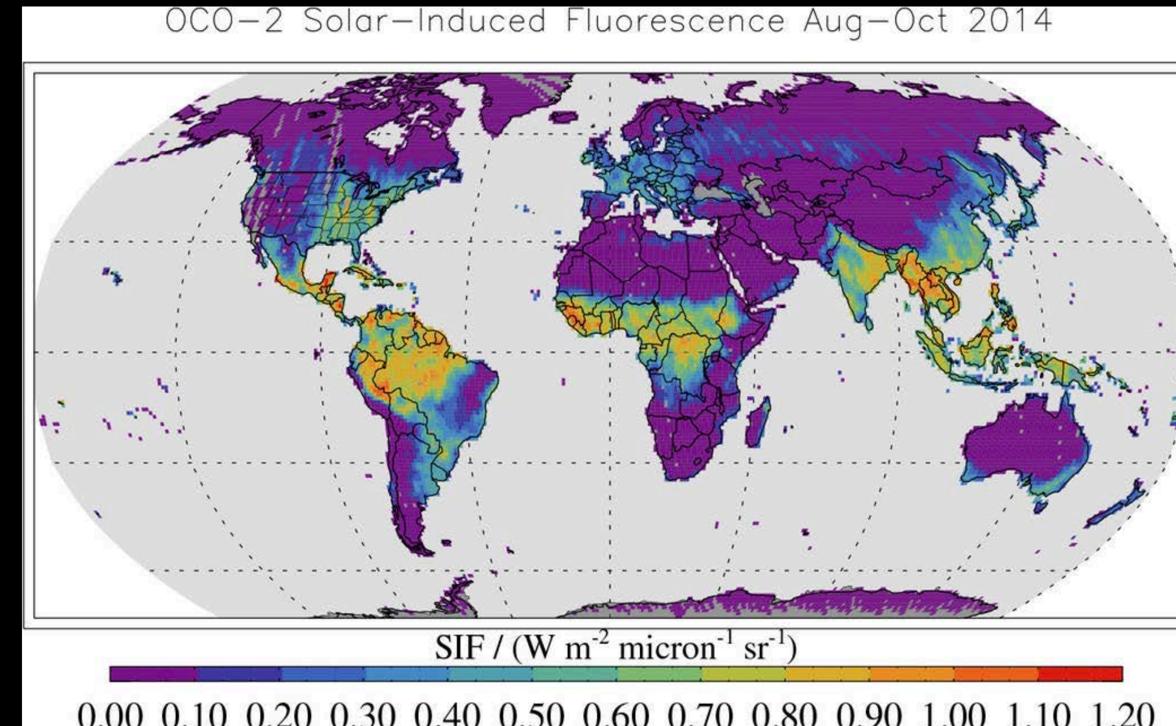
Satellite measurements of SIF

SIF from GOSAT



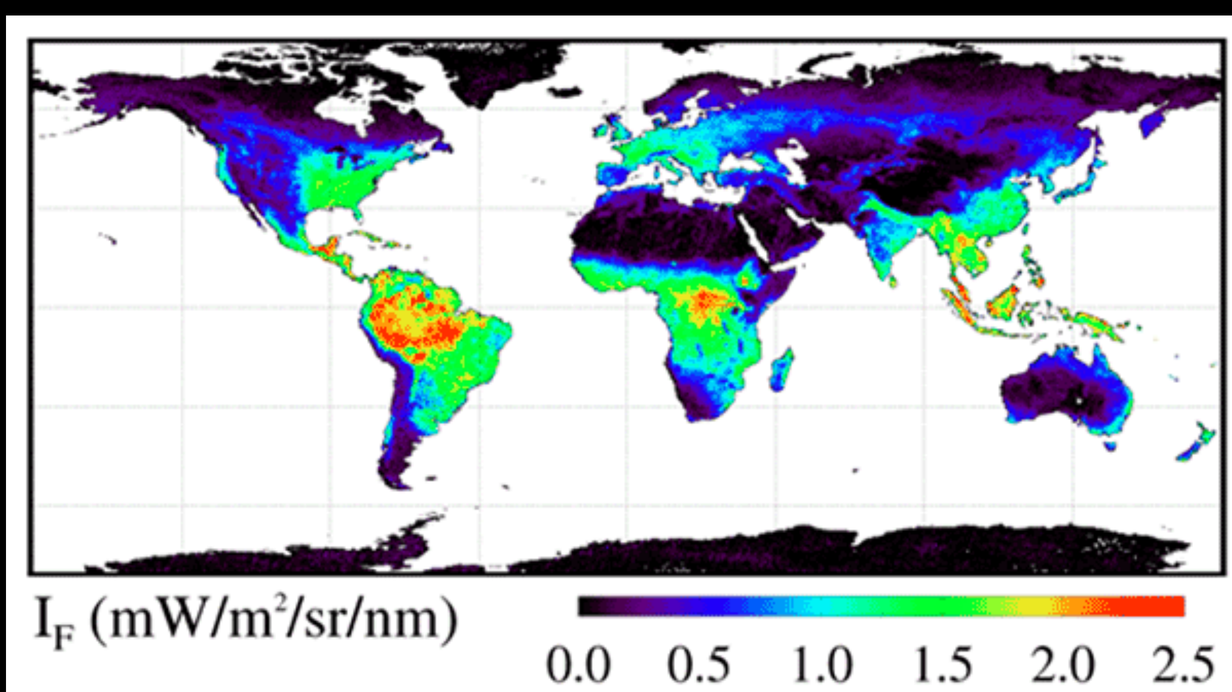
Frankenberg et al., 2011

SIF from OCO-2



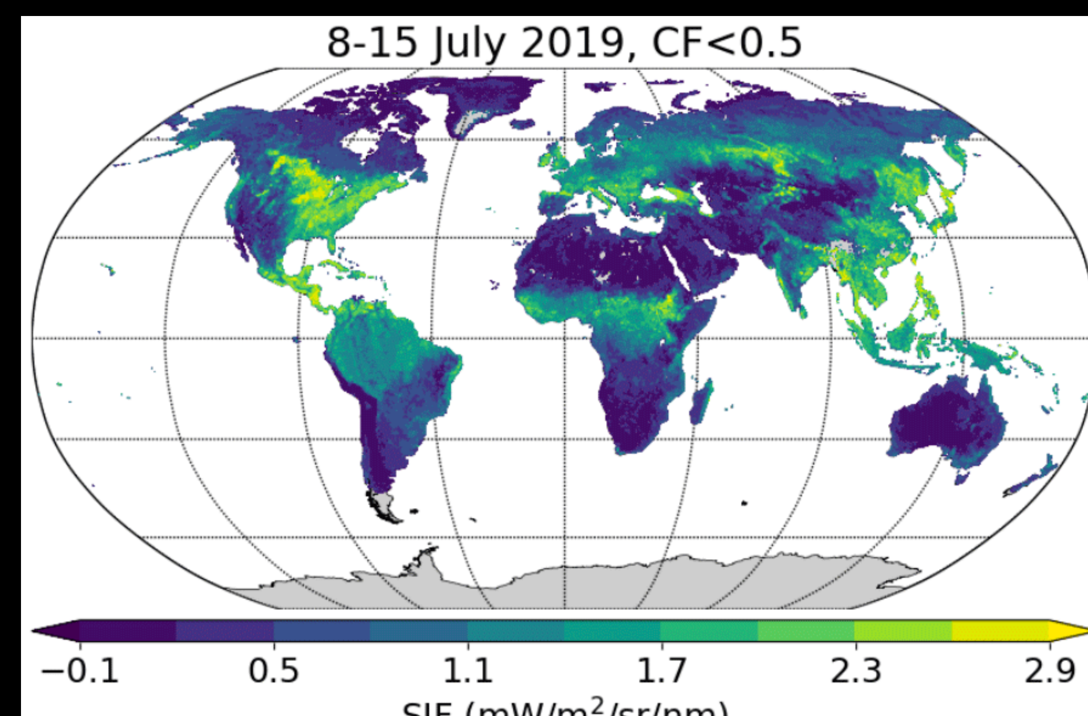
