Reflectance, fluorescence and photosynthesis in vertically heterogeneous canopies (mSCOPE)

Peiqi Yang, Wouter Verhoef, Christiaan van der Tol

Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente

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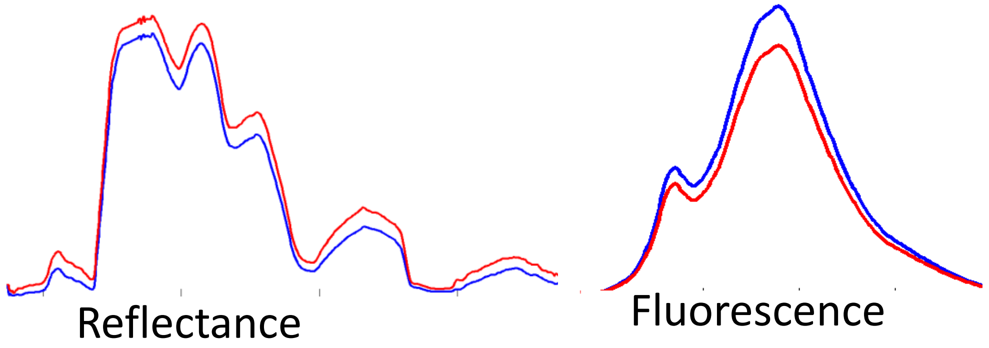
Outline

