The Soil Canopy Observation of Photosynthesis and Energy fluxes model SCOPE

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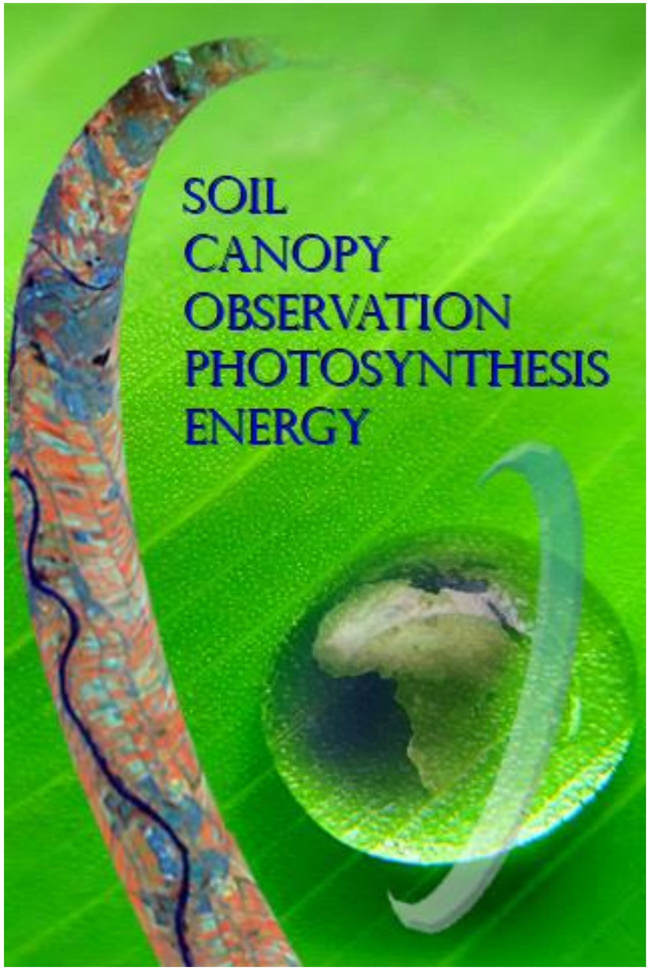
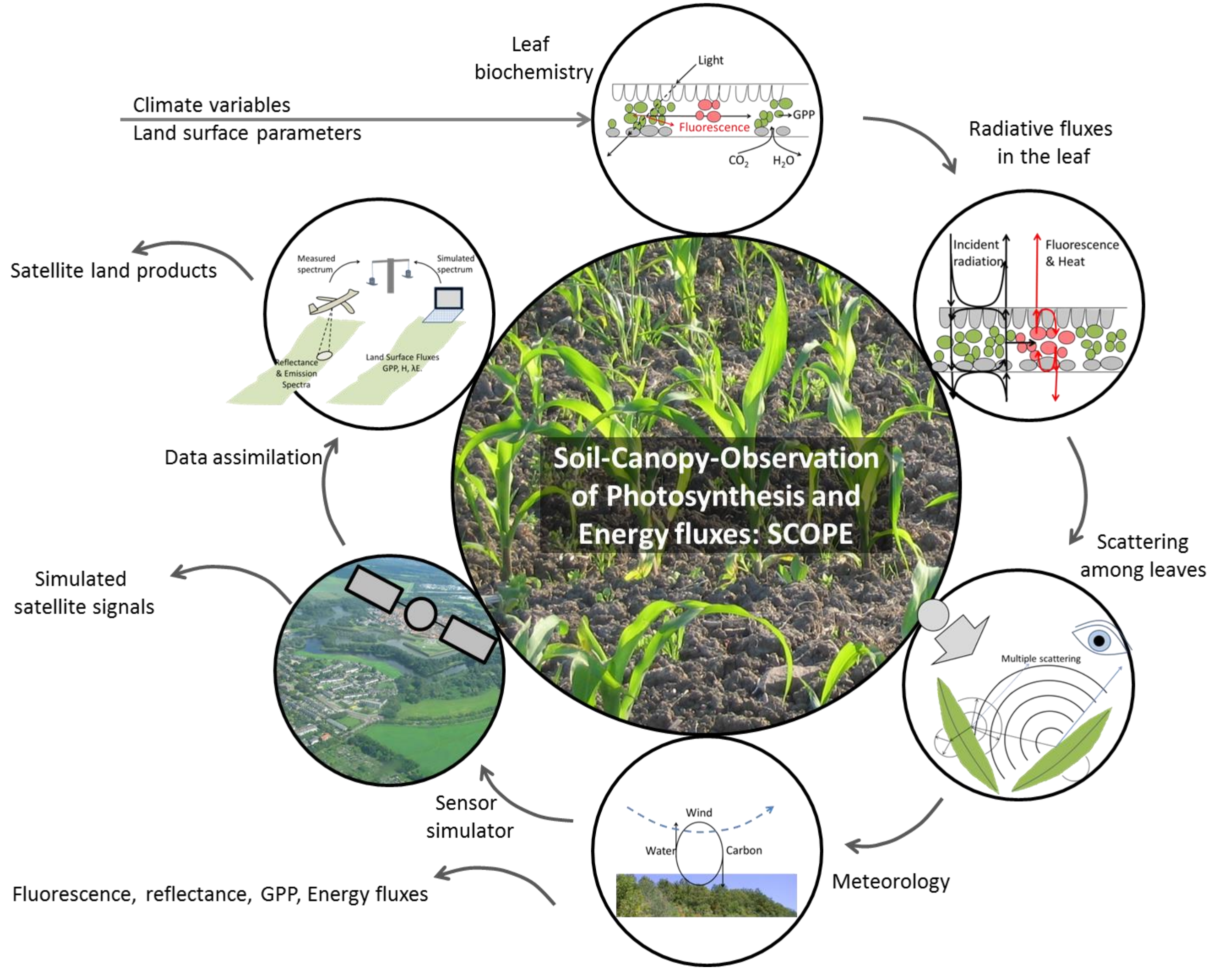
SCOPE is a classical **SVAT** (Soil-Vegetation-Atmosphere Transfer scheme combined with **Radiative transfer models** for leaf and canopy

It simulates:

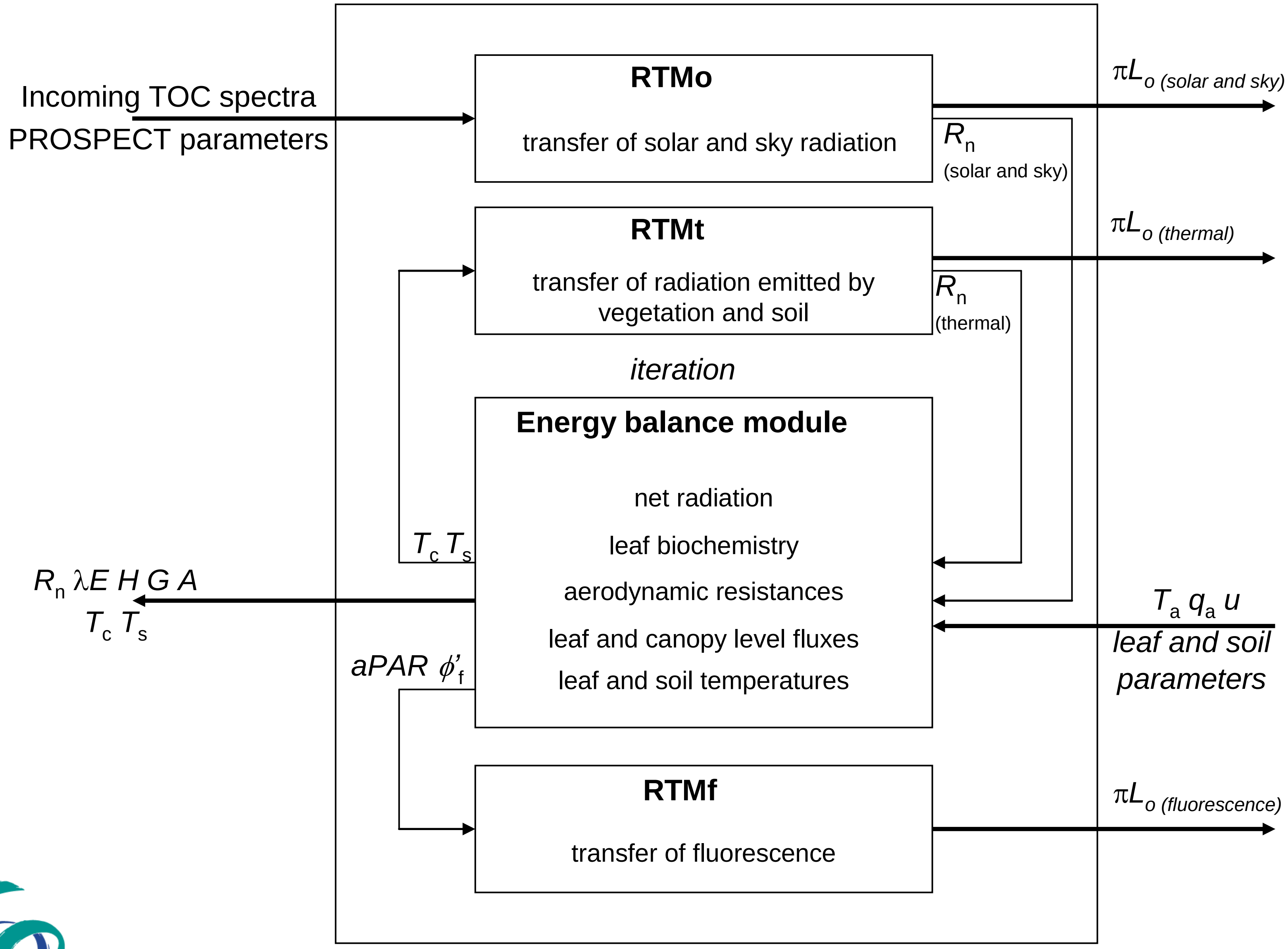
- Photosynthesis
- The surface energy balance
- Reflectance spectra and ratiation emission between 0.4 and 50 μm



THE SCOPE OF SCOPE

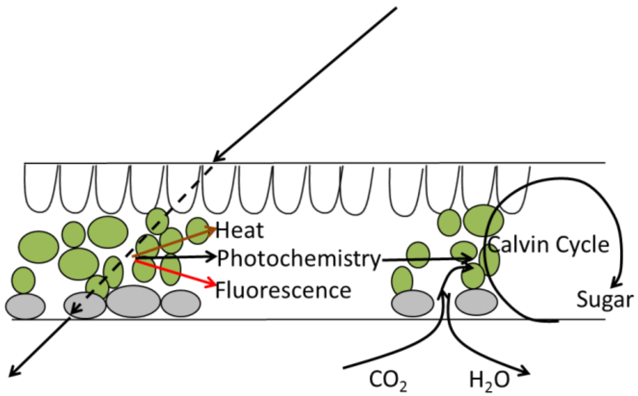


	Simulation of observations - *optical* - *thermal* - *fluorescence*	*Simulation of processes* - *hydrological* - *physiological* - *meteorological*
Leaf level	FLUSPECT	Biochemical model
Canopy level	Radiative transfer models (SAIL family)	Energy balance model

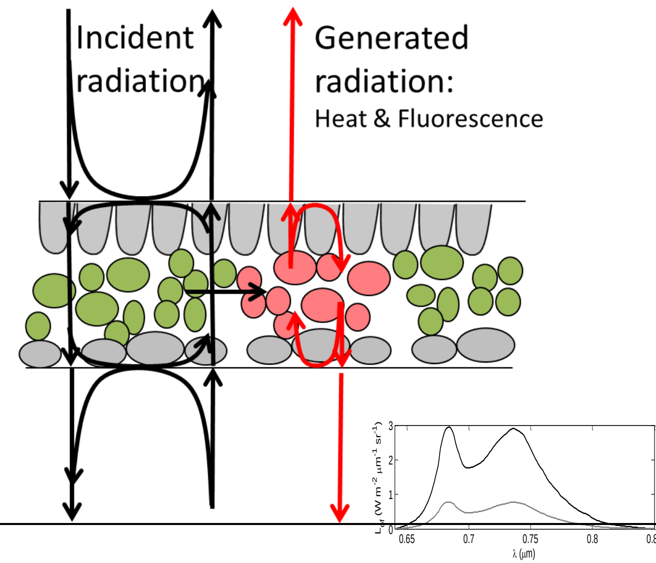

RTMo
transfer of solar and sky radiation
Incoming TOC spectra
PROSPECT parameters
$\pi L_{o\ (solar\ and\ sky)}$
R_n (solar and sky)
RTMt
transfer of radiation emitted by vegetation and soil
$\pi L_{o\ (thermal)}$
R_n (thermal)
iteration
Energy balance module
net radiation
leaf biochemistry
aerodynamic resistances
leaf and canopy level fluxes
leaf and soil temperatures
T_c T_s
R_n λE H G A
T_c T_s
T_a q_a u
leaf and soil parameters
aPAR ϕ'_f
RTMf
transfer of fluorescence
$\pi L_{o\ (fluorescence)}$

