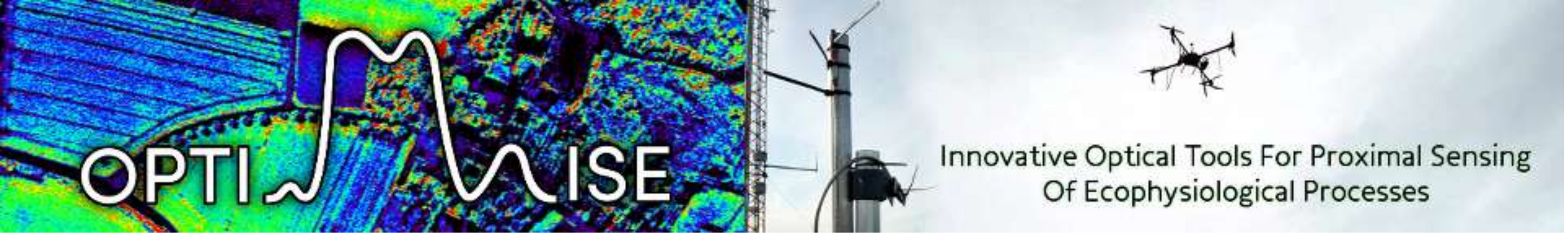


Linking canopy scattering of sun-induced chlorophyll **f**luorescence with **r**eflectance (R2F)

Peiqi Yang and Christiaan van der Tol
ITC, University of Twente
The Netherlands

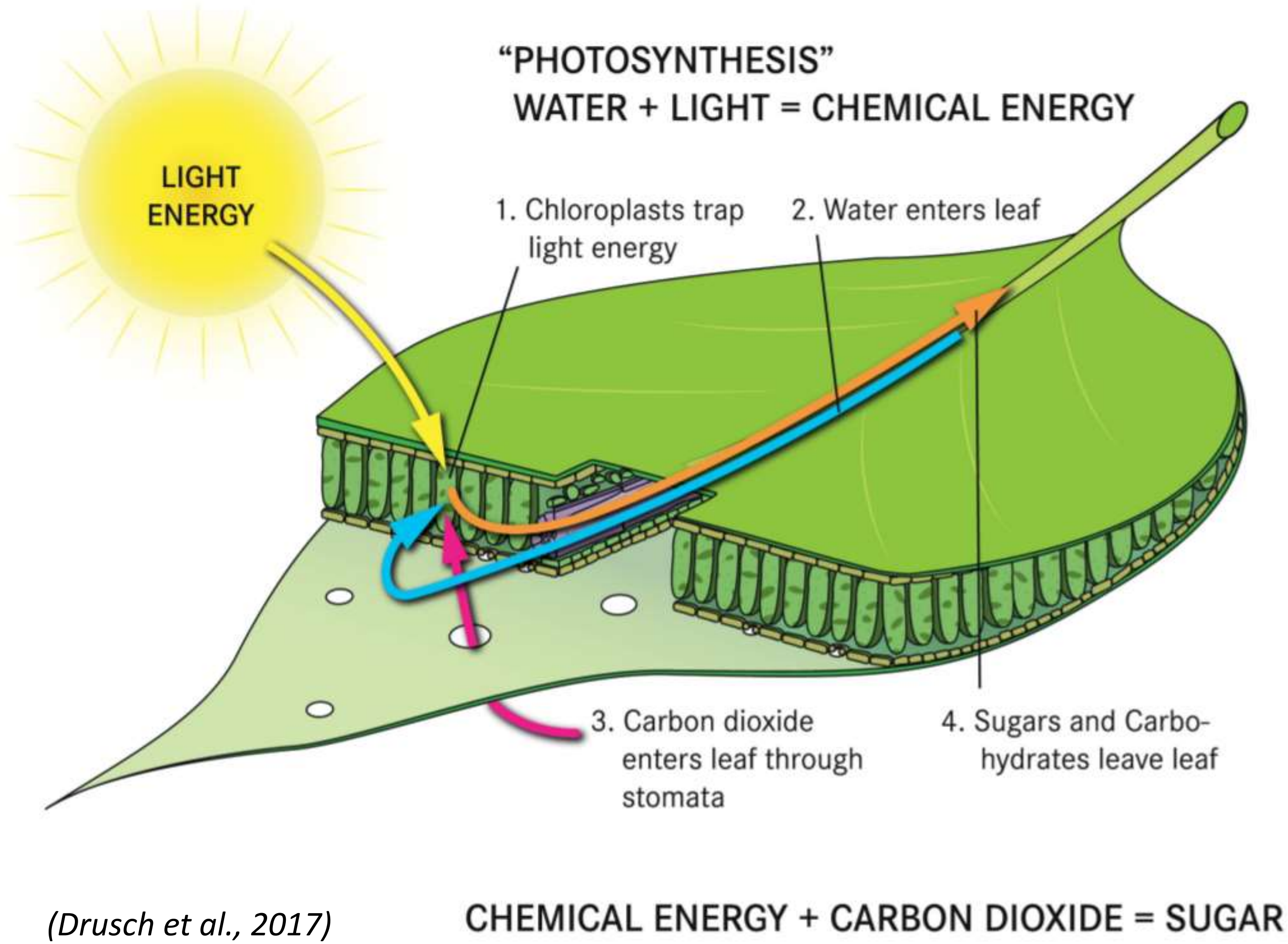
21st -Feb-2018

OPTIMISE final conference

ITC
UNIVERSITY OF TWENTE.

Introduction

Monitoring photosynthesis from space is one of the main tasks of remote sensing

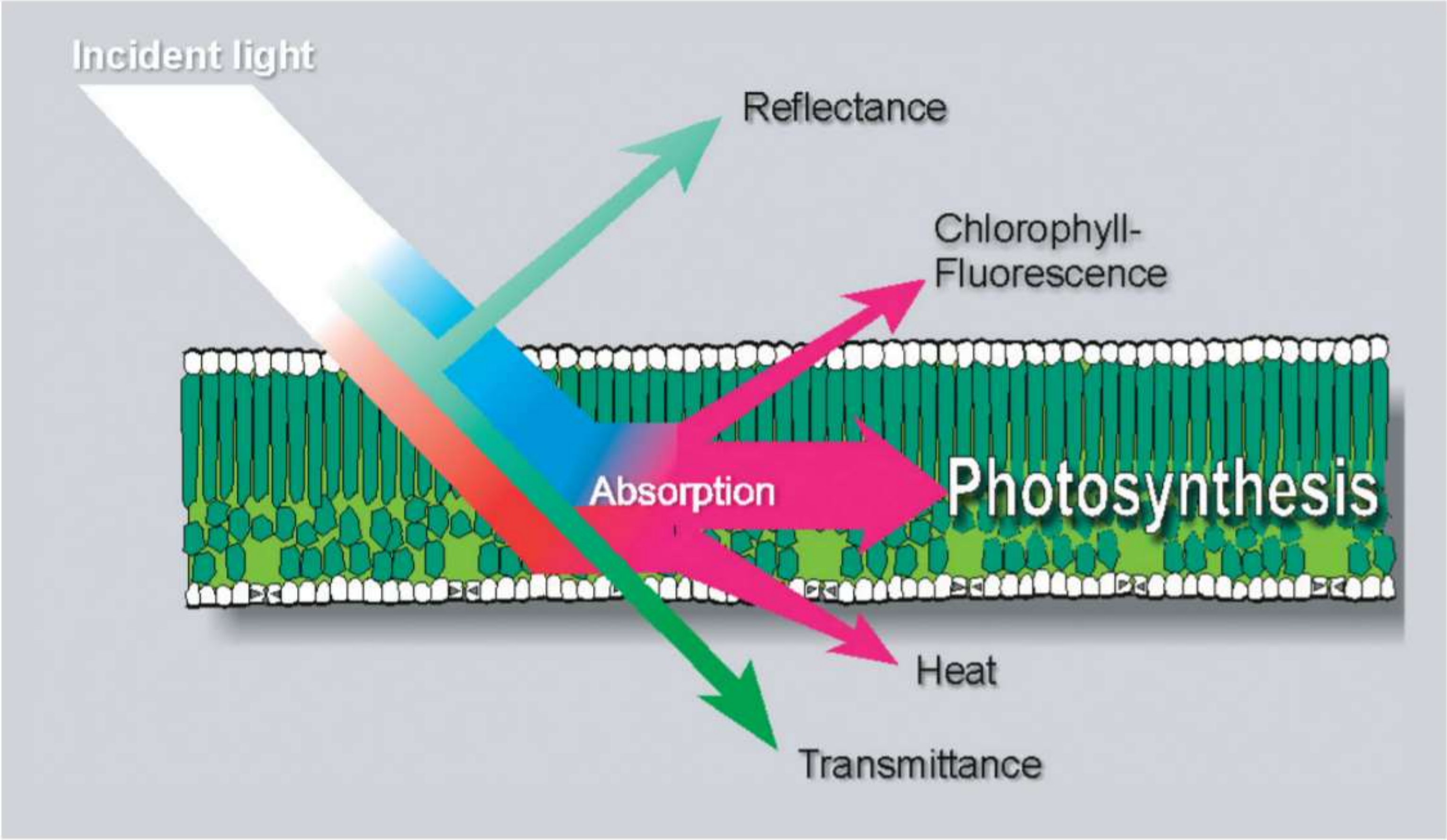


(Drusch et al., 2017)

- plant production
- global carbon cycle
- precision agriculture
- water cycle
- climate-vegetation interaction

