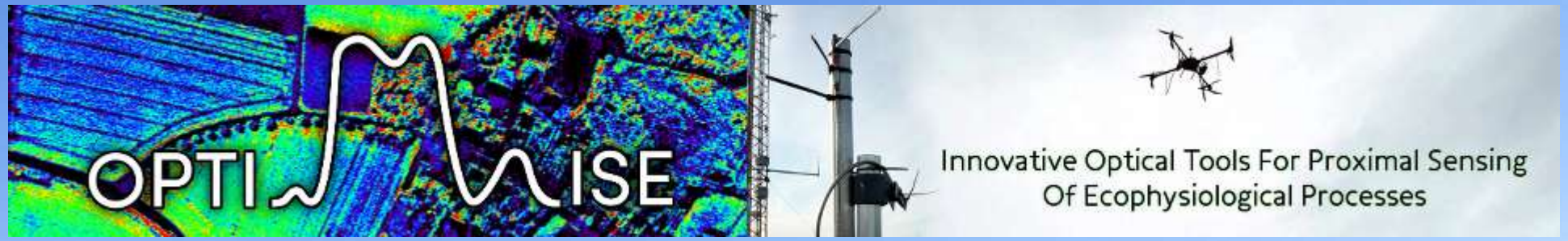


Retrieving plant traits from reflectance and solar induced chlorophyll fluorescence

Christiaan van der Tol, Nastassia Vilfan, Peiqi Yang, Cesar Cisneros, Bagher Bayat, Marco Celesti, MaPi Cendrero-Mateo, Wout Verhoef

ITC
UNIVERSITY OF TWENTE

<u>What</u>

What is the micro-climate in the vegetation?
Which light is used by which leaves?
How efficiently do plants use light and water?
What determines the shape/ life form and density of plants?

Remote sensing ought to give us answers to these questions

<u>Why</u>

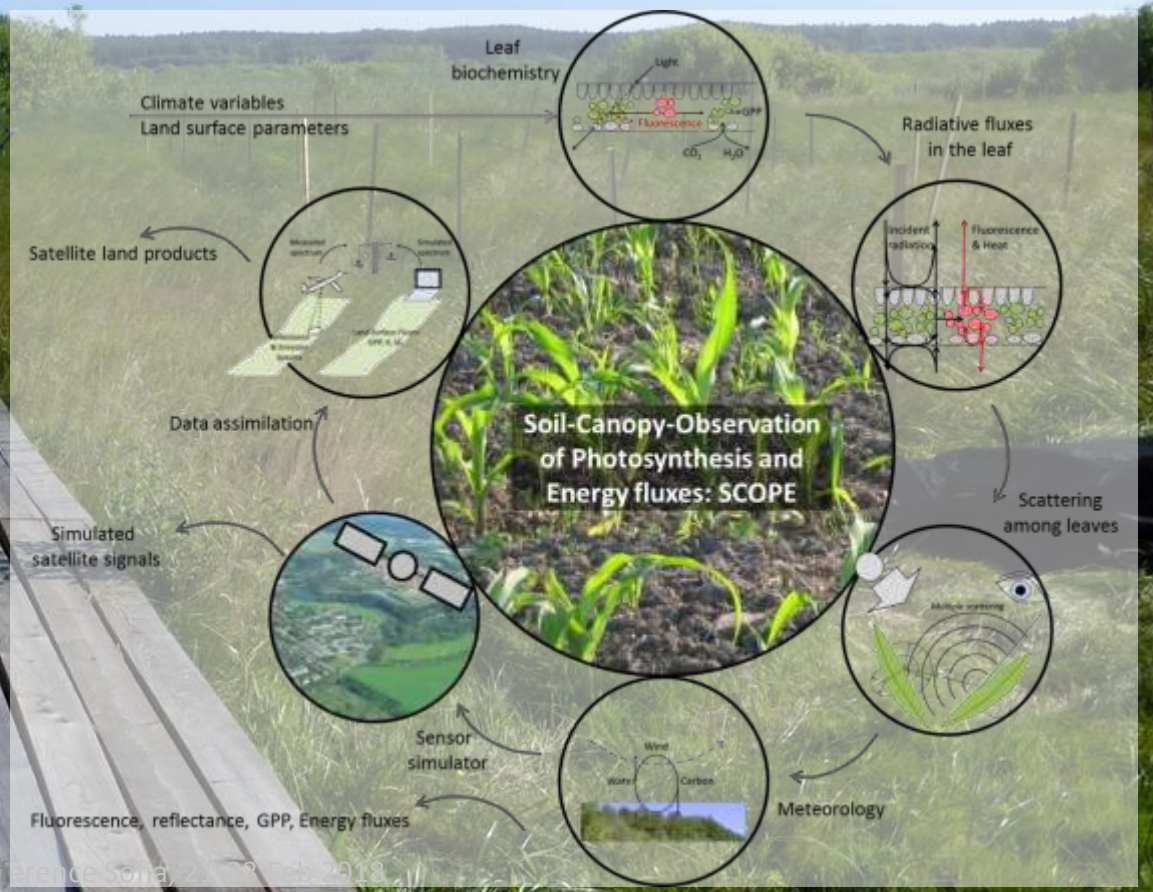
-> better understanding of ecosystems
-> understanding the role of plants in the Earth's climate
-> improving crop (water) productivity

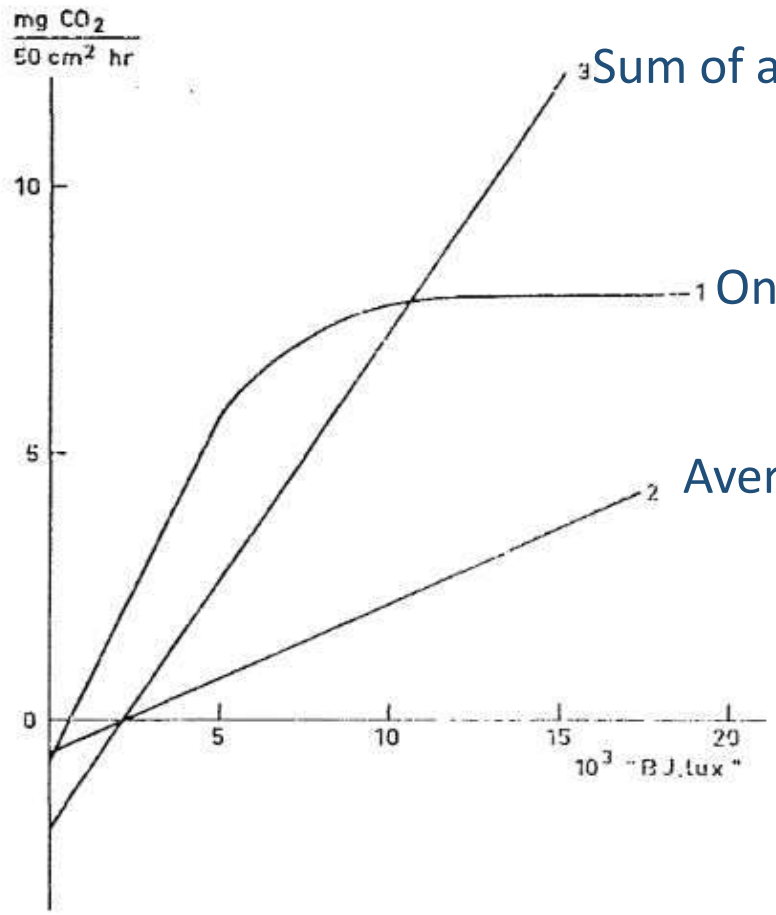
<u>How</u>

Physically based modelling:

- Hyperspectral remote sensing signals
- Energy balance
  - radiative, advective, convective, conductive fluxes
- Plant physiology

Energy conservation at the leaf and the canopy level





Sum of all leaves (LAI=3.4)