NASA JPL

SIF from GOME-2



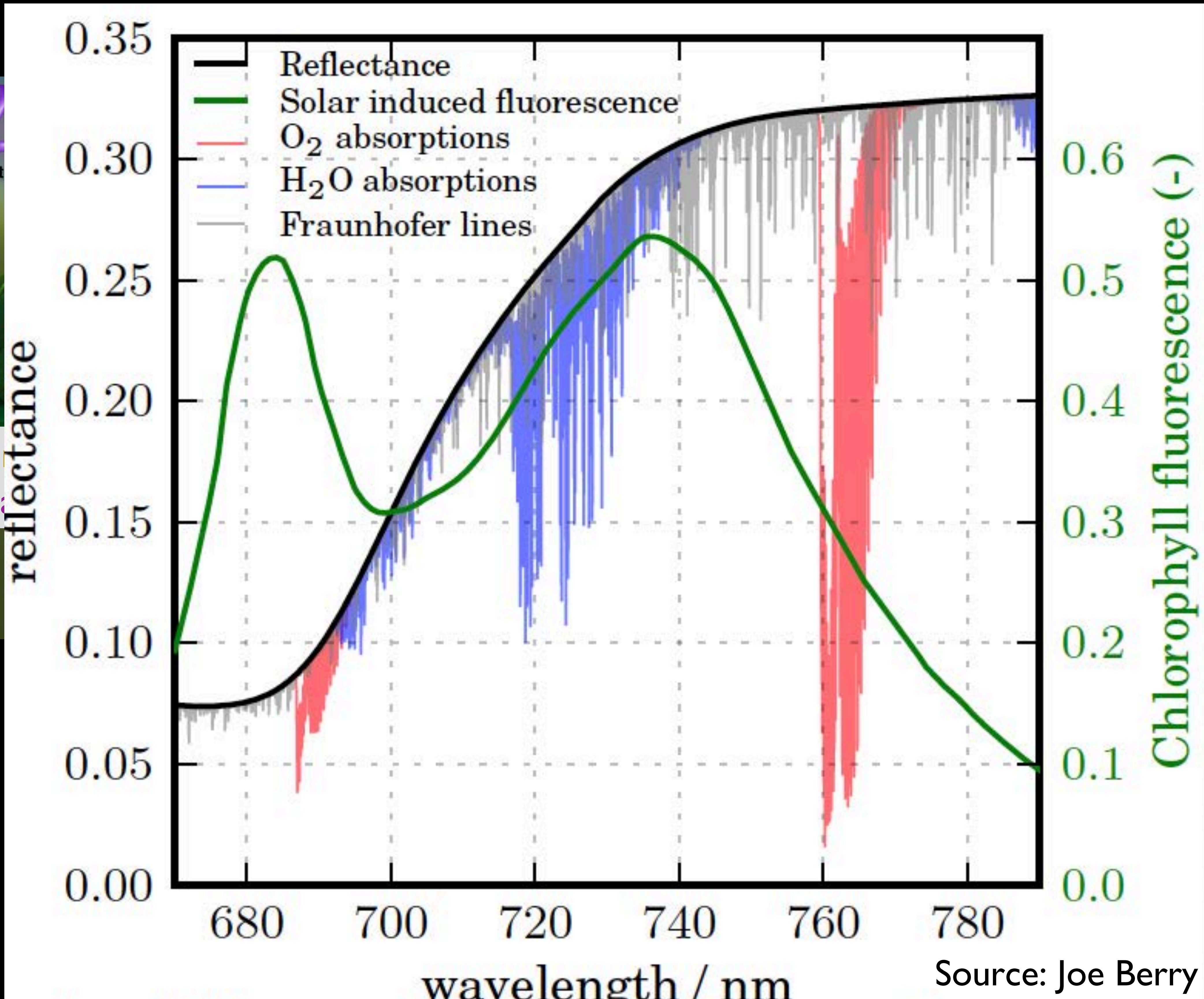
Joiner et al., 2011

SIF from TROPOMI



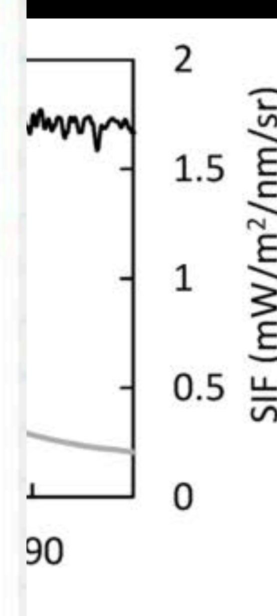
Guanter et al., 2020

Solar-induced chlorophyll fluorescence (SIF)