leaf level

1
biochemical model for the leaf



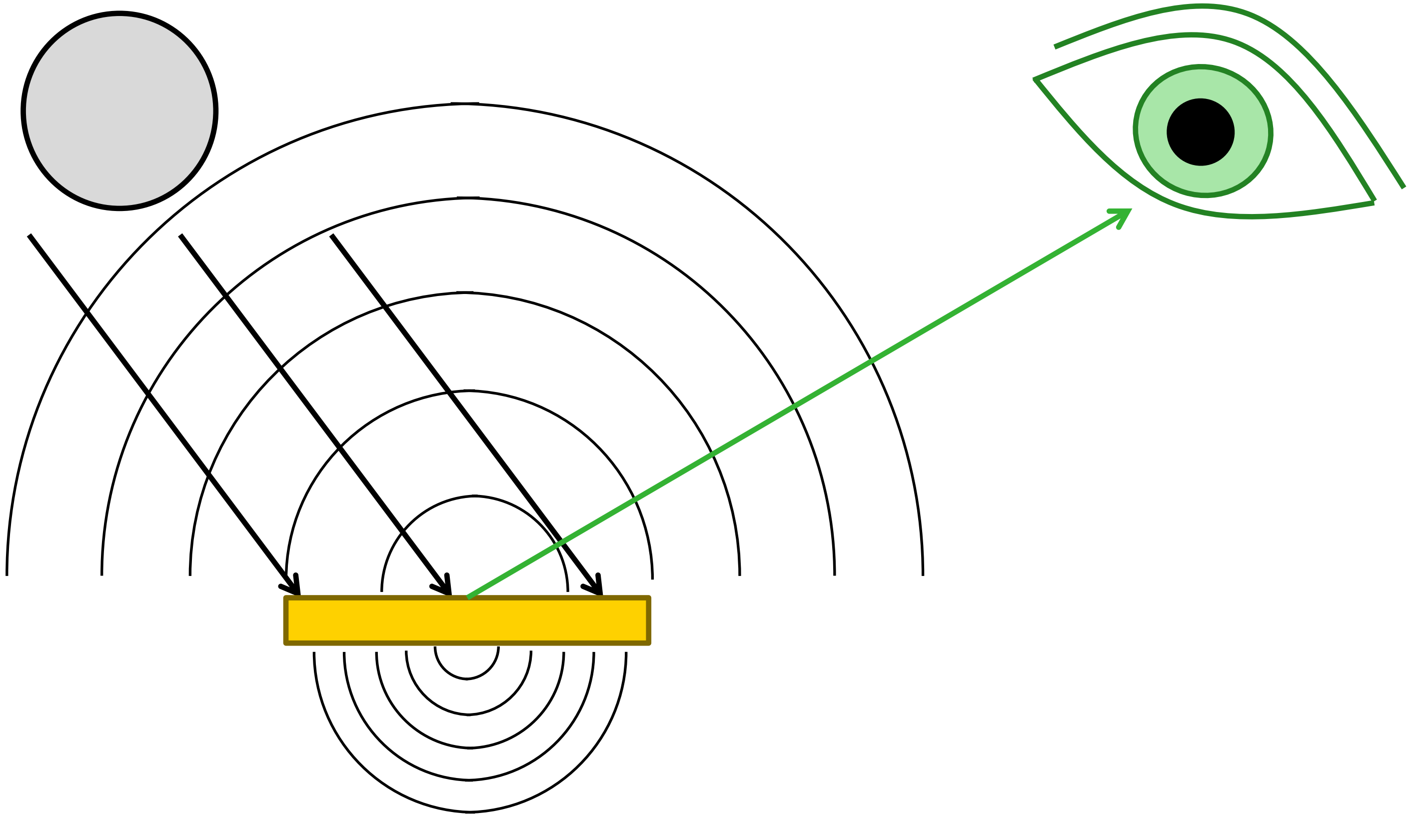
2 FLUSPECT model:
observation model for the leaf

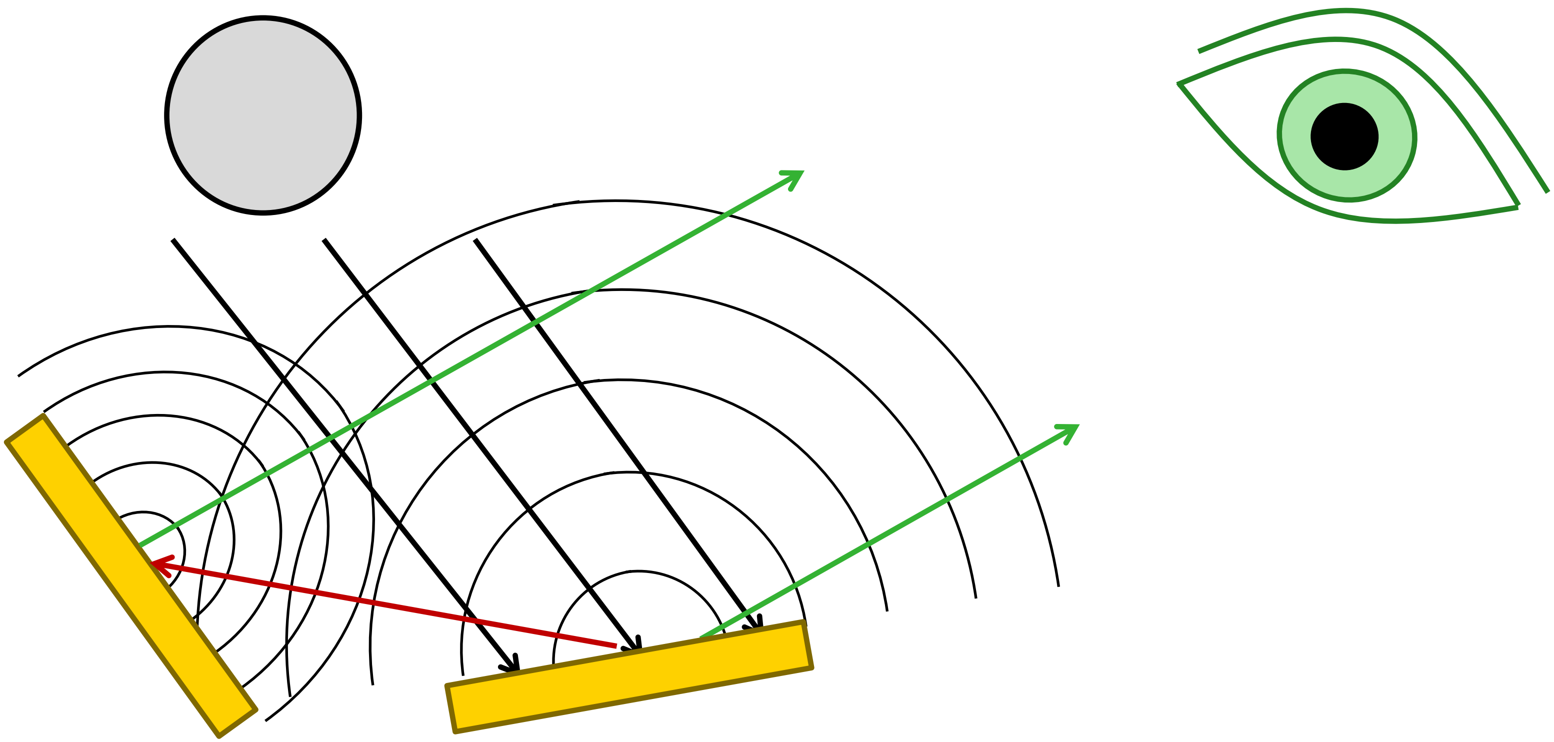


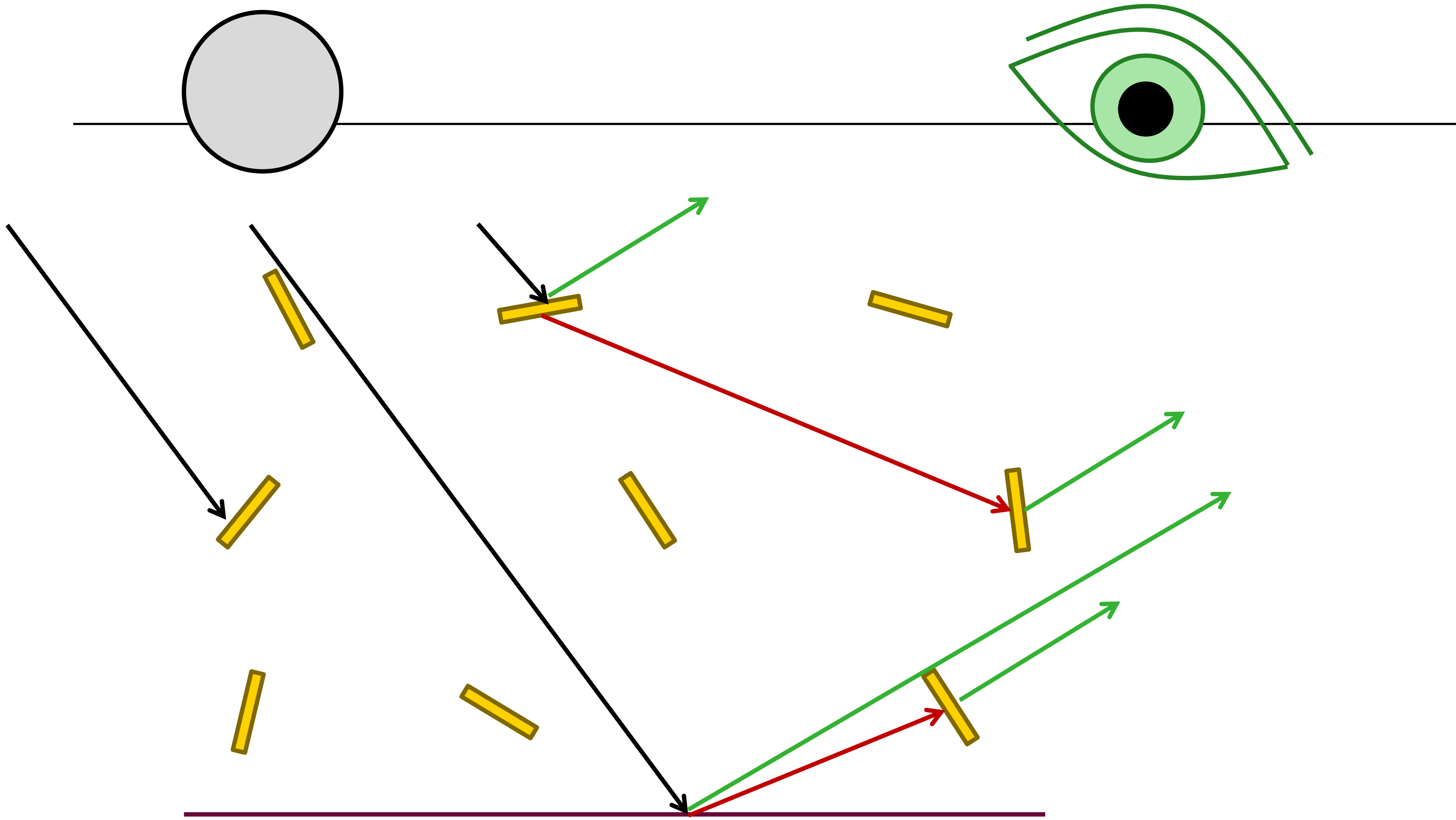
canopy level

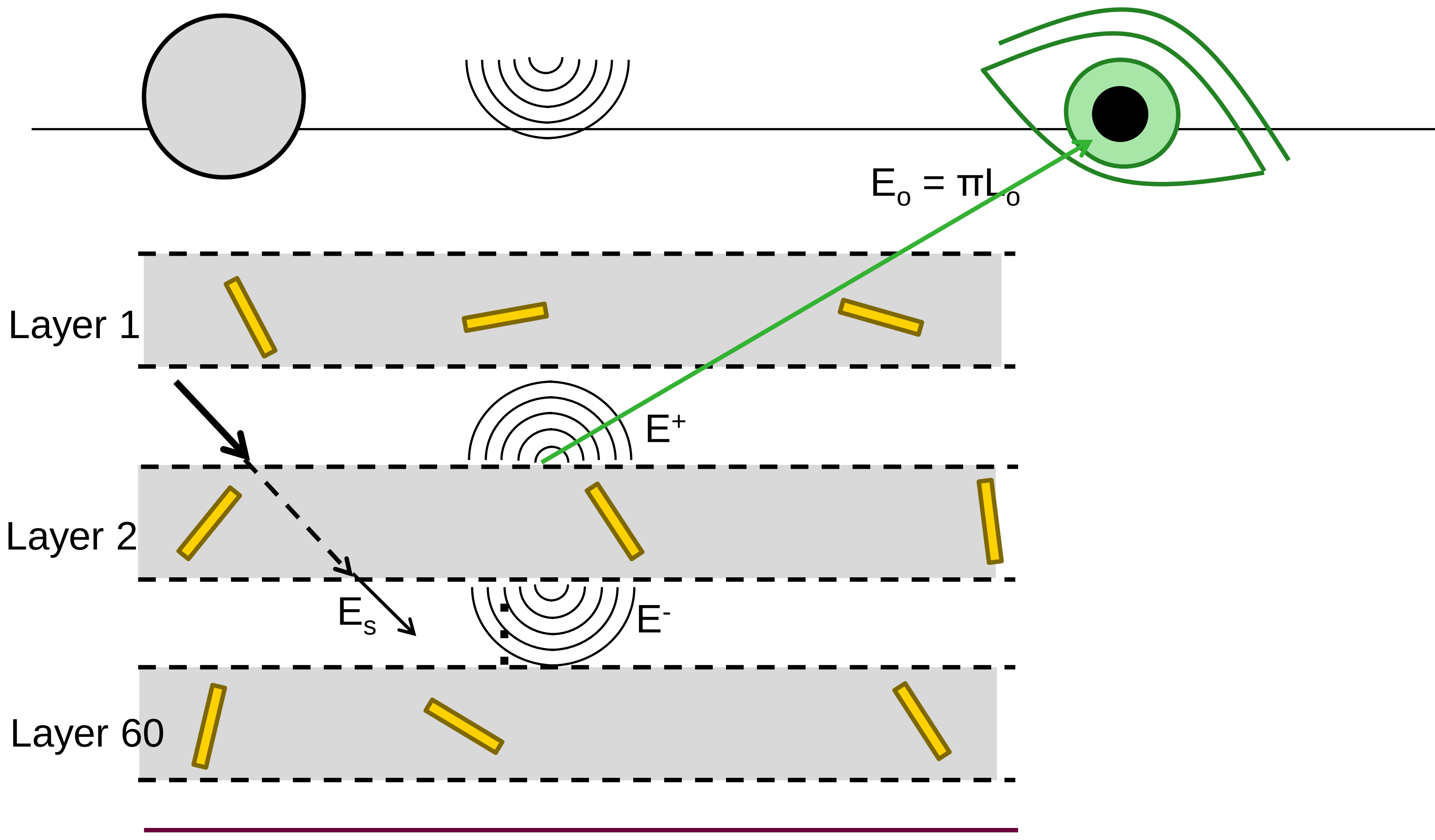
$$L^f = \int_{\text{all visible leaves}} (1) \cdot \int_{\text{input spectrum}} (2)$$

