Reflectance and solar induced fluorescence: from emission to observation

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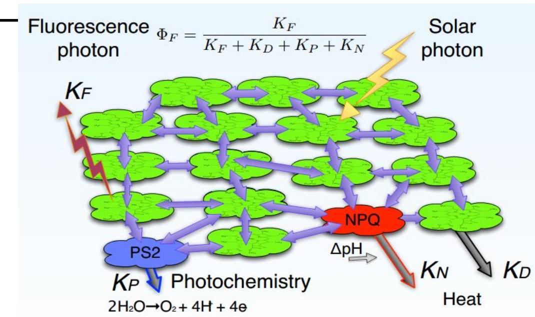
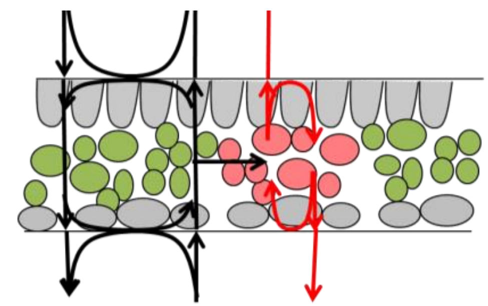
COST Action ES1309

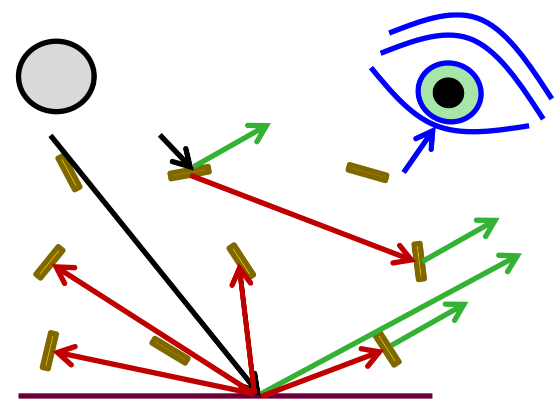
OUTLINE

- Background
- Emission of fluorescence
- Radiative transfer in the leaf
  - Of incident light
  - Of fluorescence
- Radiative transfer in the canopy
  - Of incident light
  - Of fluorescence
- GPP of the canopy

Conceptual model -> Software -> Results







BACKGROUND

Two models for reflectance:

$$[r_{\text{leaf}}, t_{\text{leaf}}] = f(\text{leaf composition})$$

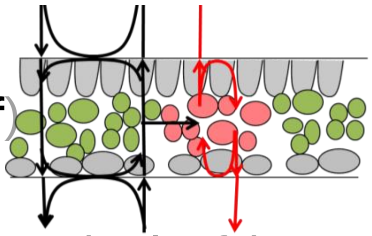
PROSPECT / Fluspect

$$[r_{\text{canopy}}, E_{\text{obs}}, E_{\text{hemis}}] = f(E_{\text{in},} r_{\text{leaf}}, t_{\text{leaf}}, LAI, \text{canopy structure})$$

SAIL/ RTMo / ray tracing …

Four models for fluorescence:

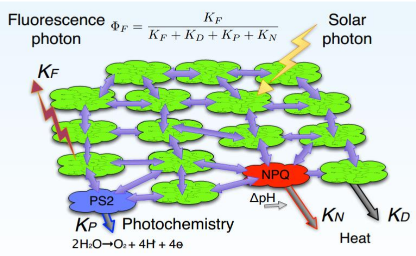
Fluorescence excitation-emission matrix: depends on leaf structure (**Fluspect/FluorModLeaf**)



$$SIF_{\mathrm{leaf}} = \varepsilon \cdot M \otimes E$$

Incident light on the leaf (**SAIL/RTMo**)

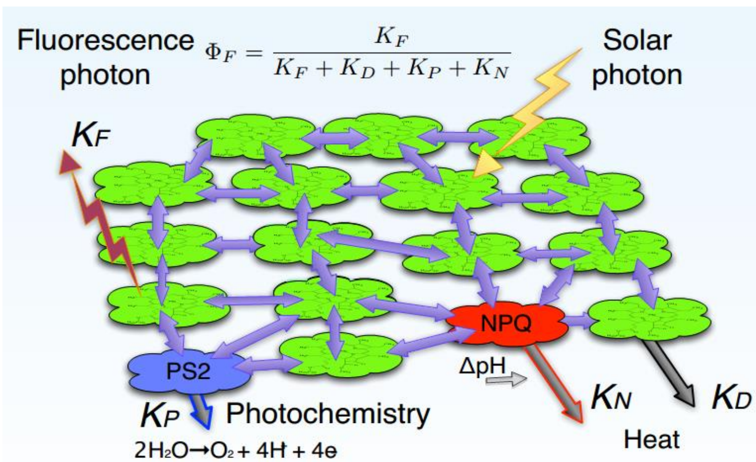
Biochemical regulation (quenching) of the fluorescence (**plant-physiological model**)

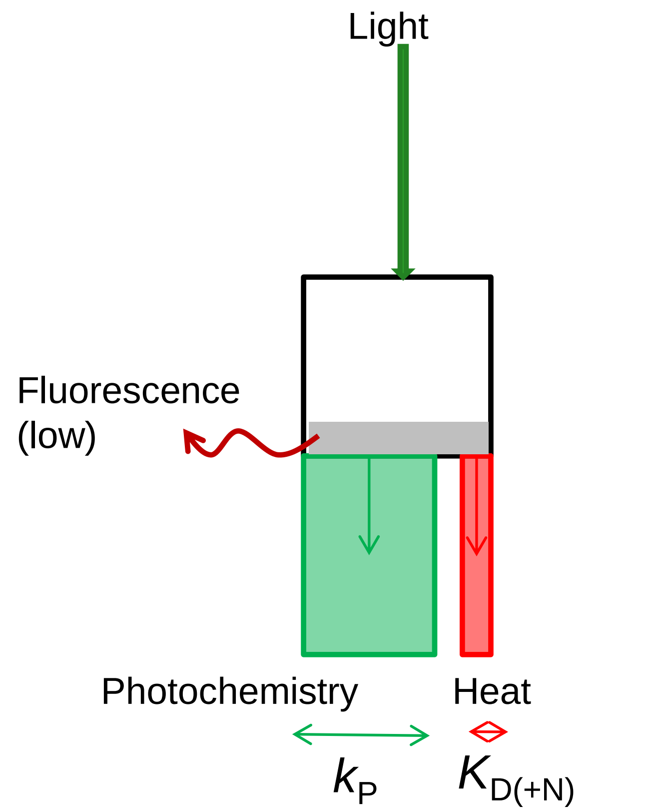


$$SIF_{\mathrm{canopy}} = f\,(SIF_{\mathrm{leaf}}, LAI, LIDF, \theta_{\mathrm{s}}, \theta_{\mathrm{o}}, \omega_{\mathrm{o,s}})$$

Radiative transfer through the canopy (**RTMf**)