Source: Joe Berry

eflected



Liu et al., 2014

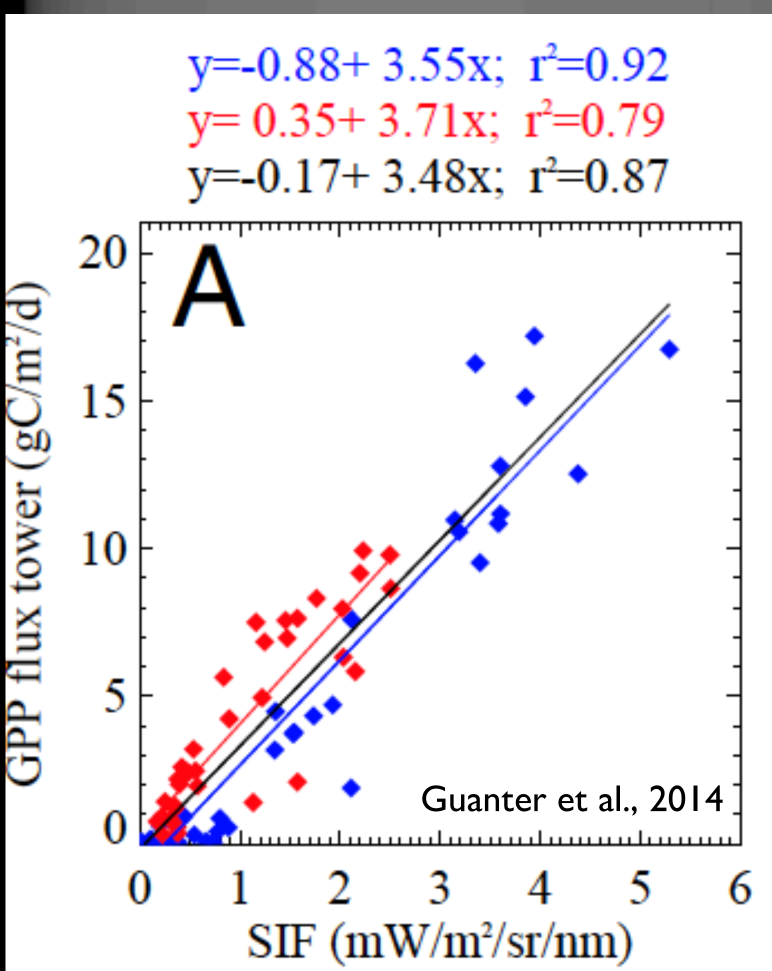
Glowing plants

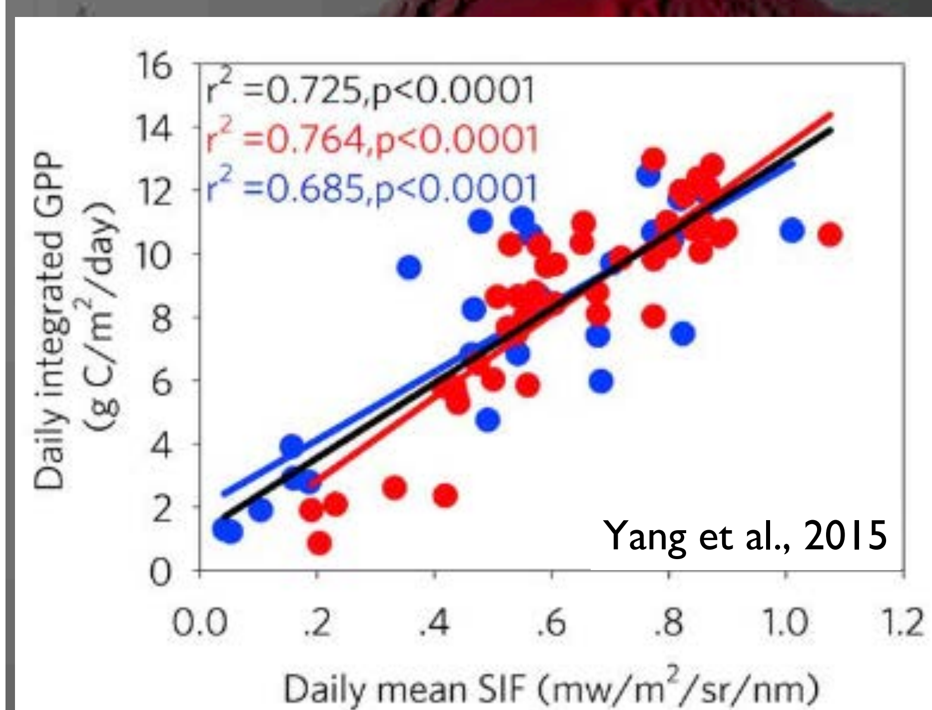
Other available SIF products:

SCIAMACHY (Joiner et al., 2016)