RTM$_O$: RADIATIVE TRANSFER OF INCIDENT LIGHT IN VEGETATION CANOPIES









$E_o = \pi L_o$
Layer 1
E^+
Layer 2
E_s
E^-
Layer 60

Differential equations to resolve for each layer:

Extinction of direct light

Extinction coefficient

$$\frac{\mathrm{d}E_s}{L\mathrm{d}x} = kE_s$$

Leaf Area index increment in the vertical

X=0 at the top of canopy, x=-1 at the soil

Upward diffuse flux

$$\frac{\mathrm{d}E^-}{L\mathrm{d}x} = -s'E_s + aE^- - \sigma E^+$$

Scattering coefficients

Downward diffuse flux

$$\frac{\mathrm{d}E^+}{L\mathrm{d}x} = sE_s + \sigma E^- - aE^+$$

Flux in observation direction

$$\frac{\mathrm{d}E_o}{L\mathrm{d}x} = wE_s + vE^- + v'E^+ - KE_o$$

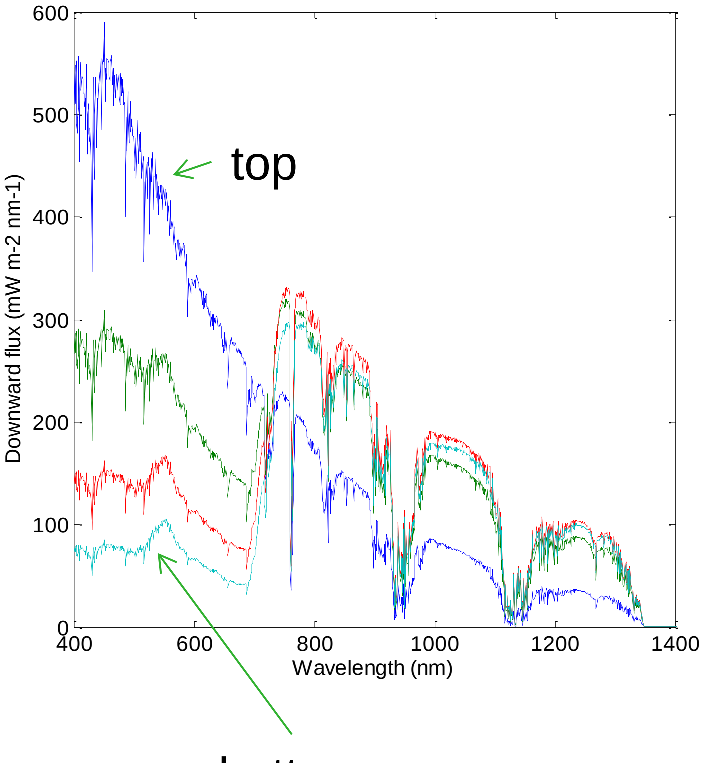
The coefficients k, s, s’, a, σ, v, v’, w, and w’ are calculated from the leaf inclination distribution

The equations are solved as followed:

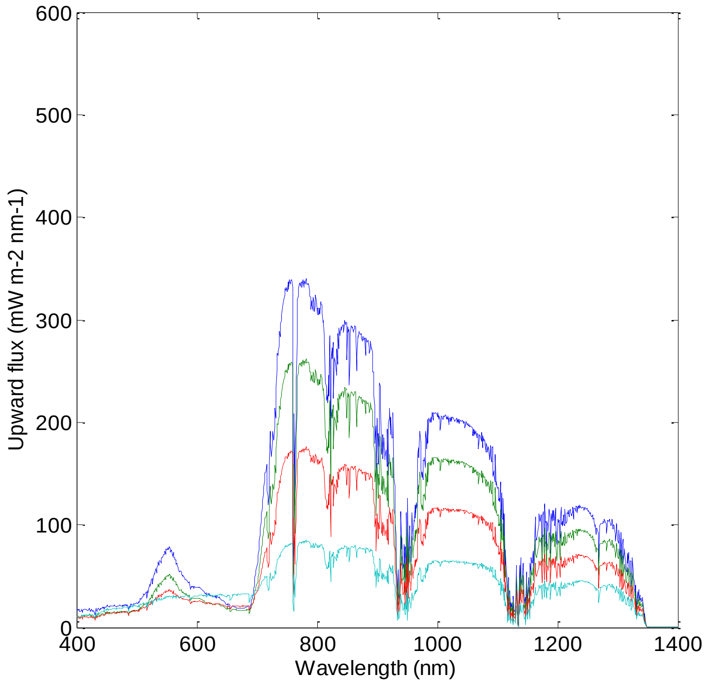
- Solar flux with depth Es(x) is solved (1st DE) $$E_s(x) = \exp(kLx)$$
- $E_s(x)$ is inserted into DE for E^- and E^+.
- E^- and E^+ solved analytically
- Diffuse incoming irradiance E_{sky} is top boundary condition
- E_{sky} is calculated from extraterrestiral radiation and MODTRAN5 outputs
- E_o at the top of canopy ($E_o(0)$) is calculated by inserting the solutions for E_s, E^- and E^+ into the DE of E_o.

Simulated spectra of E^- and E^+ at different levels in the canopy

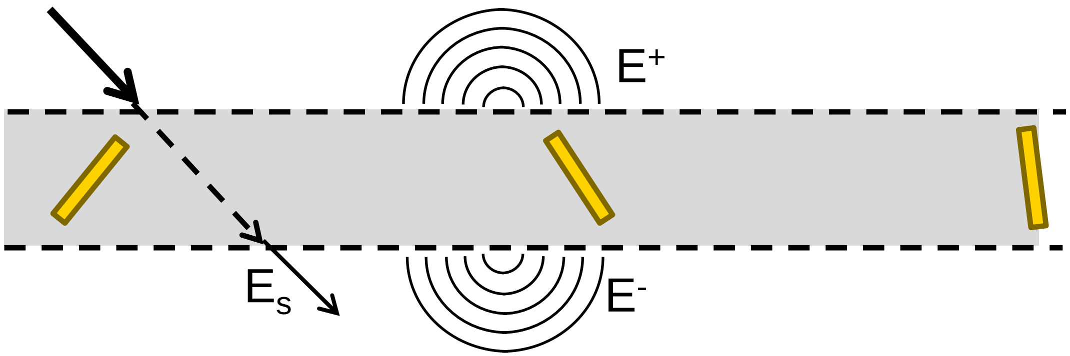
E^-



E^+

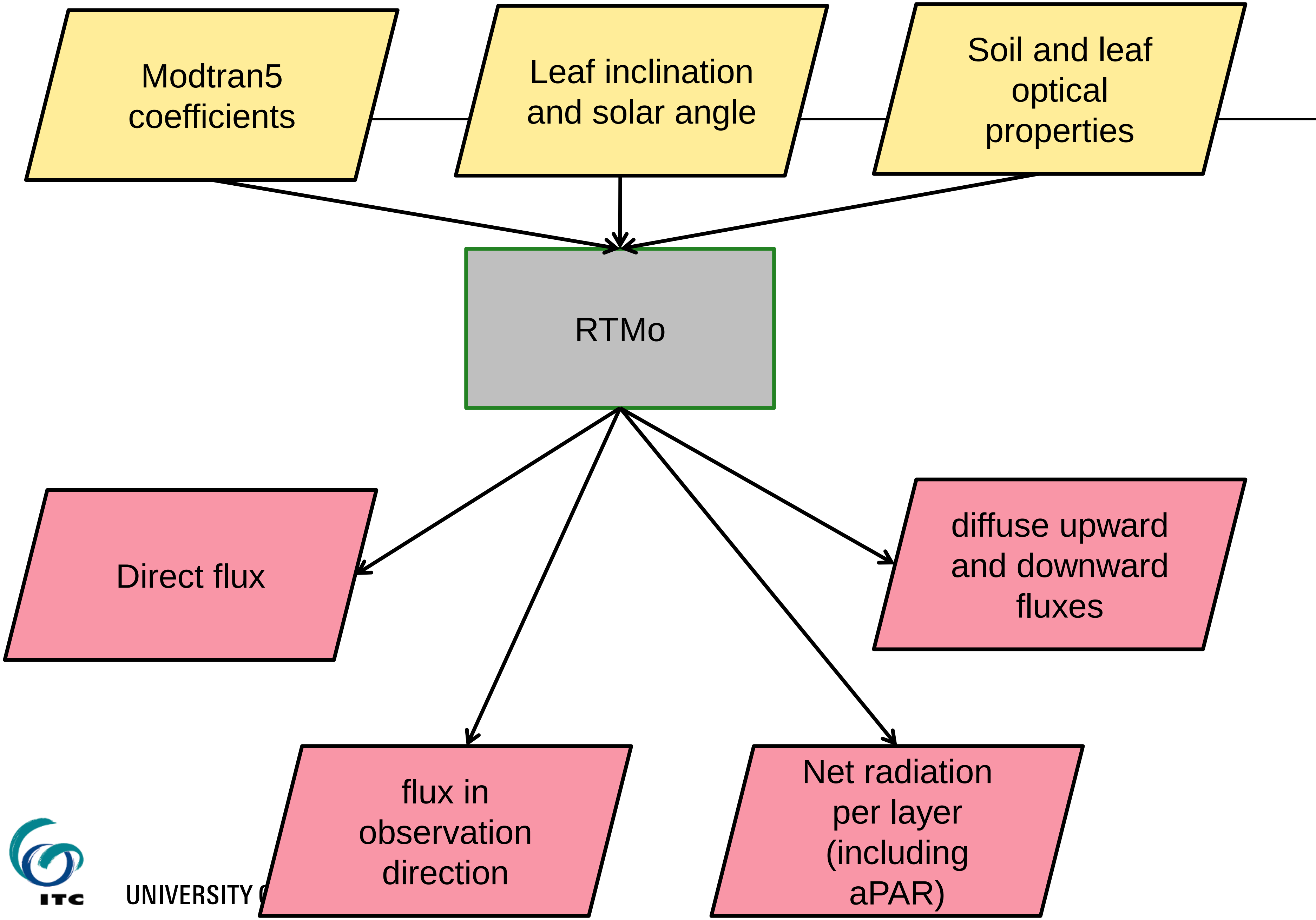


Net radiation



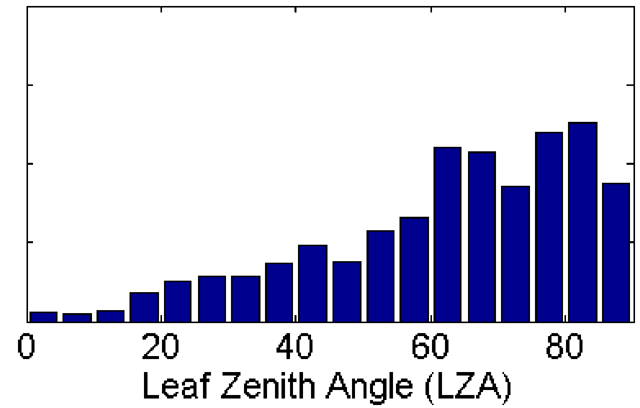
$$R_{n,dif}(x) = (1-\rho-\tau)\left(E^{+}(x+0.5dx) + E^{-}(x+0.5dx)\right)$$

$R_{n,dir}(x)$: Geometrical calculation depending on solar angle and leaf inclinations

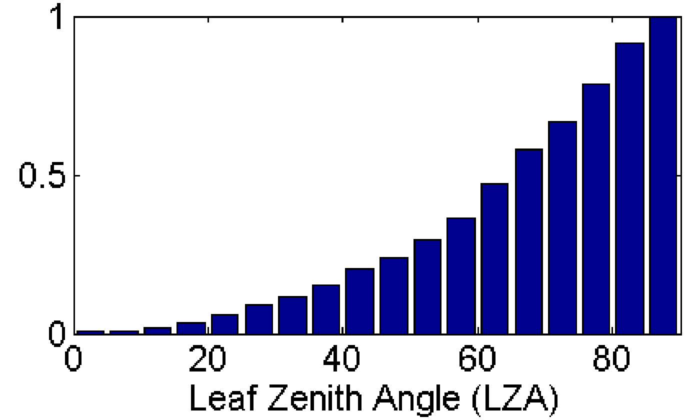

Modtran5 coefficients
Leaf inclination and solar angle
Soil and leaf optical properties
RTMo
Direct flux
diffuse upward and downward fluxes
flux in observation direction
Net radiation per layer (including aPAR)

Estimating LIDF with 'leafangles.m'

Probability density function (PDF) of leaf zenith angle



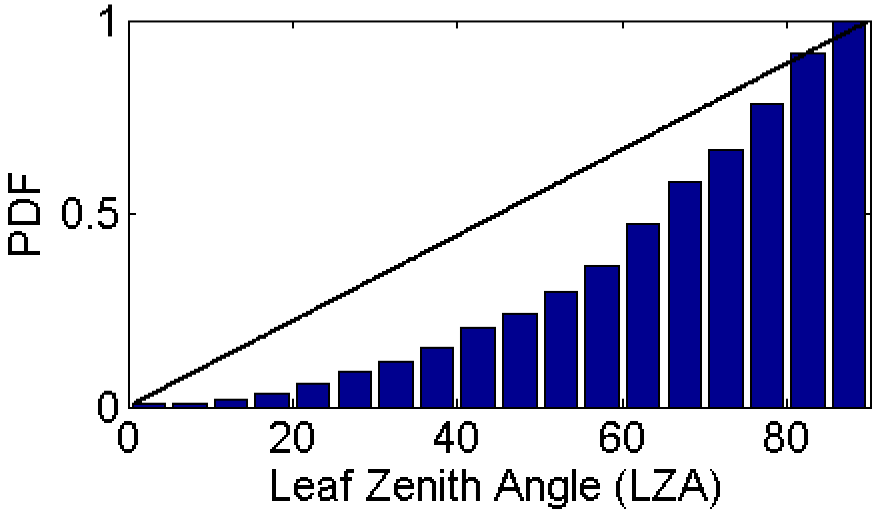
Cumulative PFD of leaf zenith angle



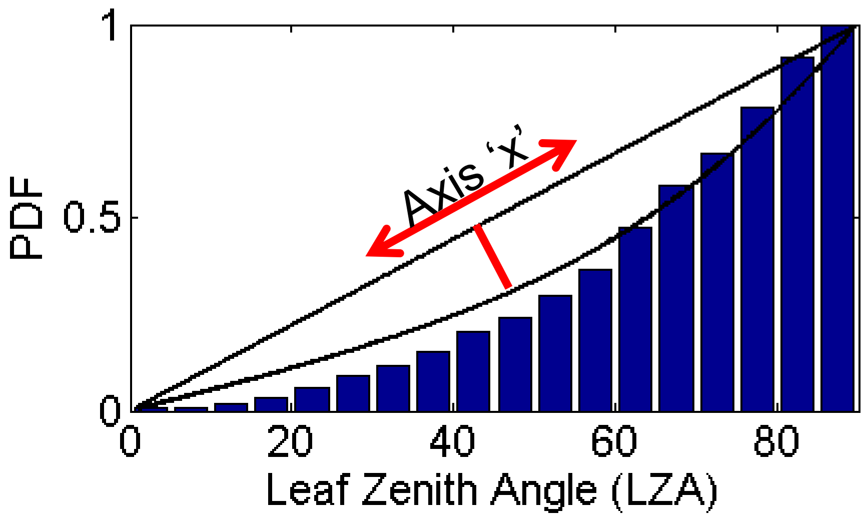
Data: Shibayama (2004), Plant Prod Sci 7(4), 297-405