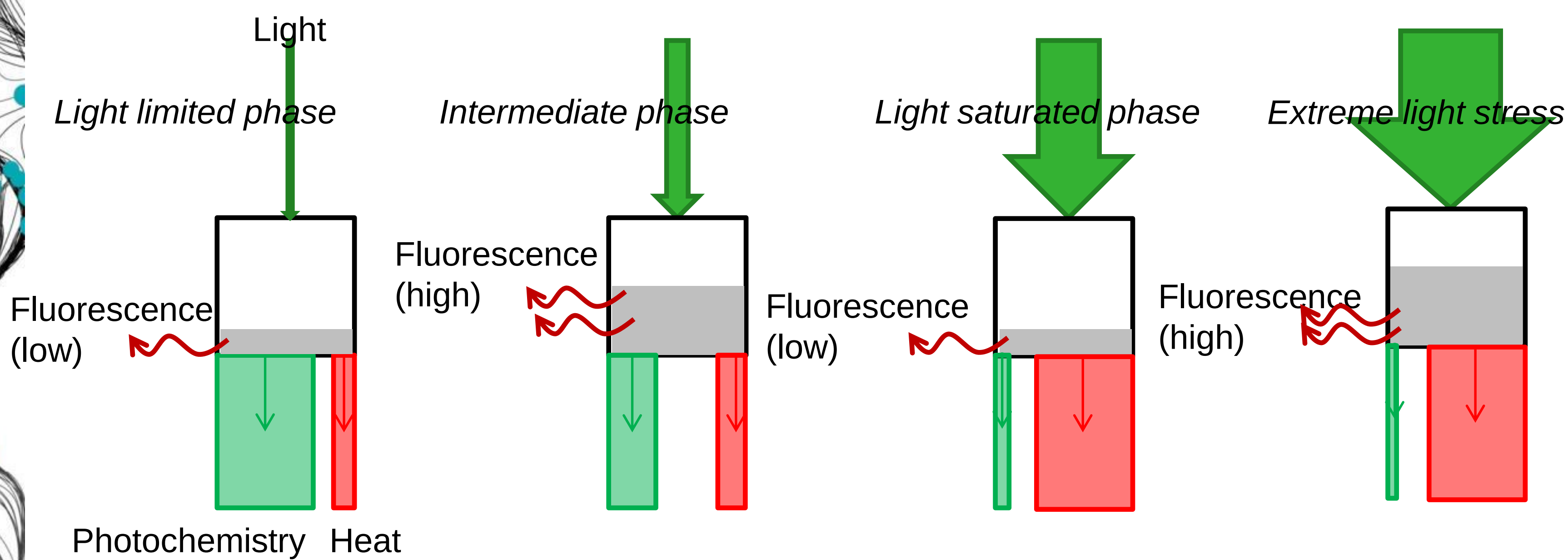
ε EMISSION EFFICIENCY (BIOCHEMICAL)

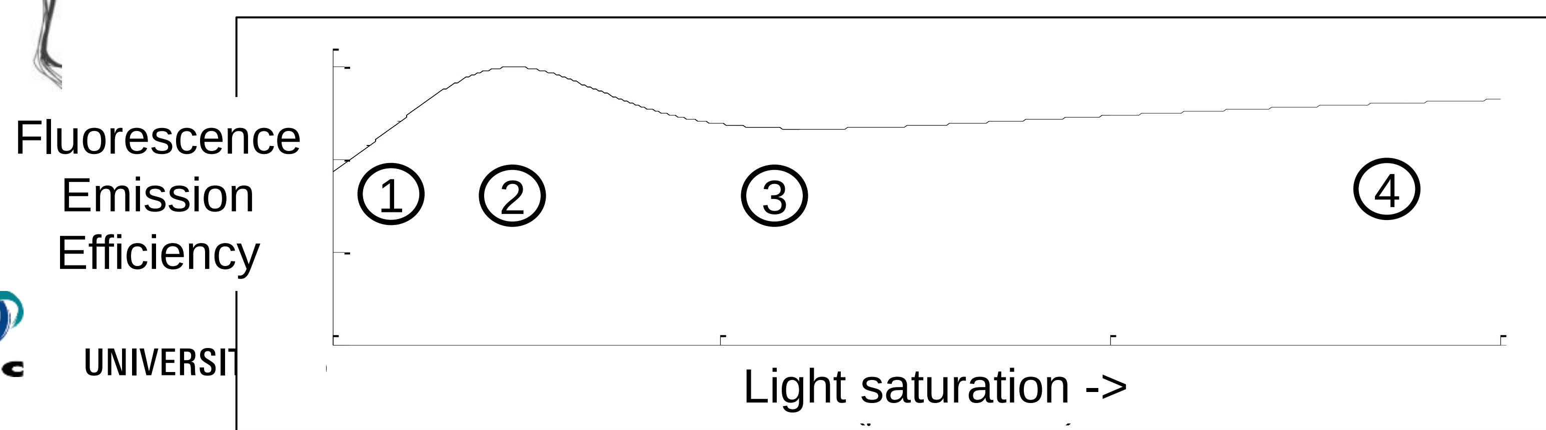




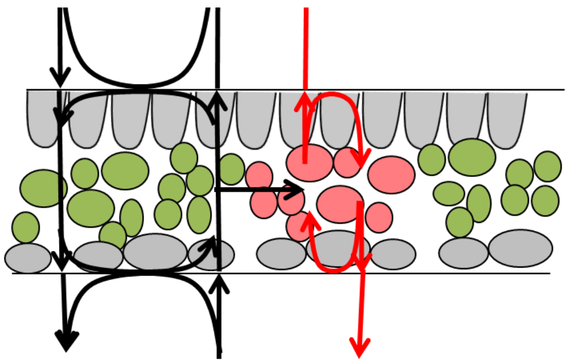
$$\Phi_f = \varepsilon_f = \frac{k_F}{k_F + k_P + k_D + k_N}$$

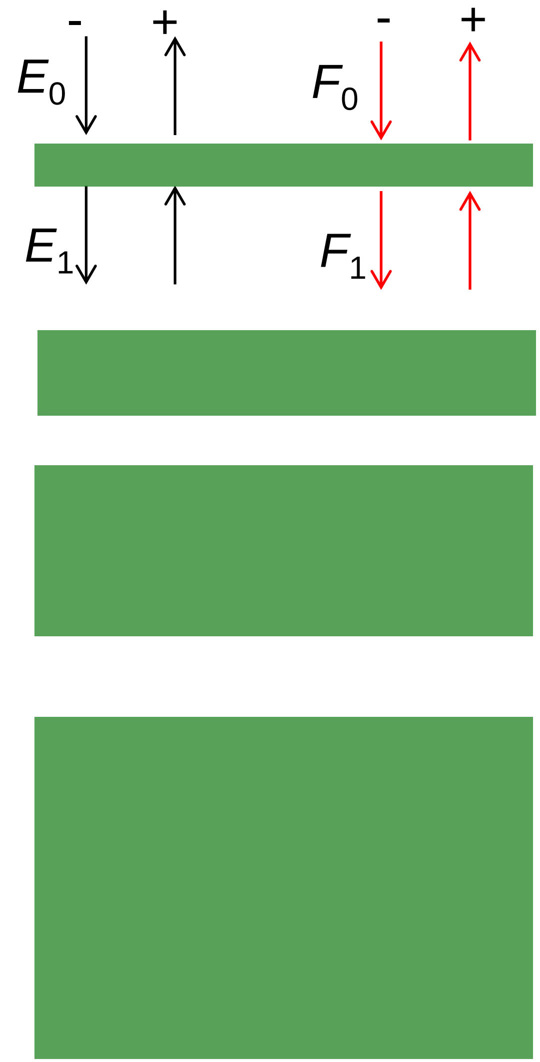
De-excitation pathways





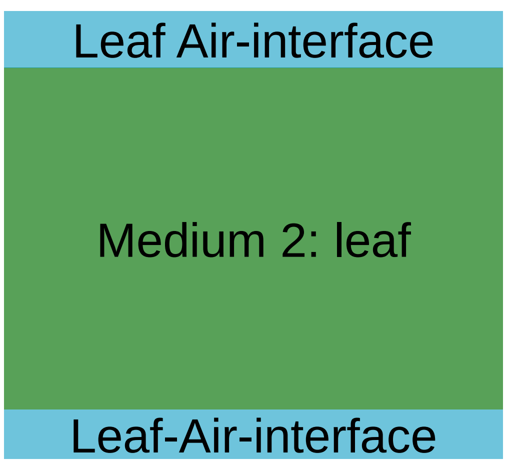
M: RADIATIVE TRANSFER IN THE LEAF (FLUSPECT)