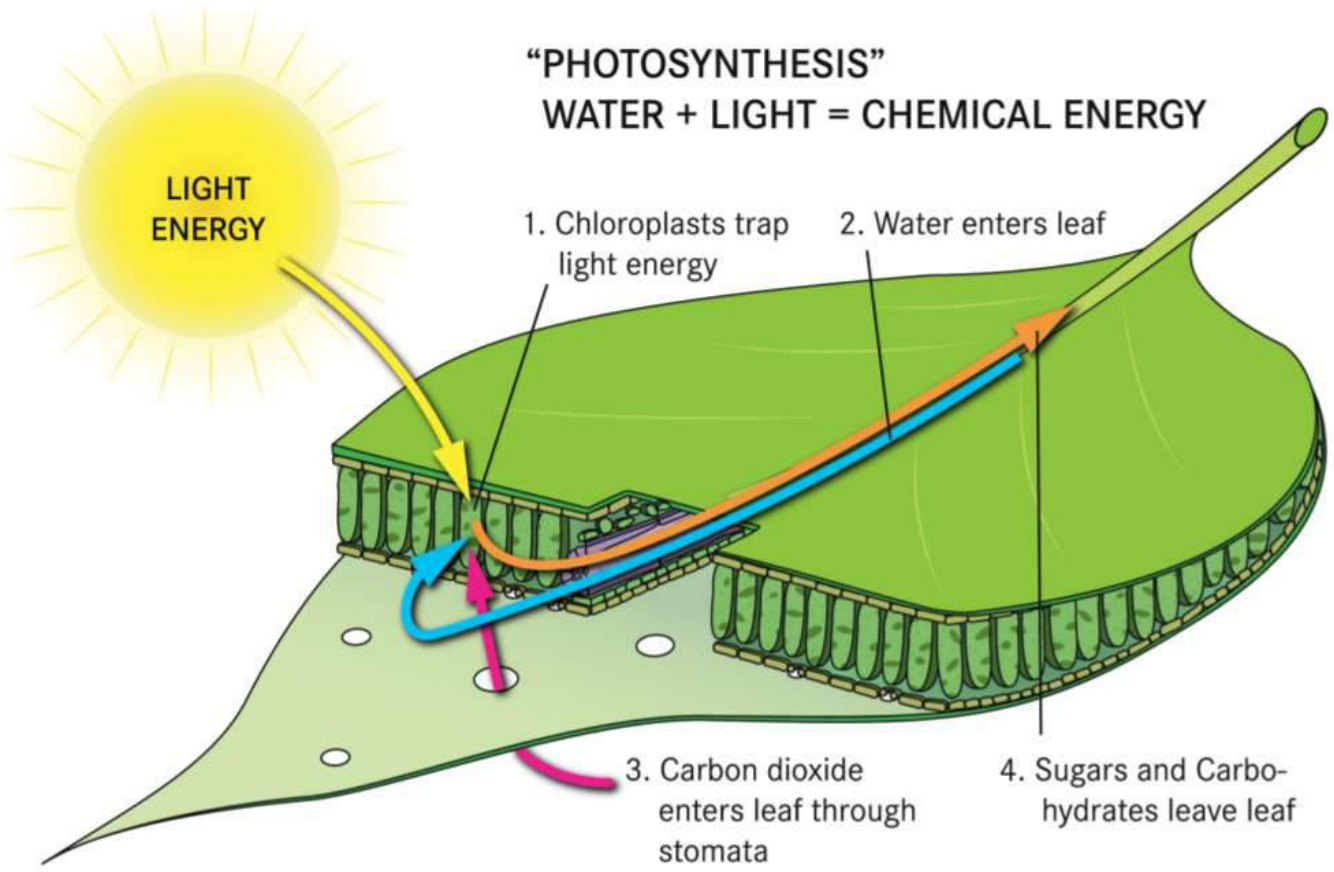
One leaf

Average of all leaves

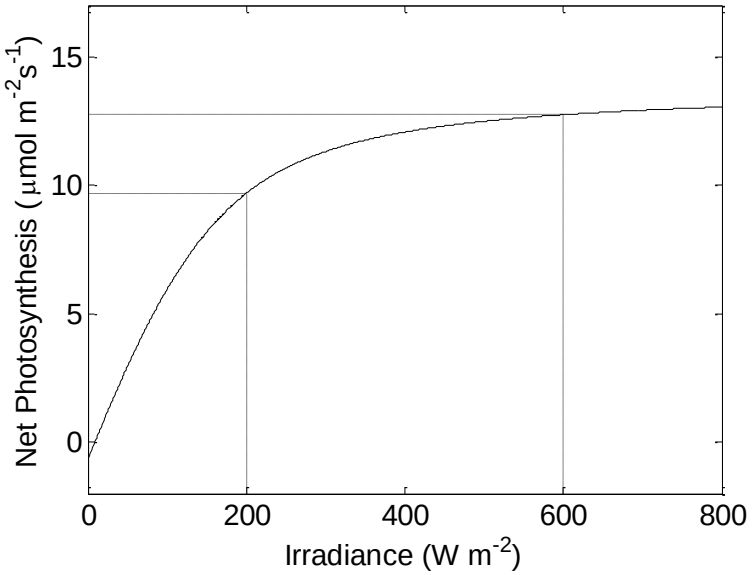
Fig. 1. Photosynthesis rates of Sinapis alba.
1. Rate per unit leaf area for one leaf.
2. Average rate per unit leaf area in a canopy with a leaf-area index of 3.4.
3. Rate per unit soil area, covered by a canopy with a leaf-area index of 3.4.
"B. J. Lux" is a light intensity unit which was used by BOYSEN JENSEN.
Data from BOYSEN JENSEN (1932, 1949).

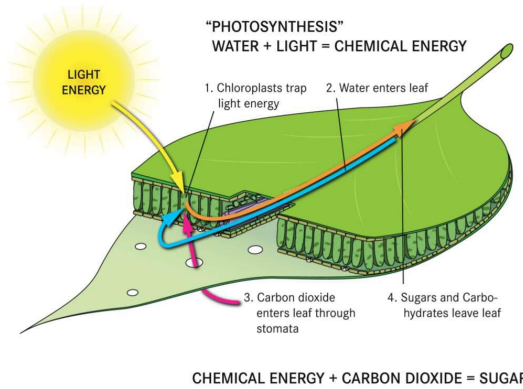
"The results for a standard set of conditions have been summarized in such a way that it ***is possible to estimate the daily photosynthesis*** *at any time and place for a wide range of photosynthesis functions* ***without computer****."*

Cornelis T. de Wit (1965)

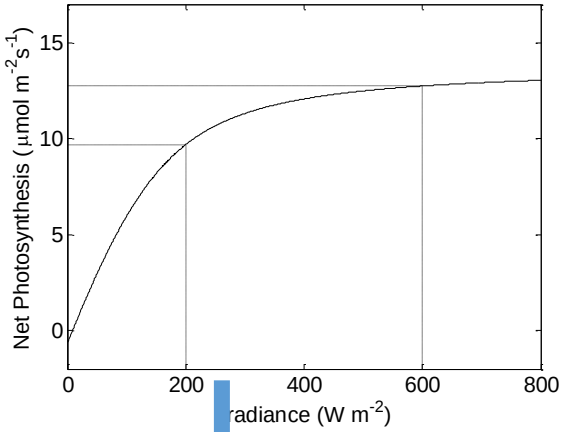


(Drusch et al., 2017)