Introduction

SIF (sun-induced fluorescence) is a novel indicator of photosynthesis



(Davidson et al., 2003)

Energy absorbed by chlorophyll is used:

- Photosynthesis (P)
- Fluorescence (F)
- Heat dissipation (H)

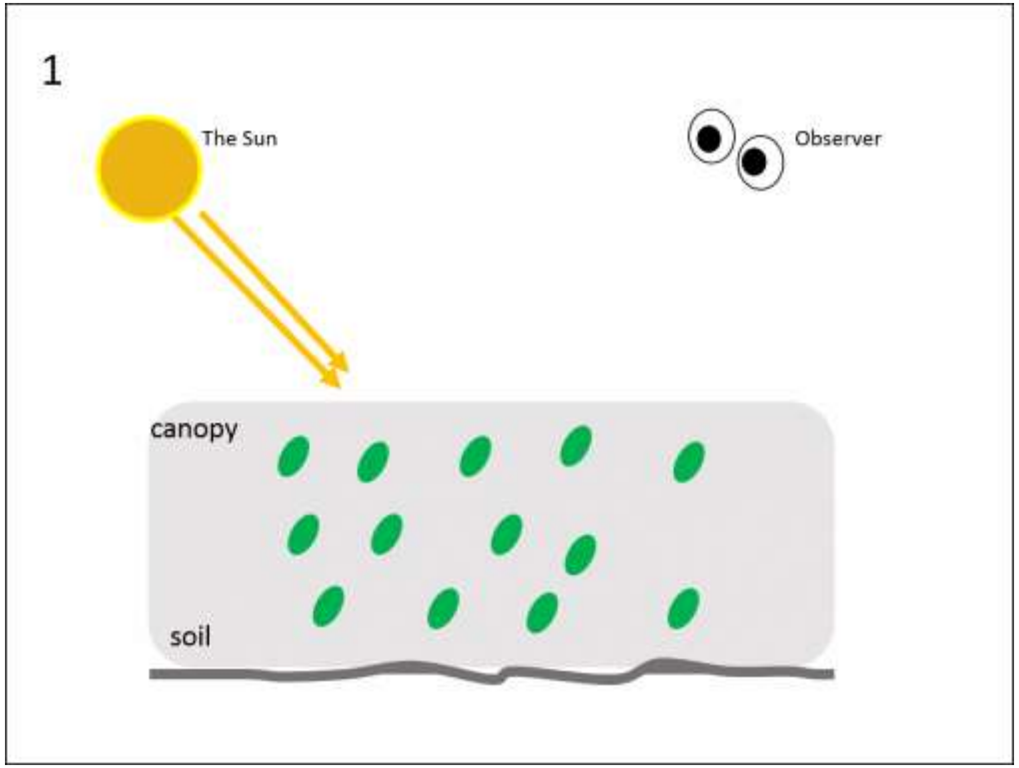
Interpreting SIF signals

- Upscaling and downscaling
- BFDF (angular effects on SIF)
- SIF-GPP relationship

Canopy structure effects

Introduction

Remote sensing only measures a part of canopy emitted SIF



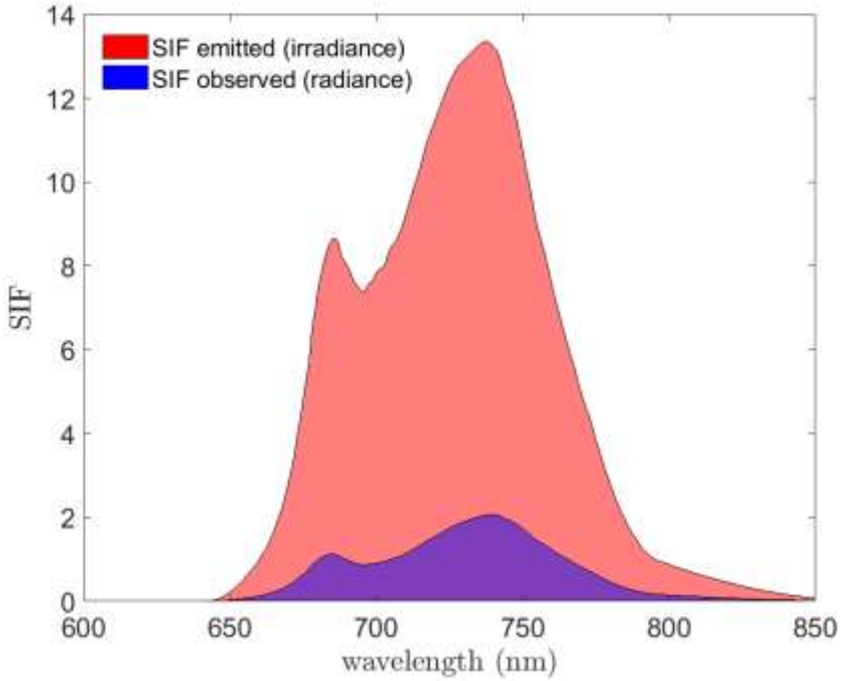
GPP = APAR x LUE_P

SIF = APAR x LUE_F x σ_F

Escape probability

scattering (σ_F) and re-absorption of emitted SIF

- Canopy structure
- Leaf properties
- Viewing angle



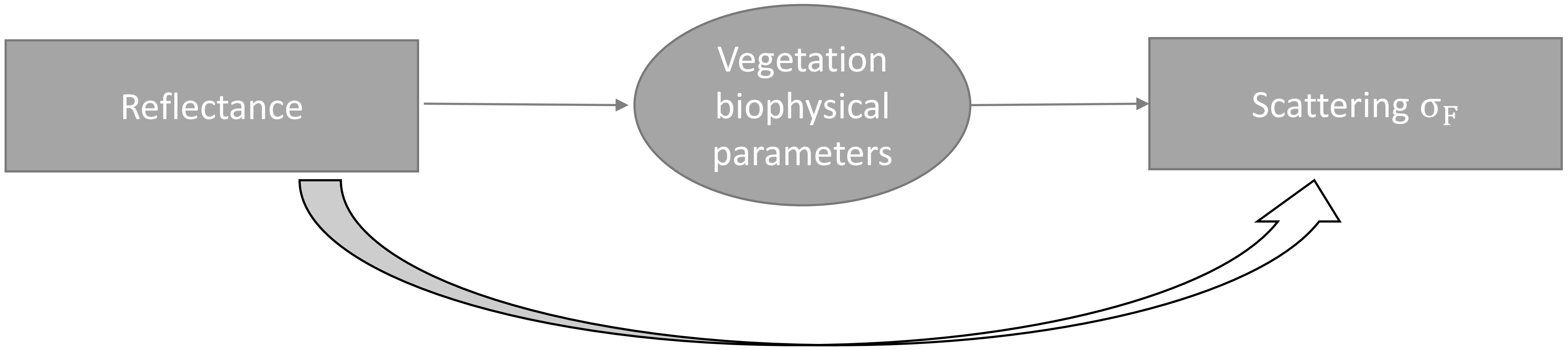
Total SIF emitted by leaves and SIF observed at top of canopy modeled by SCOPE

Introduction

RTMs (radiative transfer models) to quantify scattering (σ_F).

Require inputs of canopy structure (LAI, leaf angle), and leaf properties (chlorophylls)

Retrieve these parameters from reflectance



- time consuming

- model dependent

- uncertainty in the retrieval

Introduction

Objective: Link scattering of SIF with reflectance

$$\sigma_{FC} = f(R)$$

Scattering of incident light results into reflectance

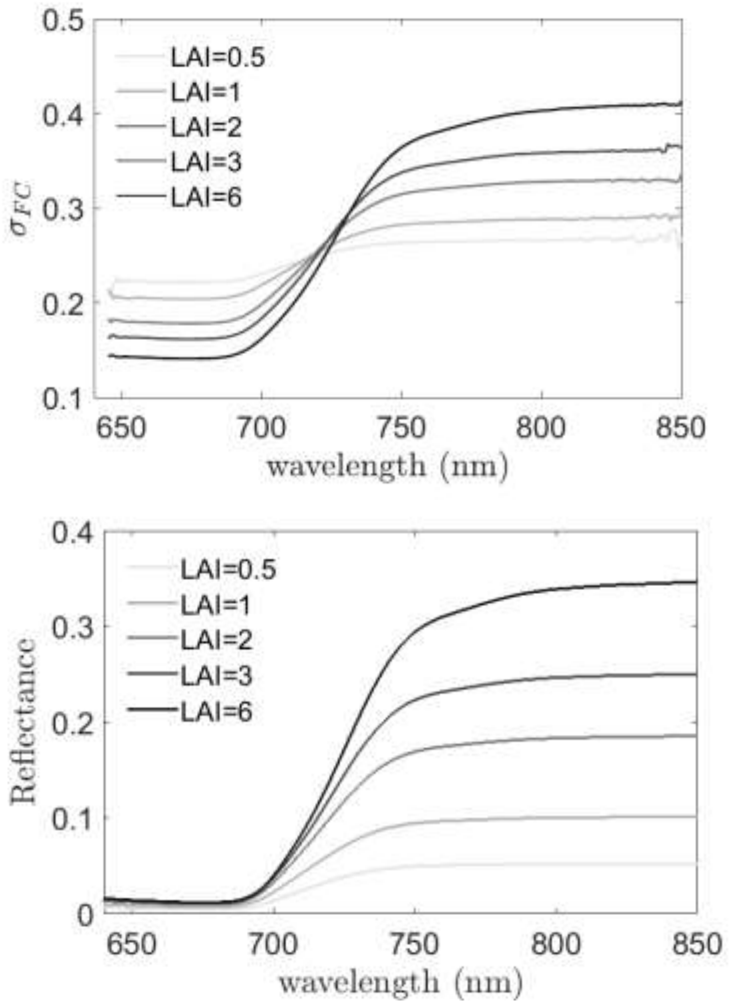
Method: Comparing scattering of emitted SIF with scattering of incident light

$$\sigma_{FC}(\lambda) = \frac{1}{i_0 \omega} R(\lambda)$$

canopy interceptance (i_0)