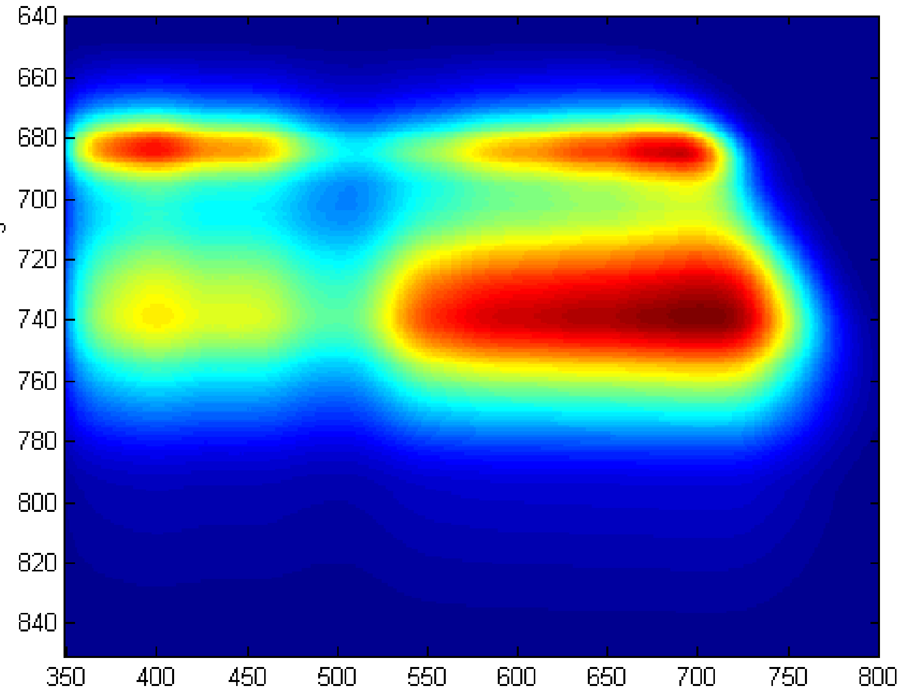
Differential Equations small sub-layer

Doubling algorithm



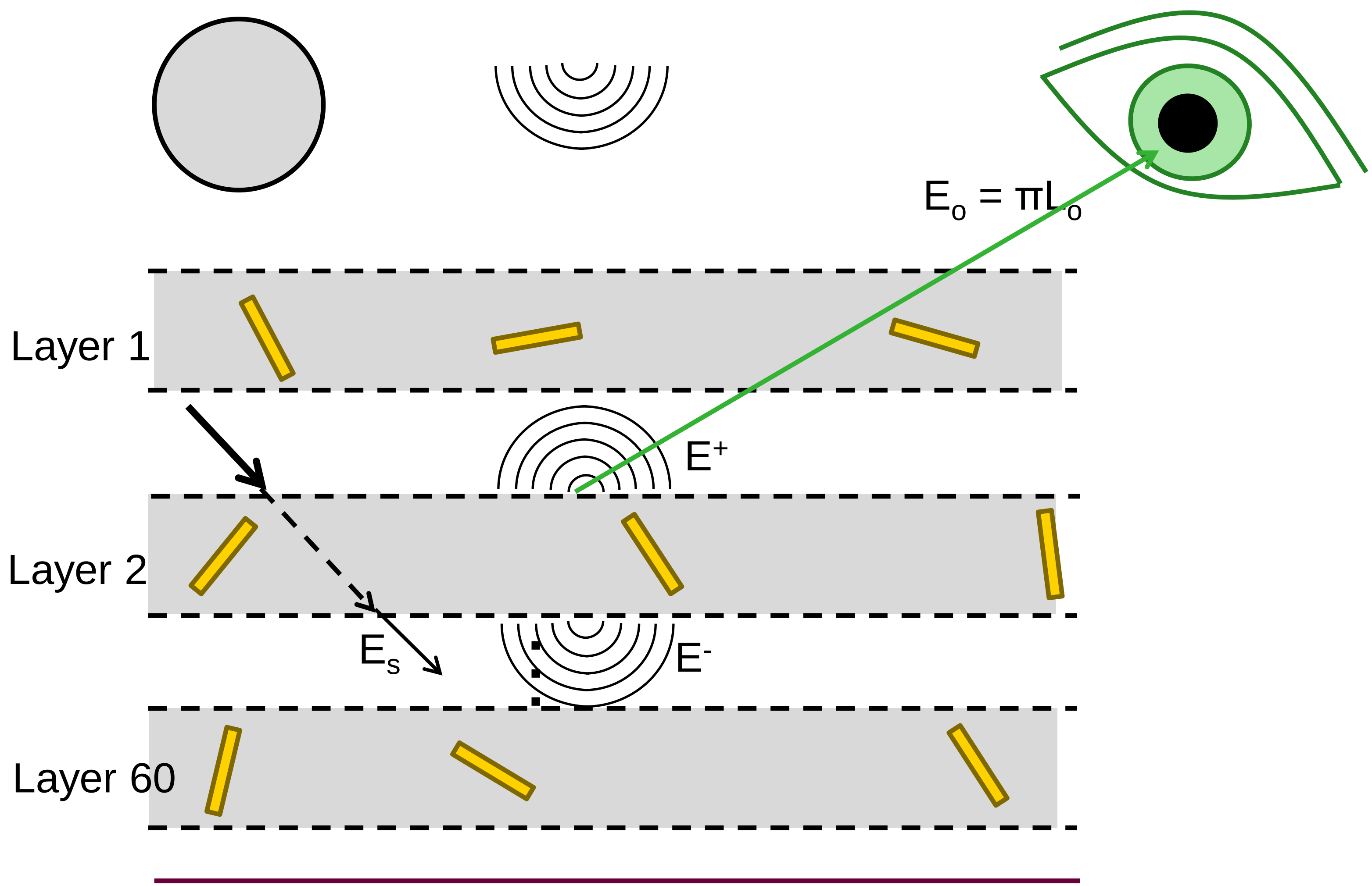
Probability of fluorescence emission (at wl_f) as a function of excitation (wl_e)

Fluorescence emission wavelength



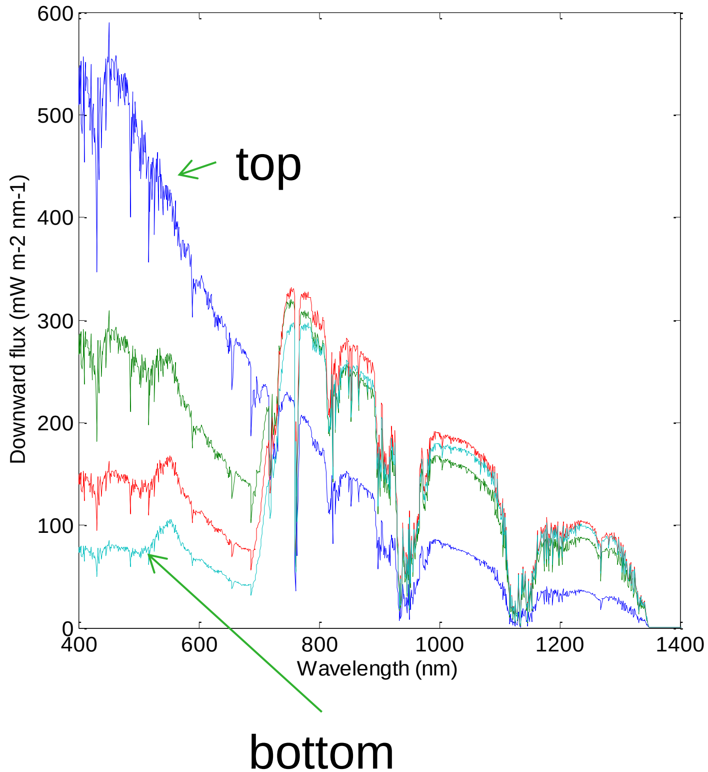
Excitation wavelength

E: INCIDENT LIGHT ON THE LEAVES (RTMO)