OCO-2 (Sun et al., 2020)
TROPOMI (Kohler et al., 2020)
GOSAT (Frankenberg et al., 2012)
GOSAT-2
TanSat (Liu et al., 2020)

OCO-3 (First product available)
GEOCarb (2024)
FLEX (2025)
TEMPO (2022)





Source: NASA

Linking SIF to GPP

$$GPP = PAR \times fAPAR \times \phi_p \times 1/k$$

$$SIF = PAR \times fAPAR \times \phi_F \times f_{esc}$$

PAR: Photosynthetically Active Radiation

fAPAR: Fraction of PAR absorbed by leaves

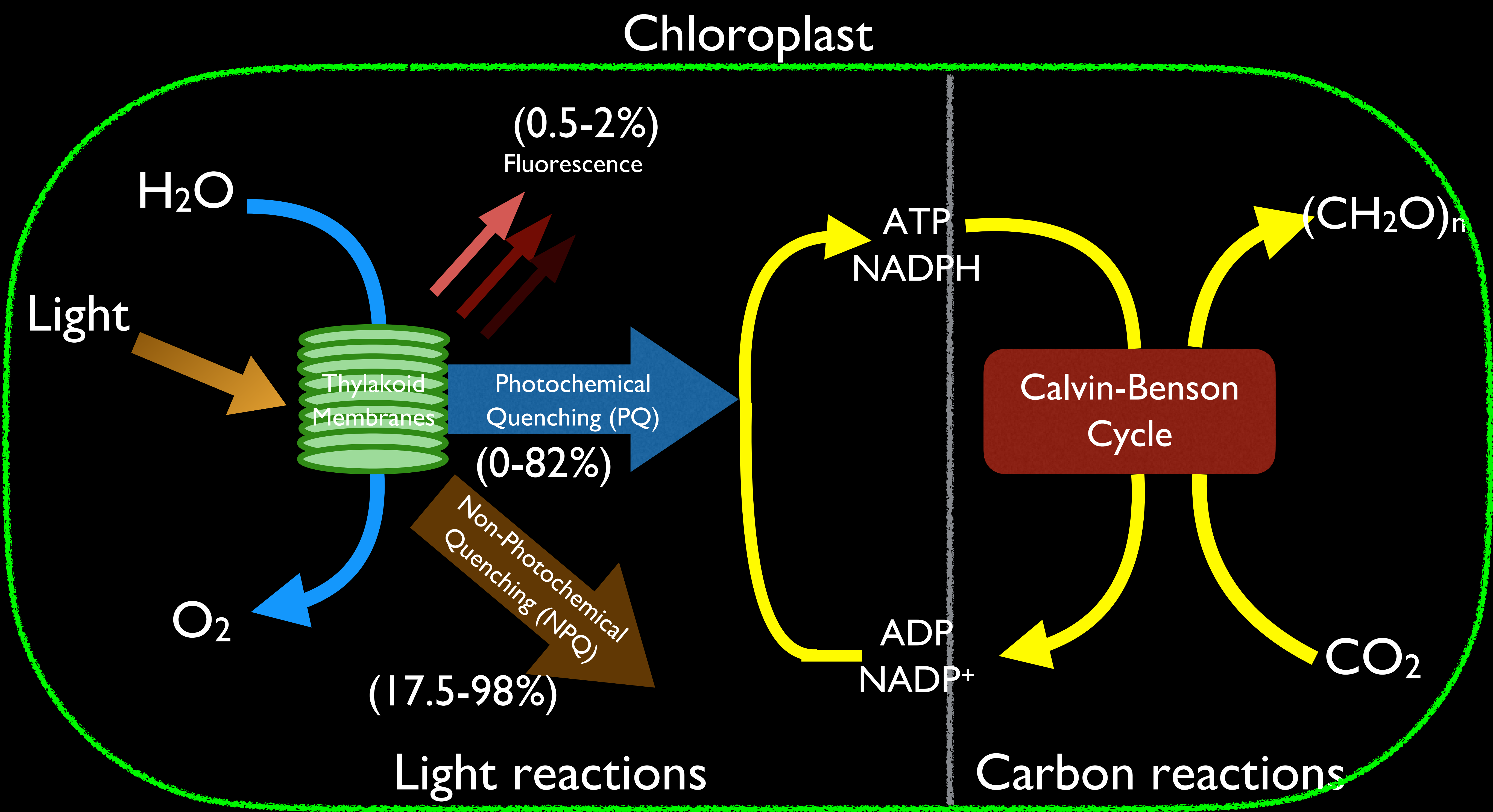
ϕ_P: Photochemical yield

k: assuming the fraction of light used by PSII is 0.5, k is k is the number of electron equivalents produced by LEF required to reduce one molecule of CO_2.