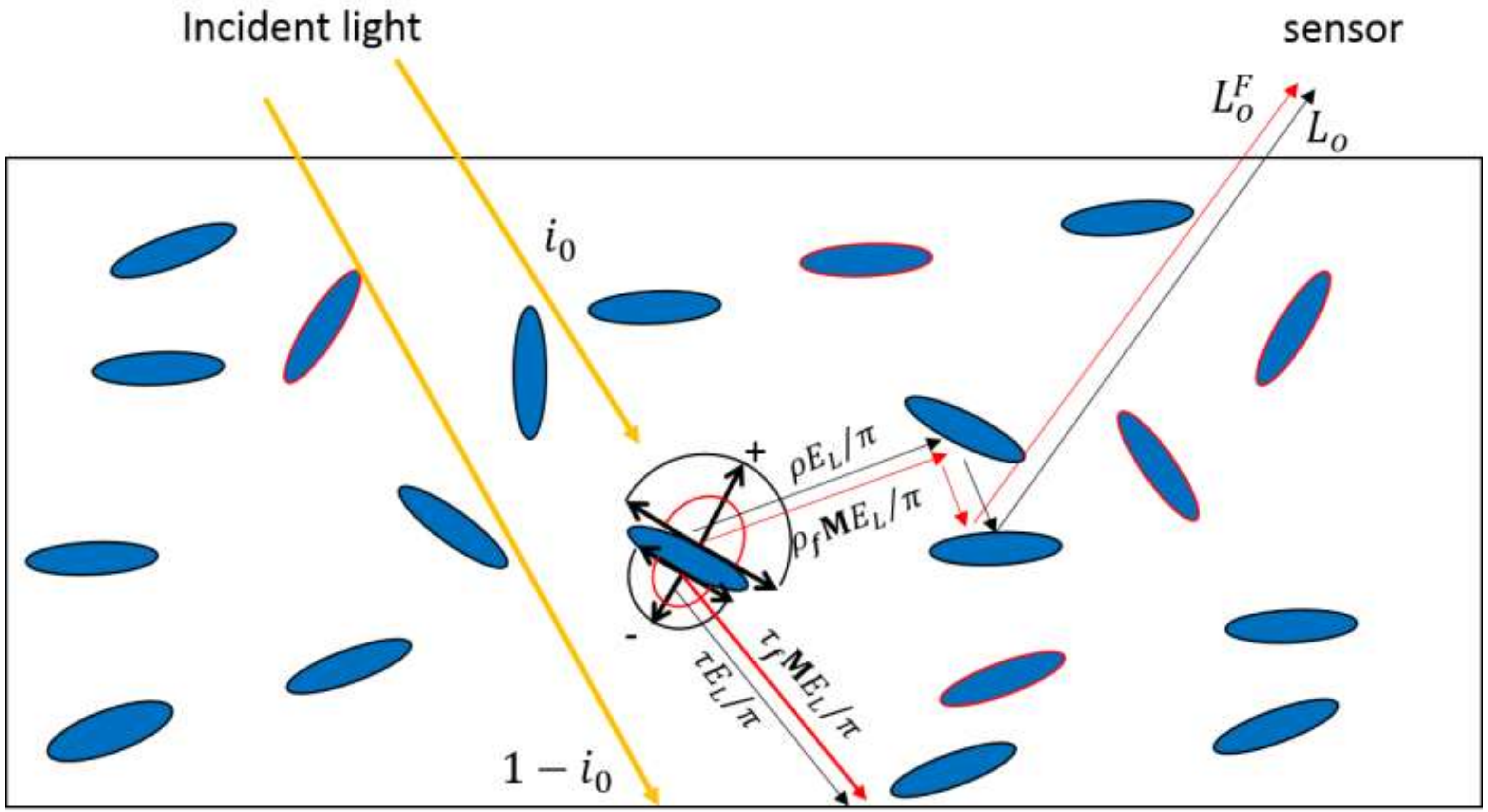
leaf albedo (ω)

$$\omega = \rho + \tau$$



Reflectance and scattering of SIF from SCOPE

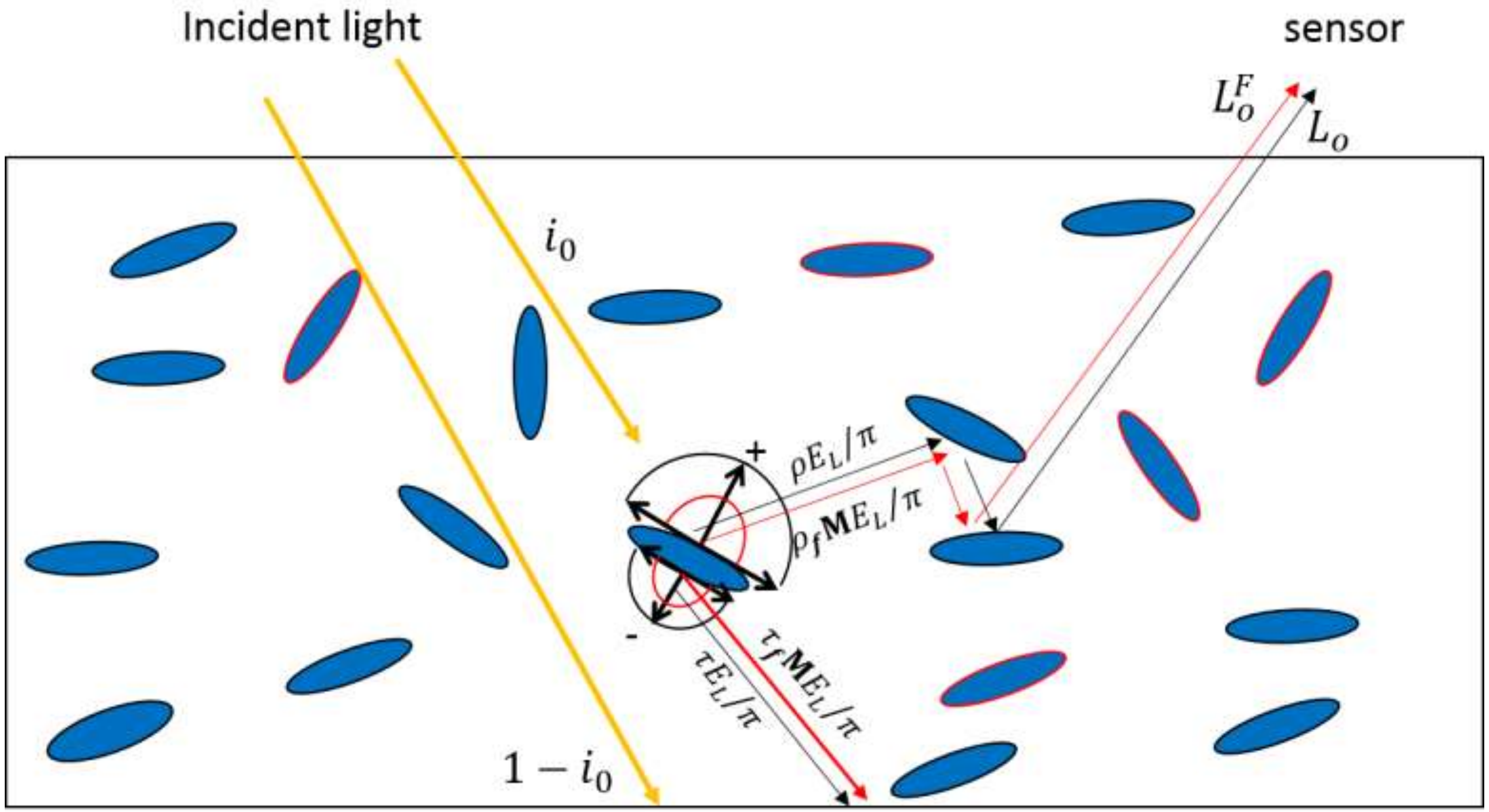
Theoretic deviation



$$R = \pi L_o / E \qquad \sigma_{FC} = \pi L_o^F / E_F$$

where E is the incident light irradiance, E_F is the total emitted SIF by leaves. Lo and Lo^F are observed reflected radiance, and SIF radiance, respectively.