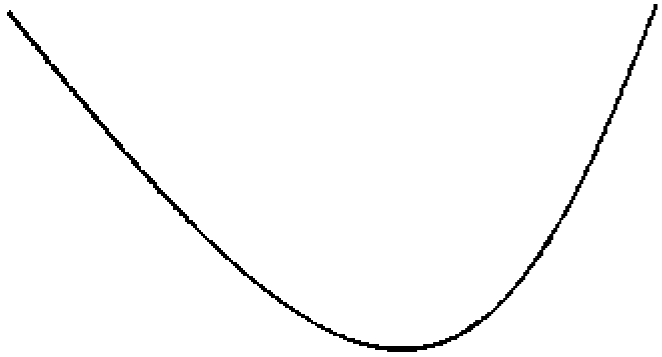
Model the Cumulative PFD of leaf zenith angle:

(1) The diagonal: all leaf inclinations are equally probable (LIDFa = 0; LIDFb=0



(2) The diagonal is the ‘x-axis’. Now add a sinus on this axis. The amplitude of this sinus is LIDFa. Modify the value of LIDFa to obtain a good fit.

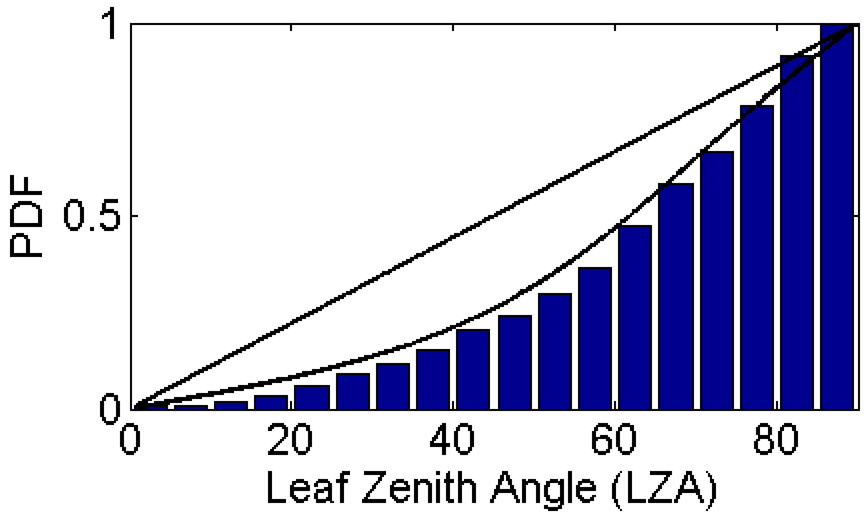


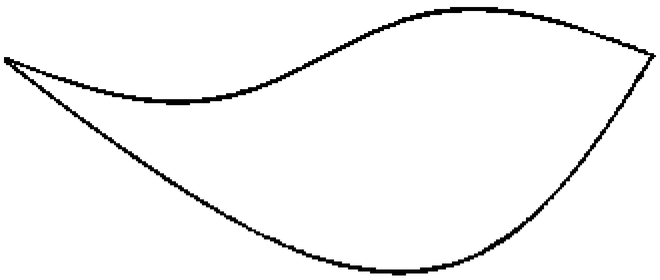


(3) Add a second sinus with 2x smaller period. The amplitude of this sine is LIDFb. Modify the value of LIDFb to obtain a good fit.

-> Now we have a mathematical expression for the leaf inclination distribution.