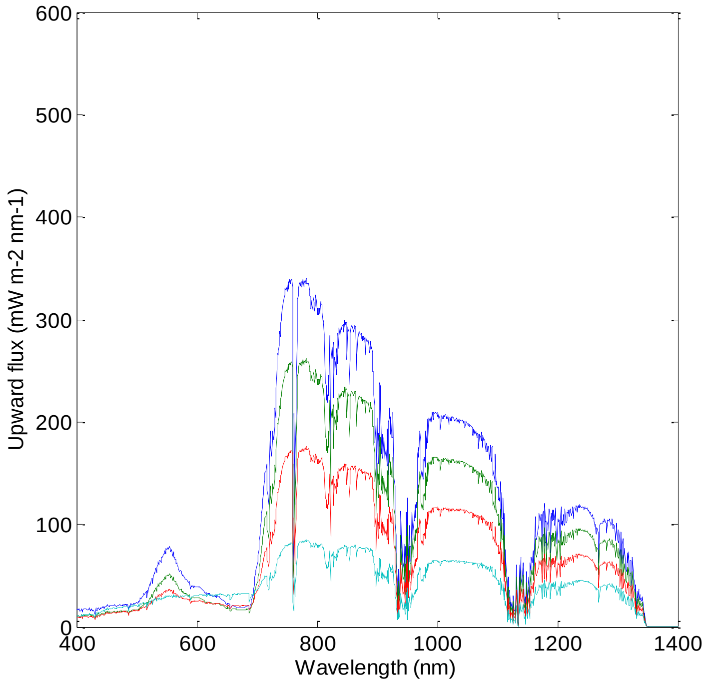


Simulated spectra of E^- and E^+ at different levels in the canopy

E^-



E^+



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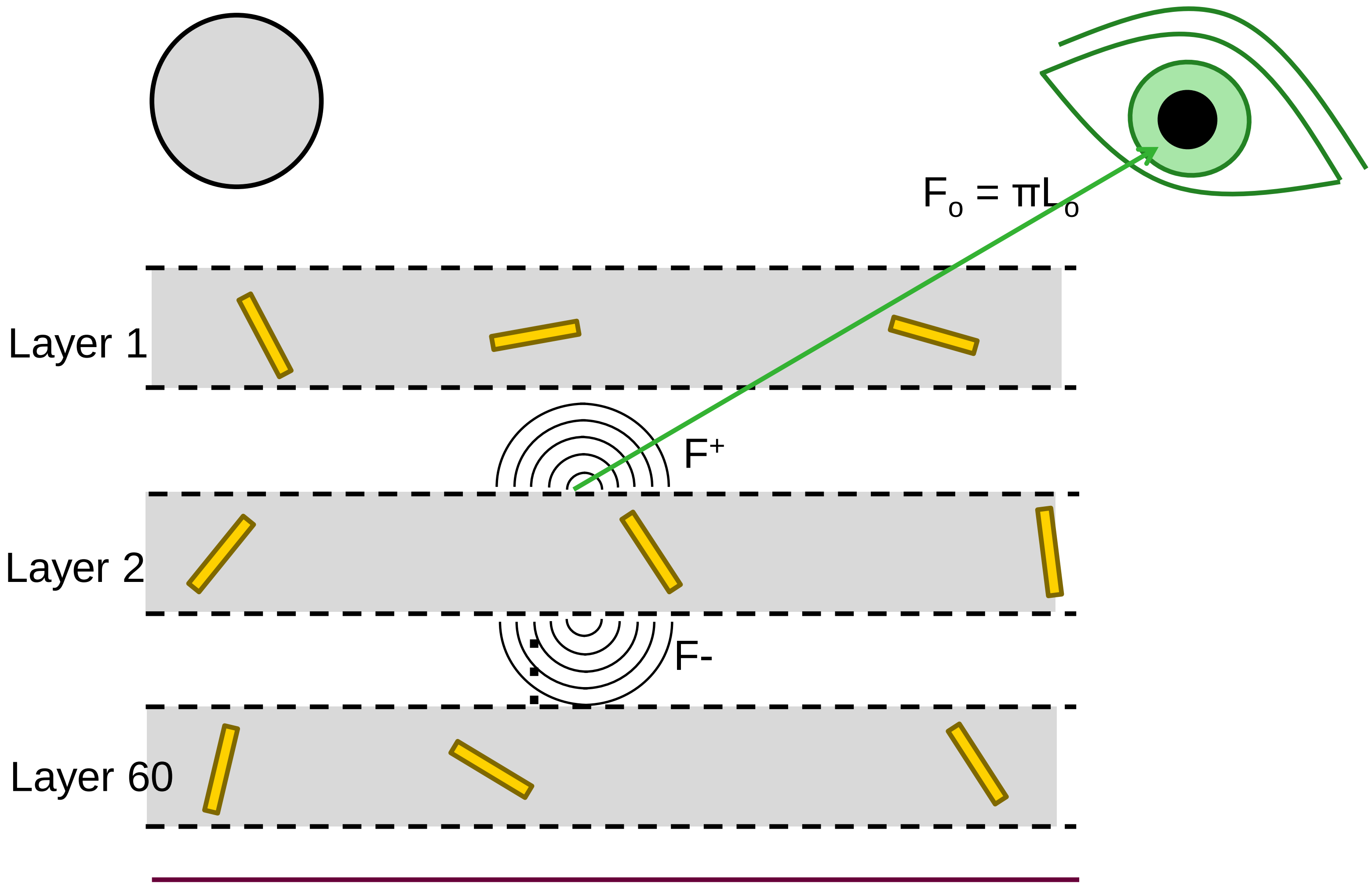
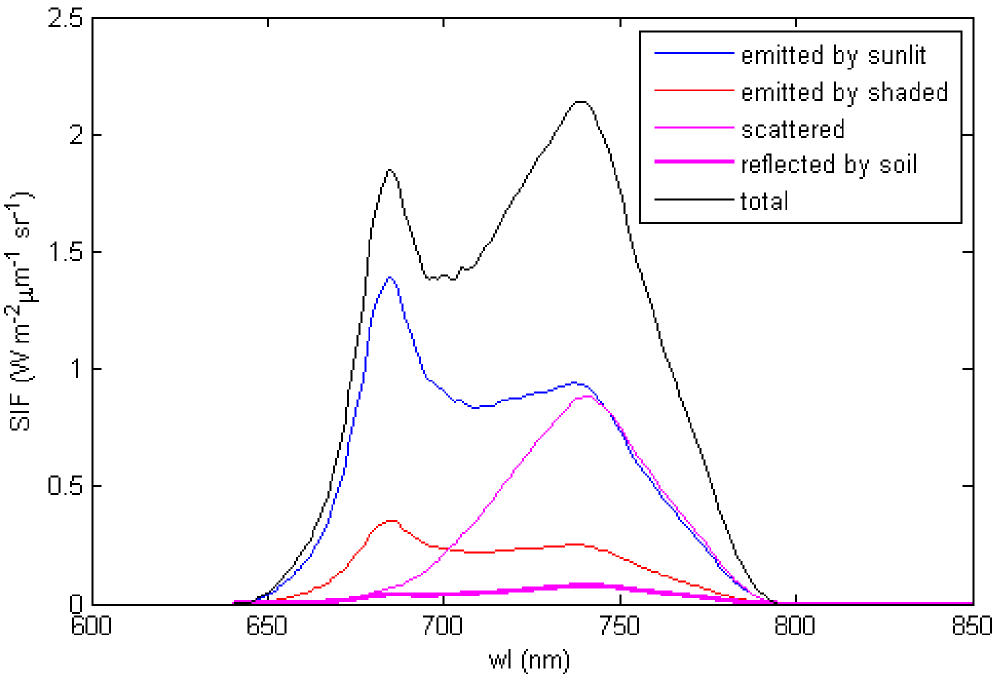
RTMF: PROPAGATION OF FLUORESCENCE