Theoretic deviation



Canopy SIF emission

$$E_F(\lambda_f) = i_0 \int_{400}^{750} \mathbf{M}(\lambda_f, \lambda_e) E(\lambda_e) d\lambda_e = i_0 \mathbf{M} E$$

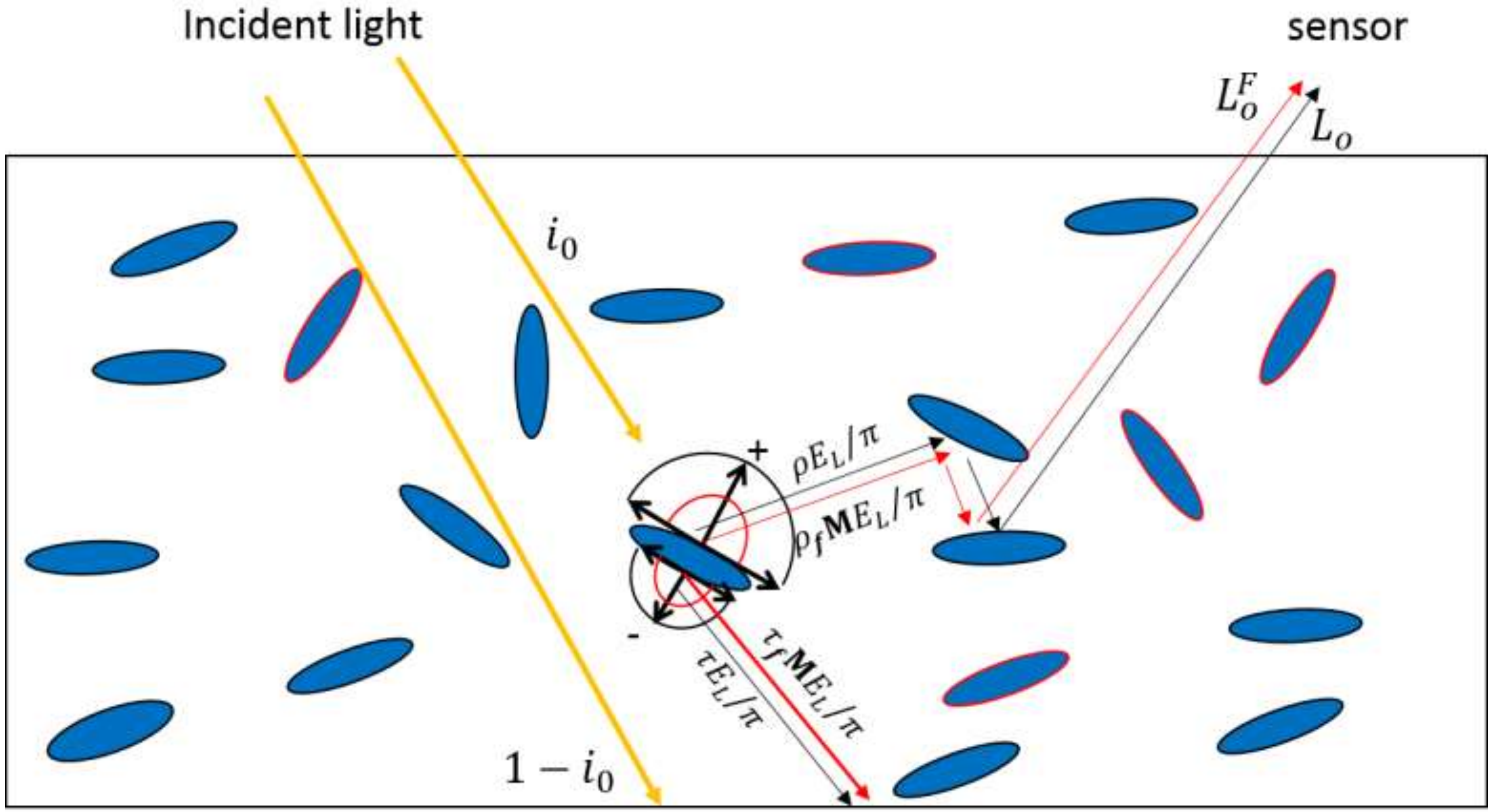
One leaf SIF emission

$$i_0 \mathbf{M} E_L$$

$$E_L(\lambda) = P_s(x, y, z) f_s(\varphi_l, \theta_l, \varphi_s, \theta_s) E(\lambda)$$

Sunlit or shaded   Sun-leaf geometry

Theoretic deviation



Contribution from one leaf

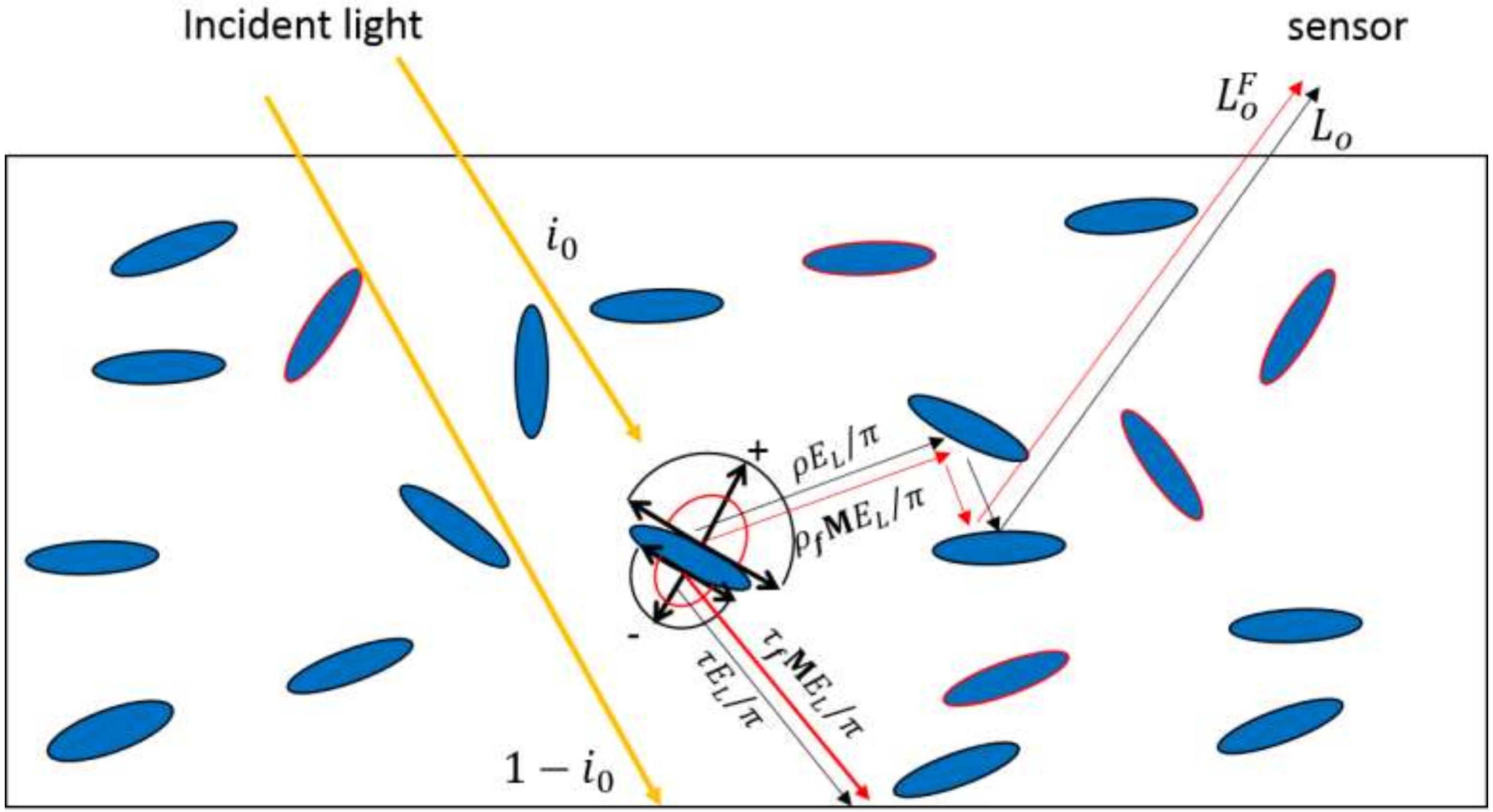
$$\Delta L_o(\lambda) = \frac{E_L}{\pi}[\rho f_o(x, y, z, \lambda, \Omega_L \to \Omega_o) + \tau f_o(x, y, z, \lambda, -\Omega_L \to \Omega_o)]$$

$$\Delta L_o^F(\lambda) = \frac{\mathbf{M}E_L}{\pi}[\rho_f f_o(x, y, z, \lambda, \Omega_L \to \Omega_o) + \tau_f f_o(x, y, z, \lambda, -\Omega_L \to \Omega_o)]$$

$$L_o(\lambda) = \frac{E}{\pi} \sum_{leaves} [P_s f_s \rho f_+ + P_s f_s \tau f_-]$$

$$L_o^F(\lambda) = \frac{\mathbf{M}E}{\pi} \sum_{leaves} [P_s f_s \rho_f f_+ + P_s f_s \tau_f f_-]$$

Theoretic deviation



$$R(\lambda) = \sum_{leaves} [P_s f_s \rho f_+ + P_s f_s \tau f_-]$$

$$\sigma_{FC}(\lambda) = \frac{1}{i_0} \sum_{leaves} [P_s f_s \rho_f f_+ + P_s f_s \tau_f f_-]$$

$$1 = \rho_f + \tau_f \qquad \omega = \rho + \tau$$

Under one of conditions $\begin{cases} f_+ = f_- \\ \dfrac{\rho}{\tau} = \dfrac{\rho_f}{\tau_f} \end{cases}$

We obtain $\sigma_{FC}(\lambda) = \frac{1}{i_0 \omega} R(\lambda)$

Simulation methods

We used 1800 synthetic scenarios to test the relationship by using SCOPE model simulation

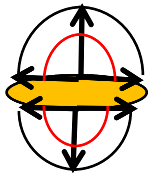
Table 1: Summary of SCOPE inputs applied for the generation of the database