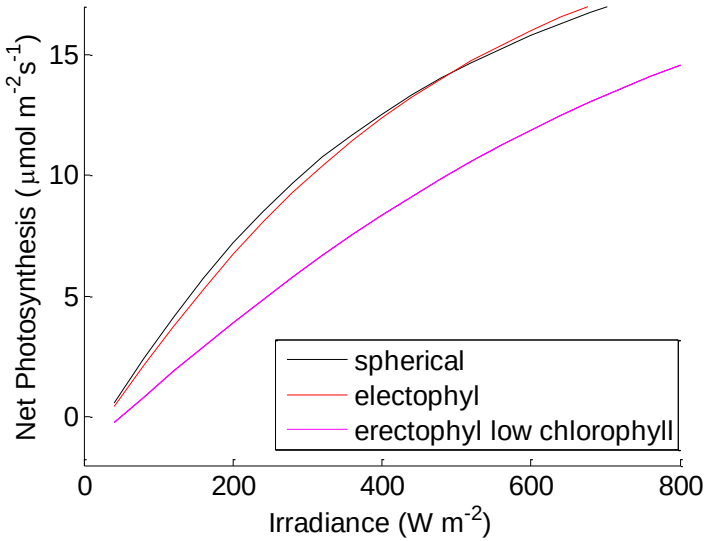


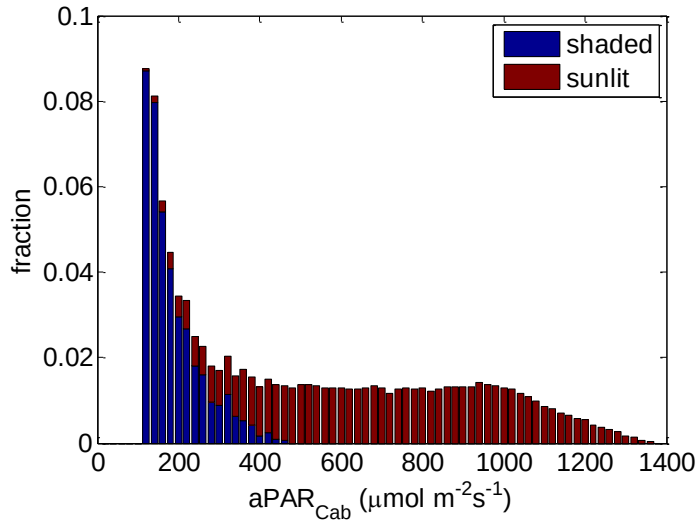


From 1 to 10^5 leaves

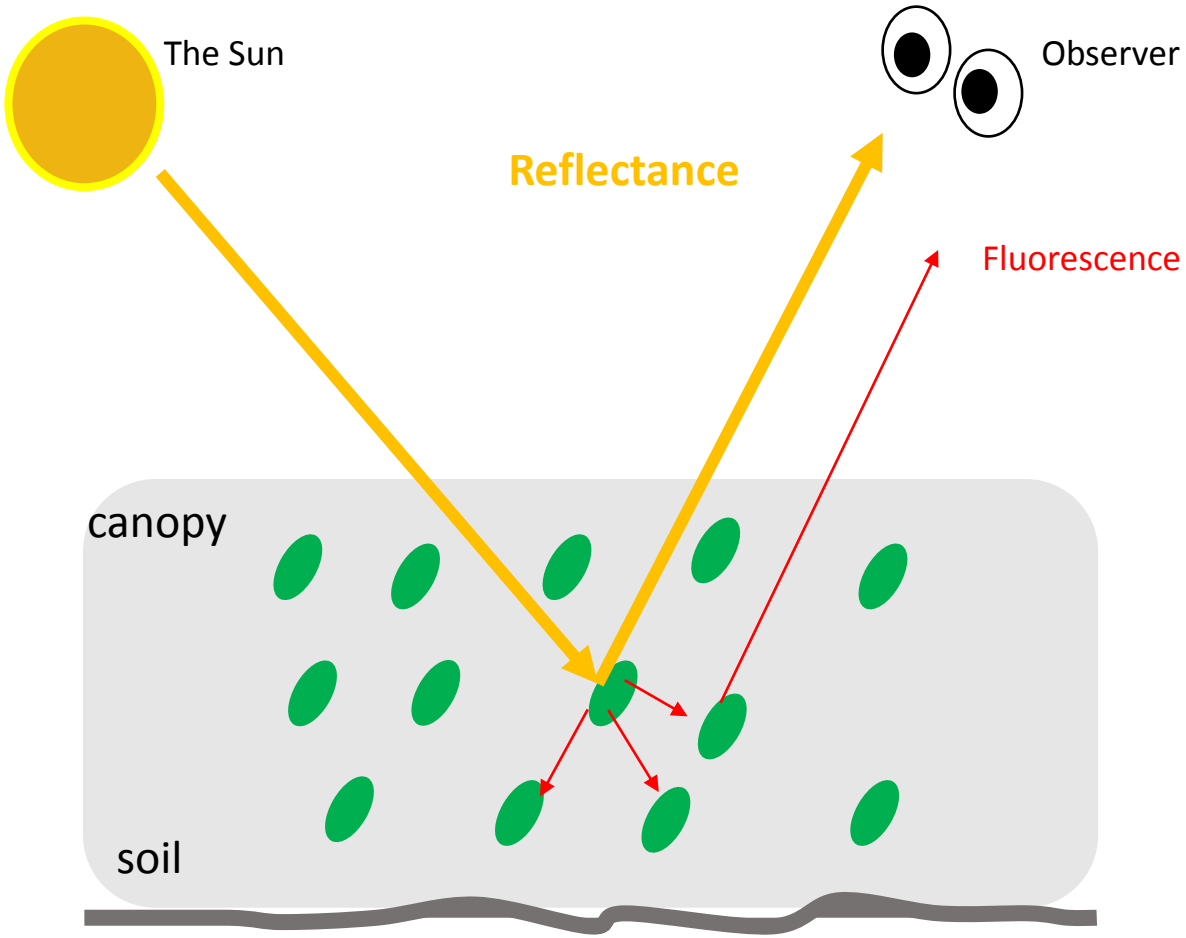


More linear light response.
Slope depends on vegetation structure





change your wish

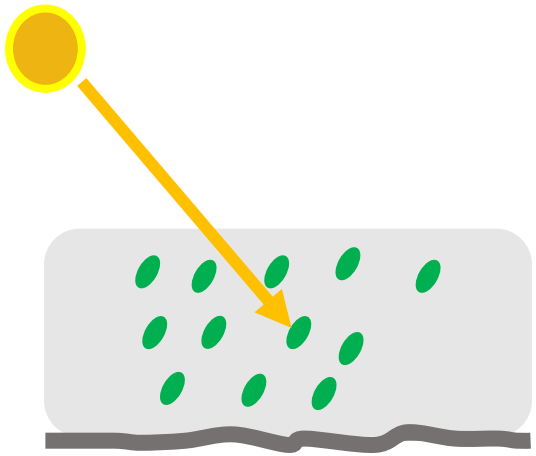


SIF involves three processes:

1. Absorption of light
2. Emission at longer wavelength
3. Scattering and re-absorption

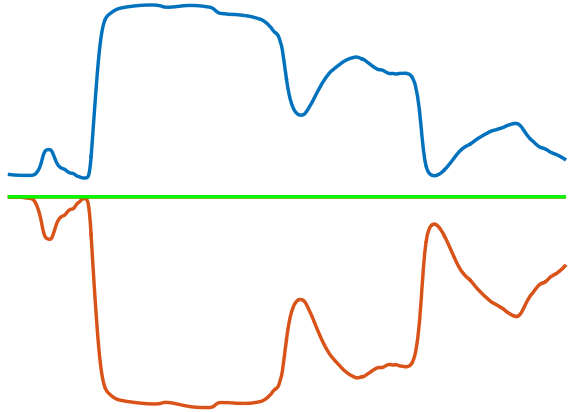
Spectral invariant properties

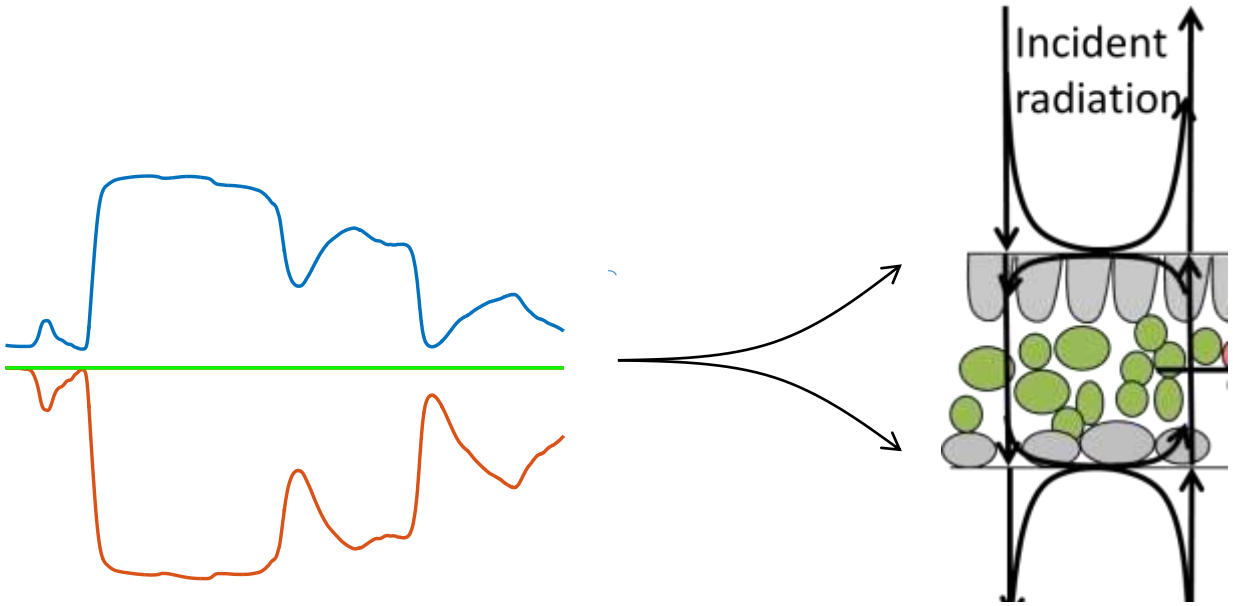
Interception, gap fractions, viewing probability, re-collision probability



Spectral variant properties

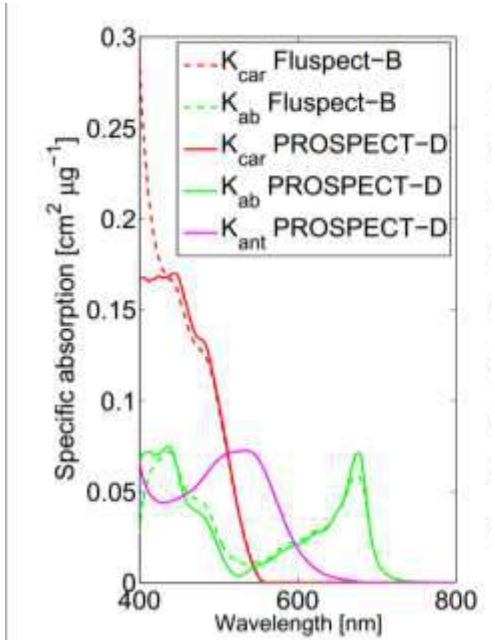
Leaf albedo = Reflectance + transmittance





$$A = \sum K_i C_i$$

K = Specific Absorption Coefficient (SAC)
C = concentration (pigments)



- Recently recalibrated for PROSPECT-D (Feret et al., 2017)
- Pigments -> inform about plant functioning

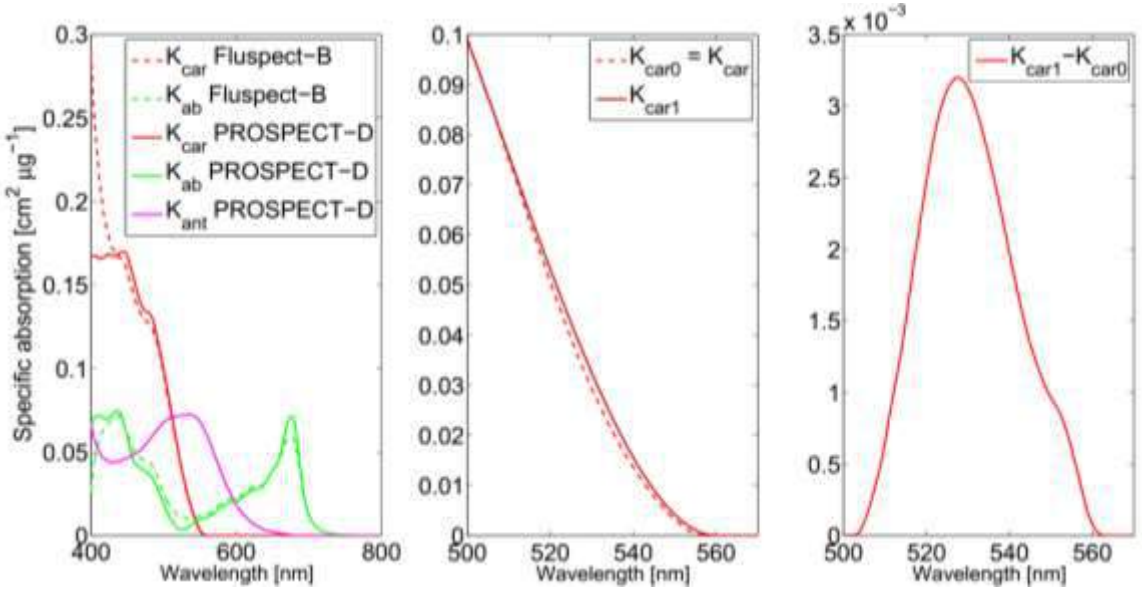
Fluspect
Simulates radiative transfer of incident light and emitted fluorescence in the leaf
Vilfan et al., (2017), RSE