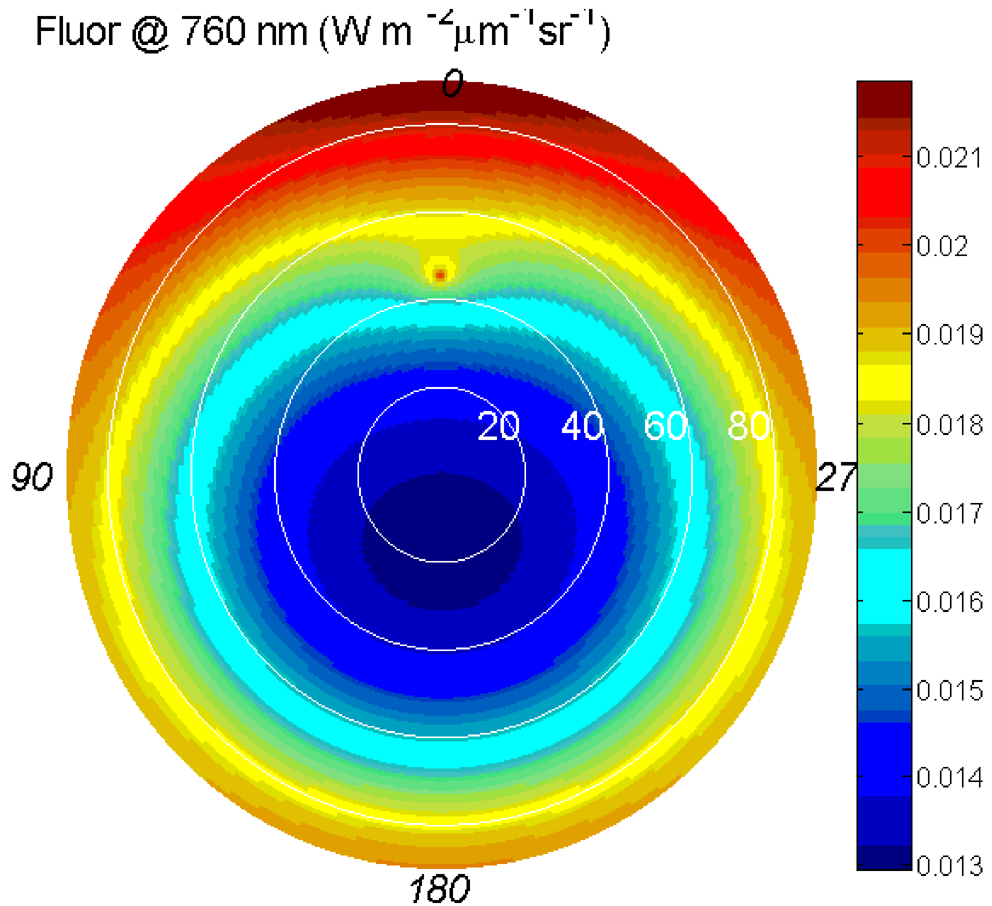


RTMF: PROPAGATION OF FLUORESCENCE

After resolving the differential equations numerically, the outgoing fluorescence consists of the following parts:

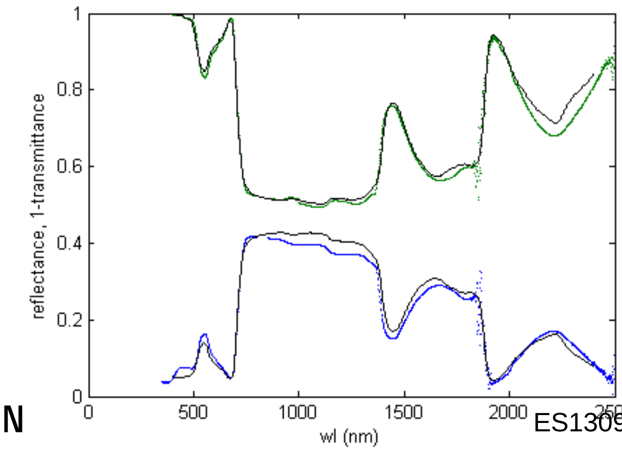
- Emitted by sunlit leaves
- Emitted by shaded leaves
- Reflected fluorescence (by the soil)
- Scattered fluorescence (by sunlit and shaded leaves)

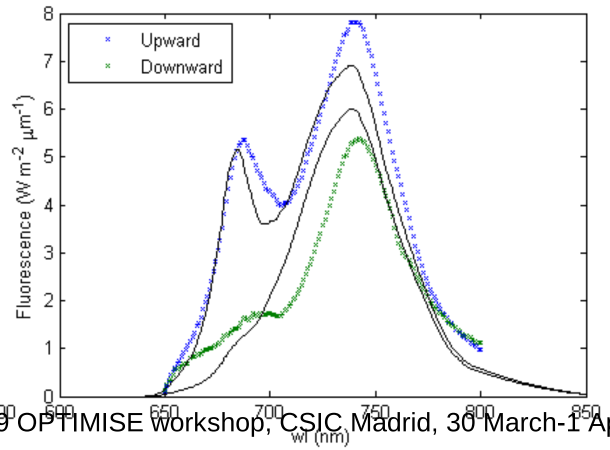


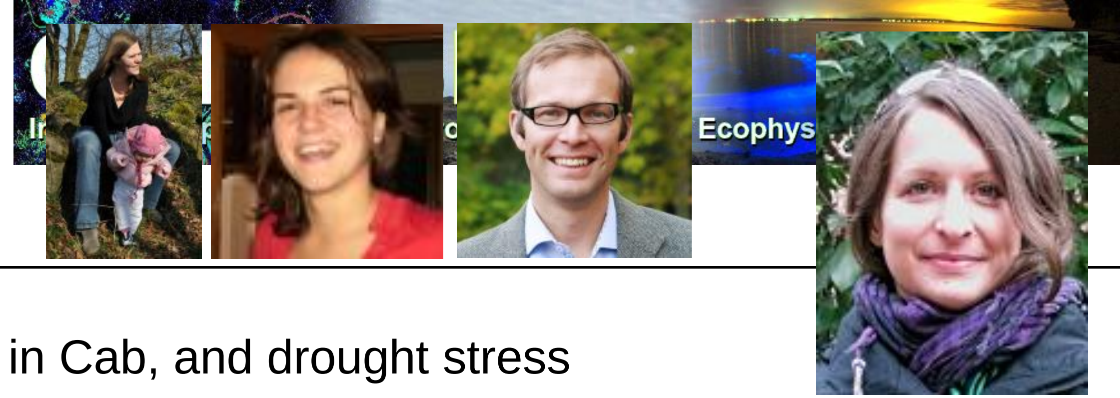

Fluor @ 760 nm (W m -2µm-1sr-1)
0
90
270
180
20
40
60
80
0.021
0.02
0.019
0.018
0.017
0.016
0.015
0.014
0.013

SOFTWARE DEMONSTRATION

- Software for tuning parameters of:
  - Emission efficiency and photosynthesis
  - Leaf reflectance and transmittance
  - Canopy radiative transfer
- Example: Fluspect executable with automatic fitting.
- Provide input data as a spreadsheet
- After running, the output appears in a spreadsheet in a folder.
- The tuned parameters can then be applied in other models (eg SCOPE)



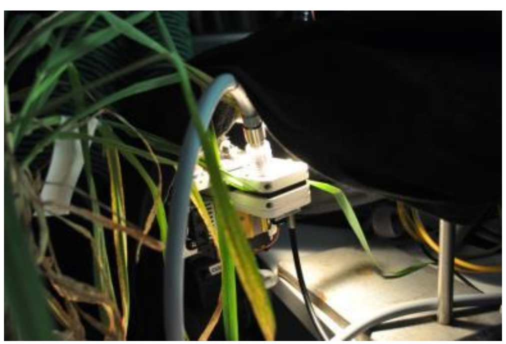




EXPERIMENTS

Two species, broad range in Cab, and drought stress

Three instruments



Goals

to validate the model simulation of

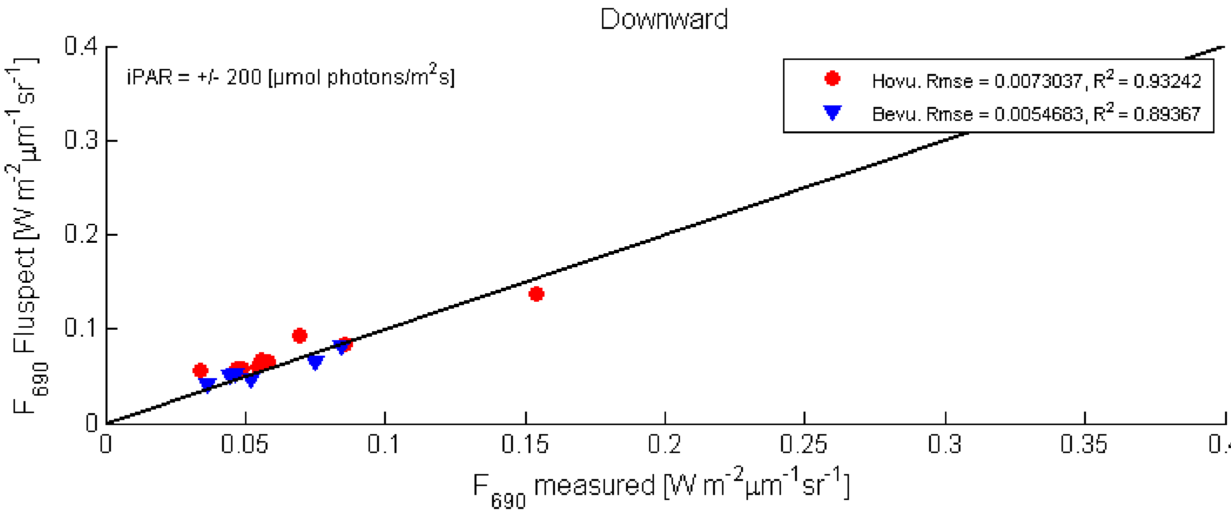
- *Effects of leaf structure*
- *Effects of emission efficiency*
- *Relation with photosynthesis*