ϕ_F: Fluorescence yield

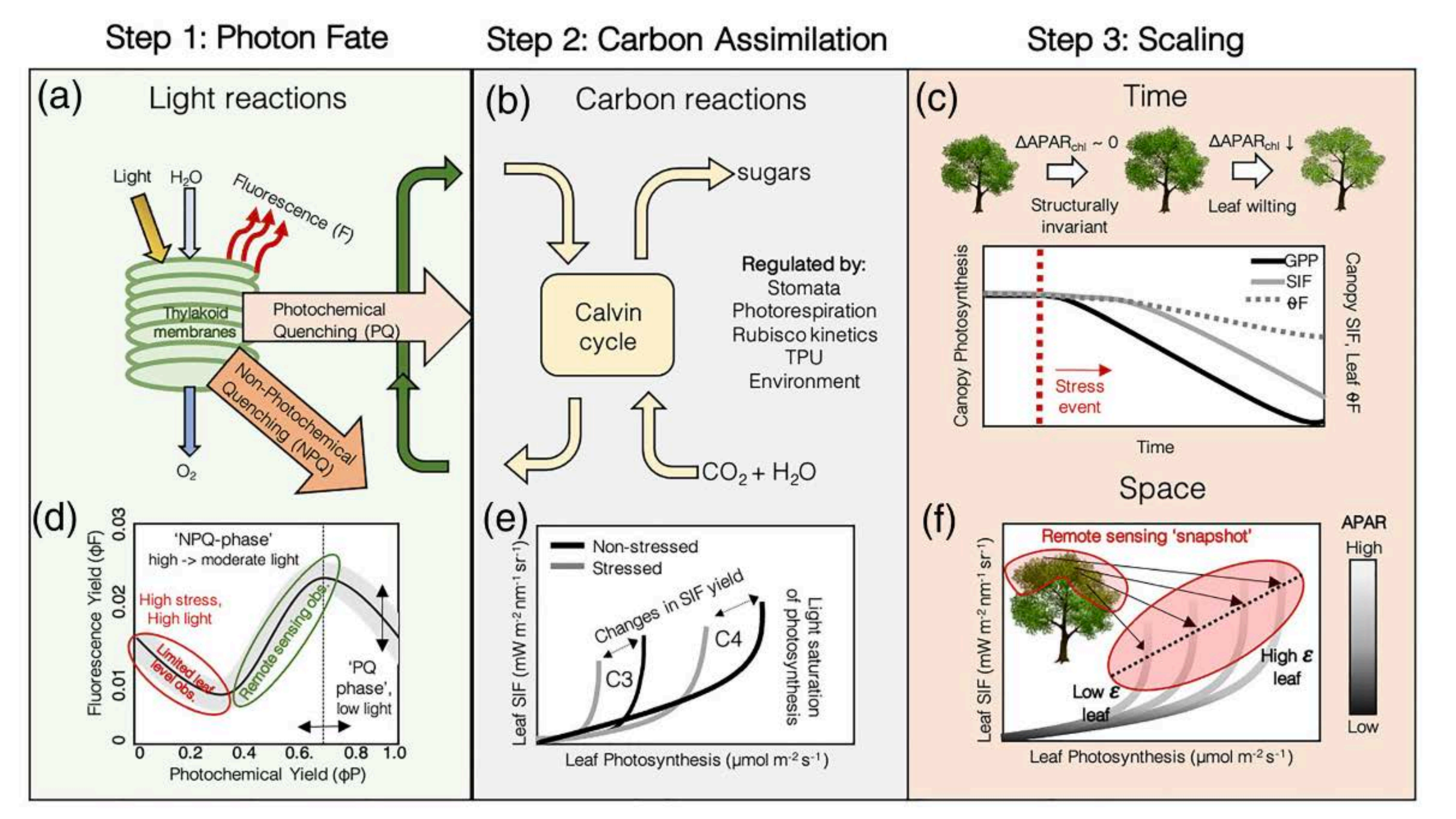
f_{esc}: escape probability (structure)

Fluorescence provides an optical probe into the photosynthetic machinery



Modified from Magney, Barnes, and Yang, GRL, 2020

What does a change in SIF tell you?



SIF = PAR * fAPAR * ϕF * fesc

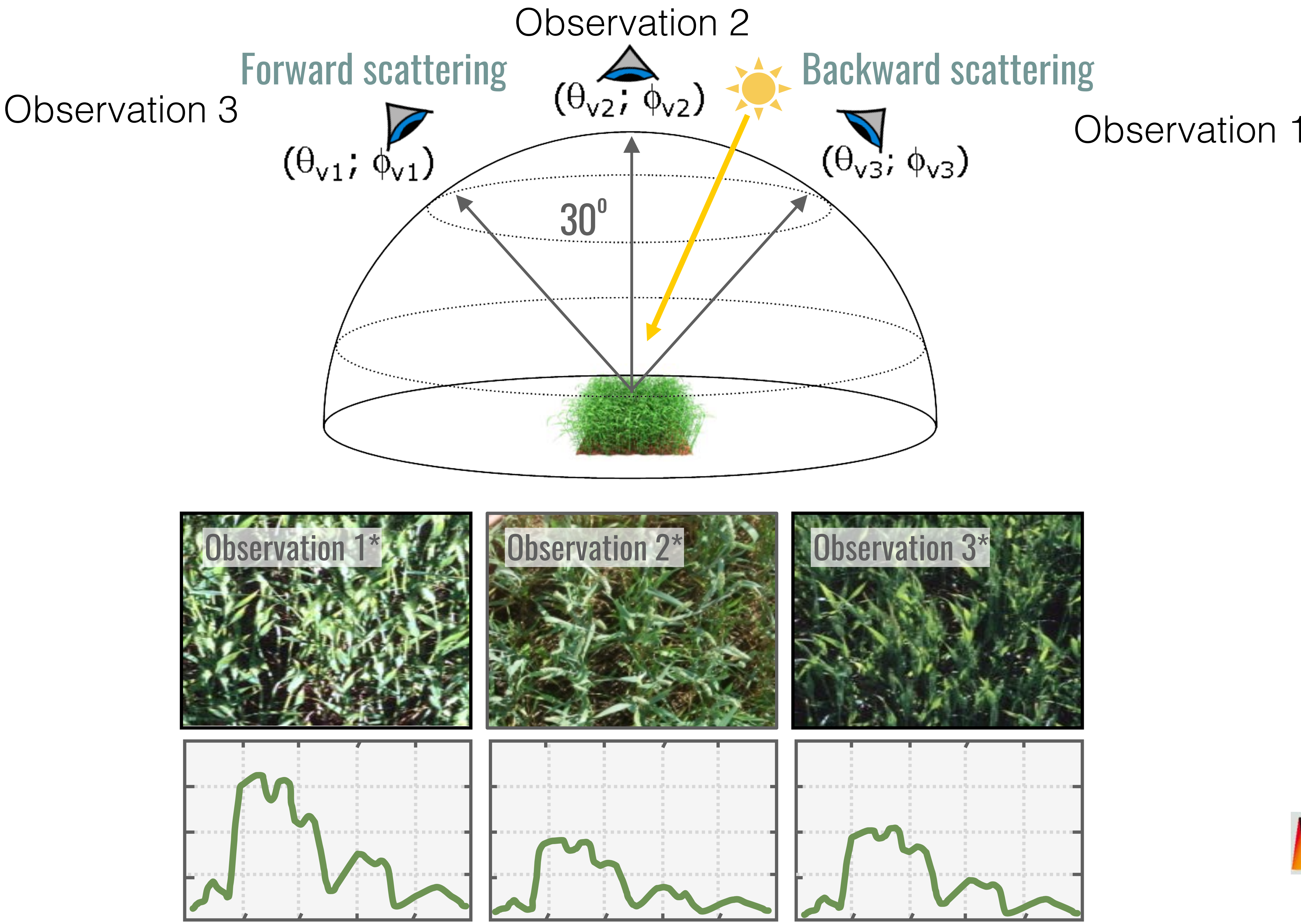
Leaf-level physiology: changes in PQ or chlorophyll content