Parameter	Explanation	Unit	Values
C_{ab}	Chlorophyll $a+b$ content	μg cm^{-2}	5, 10, 20, 40, 80
C_{dm}	Leaf mass per unit area	g cm^{-2}	0.01, 0.02
C_w	Equivalent water thickness	cm	0.015, 0.03
N	Leaf structure parameter	-	1, 1.5, 2
LAI	Leaf area index	-	0.5, 1, 2, 3, 6
LIDFa	Leaf inclination function parameter a	-	-0.5, 0.5
θ_s	sun zenith angle	°	30, 45, 60

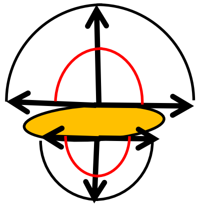
SCOPE provides
- Leaf albedo ω
- Canopy reflectance R
- SIF emitted by all the leaves E_F
- TOC SIF L_o^F

Two groups of simulations:

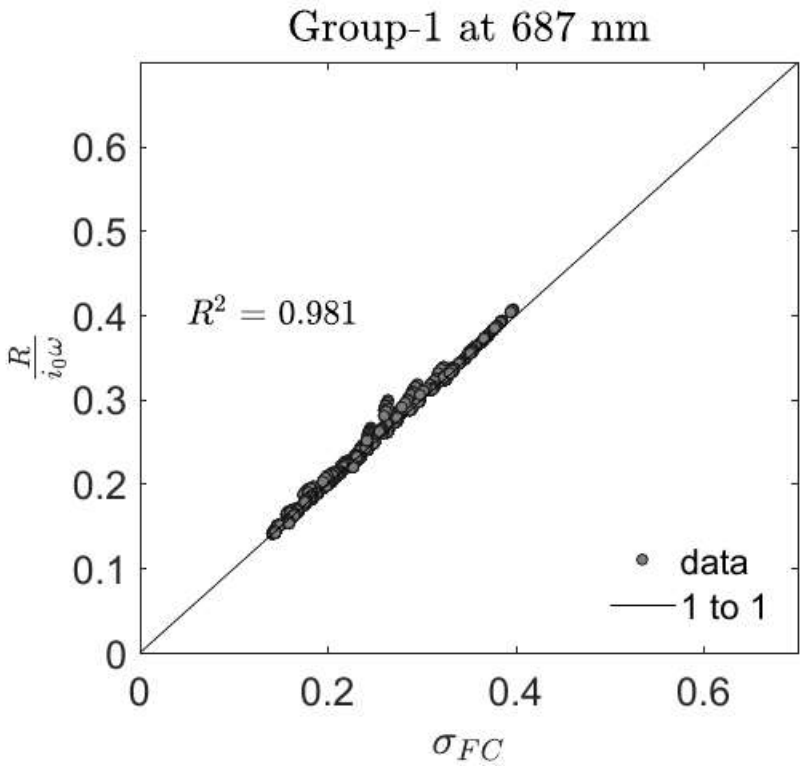
Synthetic leaves: $\rho = \tau = \frac{1}{2}\omega; \rho_f = \tau_f = \frac{1}{2}$. Thus, $\frac{\rho_f}{\tau_f} = \frac{\rho}{\tau}$

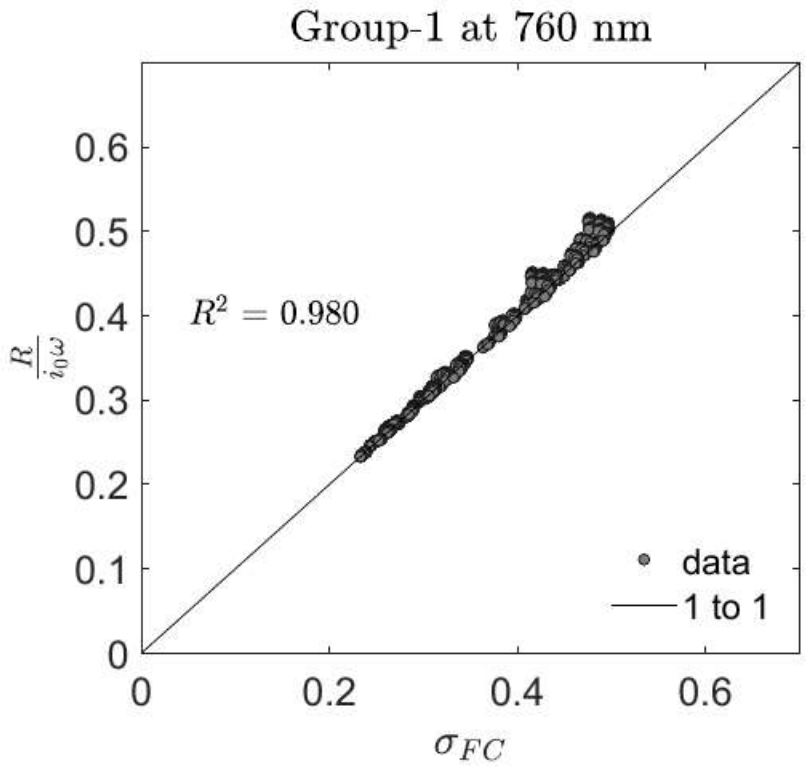


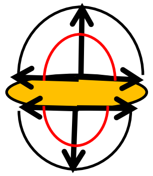
PROSPECT leaves



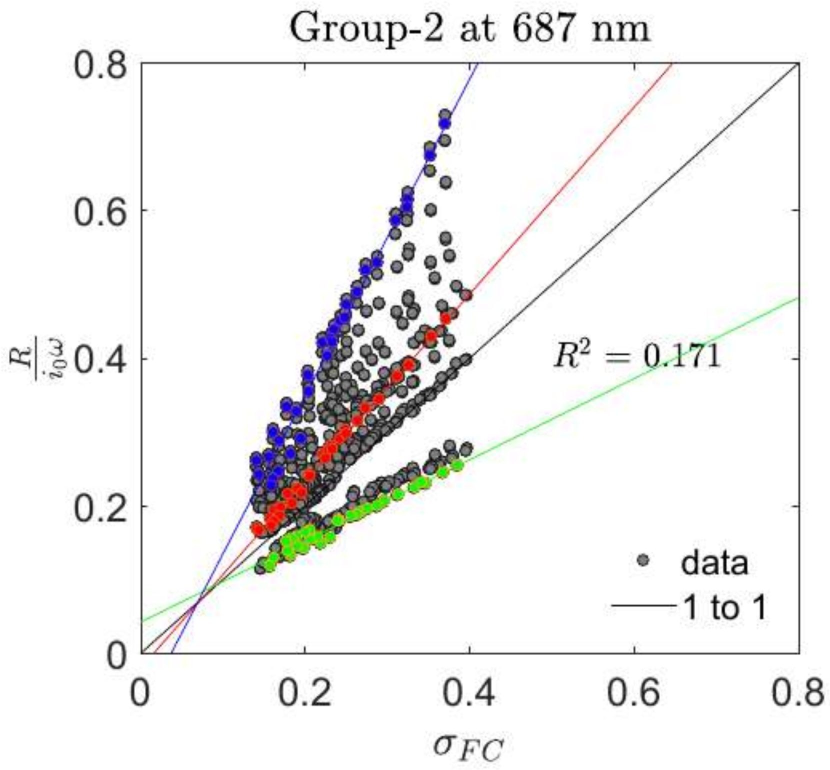
Results

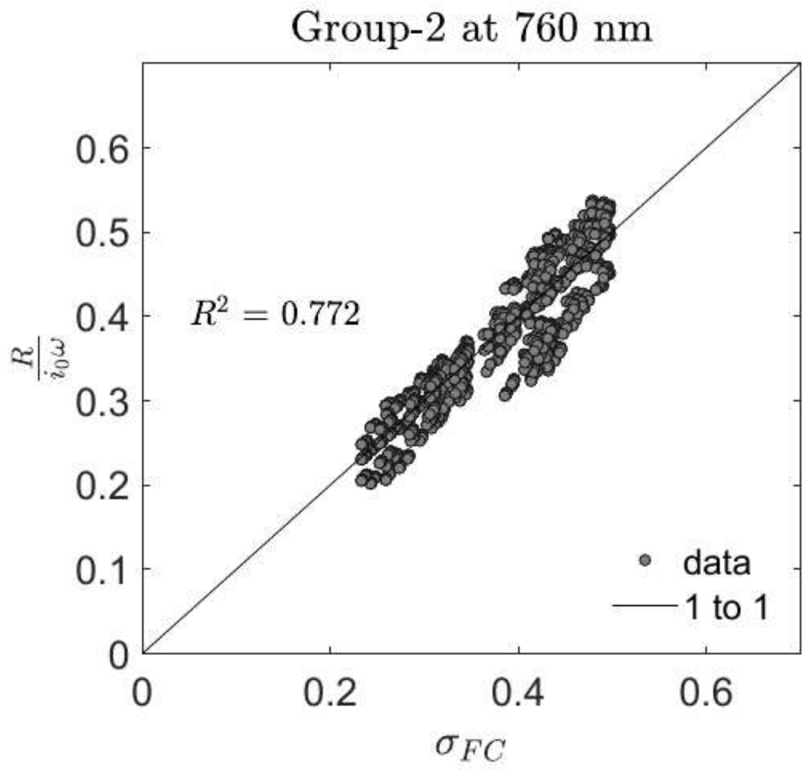

Group-1 at 687 nm
$R^2 = 0.981$
data
1 to 1
$\frac{R}{i_0\omega}$
σ_{FC}
0
0.1
0.2
0.3
0.4
0.5
0.6