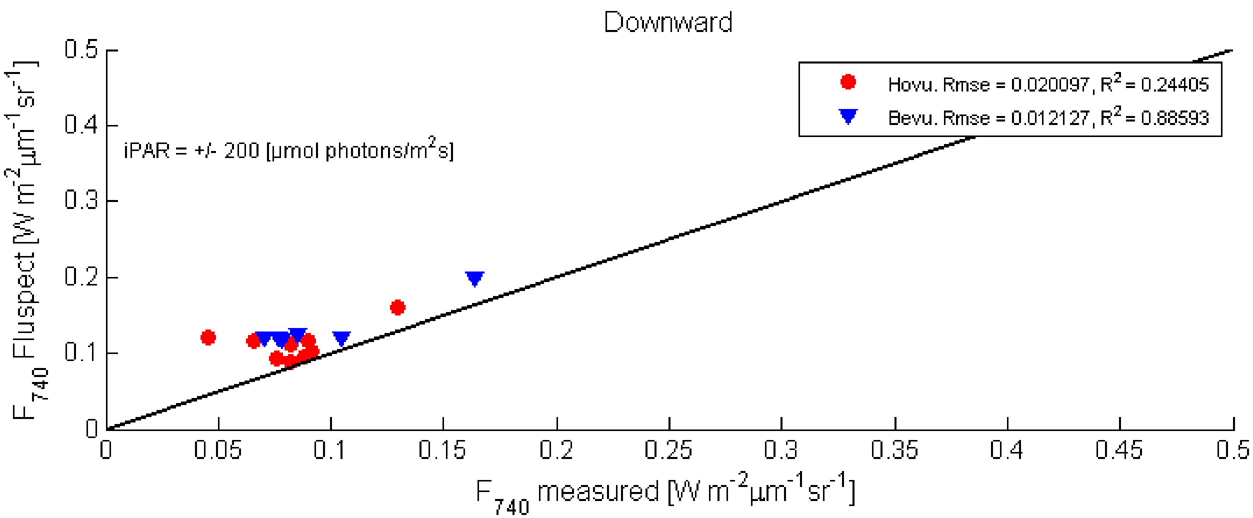
To model

- *Relation ChlF and PRI*

Instrument	Purpose
FluoWat Leaf clip + ASD	Effect of leaf structure
Leaf Chamber gas exchange	Photosynthesis
PAM fluoremetry	Fluorescence emission efficiency & electron transport rate
ASD fibre in leaf chamber	PRI and fluorescence