Particular interest: Xanthophyll cycle (500-600 nm), used for
PRI = (R531-R570)/(R531+R570)

$$A_{car} = C_x K_{car1} + (1 - Cx) K_{car2}$$

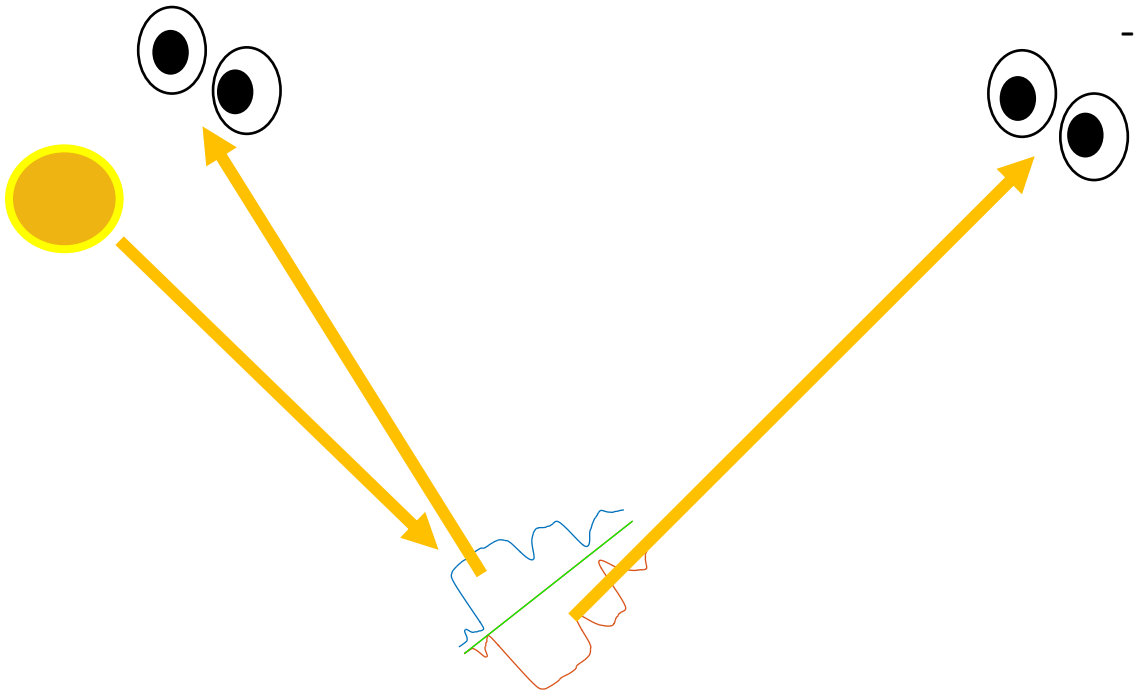
Nastassia Vilfan et al (submitted) :

- Introduced de-epoxidation status in carotenoid SAC
- Linked the de-epoxidation status C_x with NPQ



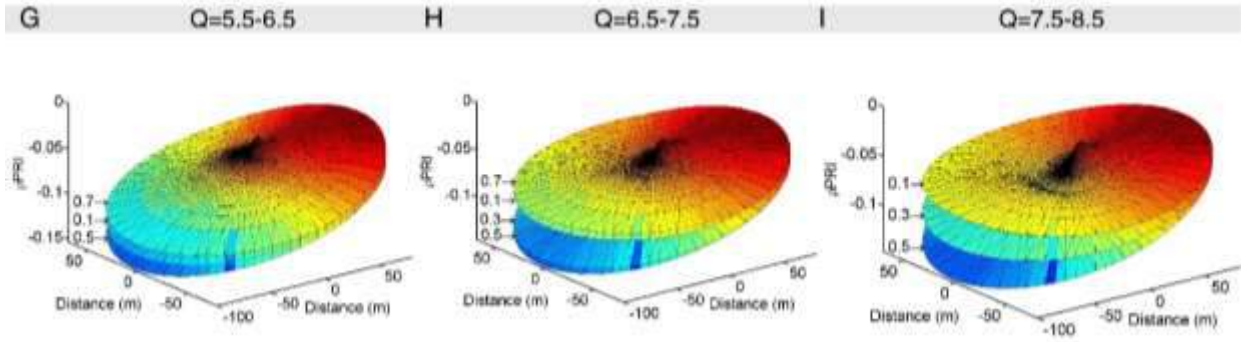
Significance

- C_x not sensitive to other pigments (unlike PRI)
- Possibility to retrieve NPQ from reflectance data

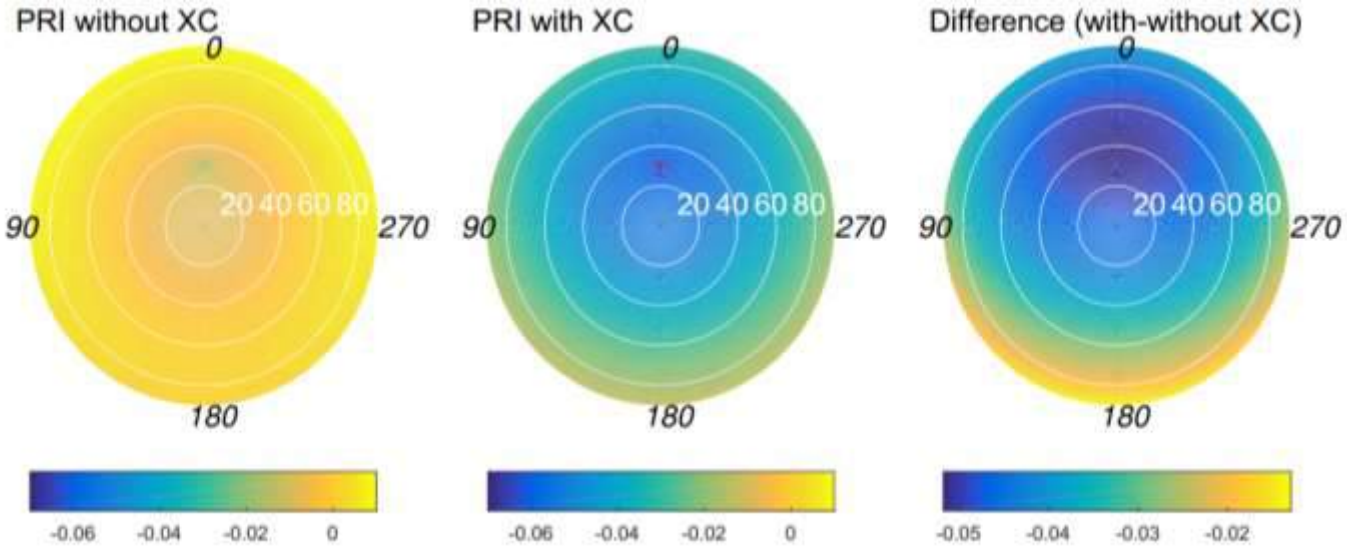


- Introducing the new Fluspect-Cx model into SCOPE

- Angular effect of PRI: partly due to BRDF of the vegetation
- Additional effect: due to sunlit leaves having higher Cx.

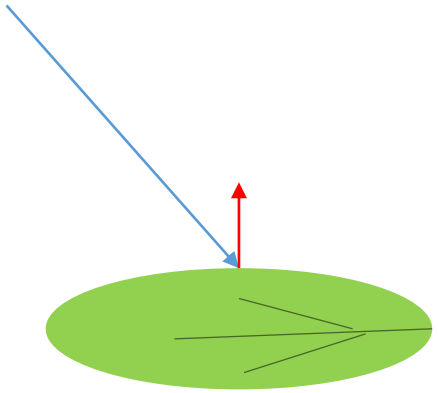


Hilker et al., 2008



Significance

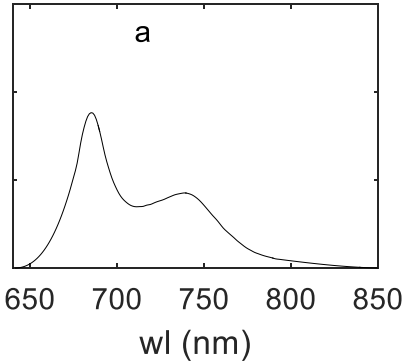
- Separates effects of pigments, sun-view geometry and Xantophylls on reflectance