In SCOPE: ***leafangles.m***

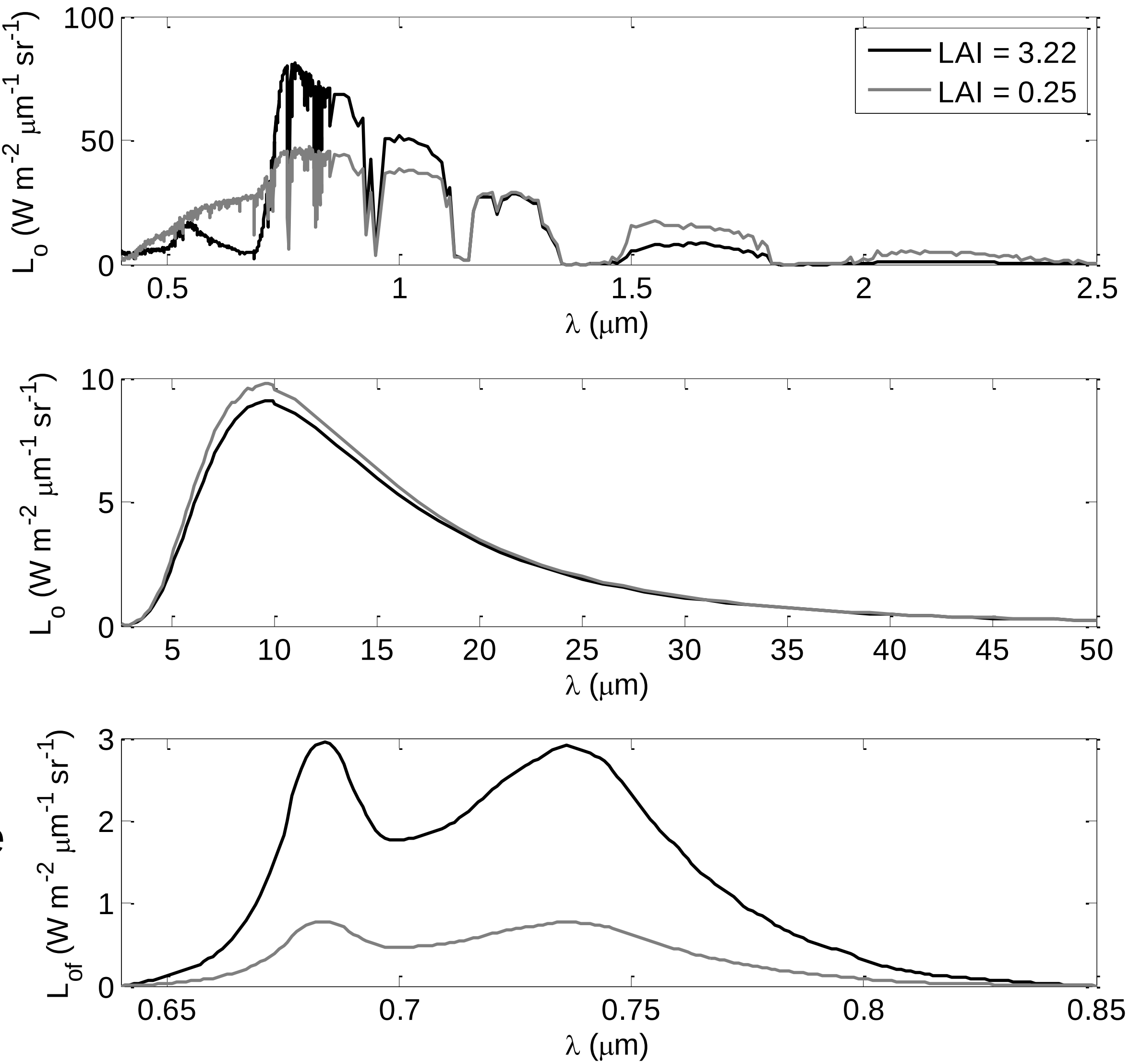




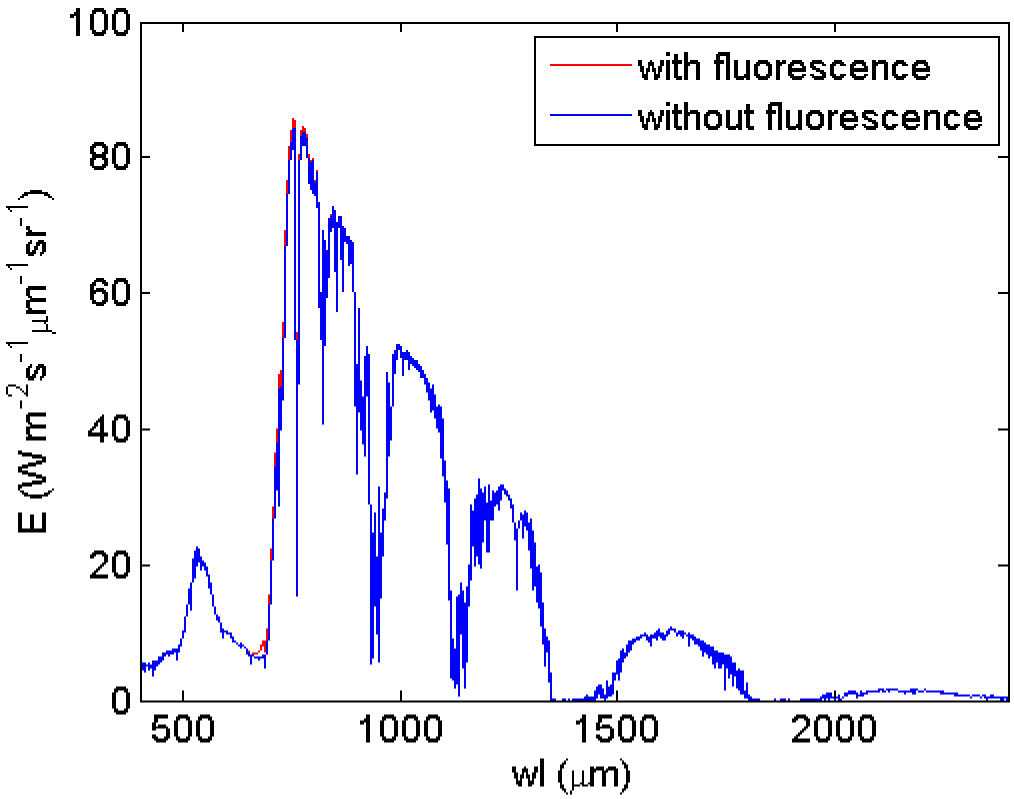
Optical-
near infrared

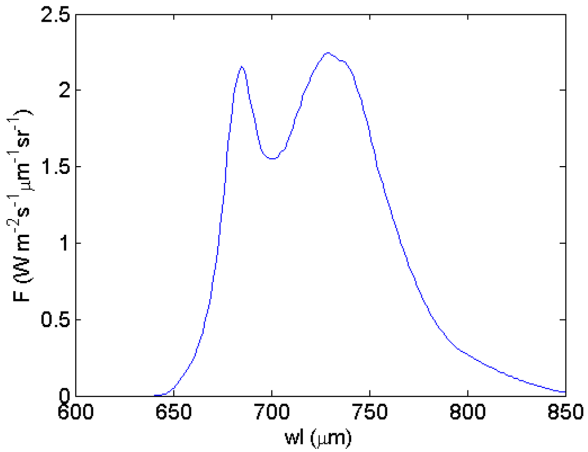
Thermal
infrared

Fluorescence



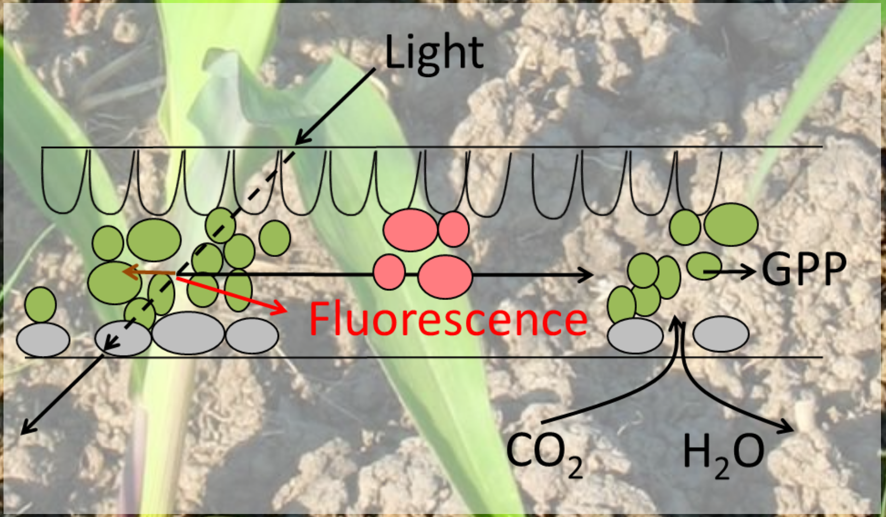
SCOPE simulations of radiance

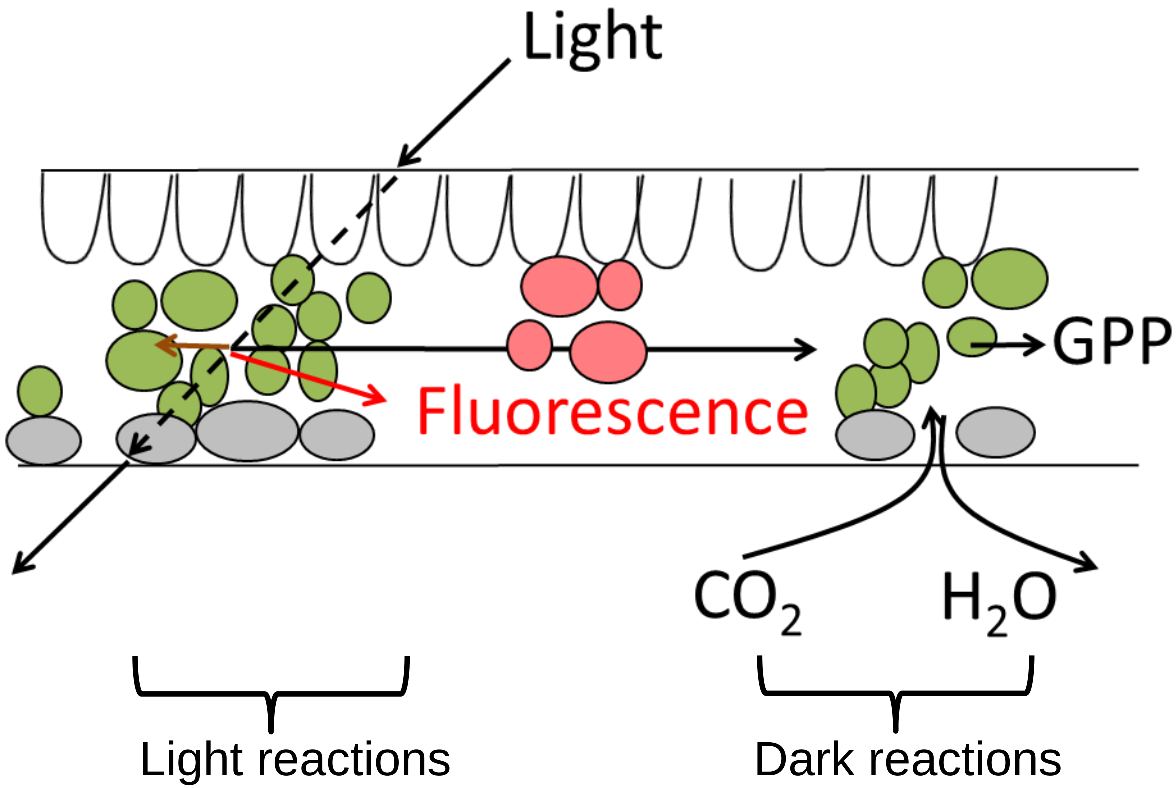




Light reactions and photosynthesis in leaves

Christiaan van der Tol
Wout Verhoef




Light
GPP
Fluorescence
CO_2
H_2O
Light reactions
Dark reactions

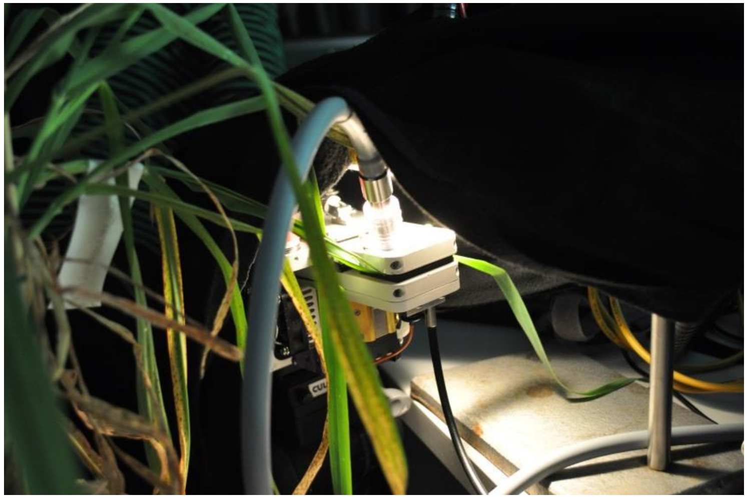
Objectives

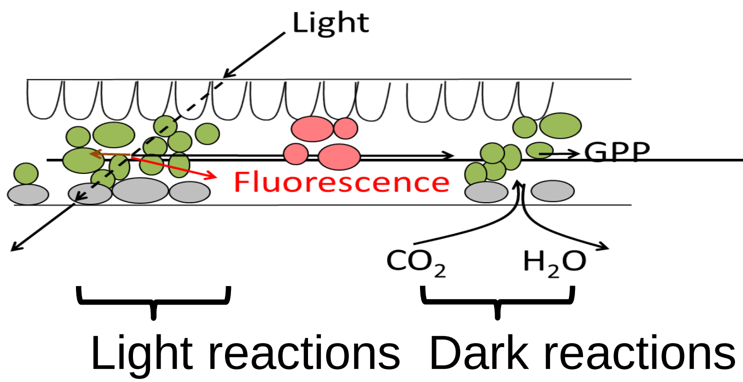
- To describe a ‘classic’ photosynthesis and stomatal condutance model
- To describe the main quenching mechanisms of excitons
- To be able to estimate electron transport from acive fluorescence measurements of Ft, Fm, and Fm’
- To describe the relation between steady state fluorescence yield and electron transport yield

Measurement systems:

(1) Leaf gas exchange: CO_2 (and H_2O) exchange

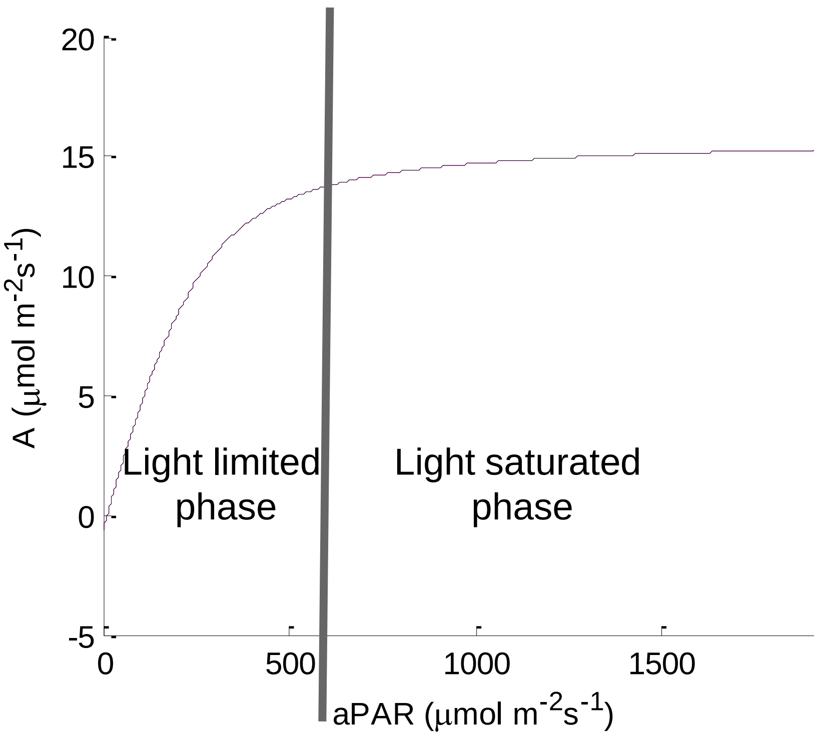
(2) Pulse-Ampitude Fluoremetry: electron transport

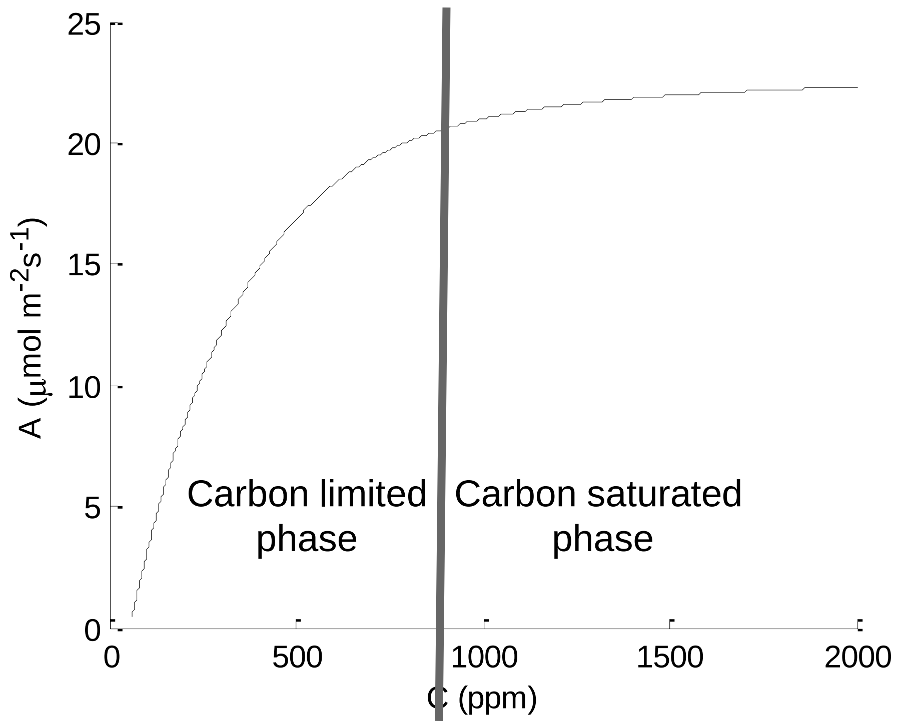




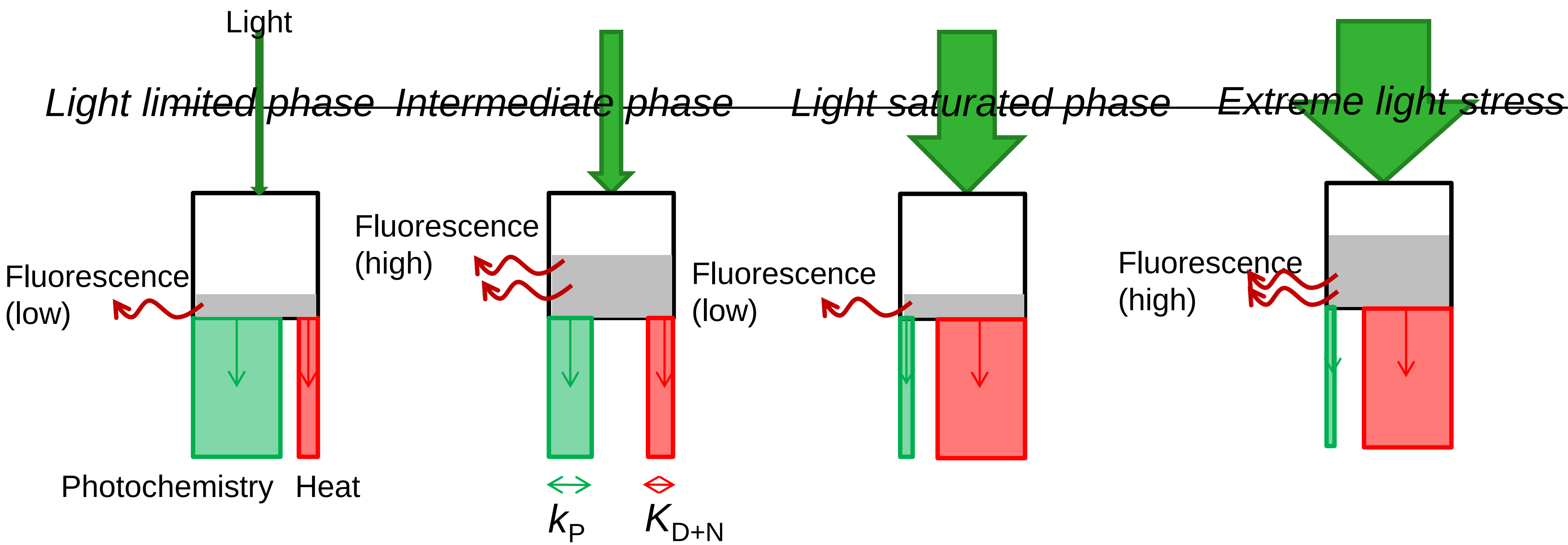
Most important parameters:

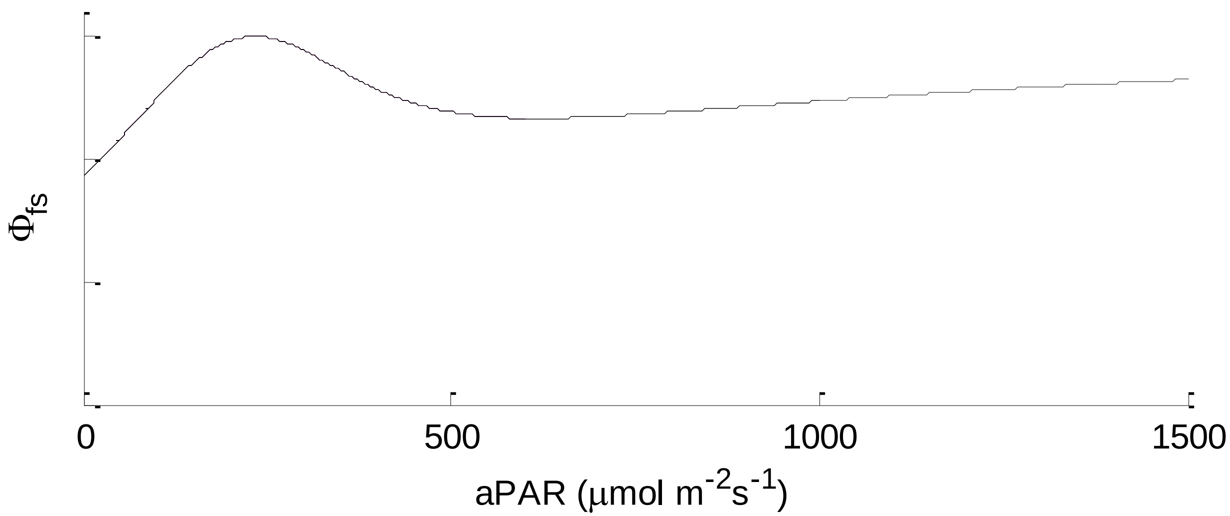
- Initial slope of light response curve
- Curvature of the light response
- Caboxylation capacity: *highly variable*