LEAVES OF DIFFERENT STRUCTURE, SAME (LOW) LIGHT

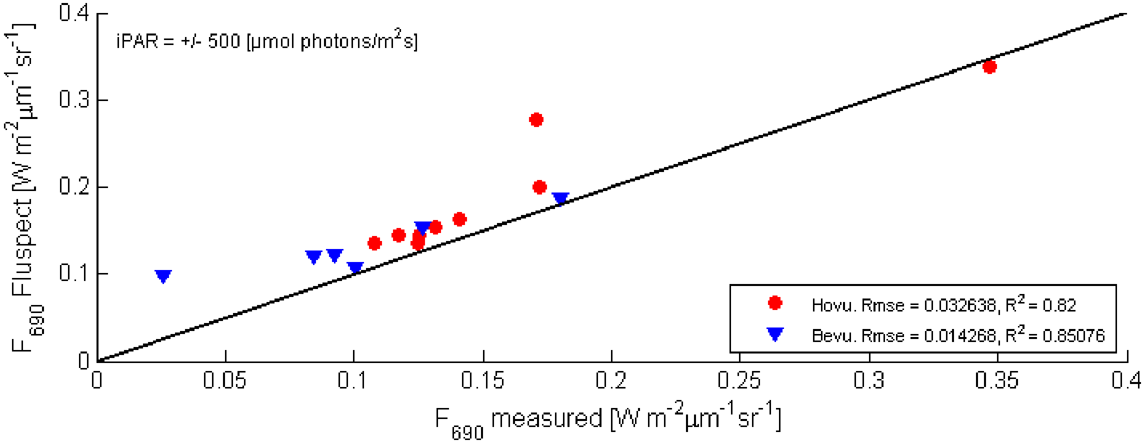




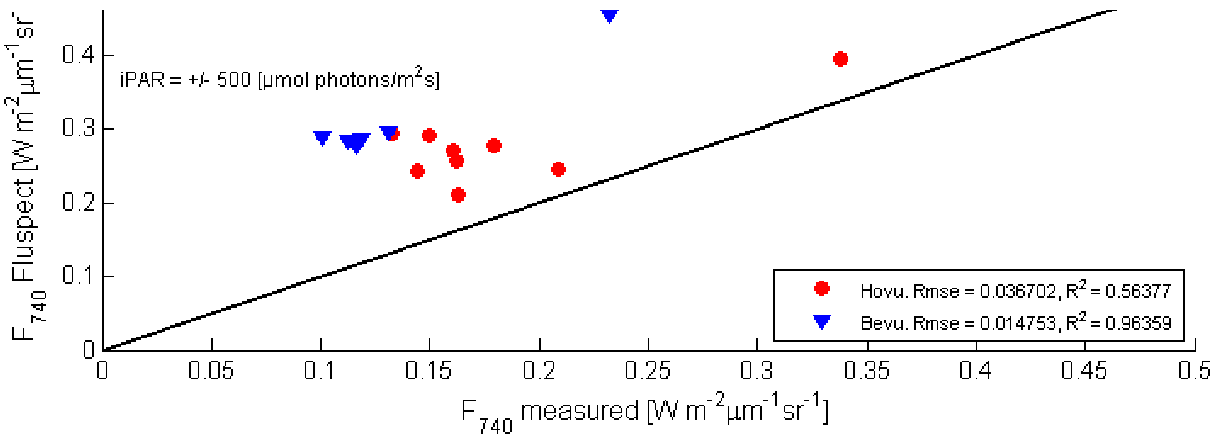
ed
lF

R
F

LEAVES OF DIFFERENT STRUCTURE, SAME (HIGH) LIGHT



Red ChlF



NIR ChlF

UNIVE

MODELLING OF HYPLANT CAMPAIGN DATA USA 2013

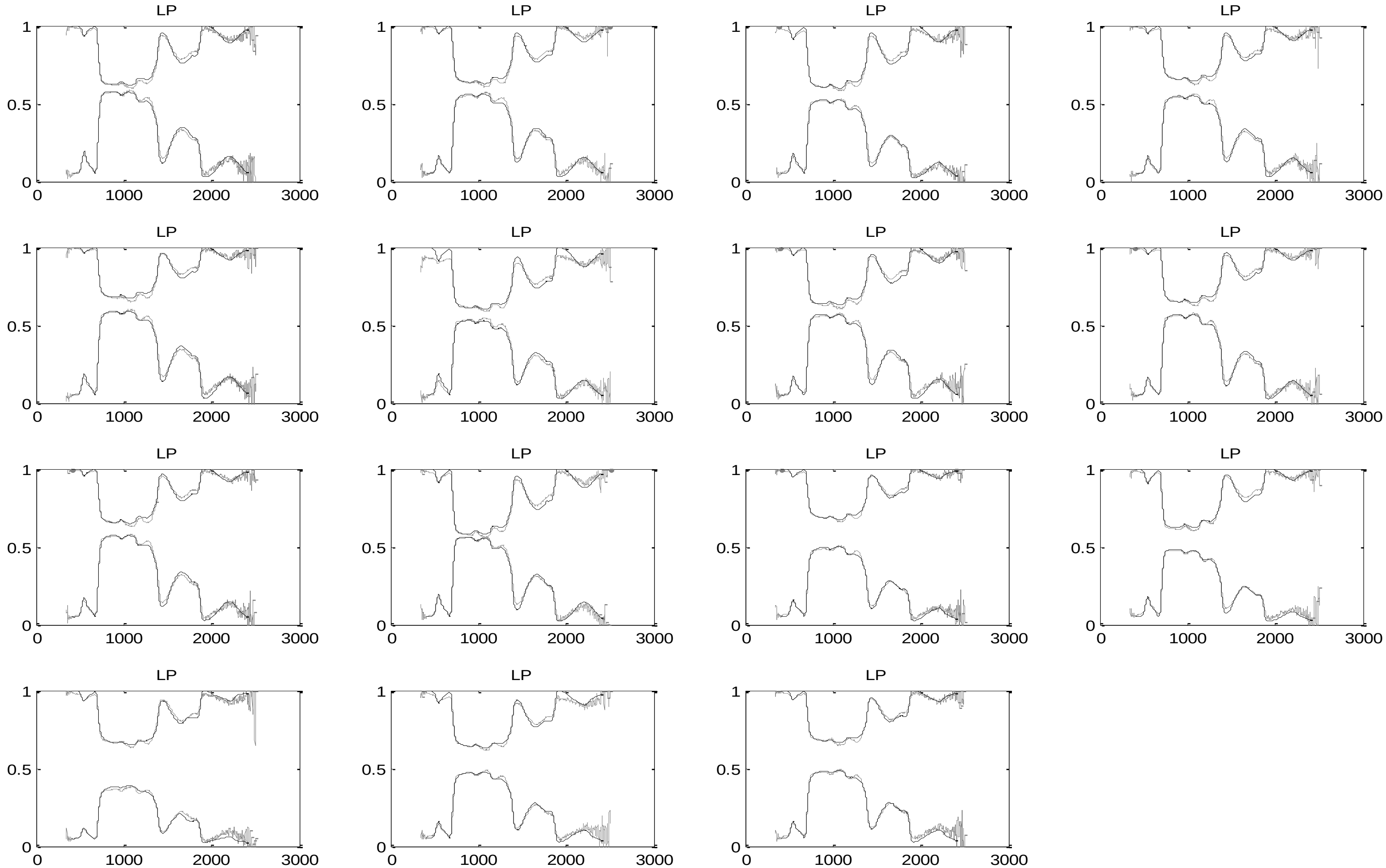
Leaf/needle

- Spectra of reflectance and transmittance (integrating sphere)
- Photosynthesis measurements

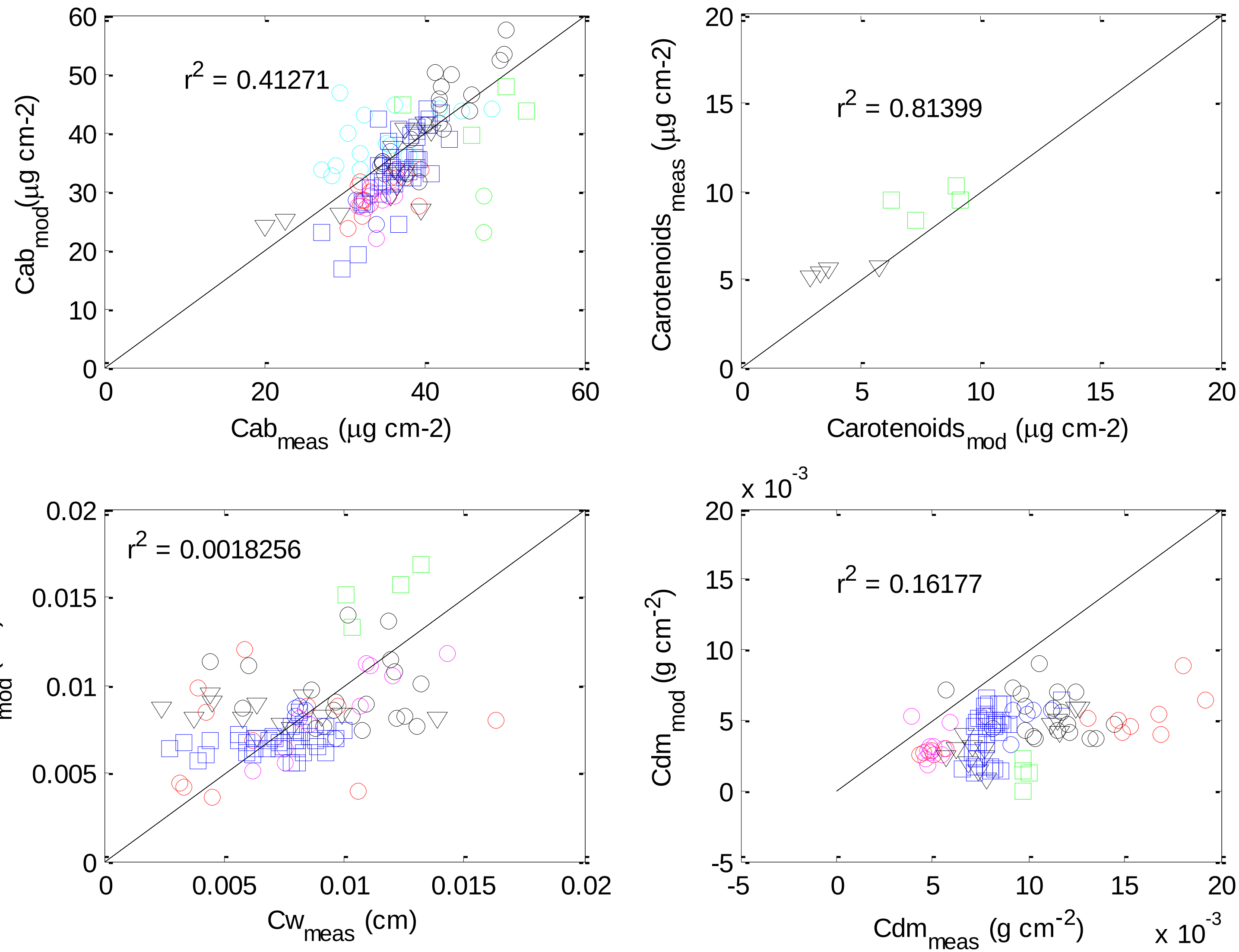
Canopy

- Time series of Top of Canopy fluorescence
- Flights with HyPlant
- Flux tower GPP

Goal: reproduce the flight line SIF and the tower GPP after first fittin the model to the leaf/needle data