Canopy structure: changes in leaf area and/or leaf angle

Viewing angle: how a sensor is angled wrt the object matters a lot

Magney, Barnes, and Yang 2020

Sun-sensor-object geometry is essential in optical remote sensing



Bidirectional Reflectance Distribution Function (BRDF)

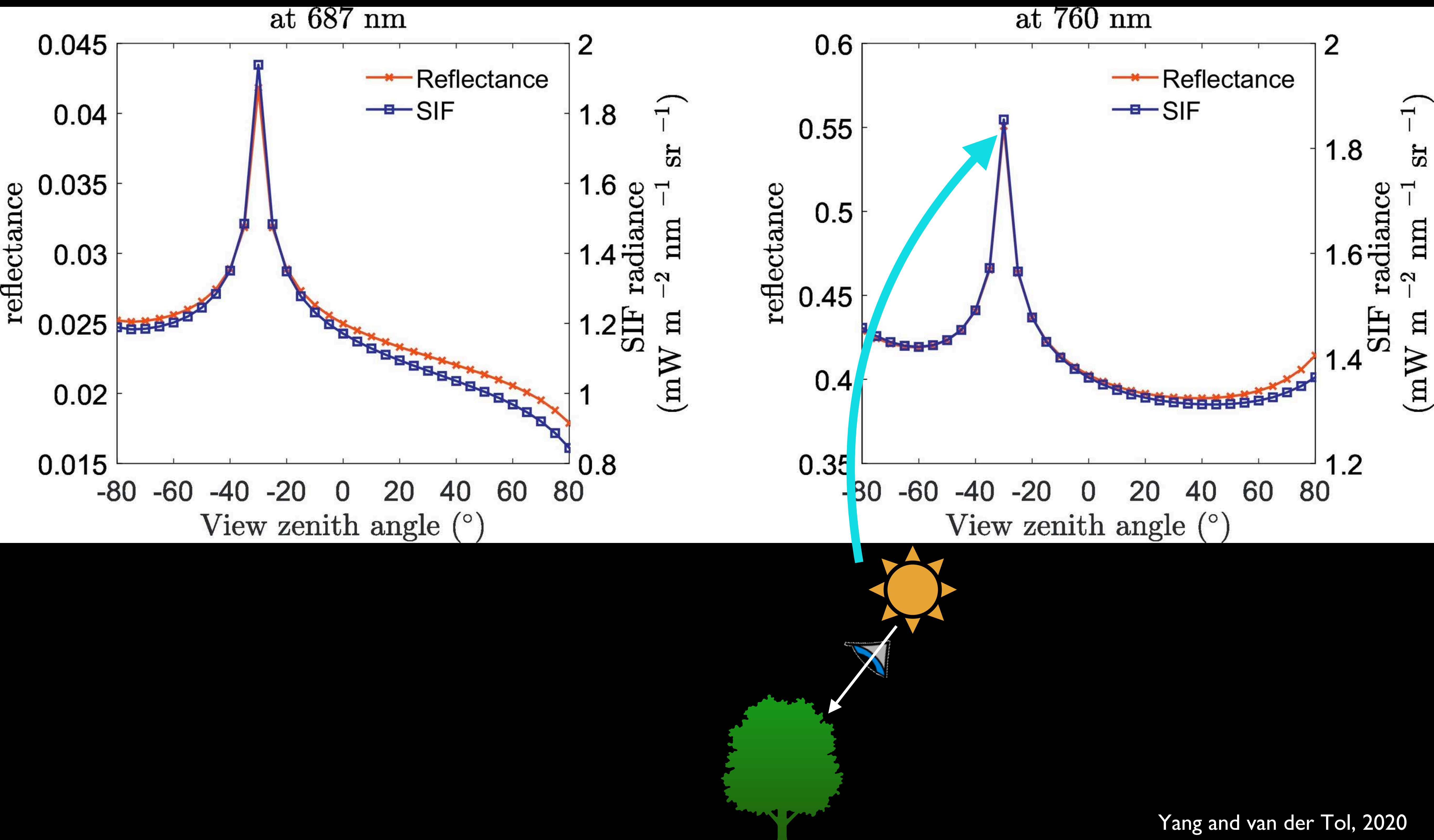
Light Rain in Early Spring
(初春小雨)
by Han Yu

草色遥看近却无
though one sees the color of grass from afar, if one gets closer it is not really there.