- 1. Introduction
- 2. Model description
- 3. Model simulations
- 4. Conclusions

Introduction

Link remote sensing observations to biochemical properties of vegetation

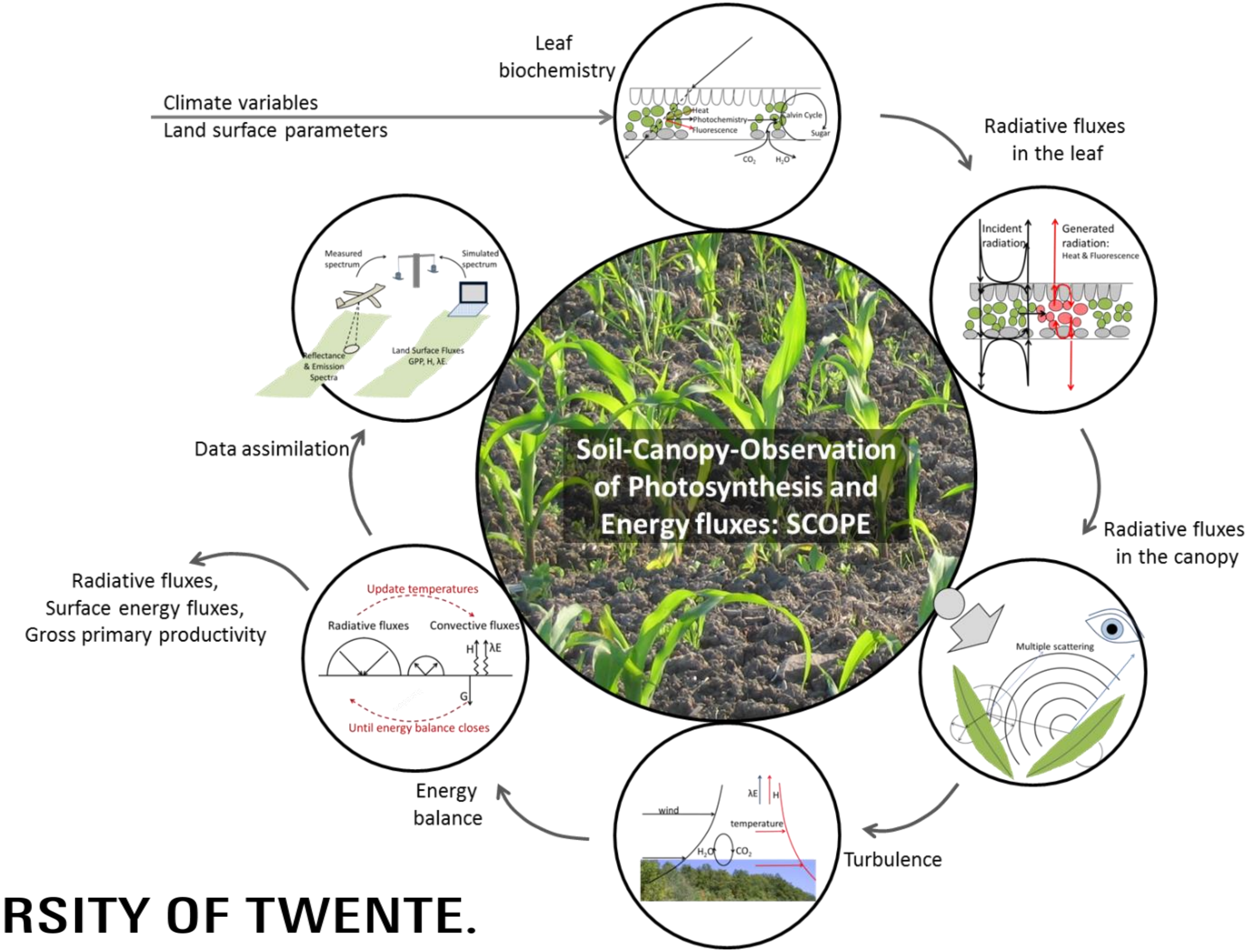


Vegetation models

LAI, Chlorophyll content, Water content, Photosynthesis, LUE…

Introduction

SCOPE, Soil Canopy Observation of Photosynthesis and Energy fluxes



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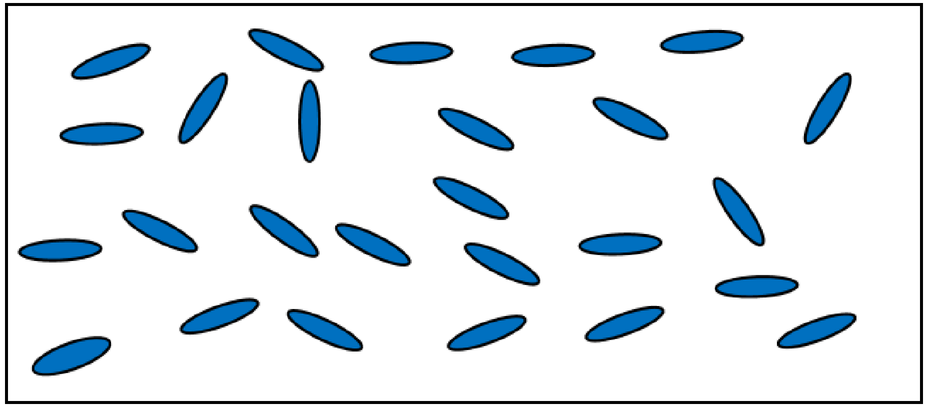
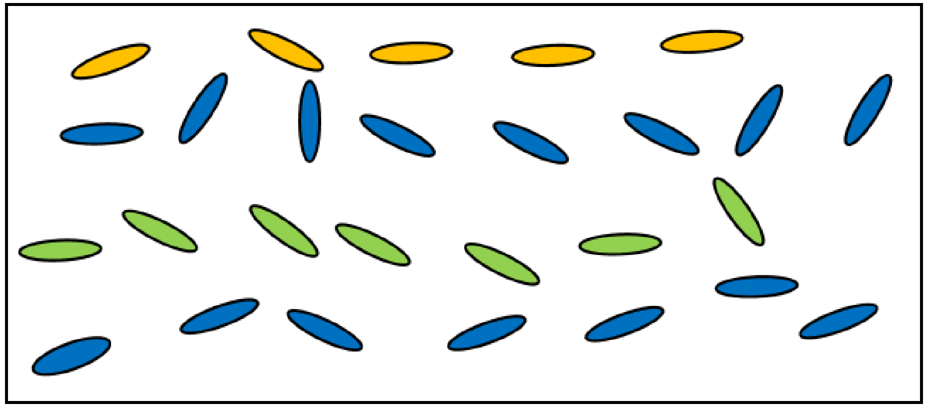
Introduction

Scale	Observation model	Process model
Leaf	Fluspect	Biochemical model (Van der Tol et al., 2014)
Canopy (SAIL based RTMs) (Verhoef, 1984 and 1985)	RTMo (0.40-2.50 μm) RTMf (0.64-0.85 μm) RTMt (2.5-50 μm)	Energy Balance Routine

SCOPE



mSCOPE



All the leaves have the same
biochemical properties

Model description overview

mSCOPE

A model for light interaction and energy balance in vegetation canopies in which **leaf biophysical and biochemical properties vary in the vertical**.