FQE = Fluorescence Quantum Efficiency, about 10^{-2}

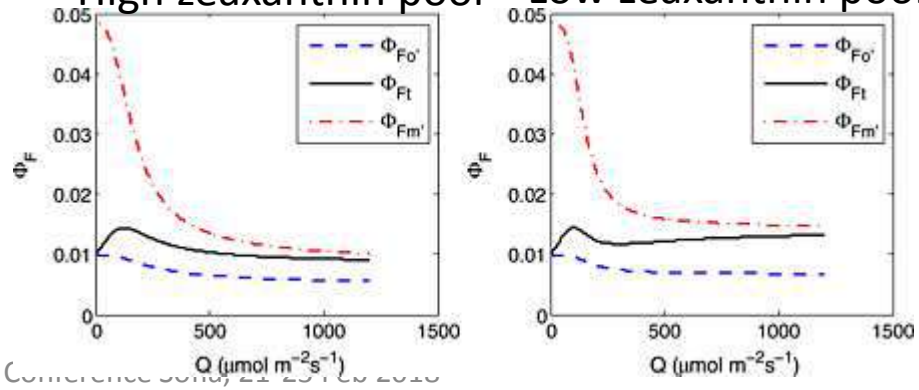
= probability that a photon is emitted as fluorescence by the chloroplast

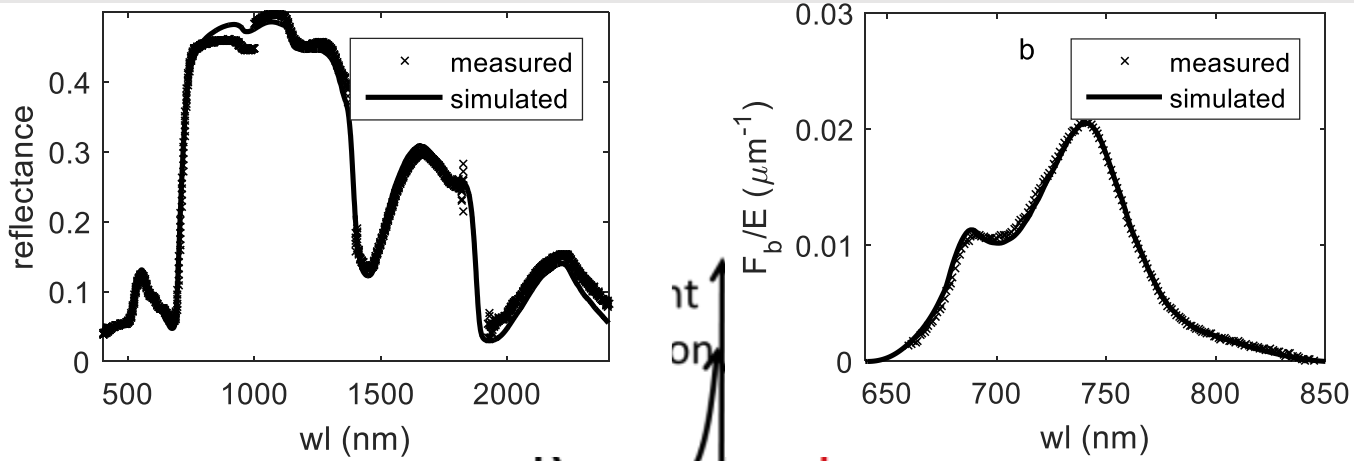
Spectral distribution is a property of the photosystems
Specific Emission Spectrum (SEC)
SEC recalibrated to in vivo-leaf spectra (FluoWat)
Van der Tol et al. (in prep)

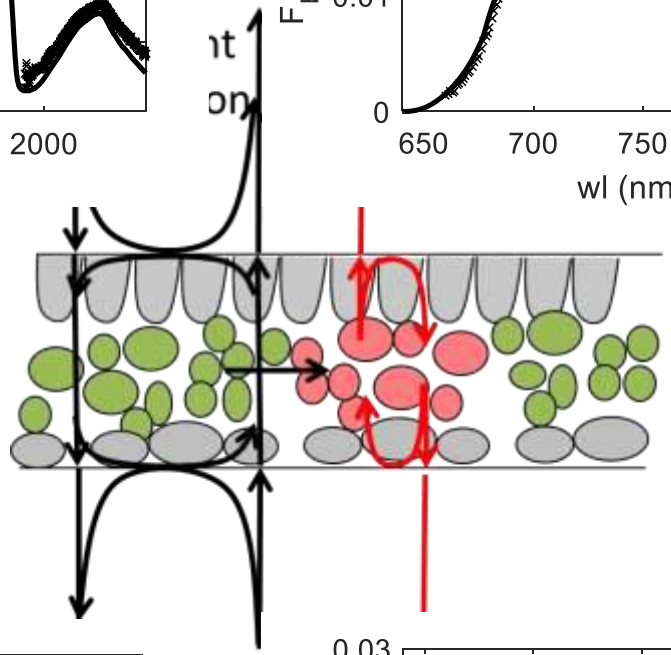


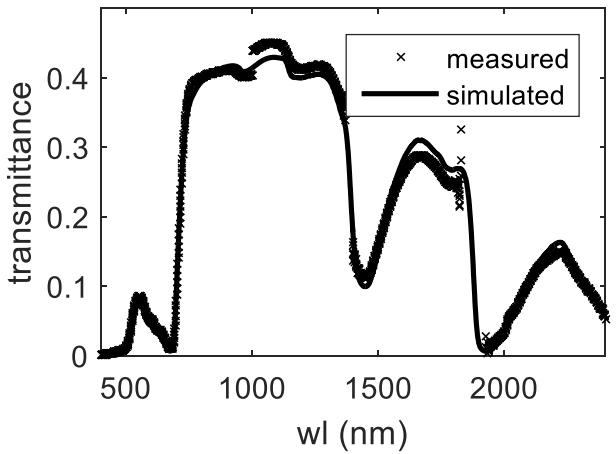
The **magnitude** depends on charge lifetime, and therefore on efficiency of the photosystems and NPQ (Van der Tol et al., 2014)

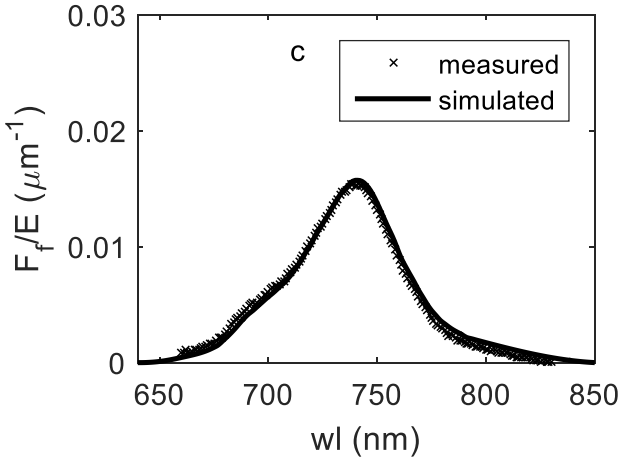
High zeaxanthin pool Low zeaxanthin pool





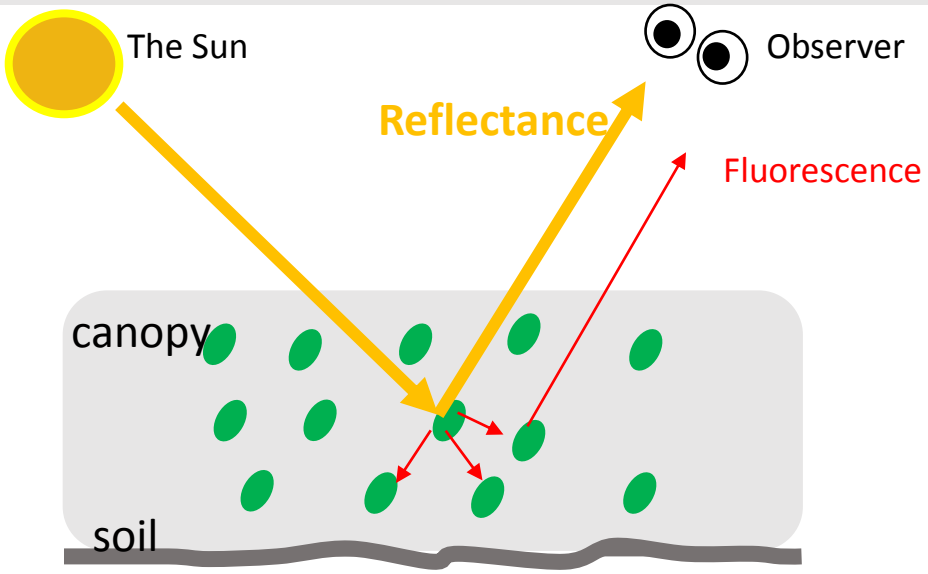






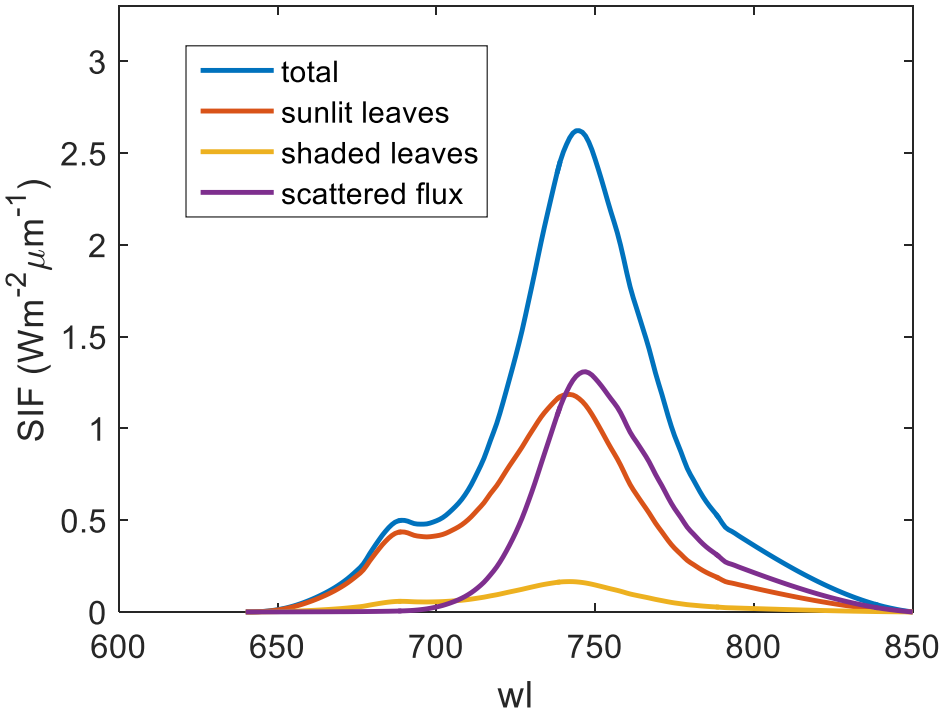
<u>Significance of the Fluspect-biochemical model:</u>