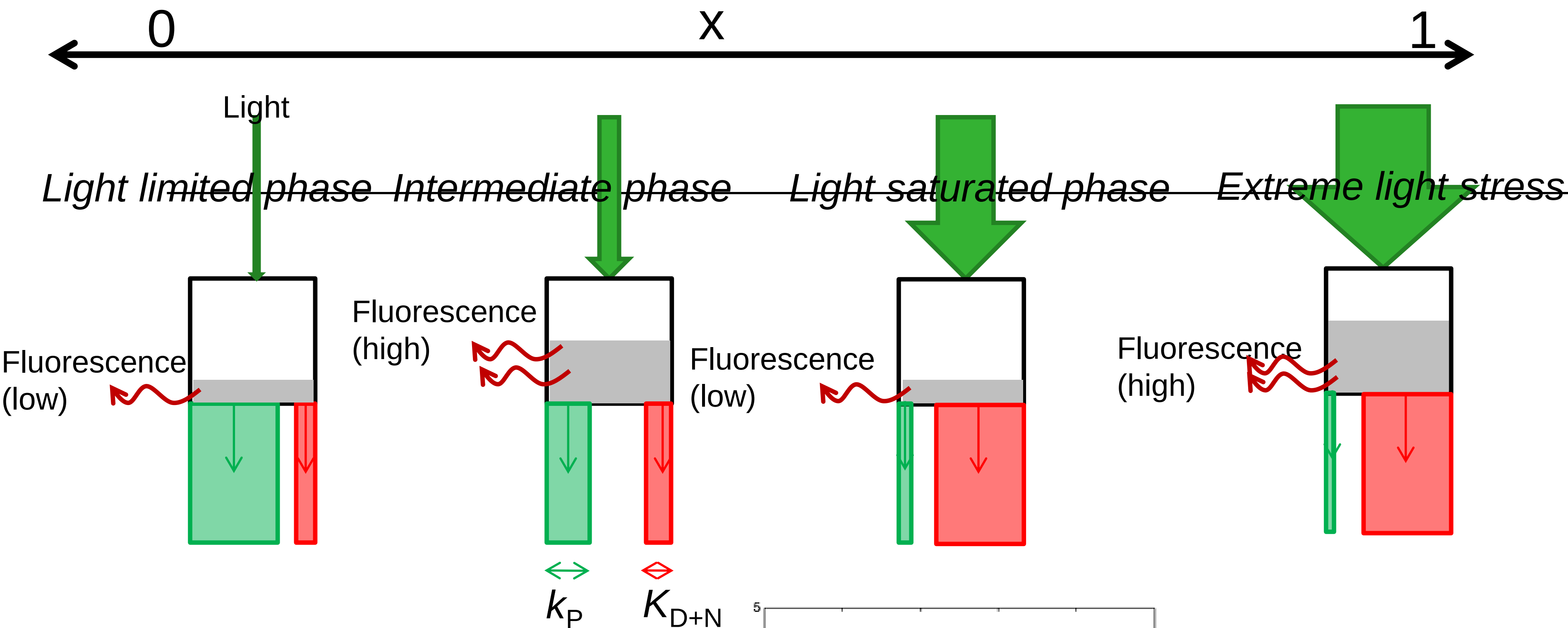


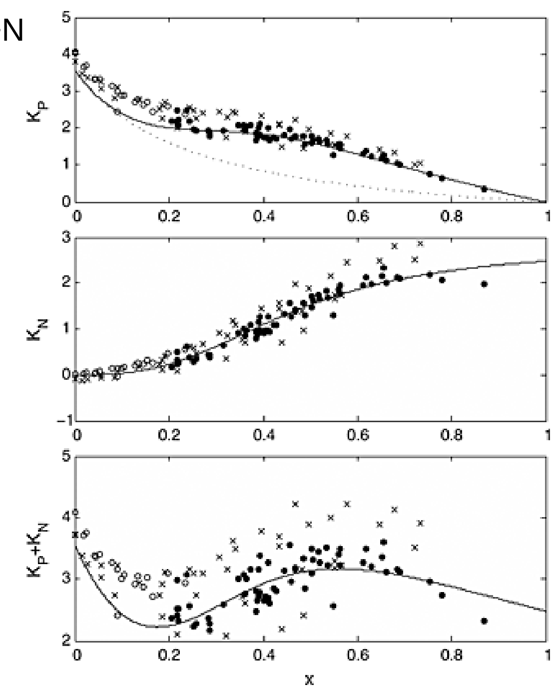


De-excitation pathways









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Volume 119, Issue 12, pages 2312-2327, 26 DEC 2014 DOI: 10.1002/2014JG002713
http://onlinelibrary.wiley.com/doi/10.1002/2014JG002713/full#jgrg20312-fig-0005

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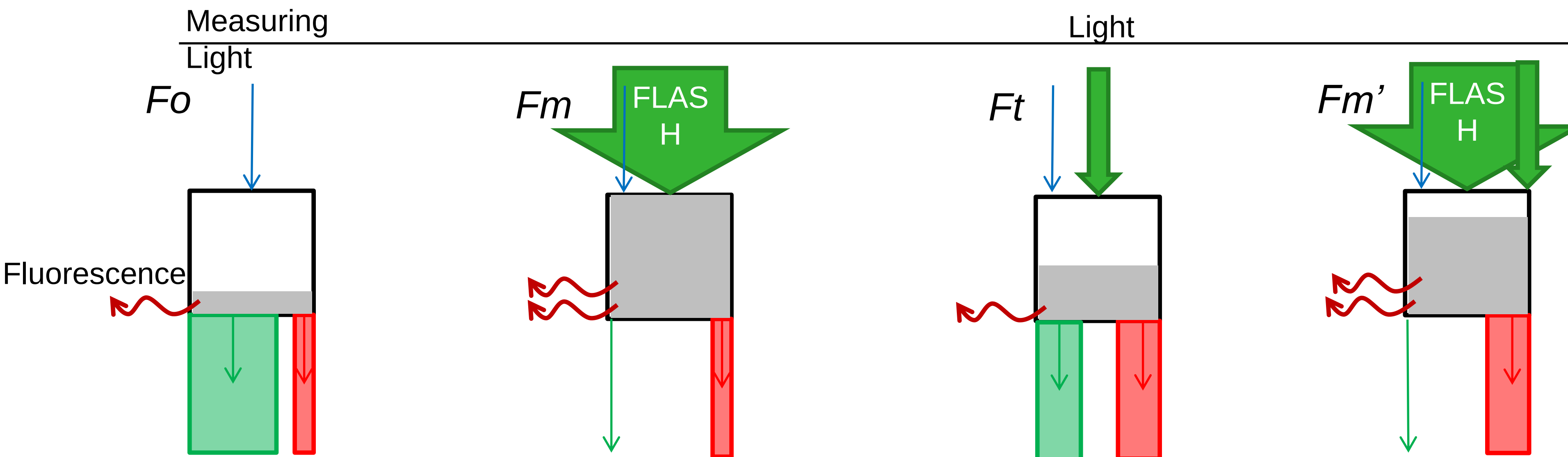
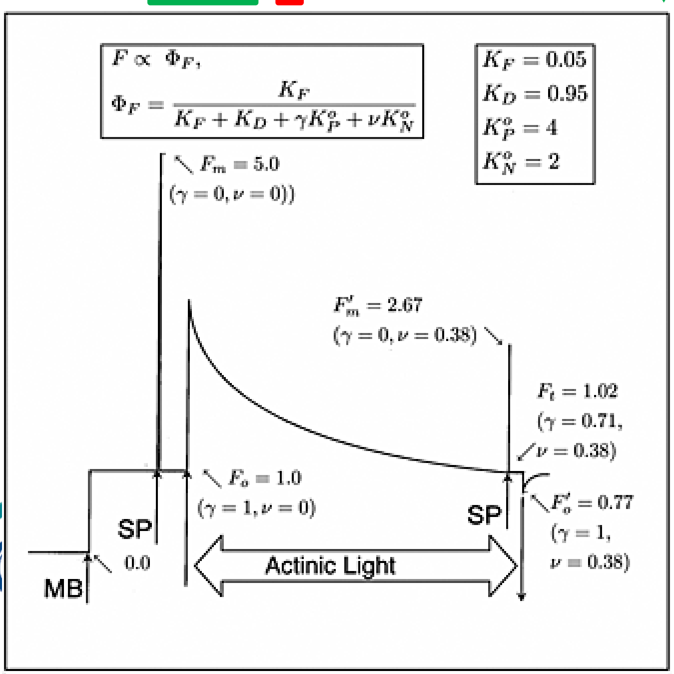
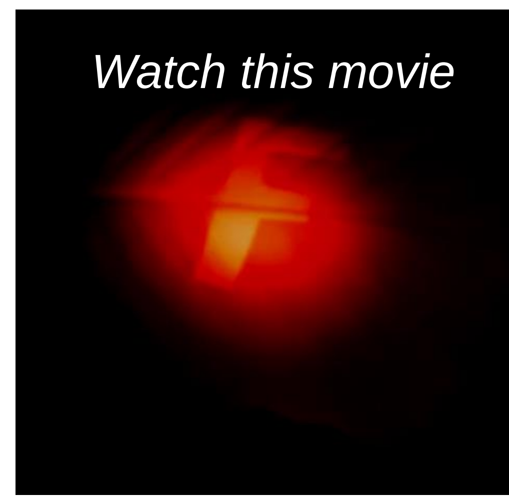
Pulse-Amplitude-Modulation: make use of the fact that k_P responds almost immediately, but k_N slowly
And get to know all k's at a specific light intensity