Input

Table 1: Main input parameters of SCOPE

Parameter	Explanation	Unit	Standard value	Range
C_{ab}	Chlorophyll $a+b$ content	$\mu g\ cm^{-2}$	40	0-100
C_{dm}	Leaf mass per unit area	$g\ cm^{-2}$	0.01	0-0.02
C_w	Equivalent water thickness	cm	0.015	0-0.05
C_s	Senescence material (brown pigments)	fraction	0.1	0-1
C_{ca}	Carotenoid content	$\mu g\ cm^{-2}$	10	0-30
N_l	Leaf structure parameter	-	1.5	1-3
LAI	Leaf area index	-	3	0-6
LIDFa	Leaf inclination function parameter a	-	-0.35	-1-1
LIDFb	Leaf inclination function parameter b	-	-0.15	-1-1
ϵ_1	fluorescence efficiency of photosystem I	-	0.004	0-0.01
ϵ_2	fluorescence efficiency of photosystem II	-	0.02	0-0.05
θ_s	sun zenith angle	$^\circ$	45	0-90
ψ	relative azimuthal angle	$^\circ$	0	0-360
PAR	photosynthetically active radiation	$\mu mol\ m^{-2}s^{-1}$	1200	0-2200

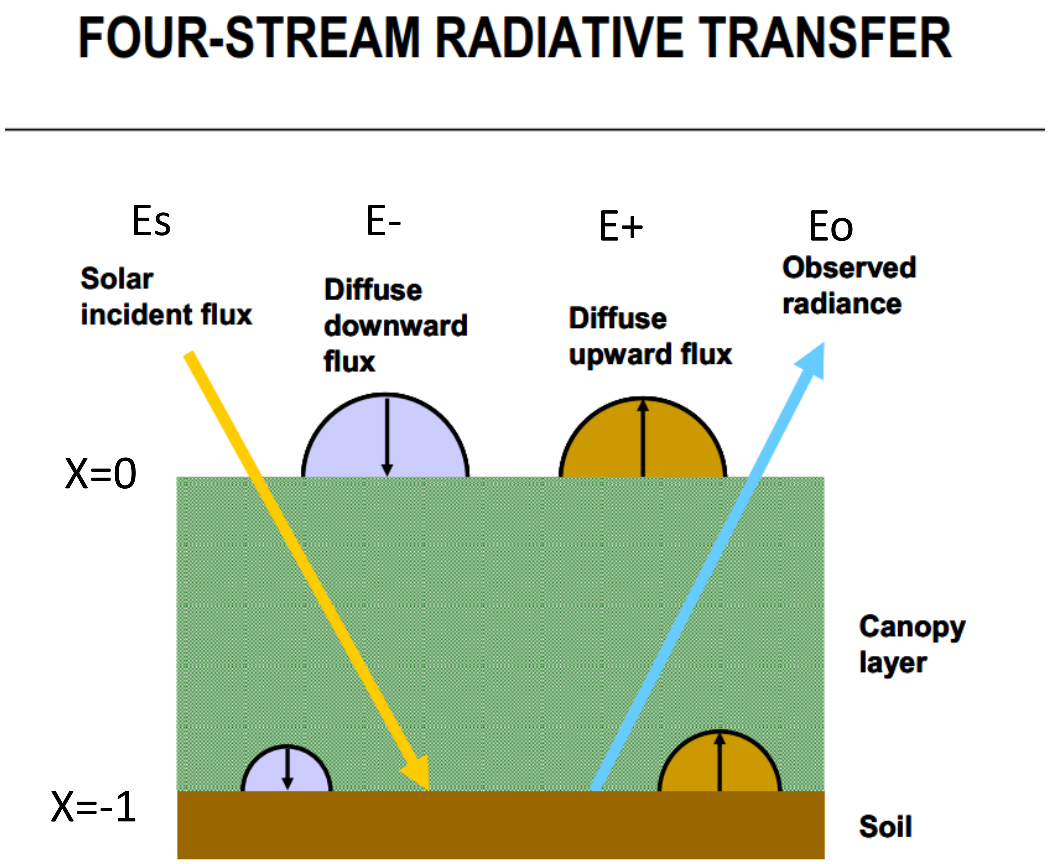
Table 2: Extra input parameters of mSCOPE compared with SCOPE

	mSCOPE				SCOPE
layer index	1	2	...	N	
leaf properties	$v(1)$	$v(2)$	...	$v(N)$	v_{canopy}
LAI	$L(1)$	$L(2)$	...	$L(N)$	L_{canopy}

Note: leaf properties parameters include C_{ab}, C_{dm}, C_w, C_s, C_{ca} and N_l.