- SEC of SIF useful for fluorescence retrieval (SFM)
- Effects of light stress, temperature, Vcmax on emission can be simulated
- Effects of pigments on leaf forward and backward emission can be simulated



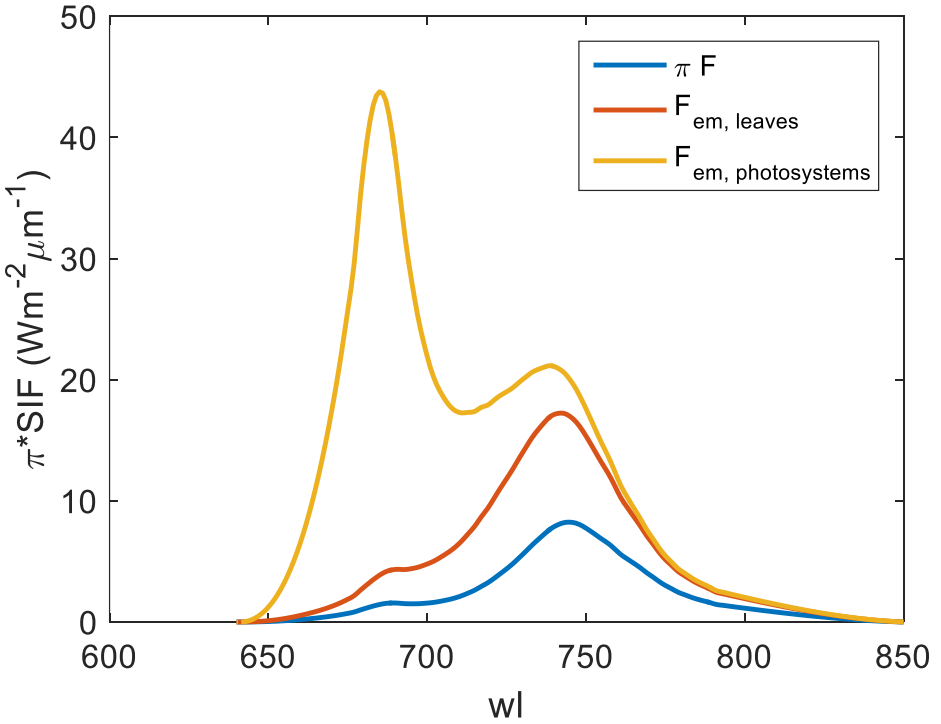
RTMf model: simulates fluorescence radiative transfer in the canopy

- Scattering after emission
- Re-absorption
- Flux in observation direction



Fluorescence Scattering/ Escape probability

$$\sigma_F = \frac{\pi L_f}{E_f}$$



Let's compare the radiative transfer of incident light (R) and fluorescence (SIF)

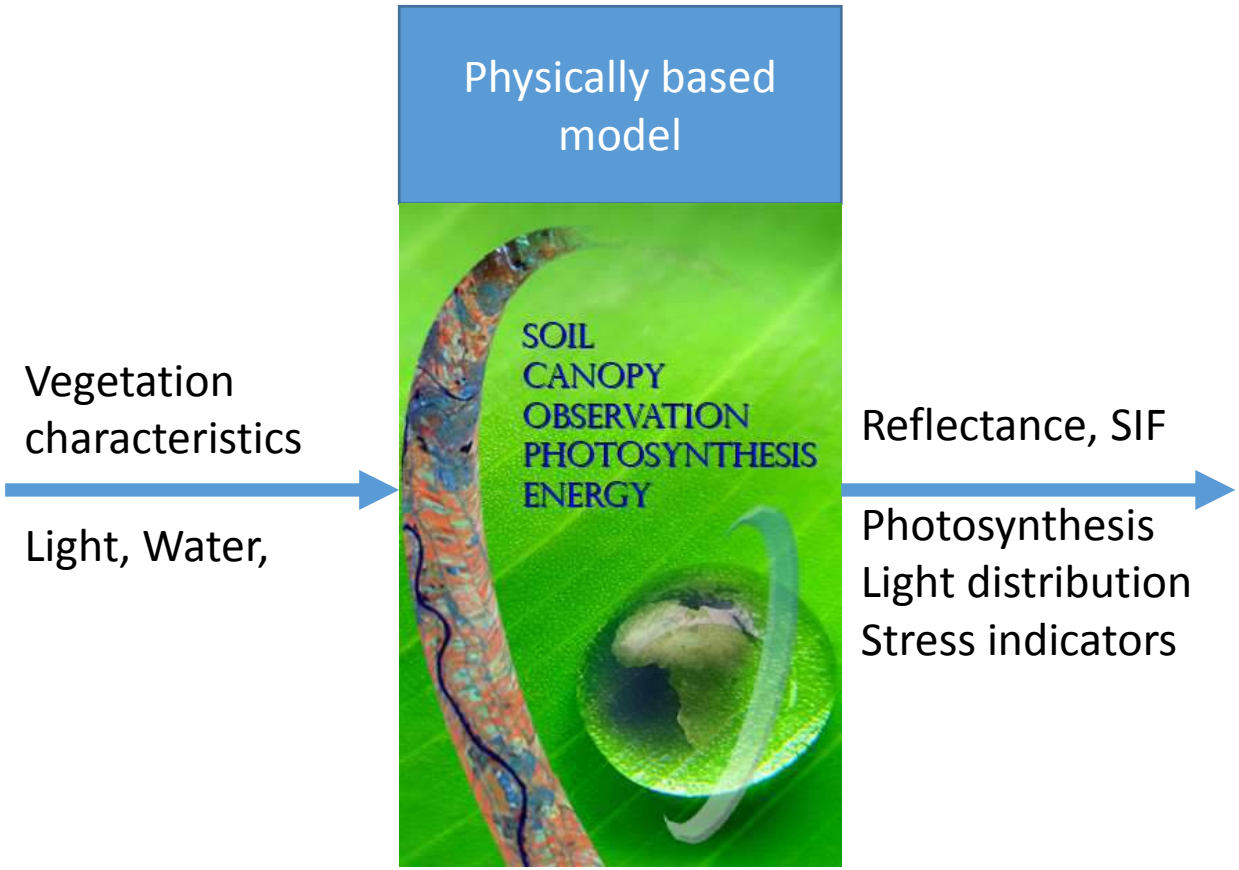
Reflectance: $R = \frac{\pi L_o}{E}$

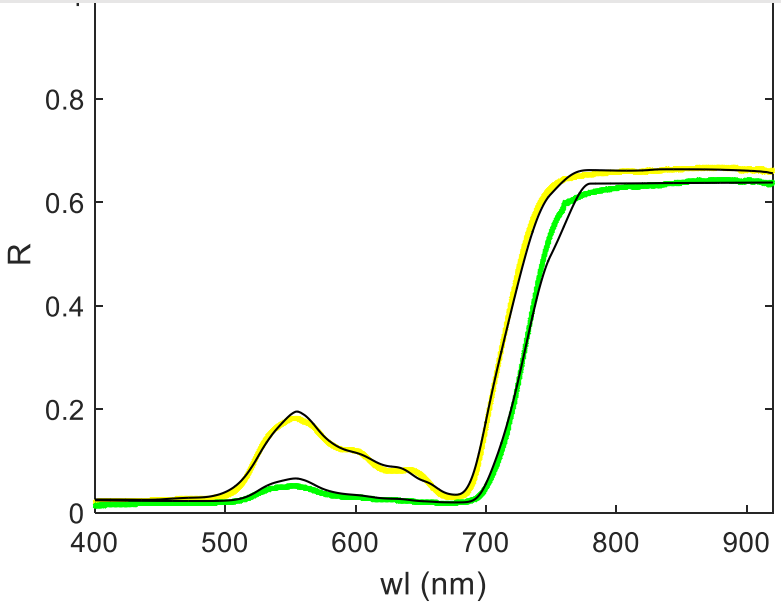
Fluorescence scattering: $\sigma_F = \frac{\pi L_f}{E_f}$

$$\sigma_F(\lambda) = \frac{R(\lambda)}{i_0 \omega}$$

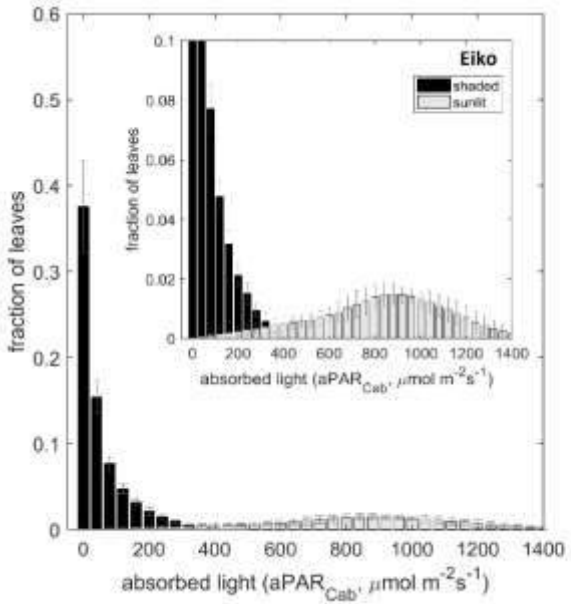
i_0 = interception of light by the canopy
ω = leaf albedo ($R + T$)