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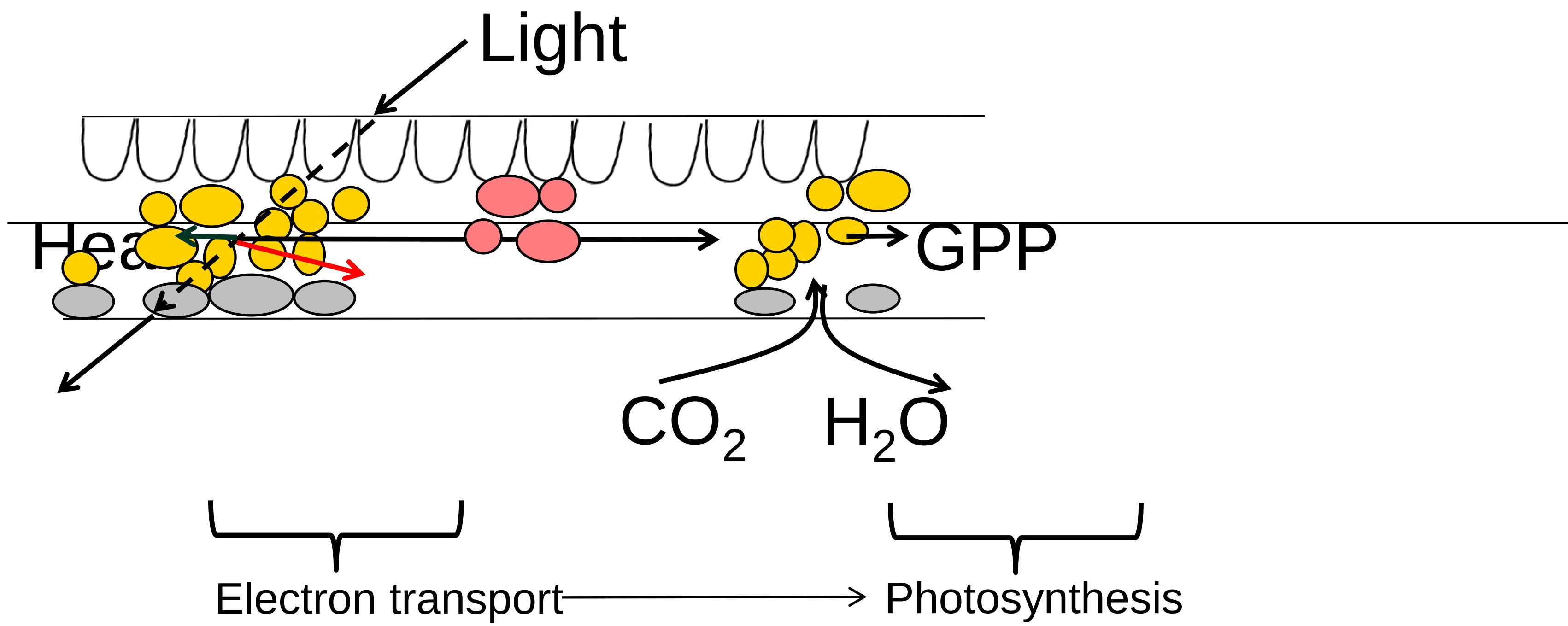
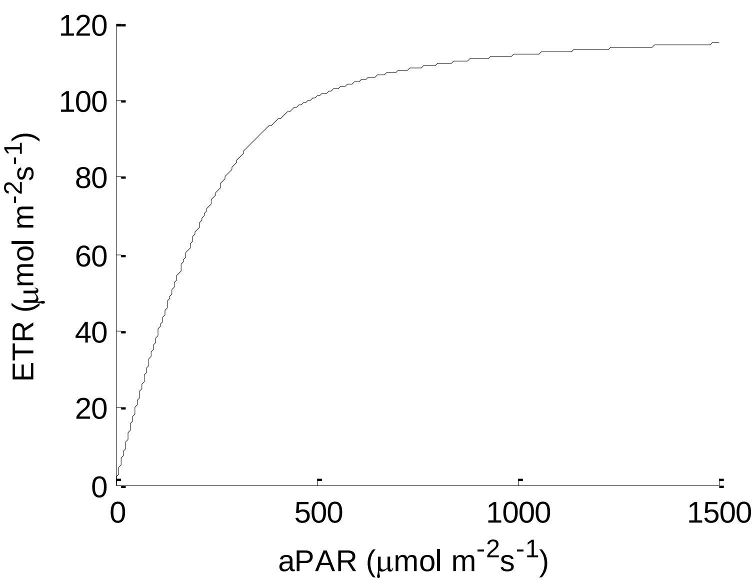
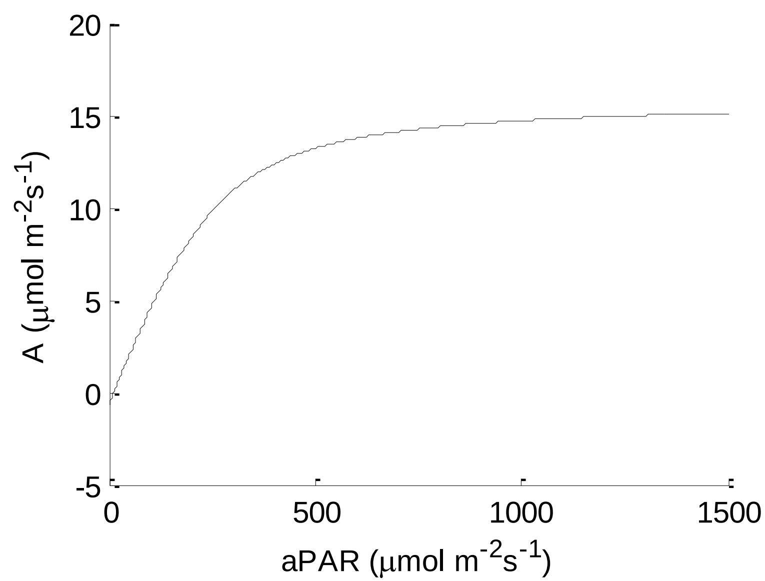
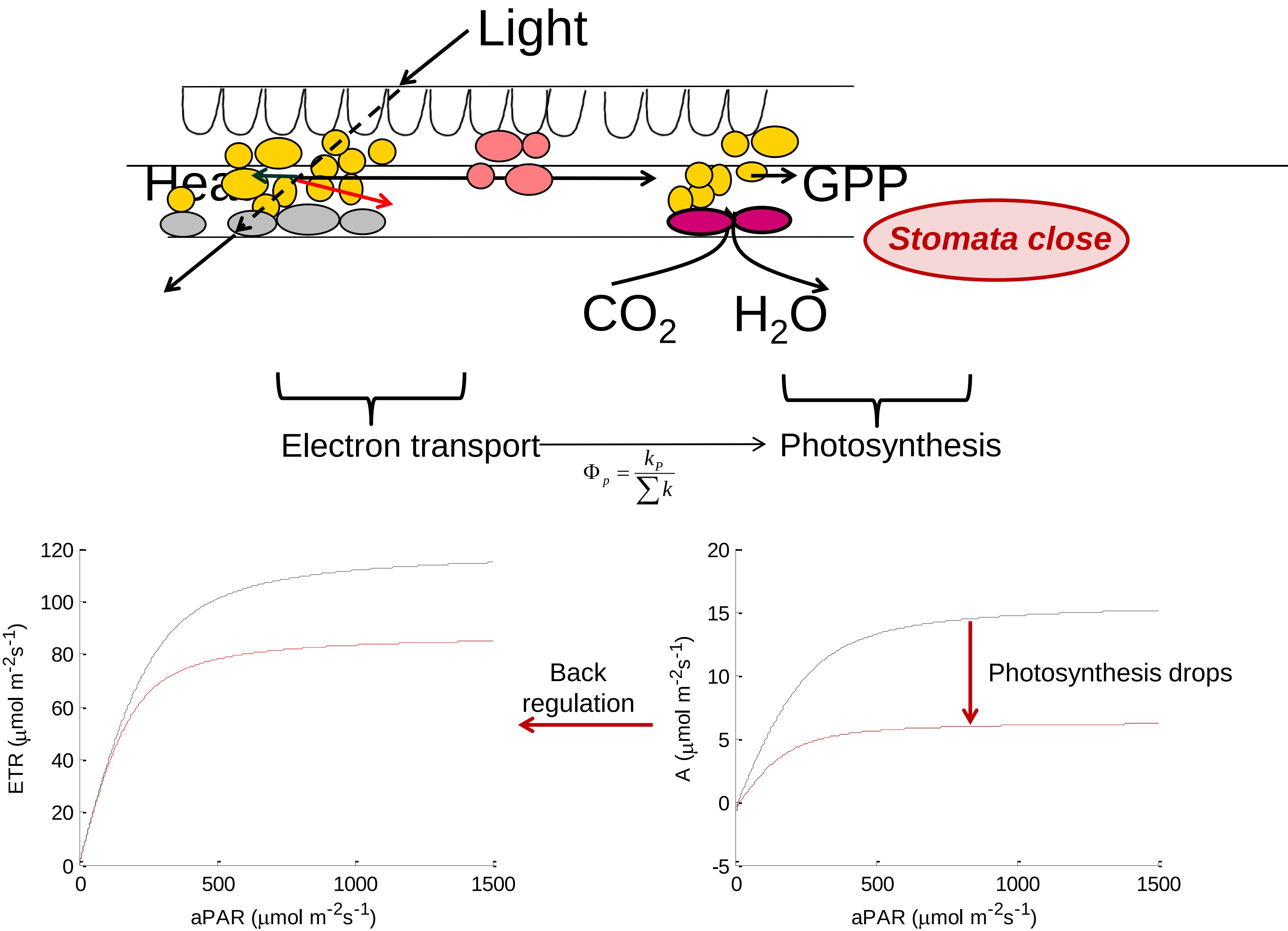
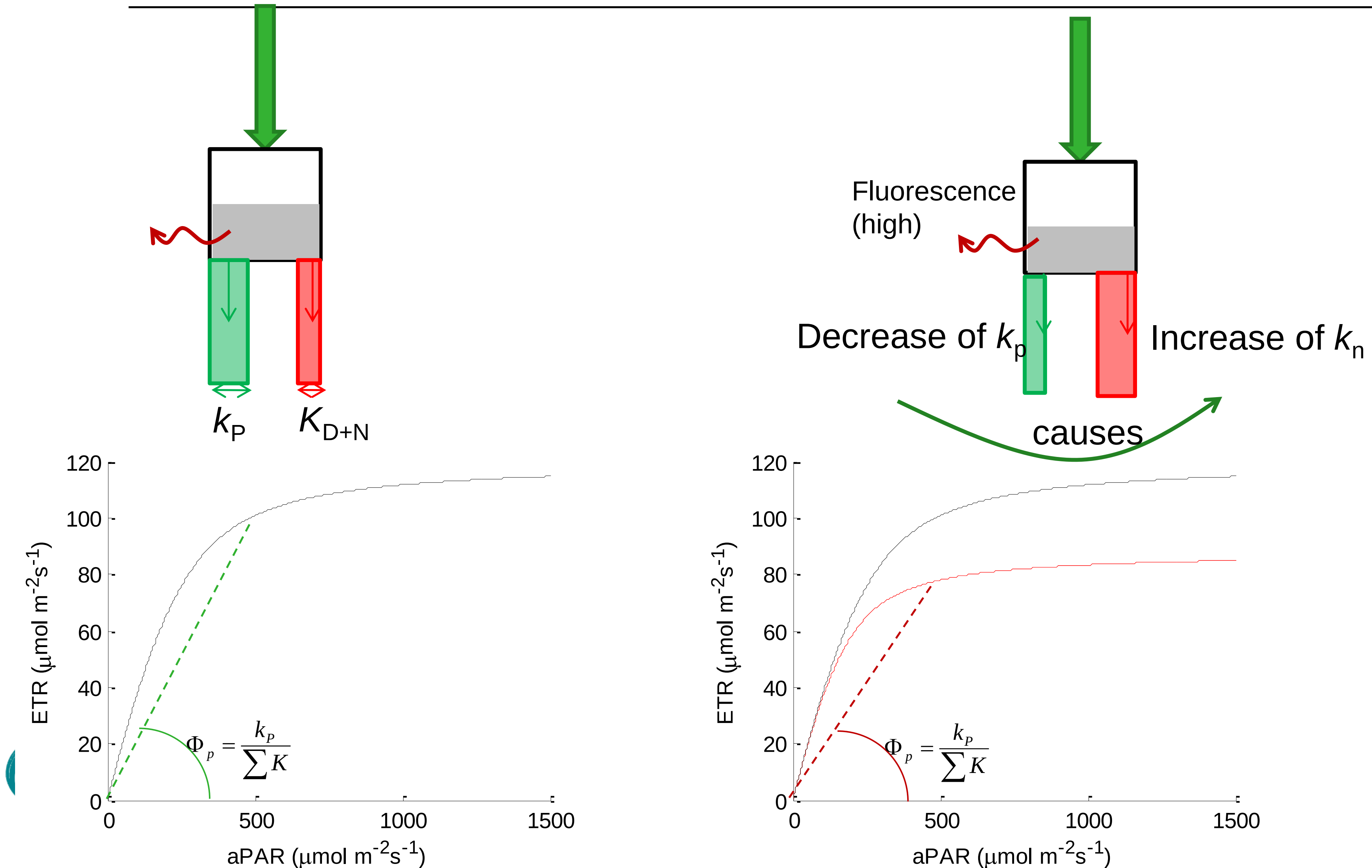

Light
GPP
CO_2
H_2O
Electron transport
Photosynthesis


120
100
80
60
40
20
0
0
500
1000
1500
ETR (μmol m^{-2}s^{-1})
aPAR (μmol m^{-2}s^{-1})


20
15
10
5
0
-5
0
500
1000
1500
A (μmol m^{-2}s^{-1})
aPAR (μmol m^{-2}s^{-1})


Light
GPP
Stomata close
CO_2
H_2O
Electron transport
Photosynthesis
$\Phi_p = \frac{k_P}{\sum k}$
120
100
80
60
40
20
0
ETR (μmol m^{-2}s^{-1})
0
500
1000
1500
aPAR (μmol m^{-2}s^{-1})
Back
regulation
20
15
10
5
0
-5
A (μmol m^{-2}s^{-1})
Photosynthesis drops
0
500
1000
1500
aPAR (μmol m^{-2}s^{-1})

Feedback from dark reactions



The question is, how can we handle the two unknowns, k_P and k_N
Pragmatic solution to this problem, is to find empirically:

$$k_N = f(\Phi_p)$$

Or:

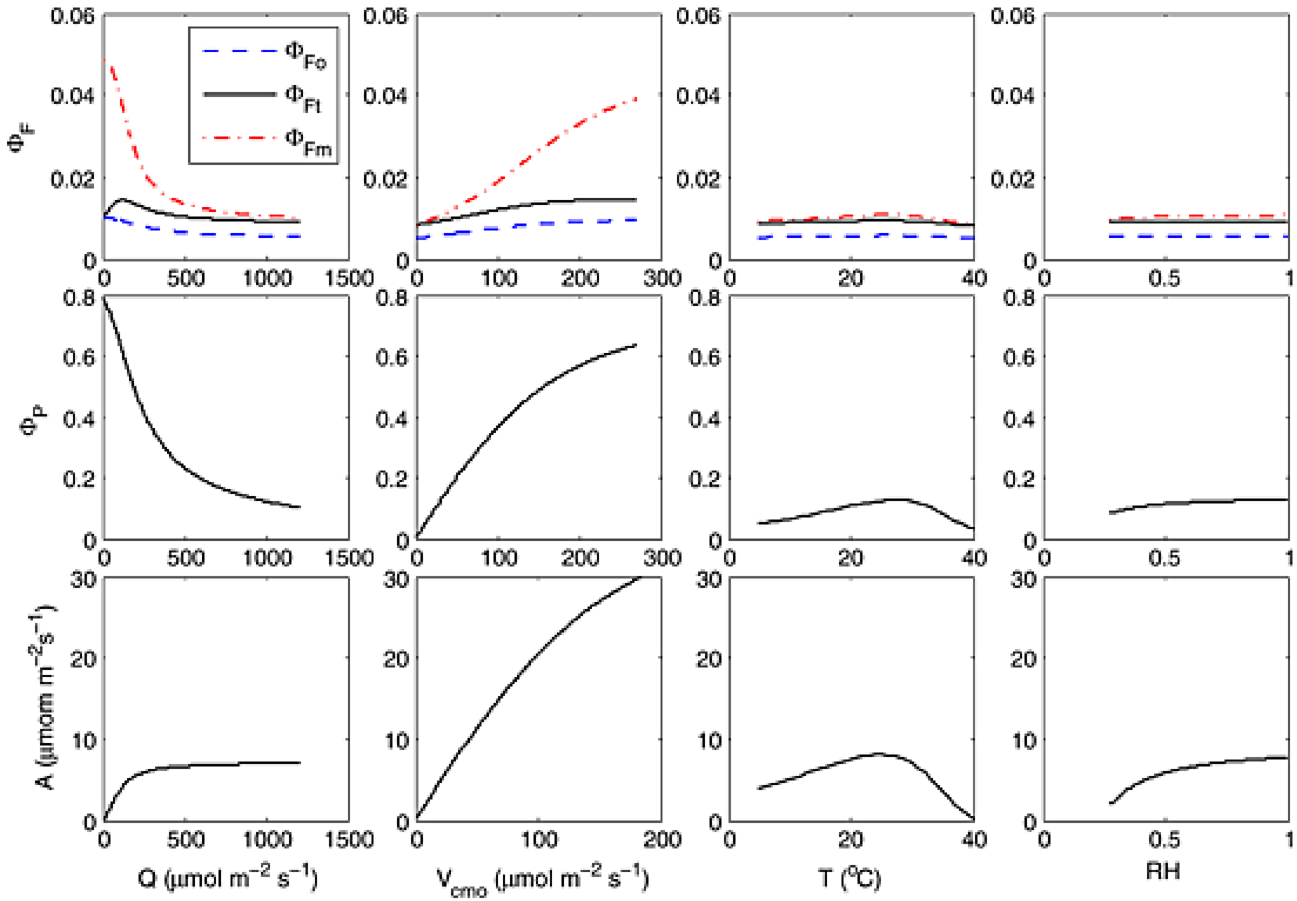
$$k_N = f(x)$$

$$x = 1 - \frac{\Phi_p}{\Phi_{p\max}} = \boxed{1 - \frac{ETR_{actual}}{ETR_{potential}}}$$

Degree of light saturation [0,1

Alternative solutions: find a mechanistic model for k_N

Coupled with a ‘traditional’ photosynthesis and gas exchange model, this links steady state fluorescence yield to photosynthesis