Output
Reflectance,
fluorescence,
photosynthesis…

Model description radiation fluxes



$$\frac{dE_s}{Ldx} = kE_s \tag{1a}$$

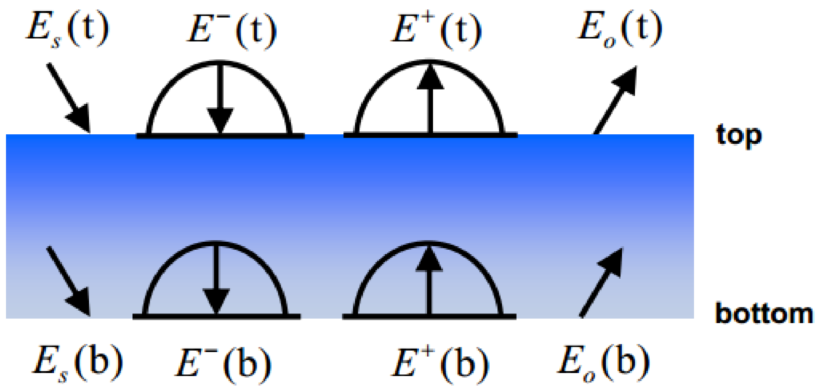
$$\frac{dE^-}{Ldx} = -sE_s + aE^- - \sigma E^+ \tag{1b}$$

$$\frac{dE^+}{Ldx} = s'E_s + \sigma E^- - aE^+ \tag{1c}$$

$$\frac{dE_o}{Ldx} = wE_s + vE^- + v'E^+ - KE_o \tag{1d}$$

In SCOPE, all the coefficients are independent to canopy depth (x).

In vertically heterogeneous (mSCOPE) canopies, only k and K are independent to x.



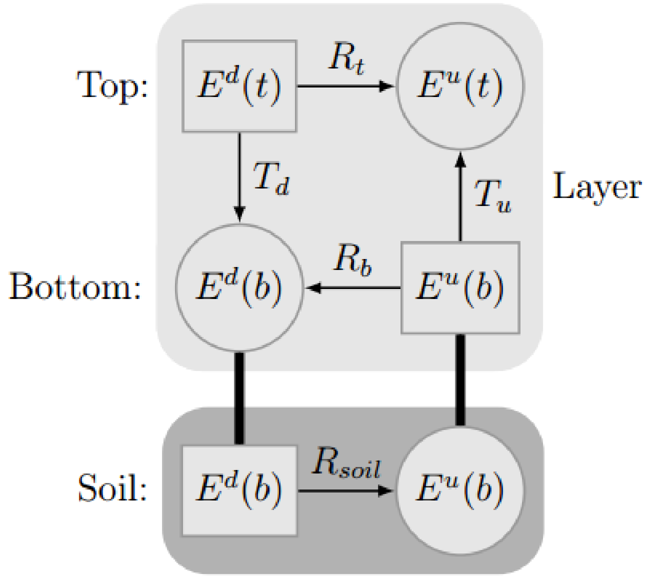


Figure 1: Flux interaction diagram for the combination of a vegetation layer on top of a reflecting surface (soil).

$$\begin{bmatrix} E^d(b) \\ E^u(t) \end{bmatrix} = \begin{bmatrix} T_d & R_b \\ R_t & T_u \end{bmatrix} \begin{bmatrix} E^d(t) \\ E^u(b) \end{bmatrix},$$

$$E^d = \begin{bmatrix} E_s \\ E_- \end{bmatrix}, E^u = \begin{bmatrix} E_+ \\ E_o \end{bmatrix}.$$

For a homogenous vegetation layer (SCOPE and SAIL), Td, Rb, Rt and Tu are expressed by using the nine coefficients and LAI.

Modelling approach

1. divide the vertical heterogeneous layer into several homogeneous layers;
2. start from the bottom homogeneous layer, calculate the surface reflectance of the combined system of the bottom surface (e.g., soil) and this layer;
3. add a new homogeneous vegetation layer above the surface of the previous system in step 2, and calculate the surface reflectance of the new system;
4. repeat step 3 until all homogeneous layers are added.;
5. once the surface reflectance at each vertical level is obtained, the fluxes profile can be computed from top to bottom, given the incident flux at top of the canopy.