Bidirectional Reflectance Distribution Function (BRDF)

http://www.doc.gold.ac.uk/~mas02fl/MSC101/Graphics/Render.html

Sun-sensor-object geometry is essential in optical remote sensing



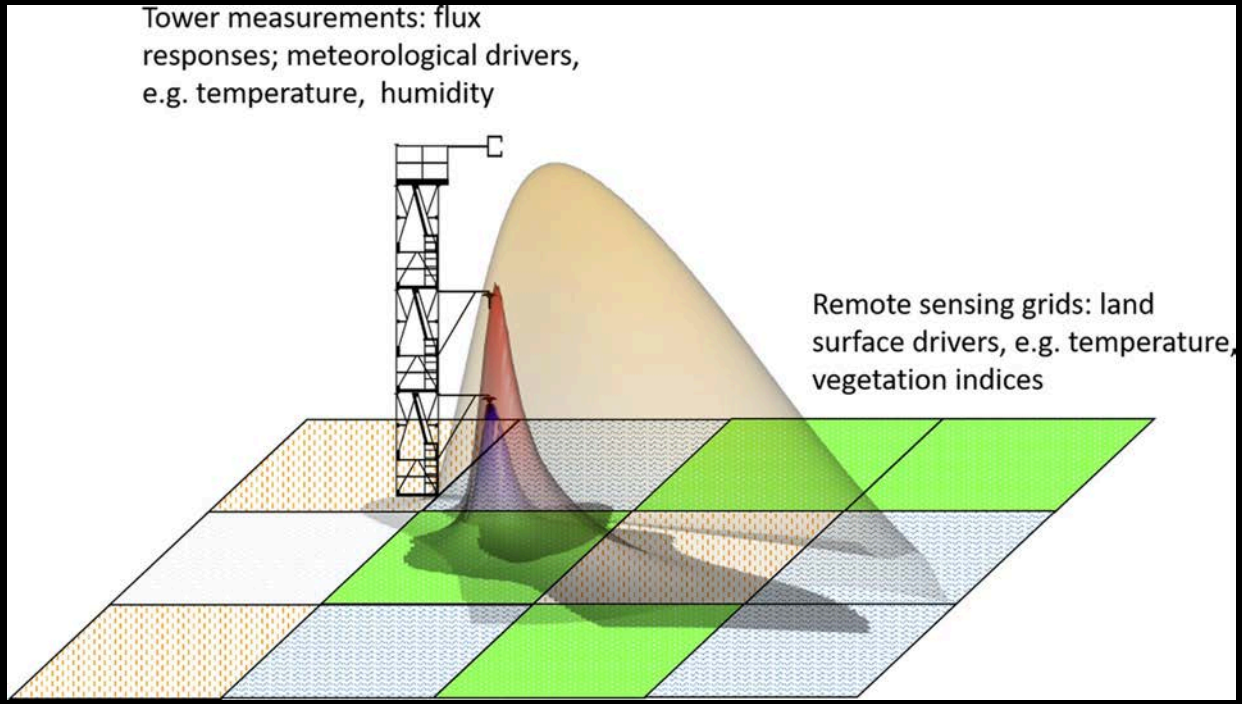
Yang and van der Tol, 2020

What does a change in SIF tell you?

GPP?
Drought?
Transpiration?
Impacts of diffuse radiation?
CO_2 fertilization?
Heat stress?
Flooding?
Beetle attack?
Changes in forest composition?

A few considerations when linking RS with Flux tower measurements

Satellite vs. Flux Tower



Metzger 2018

- RS data should match the footprint of the EC tower measurements
- Optical & thermal satellite measurements are only good on sunny days
- For ecosystems with complicated canopy structures, note that *some* RS measurements are most sensitive to the top of the canopy
- Remember that GPP from EC tower measurements is also "modeled" with assumptions
- SIF and vegetation indices, to the best, tell us about the electron transport part of photosynthesis

Optical tower-based instruments vs. Flux Tower

Source: Wayne Dawson

- Tower-based optical sensors usually have smaller footprints compared with EC towers, but they also can provide measurements of individuals
- With careful consideration, tower-based optical data are good for cloudy days too
- RS data can provide information beyond GPP!