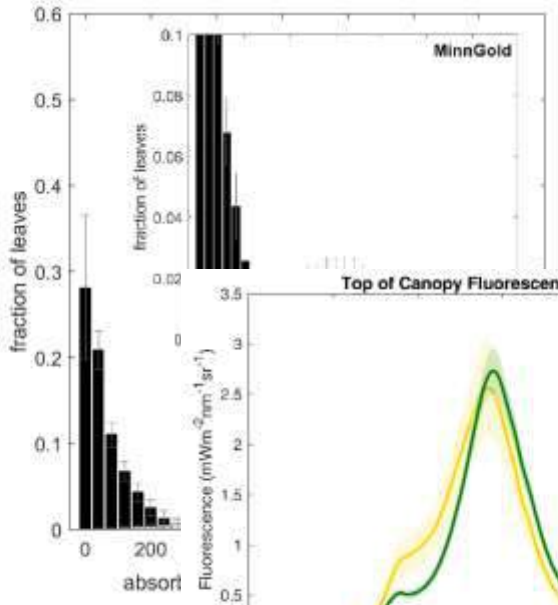
Significance:
- Explains the high correlation between R and SIF
- Enables the estimation of total emission of SIF


Physically based model
SOIL
CANOPY
OBSERVATION
PHOTOSYNTHESIS
ENERGY
Vegetation characteristics
Light, Water,
Reflectance, SIF
Photosynthesis
Light distribution
Stress indicators

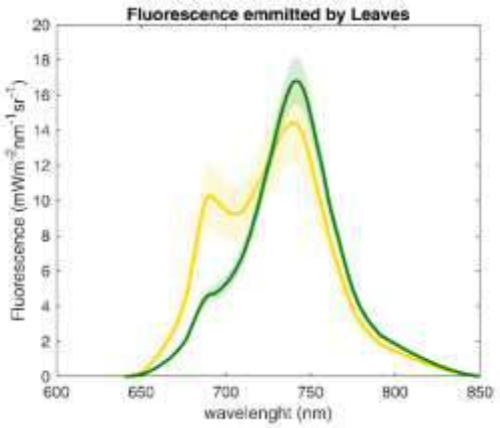


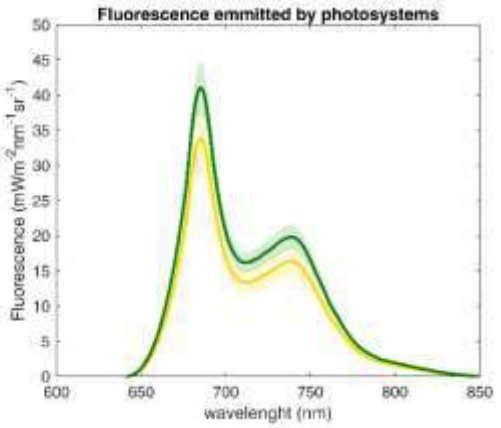
	MinnGold	Eiko
Chlorophyll (µg cm^{-2})	13	59
Carotenoids(µg cm^{-2})	6.1	20
Dry matter (µg cm^{-2})	2.7	2.9
Brown pigments (a.u.)	0.00	0.00
Mesophyll structure	1.18	1.68
Leaf Water (mg cm^{-2})	*22*	*0.8*
Zeaxanthin fraction	0.49	0.79
LAI	4.79	4.49
LIDF	0.49/-0.074	0.43/-0.13





Rice/ alfalfa: Van der Tol et al., (2016)
Soybean: Cendrero et al. (in prep)





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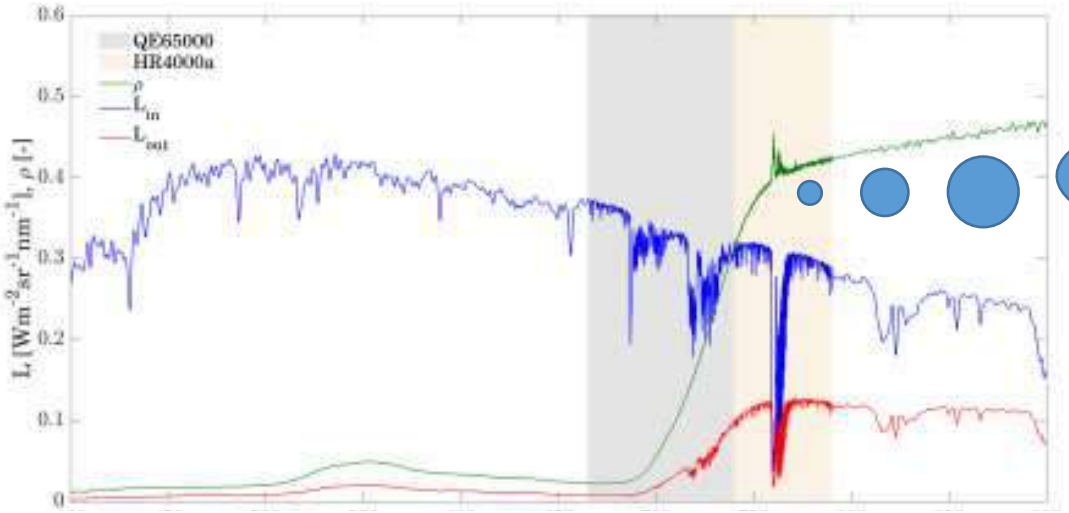
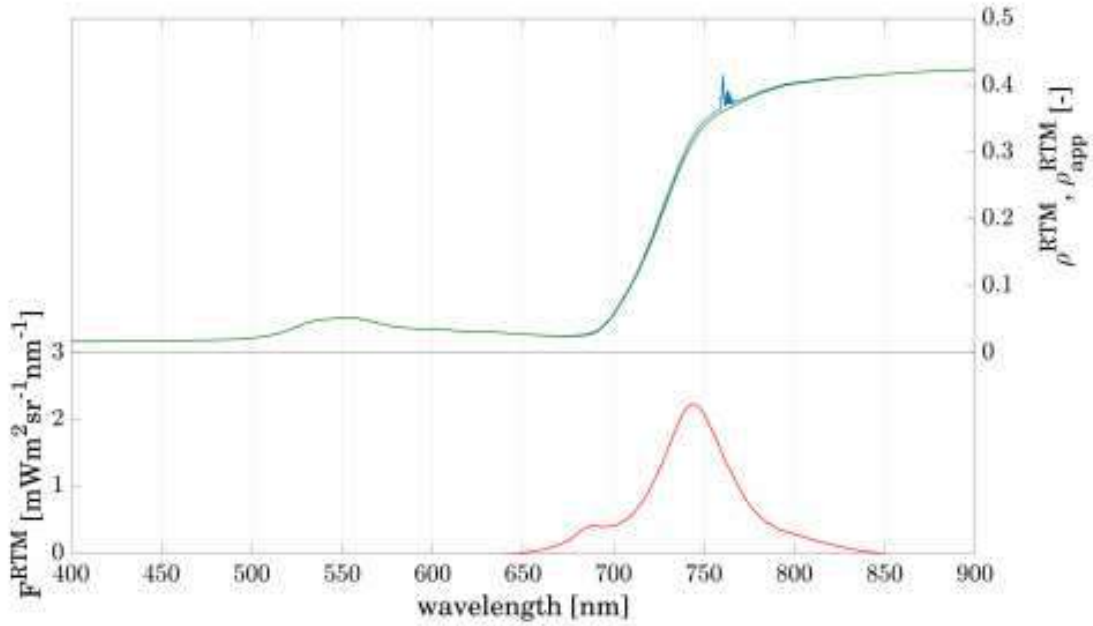


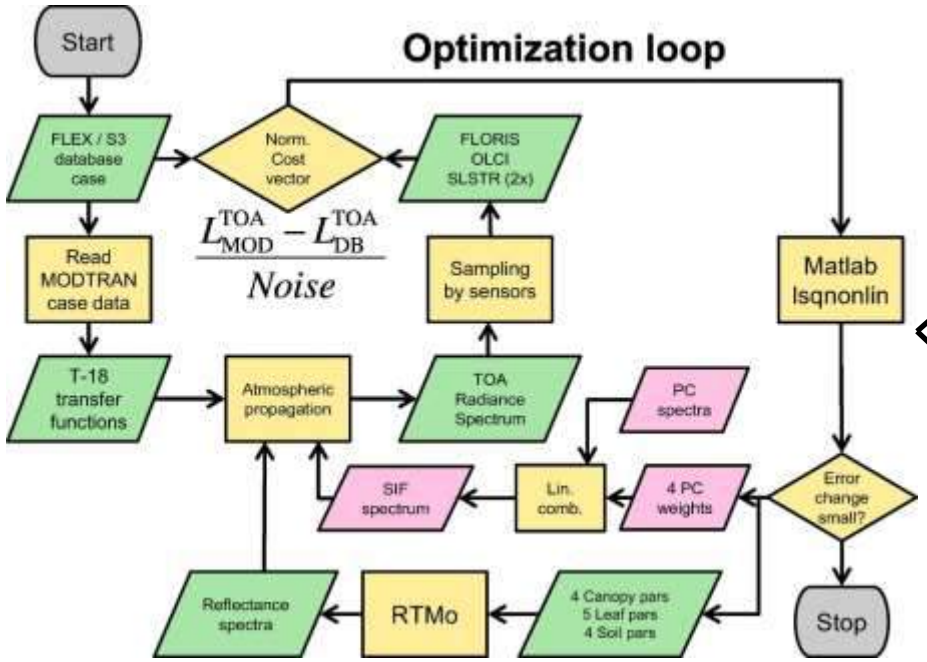


Let's directly tune SCOPE to radiance or apparent reflectance, skip the step of SIF retrieval (iFLD/ SFM)