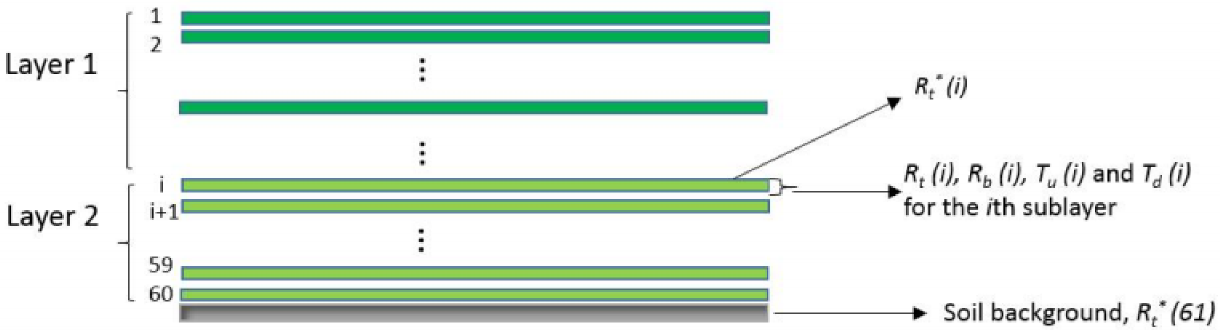
$$E^u(1) = R_{bottom} E^d(1)$$

$$\begin{bmatrix} E^d(1) \\ E^u(2) \end{bmatrix} = \begin{bmatrix} t_d(1) & r_b(1) \\ r_t(1) & t_u(1) \end{bmatrix} \begin{bmatrix} E^d(2) \\ E^u(1) \end{bmatrix}$$

$$\vdots$$

$$\begin{bmatrix} E^d(60) \\ E^u(61) \end{bmatrix} = \begin{bmatrix} t_d(60) & r_b(60) \\ r_t(60) & t_u(60) \end{bmatrix} \begin{bmatrix} E^d(61) \\ E^u(60) \end{bmatrix}$$

$$E^d = \begin{bmatrix} E_s \\ E^- \end{bmatrix} ; E^u = \begin{bmatrix} E^+ \\ E_o \end{bmatrix}$$



Photosynthesis simulation

$$A = \Delta L \sum_{j=1}^{60} \{[1 - P_s(j)] \cdot A_h(j) + \sum_{36\varphi_l, 13\theta_l} P_s(j) \cdot P(\varphi_l, \theta_l) \cdot A_s(j, \varphi_l, \theta_l)\}$$

Ps is the probability of sunlit leaves and (1-Ps) is the probability of shaded leaves in sublayer j.

Ah and As is the photosynthesis of sunlit and shaded leaves in sublayer j, respectively.

For each leaf,

A = Absorbed PAR x LUE

RTMo and biochemical model

Radiative transfer of fluorescence fluxes

$$E_F^-(j) = \tau_{dd}(j)E_F^-(j+1) + \rho_{dd}(j)E_F^+(j) + \boxed{F_{em}^-(j)}$$

$$E_F^+(j) = \rho_{dd}(j)E_F^-(j+1) + \tau_{dd}(j)E_F^+(j) + \boxed{F_{em}^+(j)}$$

Adding fluorescence emission

Application in media other than vegetation, such as water and atmosphere which have a clear multi-layer structure.

Application in the calculation of thermal fluxes in various media as similar to the calculation of fluorescence fluxes.

Simulations

Synthetic dataset of two-layer canopies

Scenario	upper layer		lower layer	
	C_{ab}	C_w	C_{ab}	C_w
S0	40	0.015	40	0.015
S1	60	0.02	20	0.01
S2	20	0.01	60	0.02
S3	40	0.015	0	0.01
S4	40	0.015	20	0.02
S5	40	0.015	60	0.03