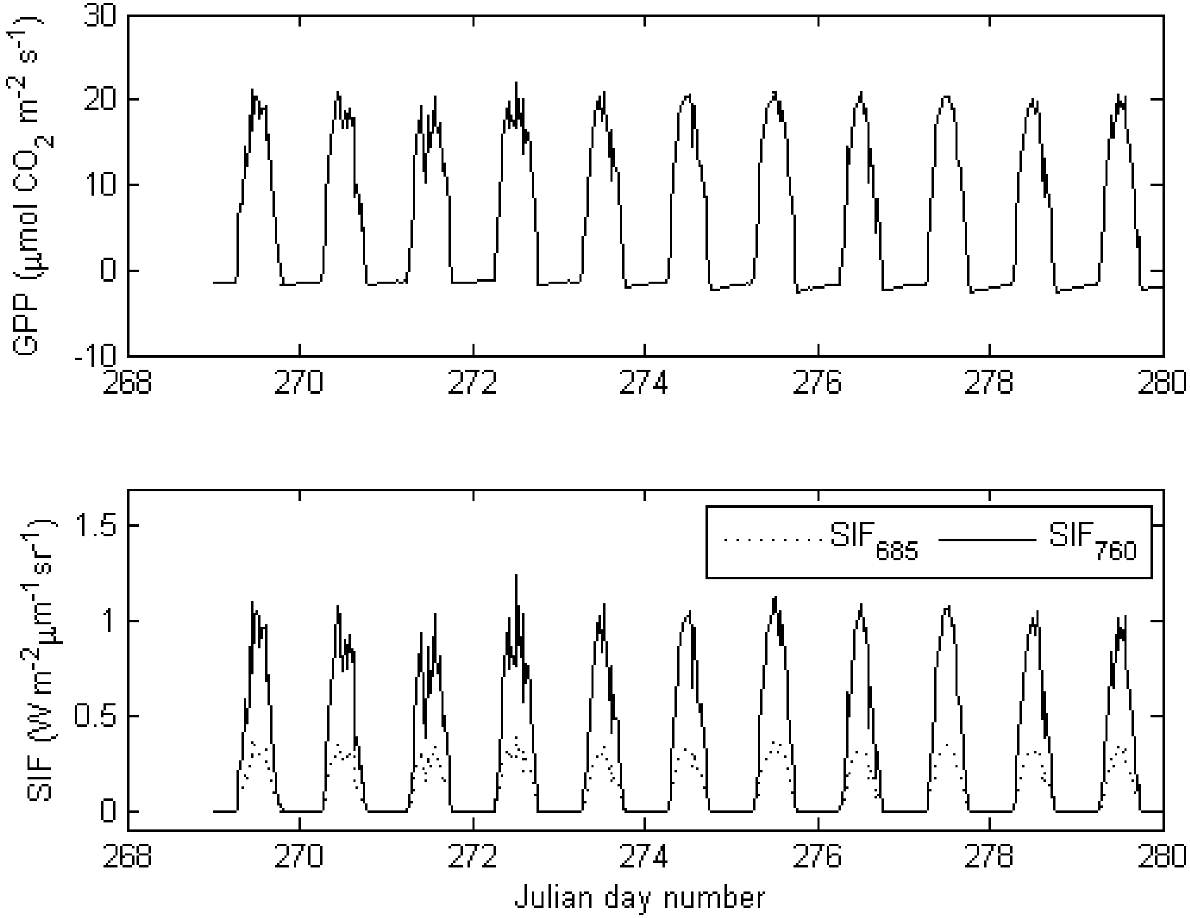

LP
1
0.5
0
0
1000
2000
3000

Retrieved from spectra



Chemical analysis

TIME SERIES AT THE CANOPY LEVEL



DATA ASSIMILATION

A winter wheat crop at Merzenhausen:

- Seasonal cycle of reflectance and SIF at 760 nm from FluorBox
- Seasonal cycle of fluxes from flux tower

Goal: improve the estimate of GPP using measurements of fluorescence.

Maximizing probability

Accuracy of measurement

Accuracy of a priori parameters

$$\underline{\hat{\theta}} = \arg\max_{\underline{\theta}} p(\theta|\underline{x}) = \arg\min_{\underline{\theta}} \left(\left| C_F^{-1/2}\left(F_{SCOPE}(\theta) - F_{meas}\right) \right|^2 + \left| C_\theta^{-1/2}\left(\underline{\theta} - \theta_0\right) \right|^2 \right)$$

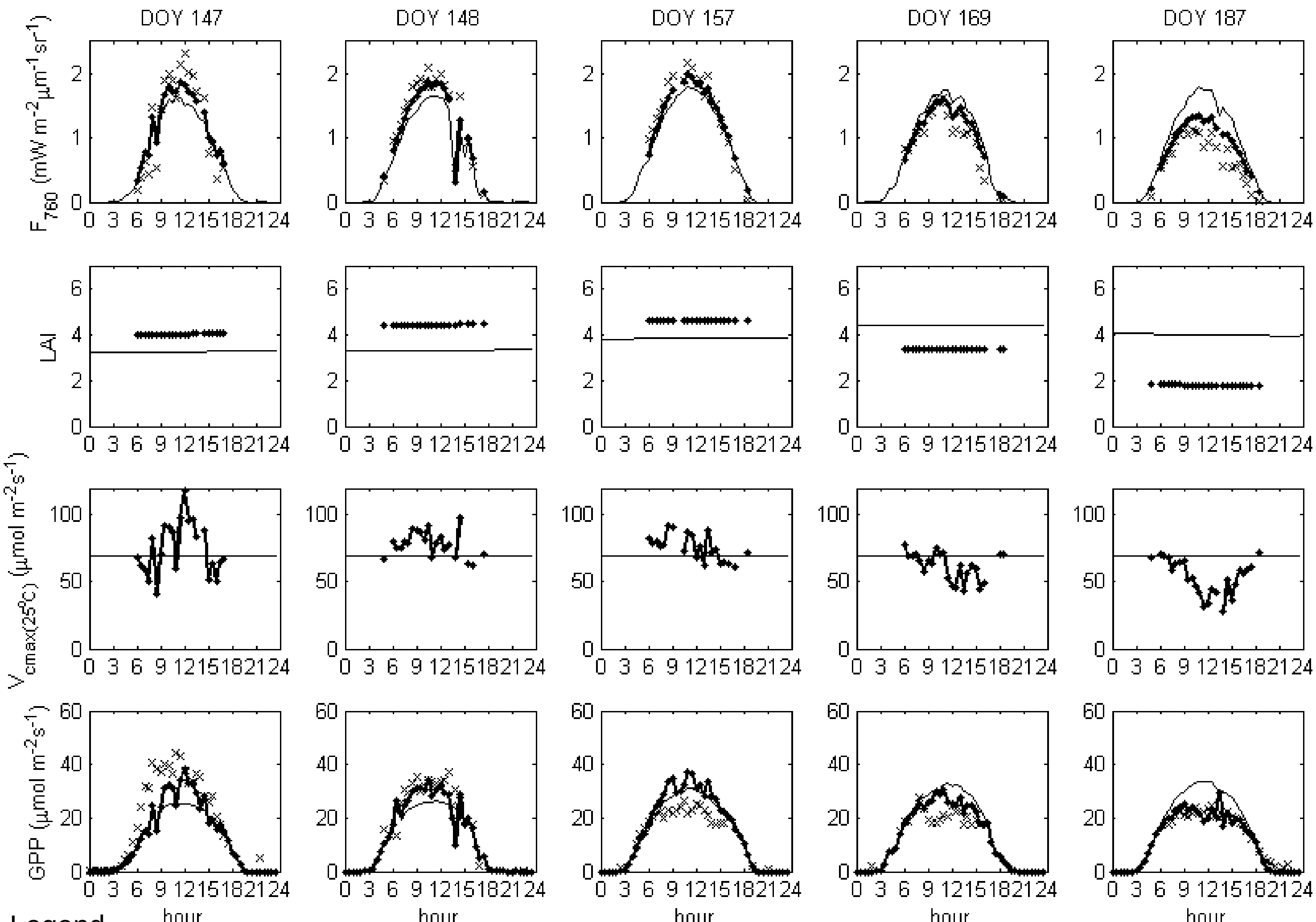
Tuning parameters (θ) to minimize quatratic error

Difference between modelled and measured ChlF

Difference between known and tuned parameter value

Data Assimilation: use all information to constrain SCOPE and get GPP.

- Computation time to obtain graph below is 1.6 seconds on normal PC*



What F760 tells u

1. Model was forced with total LAI, but green LAI decreased in reality. The a priori model did not know that. It shows up in posterior (i.e. using F760 measurements).

2. Vcmax decreases during season and some diurnal cycle appears.

3. RMSE of GPP improved from 8.1 to 6.6 umol m-2 s-1 and r^2 improved from 0.57 to 0.67 after tuning to F760

Legend

x: measurements

Fine line: a priori model simulations (field meteorology and basic plant information as input).

Bold dotted line: after tuning the model to F760.

HOW CAN WE USE HYPERSPECTRAL R AND CHLF DATA

- **Leaf composition** : measure **leaf reflectance/transmittance**
- **Fluorescence emission efficiency:** measure **fluorescence with active technique**
- **LAI and leaf inclination**: measure **canopy reflectance** from a number of angles

Combine the information