Celesti et al, (submitted to RSE): field spectroscopy

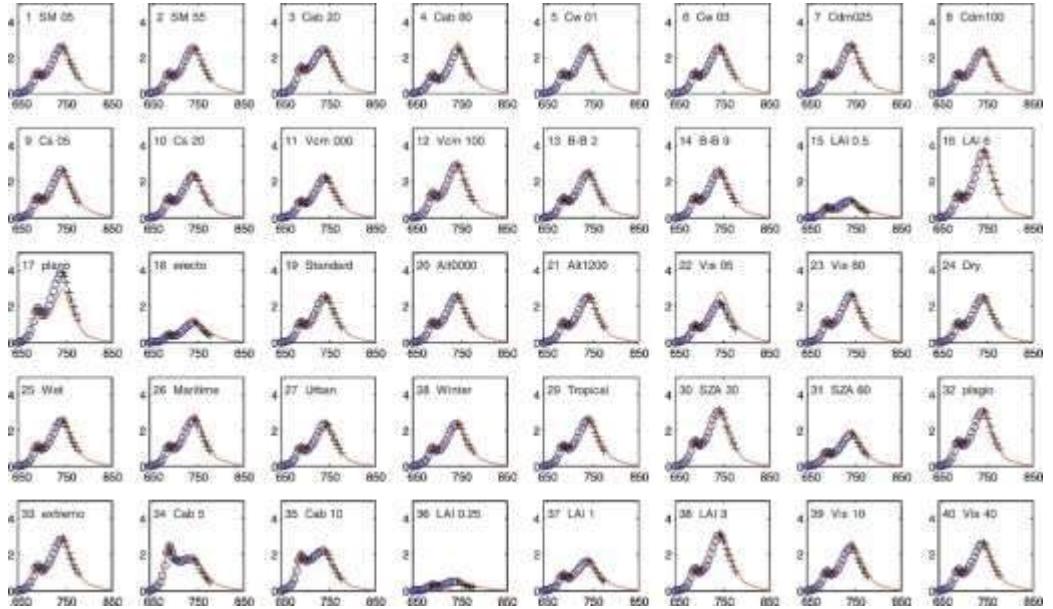
Verhoef et al., (2017): synthetic FLEX/S3 data

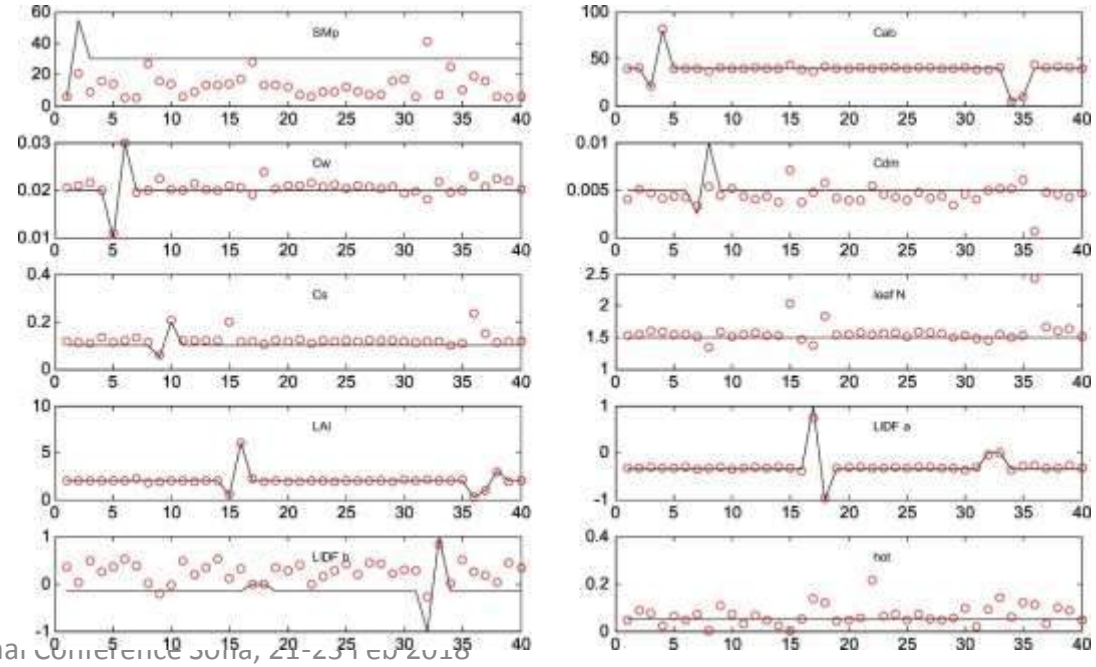
Verhoef et al., (2017)

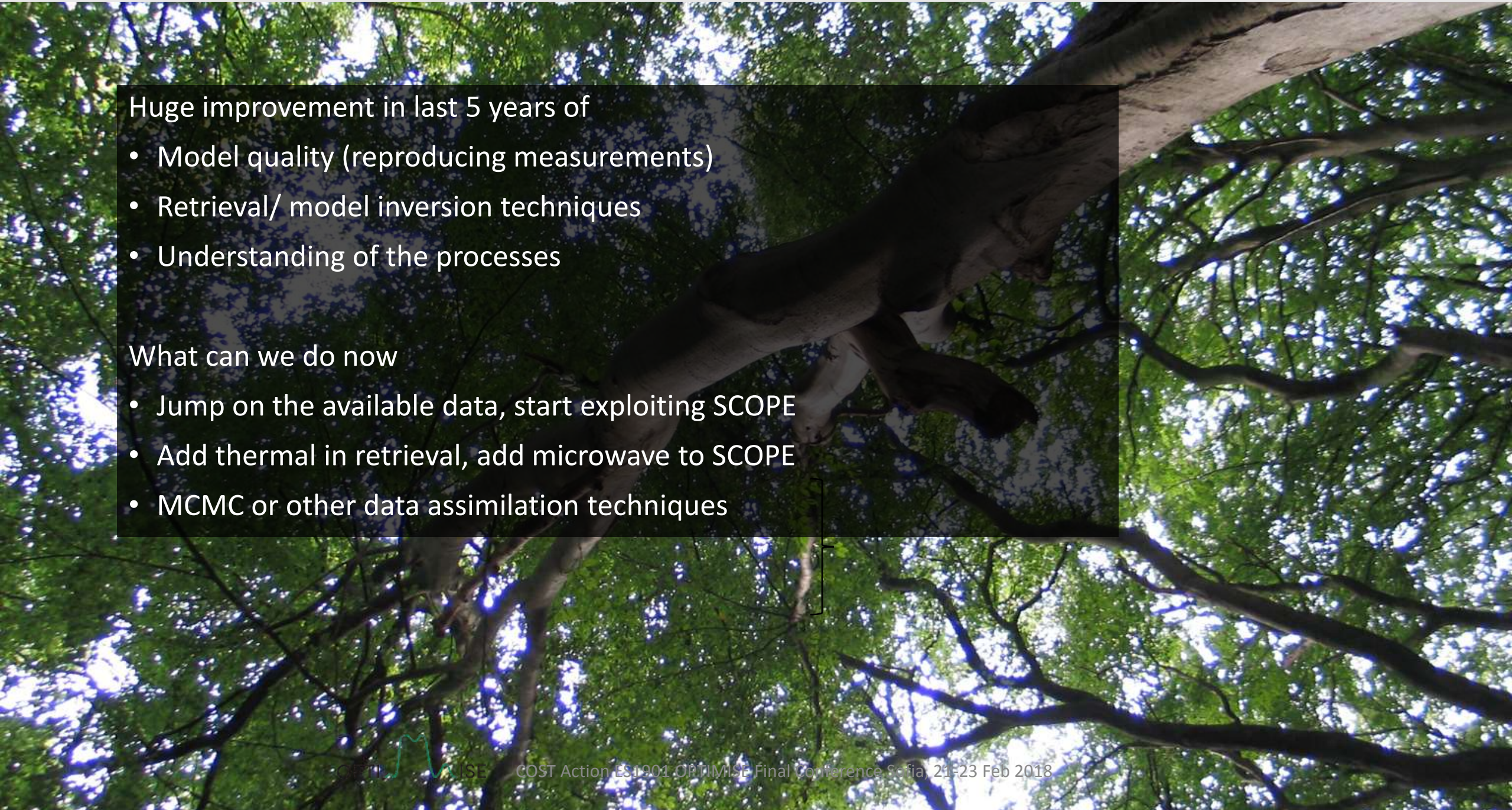


Fluorescence retrievals

Parameter retrievals







Huge improvement in last 5 years of

- Model quality (reproducing measurements)
- Retrieval/ model inversion techniques
- Understanding of the processes

What can we do now

- Jump on the available data, start exploiting SCOPE
- Add thermal in retrieval, add microwave to SCOPE
- MCMC or other data assimilation techniques

Thank you