LAI =3

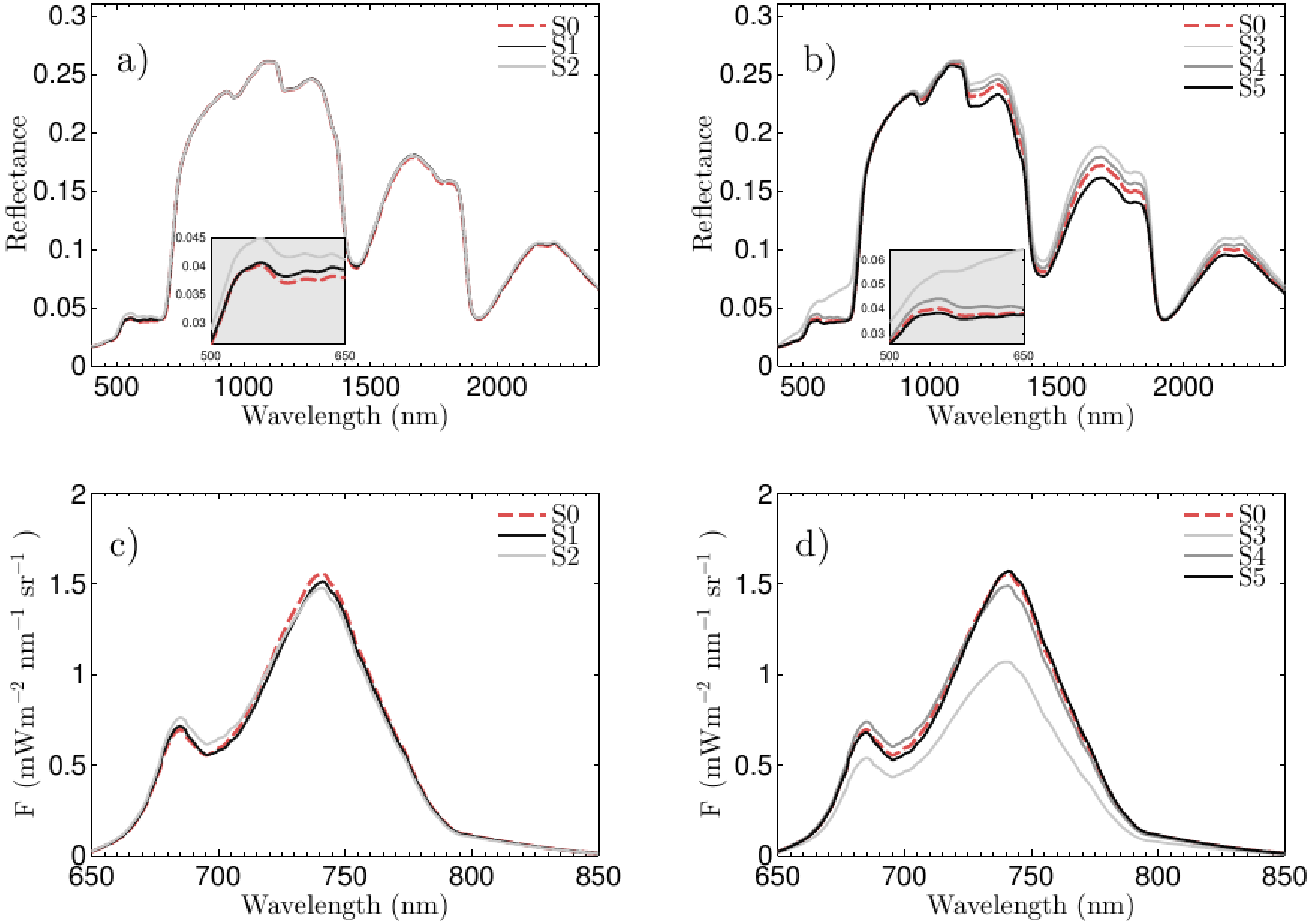


Fig. Reflectance and fluorescence simulation results of the six synthetic scenarios

Scenario	aPAR (μmol $m^{-2}s^{-1}$)	A (μmol CO_2 $m^{-2}s^{-1}$)	LUE (mol CO_2 mol^{-1}photon)
S0	943.02	25.17	0.027
S1	973.07	25.07	0.026
S2	842.40	24.78	0.030
S3	788.28	20.47	0.026
S4	922.50	24.85	0.027
S5	951.64	25.28	0.027

Photosynthetically active radiation absorbed (aPAR), net photosynthesis (A) and light use efficiency (LUE) simulated from mSCOPE of the six synthetic scenarios.