Synergy of RS methods

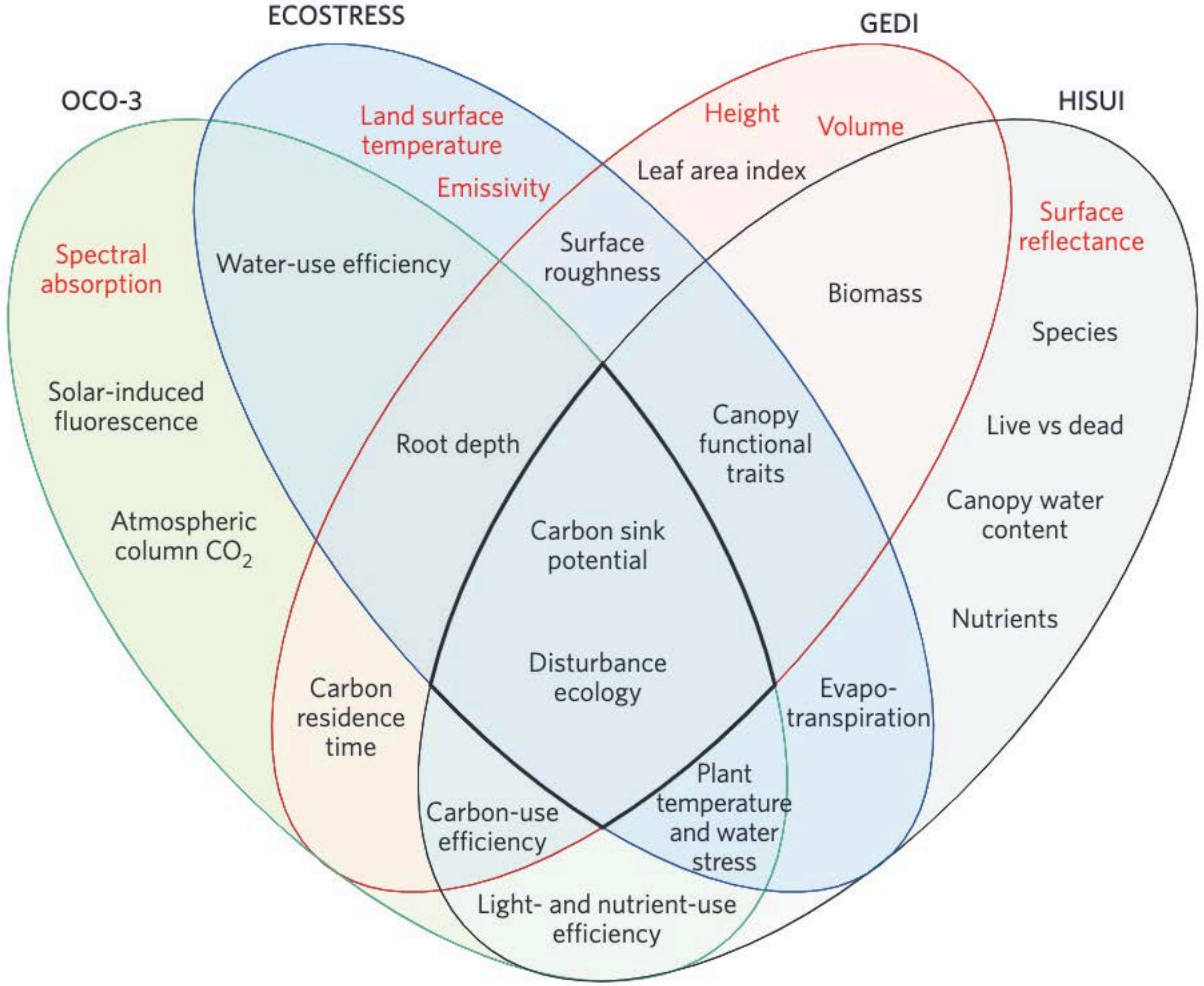
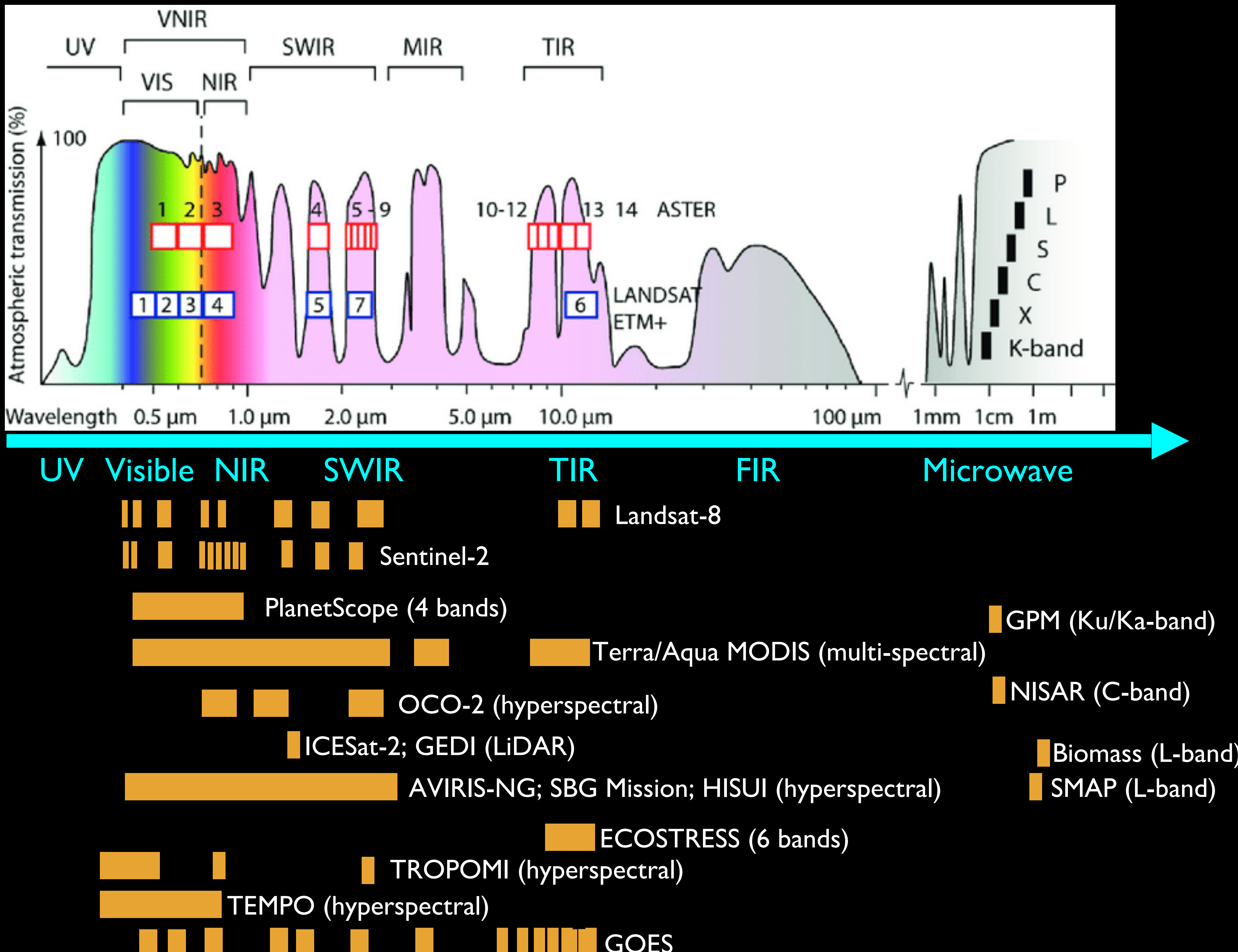


Figure 1 | Spatial and temporal synergy of observations and their applications. A pretzel diagram of observations (red text) from each instrument (coloured shapes) and the synergistic physical parameters that can be derived (black text) when observations are taken at synchronous and complementary spatial and temporal resolutions.

Stavros et al., 2017

RS sensors at a glance



Trade-off between the spatial & temporal resolutions