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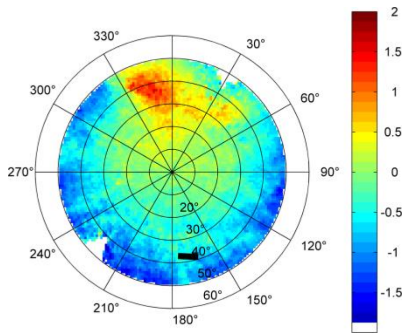
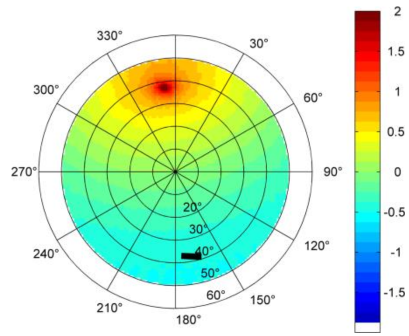
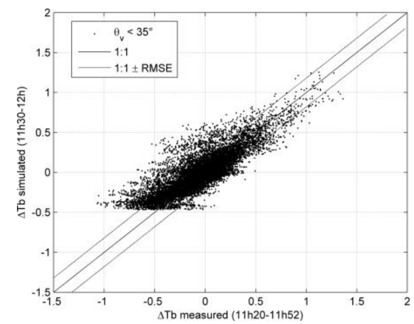
Applications of SCOPE

Example 1

- Multi-directional observations (left) and model simulations (right) of brightness temperatures (Duffour et al., 2015, AFM, in press)

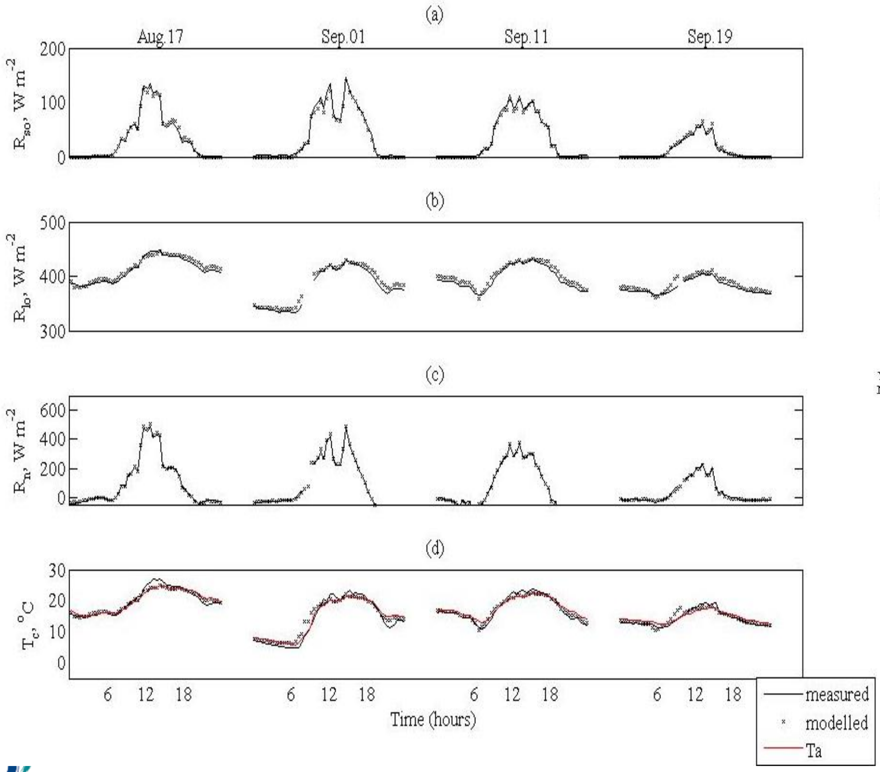


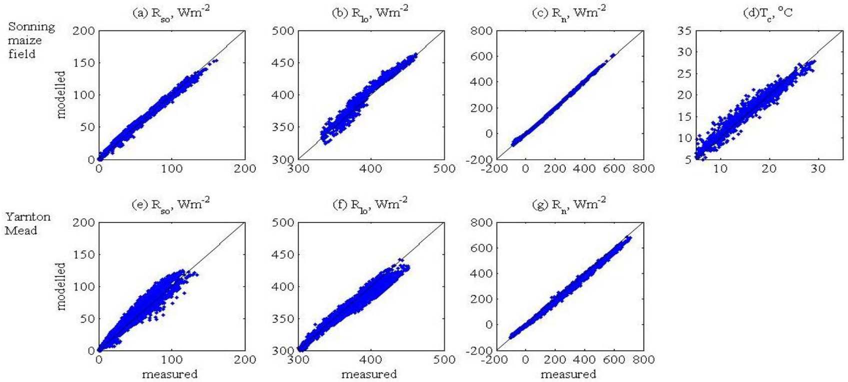




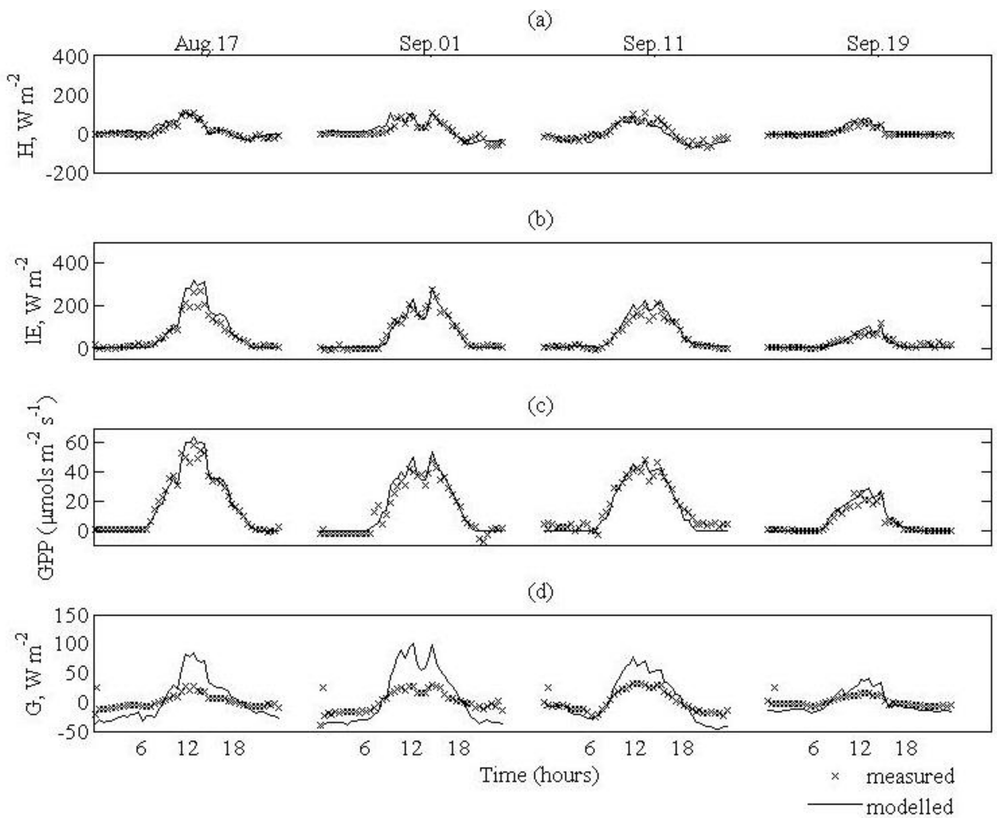
Example 2

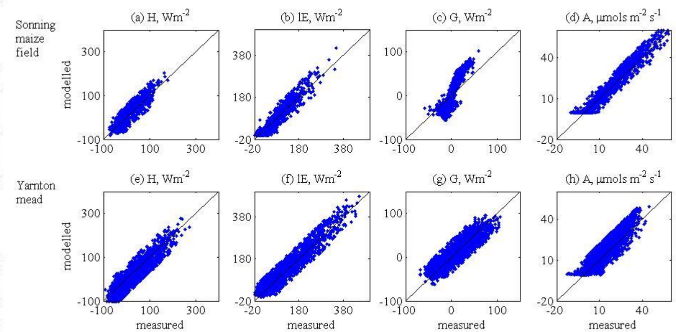
- Comparison of measured (symbols) and modelled (lines) diurnal cycles of fluxes and temperature (Punalekar et al., sumbitted to AFM)





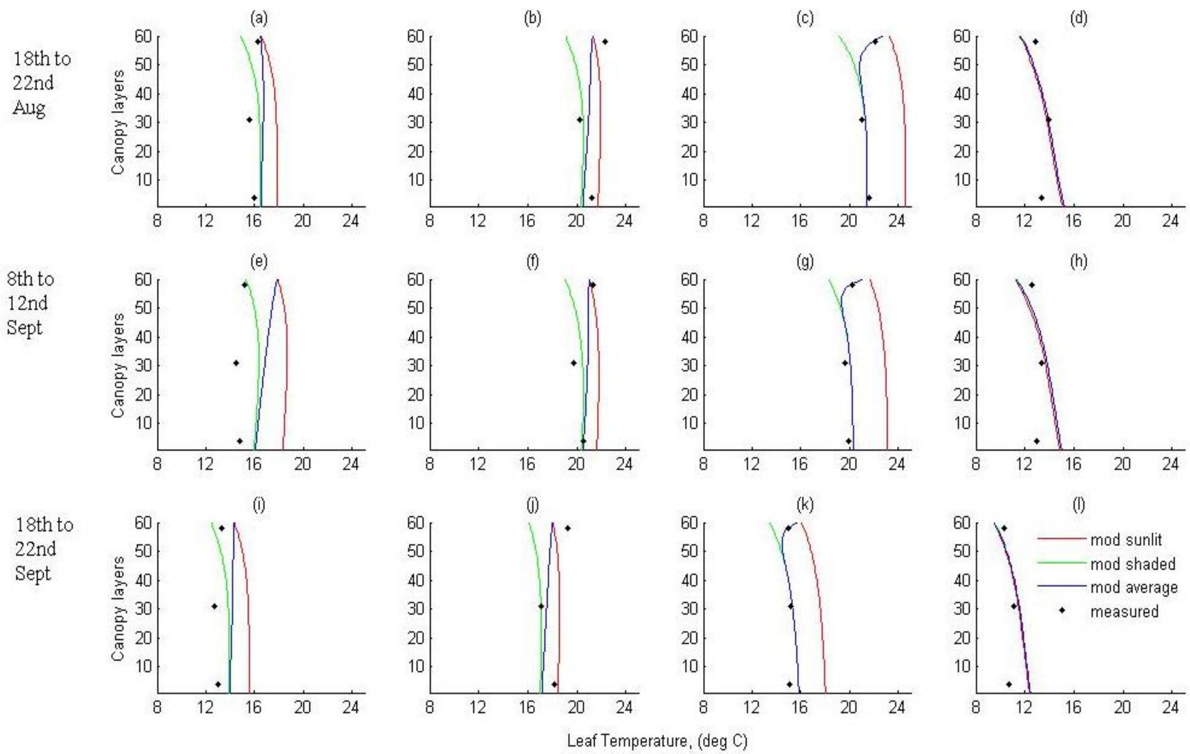
Example 2, continued





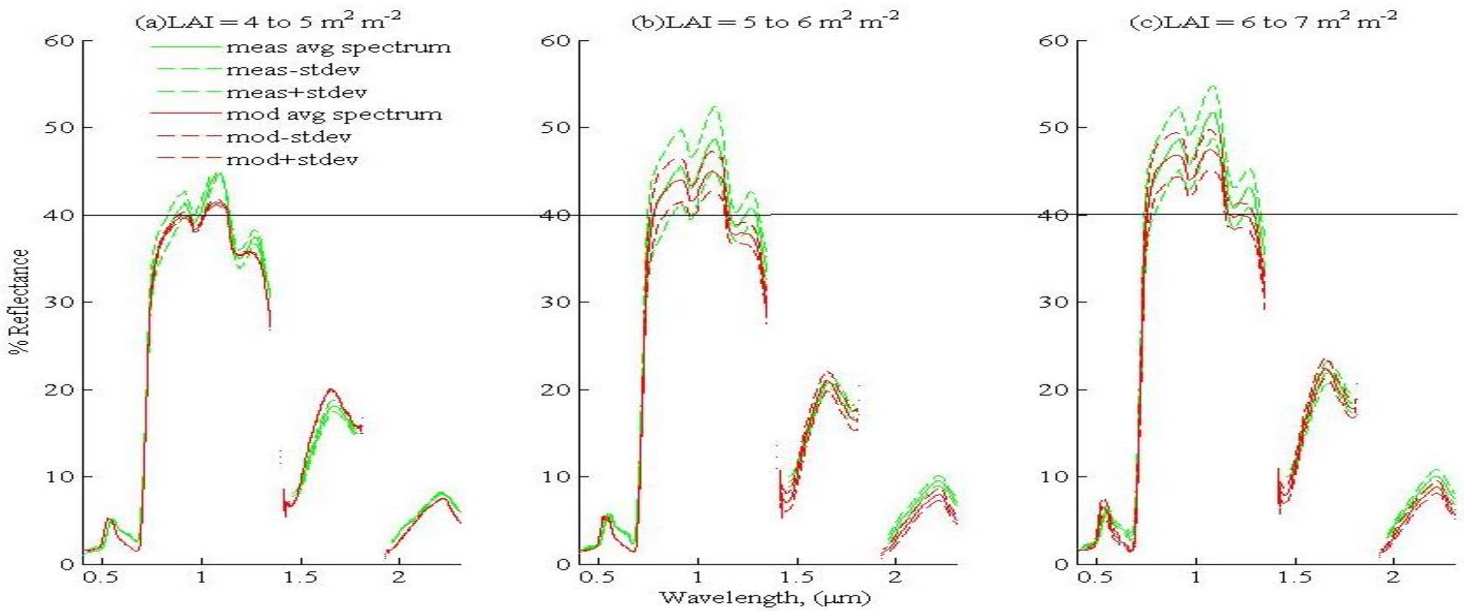
Example 3.

- Vertical profiles of temperature in the canopy (Punalekar et al., submitted to AFM)



Example 4.

- Modelled and measured canopy reflectance spectra (Punalekar et al., submitted to AFM)



Example 5.

- Measured (left) and modelled (right) responses of GPP and Chlorophyll fluorescence to irradiance.Diurnal cycles of Chlorophyll fluorescence (Van der Tol et al, in prep)