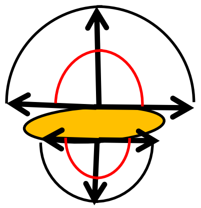

Group-1 at 760 nm
$R^2 = 0.980$
data
1 to 1
$\frac{R}{i_0\omega}$
σ_{FC}
0
0.1
0.2
0.3
0.4
0.5
0.6



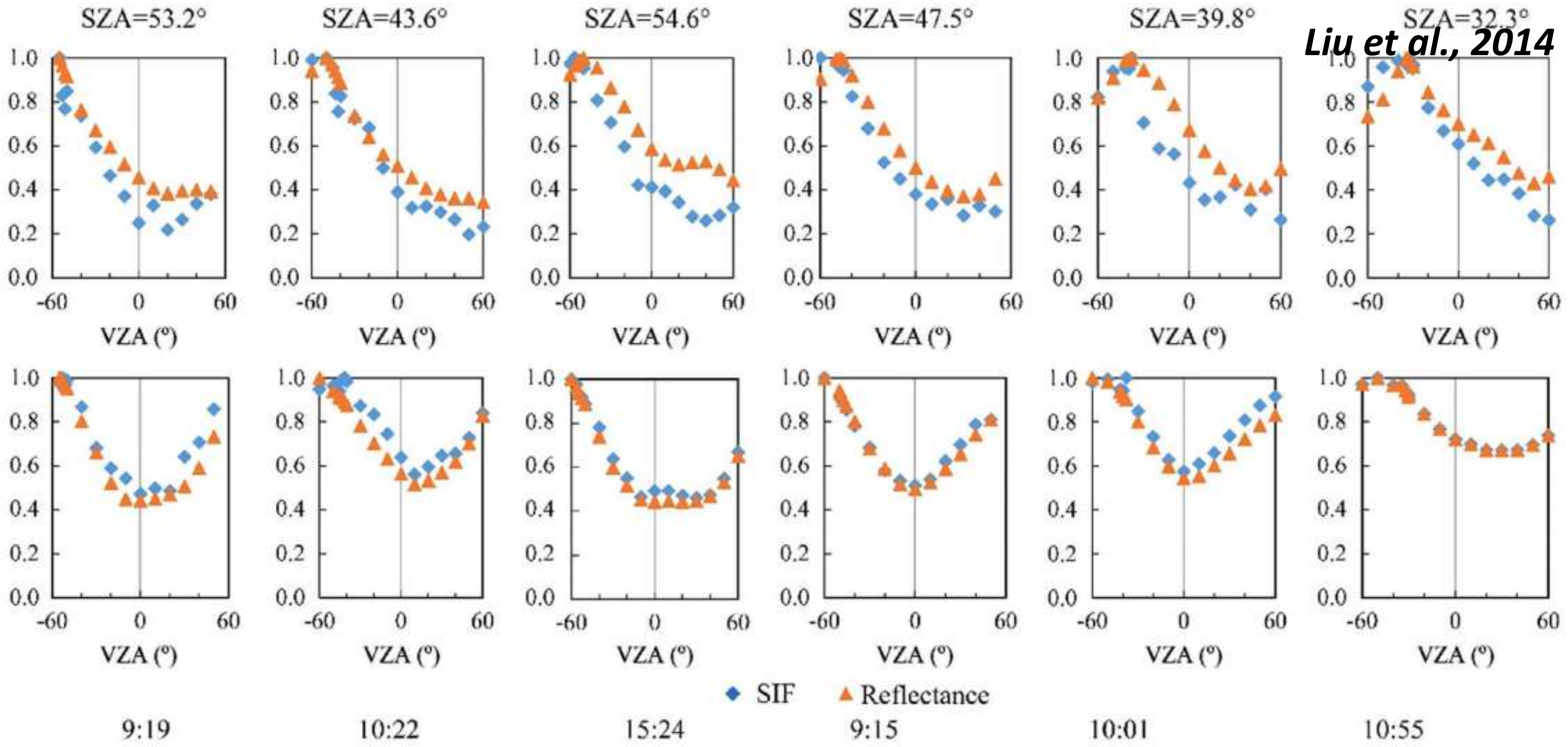
Results







$$\frac{\rho}{\tau} = \frac{\rho_f}{\tau_f}$$



Liu et al., 2014

F

EM

$\boldsymbol{i_0\omega}$

$/\omega$ x R($\boldsymbol{\Omega}$)

Estimation of canopy fluorescence emission and GPP

GPP = APAR x LUE_P

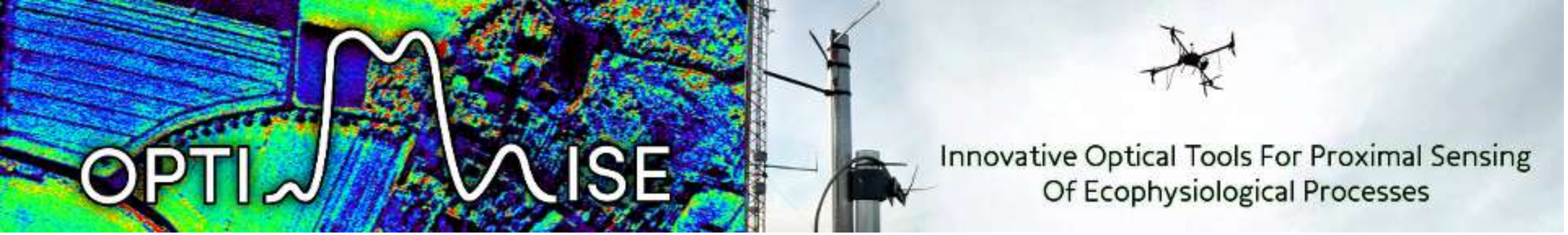
SIF = APAR x LUE_F x σ_F

Conclusion

- Canopy scattering of far-red SIF is expressed as a simple function of reflectance
- The link allows decoupling canopy structural and functional regulation on SIF
- The link allows correcting directional effects on SIF measurements

Future work

- ➢ Testing the relationship by using 2D (mSCOPE) and 3D model (DART)
- ➢ Applying the relationship for field measurements
- ➢ Spectral invariant theory



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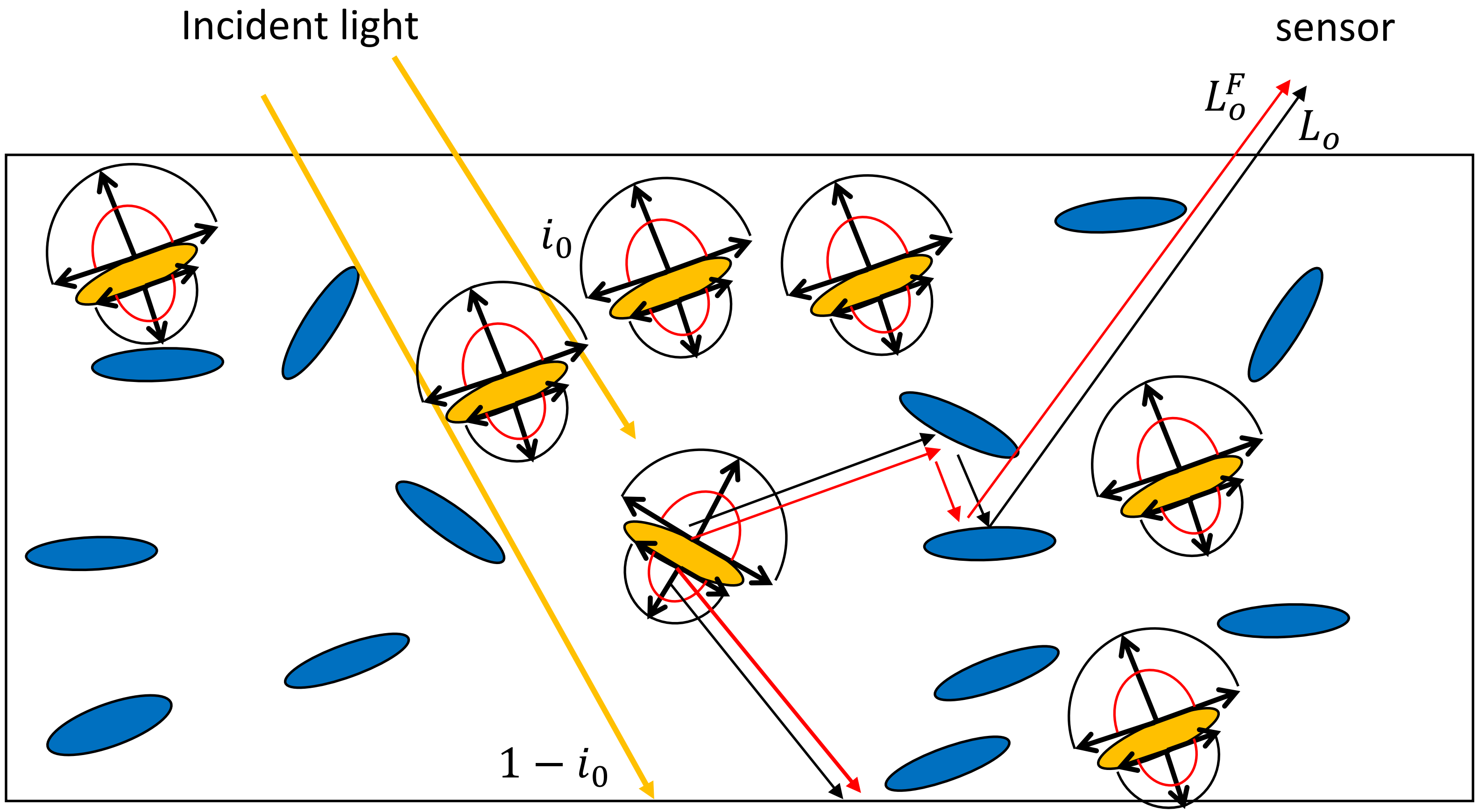
Spectral invariants

$$R = i_0 \rho(\Omega) \frac{\omega(\lambda)}{1 - p\omega(\lambda)}$$

$$\sigma_{FC}(\lambda) = \rho(\Omega) + p\omega(\lambda)\rho(\Omega) + p^2\omega(\lambda)^2\rho(\Omega) + ... = \frac{\rho(\Omega)}{1 - p\omega(\lambda)}$$

$$\text{DASF} = \frac{\rho(\Omega) i_0}{1 - p}$$

Theoretic deviation



Leaves involved in the first order interactions between incident light and the canopy (light interception, i_0E