Simulations

Field measurement dataset of corn canopy

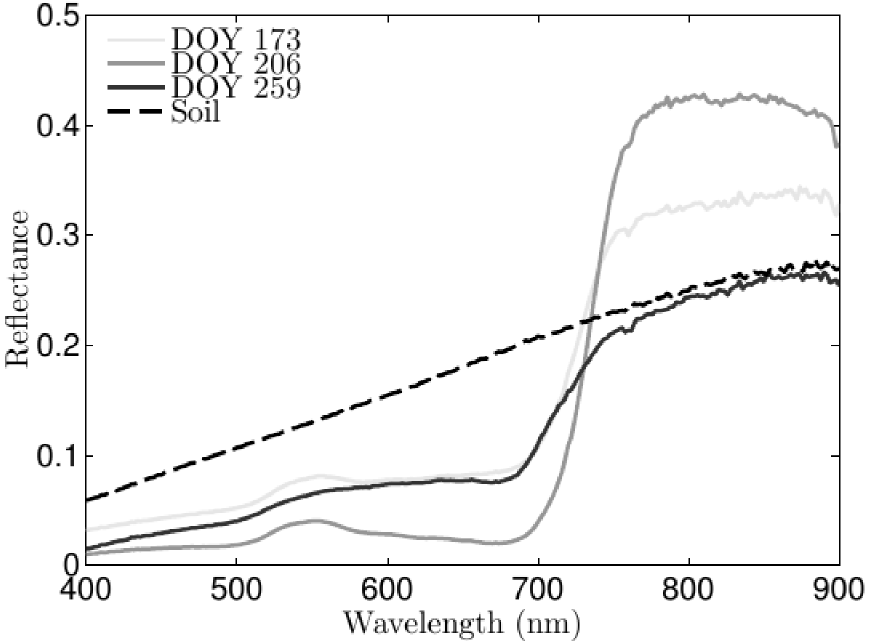


Fig. Reflectance measurements

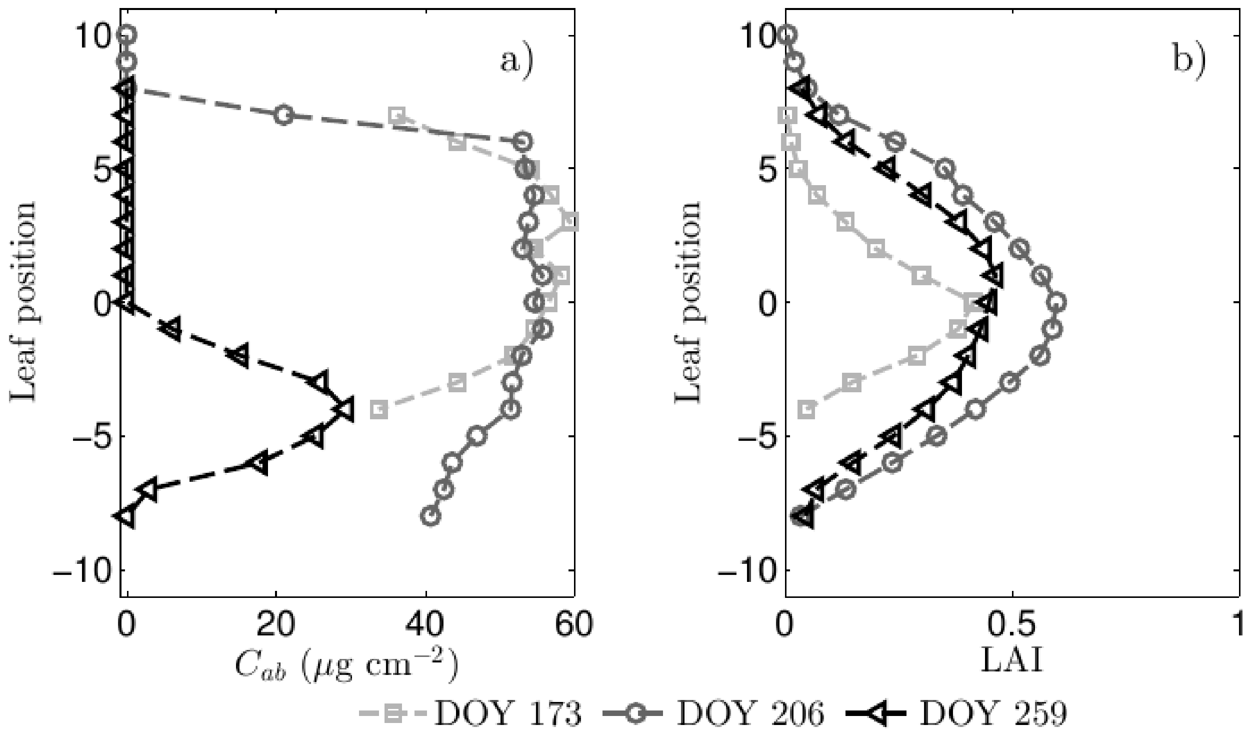


Fig. Cab and LAI profile measurements

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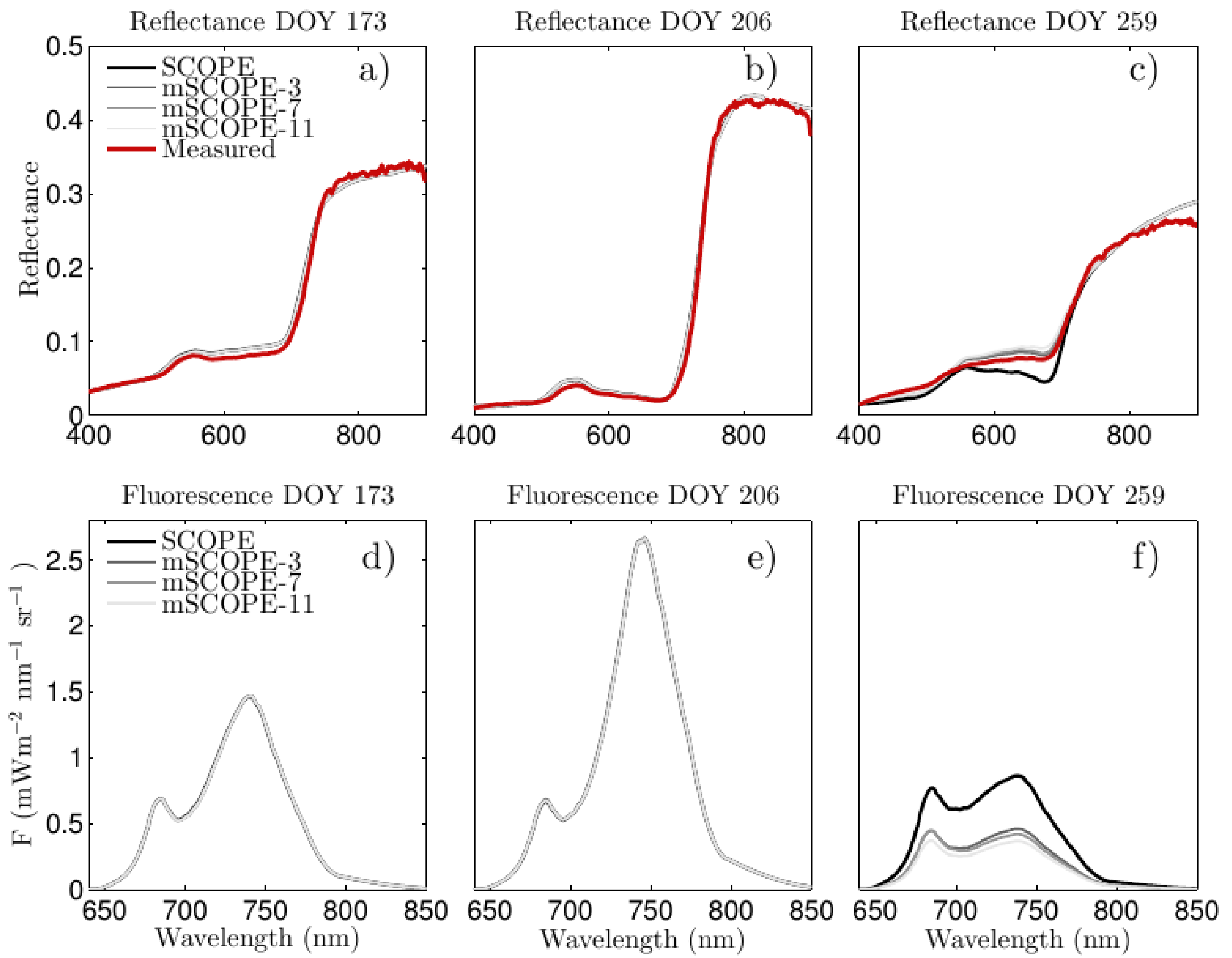
$$C = \sum_{i=1}^{n} [R_m(i) - R_s(i)]^2$$

Parameter	DOY 173	DOY 206	DOY 259
C_{dm} (g cm^{-2})	0.01	0.04	0.005
C_w (cm)	0.04	0.05	0.01
C_s	0	0	0.4
N_l	1.5	1.7	1.4
C_{ca} (μg cm^{-2})	5.6	3.7	1.4
C_{ab} (μg cm^{-2})	55	38	25
LIDFa	-0.79	-0.97	-1
LIDFb	0.21	0.03	0

Table. Retrieval of vegetation parameters



Various simplifications were applied in mSCOPE, notably, 3 layers, 7 layers and 11 layers.

Fig. Reflectance and fluorescence simulation results of the corn canopies

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	Photosynthesis (μmol CO_2 $m^{-2}s^{-1}$)		
	DOY 173	DOY 206	DOY 259
SCOPE	23.8	37.7	$\boxed{27.9}$
mSCOPE-3	23.9	37.1	6.7
mSCOPE-7	23.9	37.0	5.9
mSCOPE-11	23.9	37.0	5.9

Table. Photosynthesis

Conclusion

- Homogeneous models are in some cases insufficient in their representation of the canopy for understanding the remote sensing signal of reflectance, fluorescence and canopy photosynthesis.
- The model mSCOPE simulates TOC reflectance, fluorescence and photosynthesis, for vertically heterogeneous canopies.

For the details, see Yang et al, (2017).
The mSCOPE model: a simple adaptation to the SCOPE model to describe reflectance, fluorescence and photosynthesis of vertically heterogeneous canopies

Thank You!