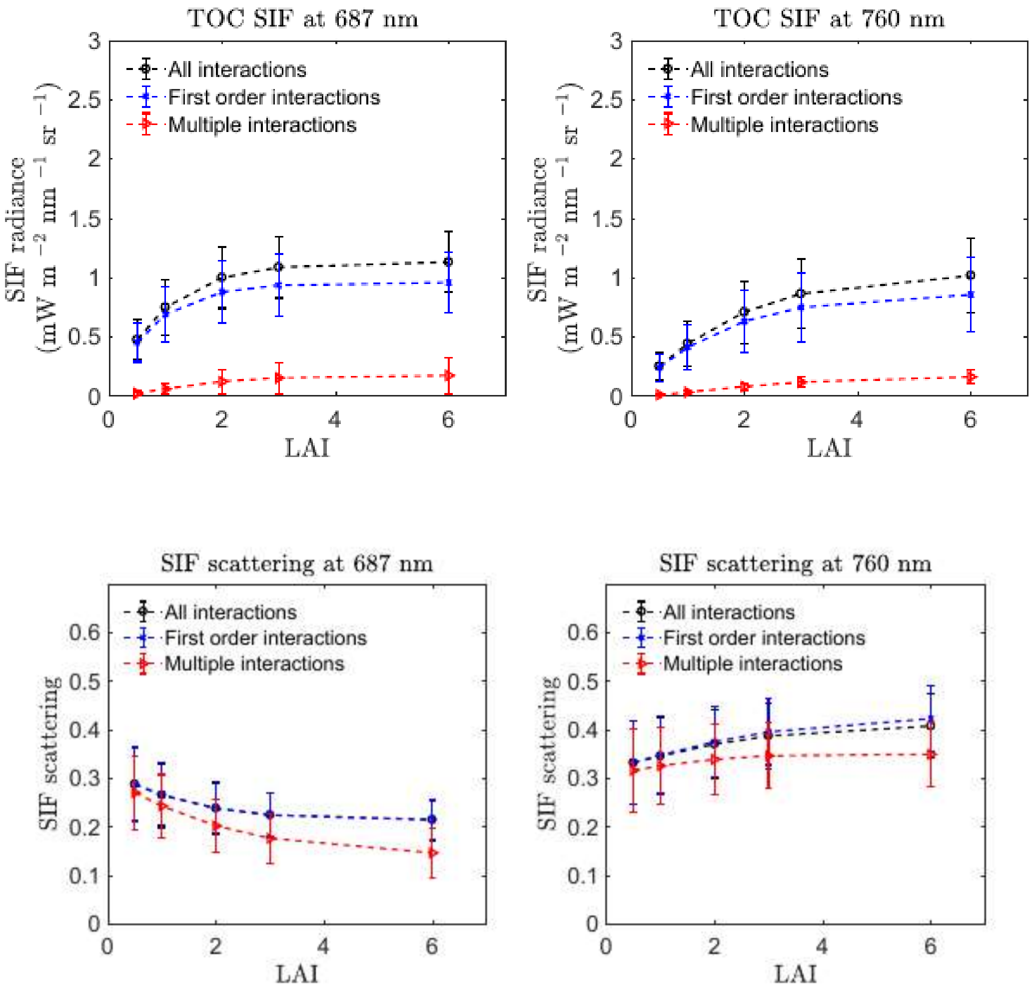
Leaves not involved in first interactions

$$\sigma_F = c_1 \times \sigma_F^1 + c_m \times \sigma_F^m$$

$$c_1 + c_m = 1$$

Comparing the radiative transfer of intercepted radiation with emitted SIF in the first order interactions.

Results



Testing assumption

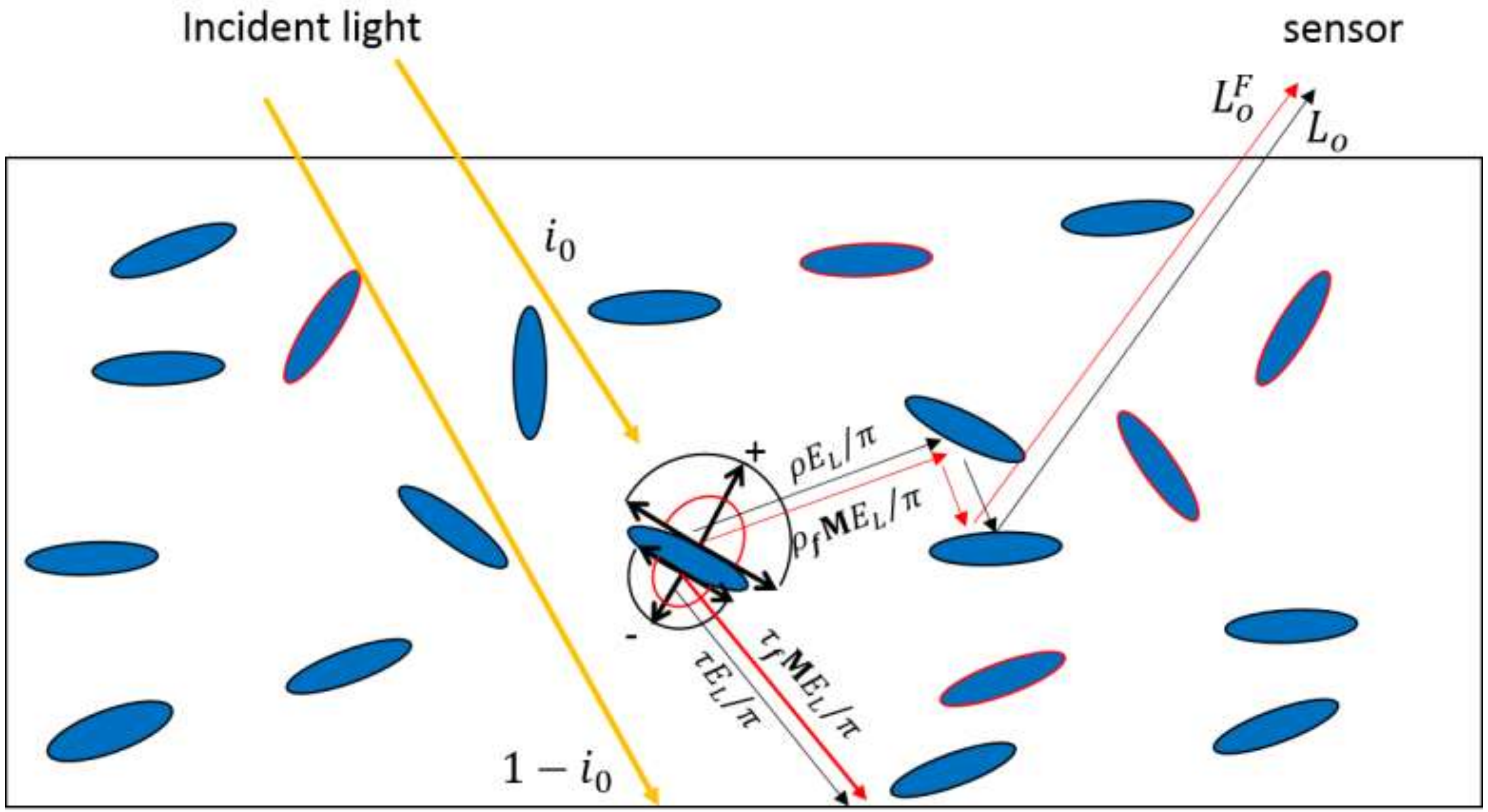
$$\sigma_F = c_1 \times \sigma_F^1 + c_m \times \sigma_F^m$$

$$c_1 >> c_m$$

$$\Rightarrow \sigma_F^1 \approx \sigma_F$$

$$\sigma_F^1 \approx \sigma_F^m$$

Theoretic deviation

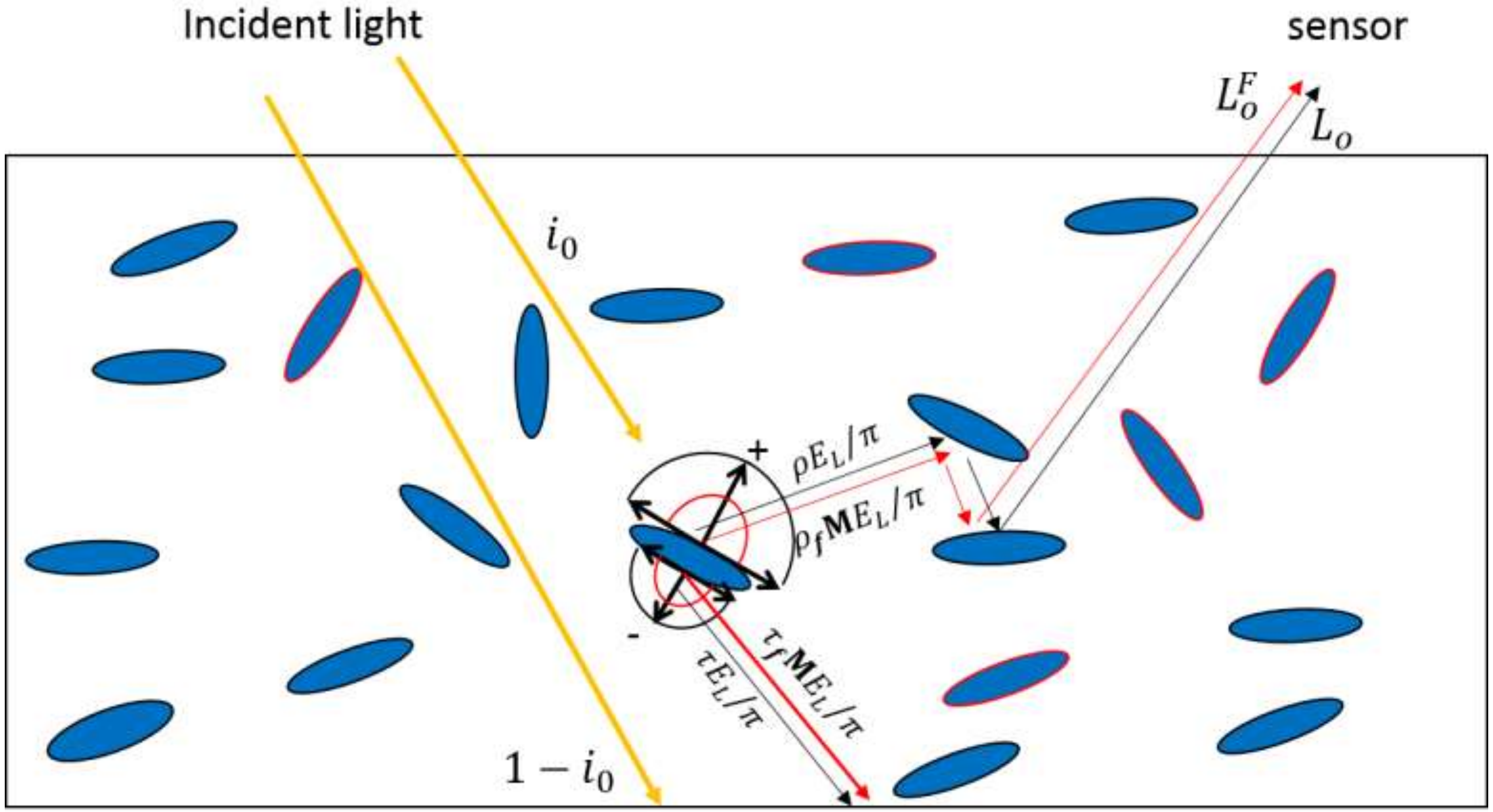


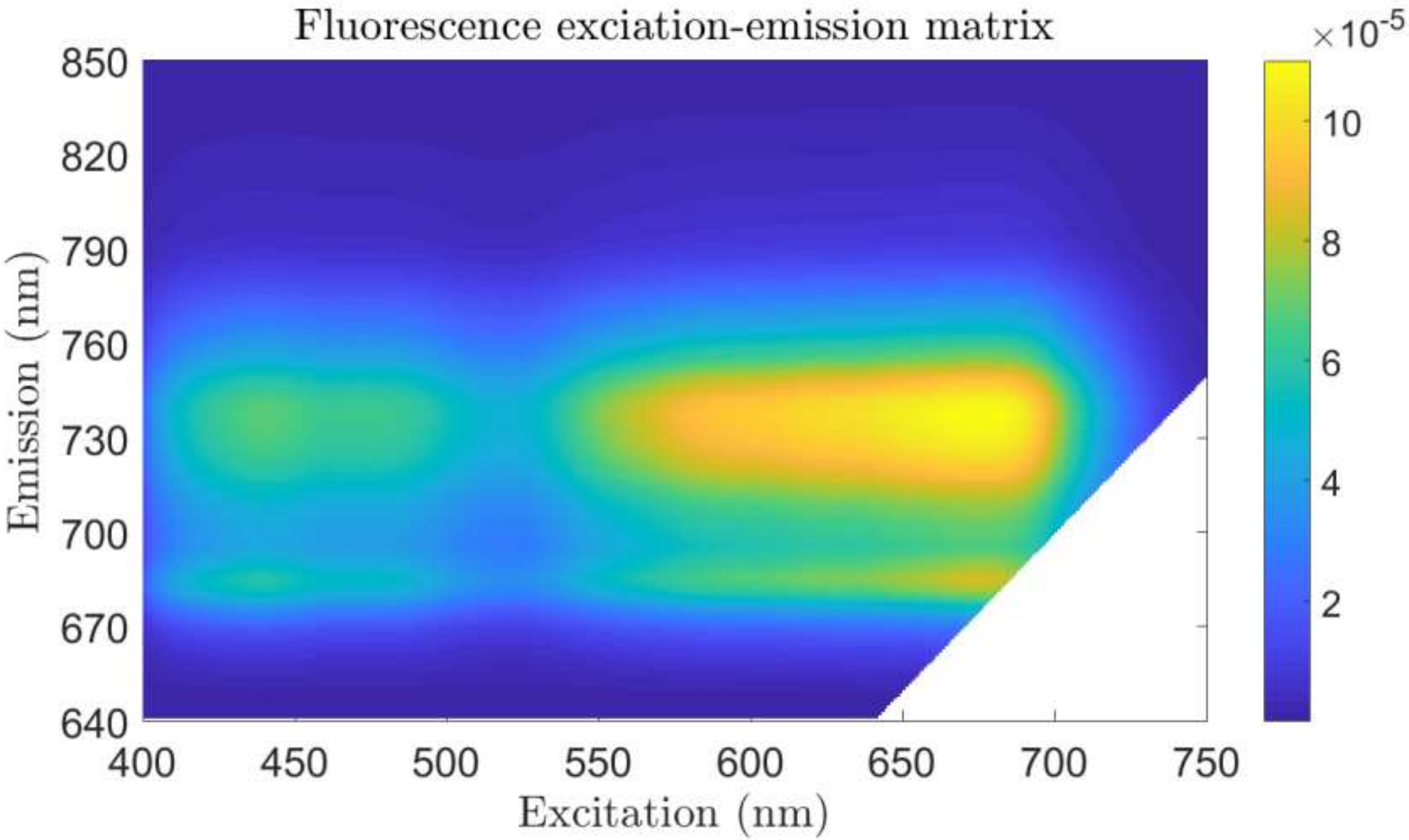
$$R = \pi L_o / E \qquad \sigma_{FC} = \pi L_o^F / E_F$$

where E is the incident light irradiance, E_F *is the total emitted SIF by leaves. Lo and* Lo^F *are observed reflected radiance, and SIF radiance, respectively.*

Soil background

$$(1 - i_0) r_s P_o;$$




Fluorescence exciation-emission matrix
×10^-5
850
820
790
760
730
700
670
640
Emission (nm)
400
450
500
550
600
650
700
750
Excitation (nm)
10
8
6
4
2

Within-leaf scattering

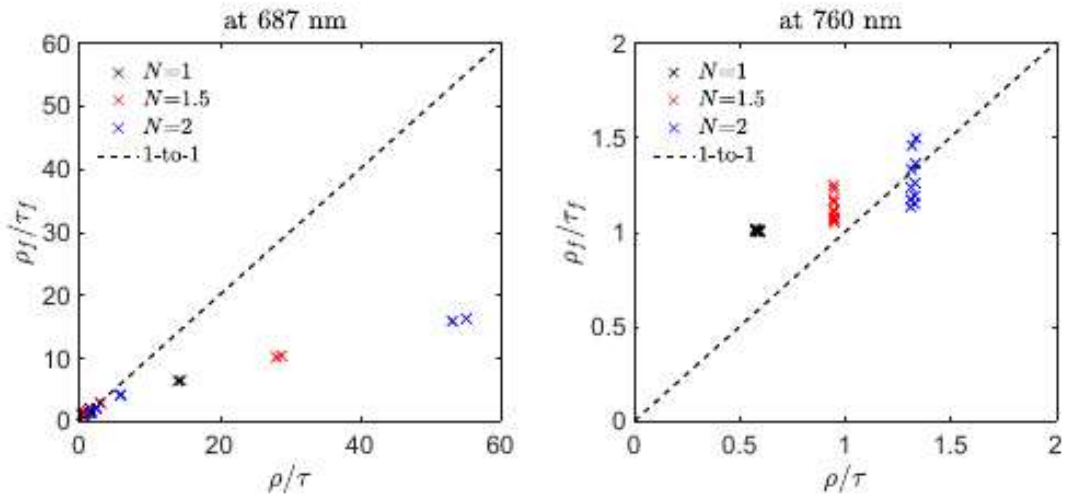


Figure 8: The comparison of partitioning of scattered radiation (ρ/τ) and partitioning of emitted SIF (ρ_f/τ_f) over the two sides of leaves at 687 nm and 760 nm simulated with Fluspect. Simulations with the same leaf structure parameter (N) are marked with the same colour.