Scaling fluorescence from leaf to canopy

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- What happens to fluorescence and photosynthesis when we scale from photosystem to canopy level?

- How does the shape of the spectrum of fluorescence change with scaling?

- What are the relations among
  - greenness (EVI or NDVI)
  - absorbed PAR
  - fluorescence
  - photosynthesis?
Photosystem

Light harvest for photosynthesis takes place in photosystems
Fluorescence is generated at photosystem level

Leaf

Photosynthesis models calibrated against measurements at leaf level
Active fluorescence measurements usually taken at leaf level

Canopy

Observations with flux towers at canopy level
Remote sensing: viewing the top of canopy
Photosystem level

Fluorescence spectral distributions from photosystems I and II

Based on the literature
Croce et al. (1996, 2000) and Franck et al. (2002)
Leaf level

Two matrices Fb and Ff for irradiance -> fluorescence

<table>
<thead>
<tr>
<th>Inc/ F</th>
<th>640</th>
<th>641 etc</th>
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<tbody>
<tr>
<td>400</td>
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<td>401</td>
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<td>etc</td>
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Leaf level: Fluspect model

Interactive version of the Fluspect2 model, programmed in Visual Basic 5

Parameters:
- Cab, Cw, Cdm, Cs, N (PROSPECT)
- FQE, PSI/PSII ratio (Fluspect)

New development: Xanthophylls
Leaf level: sensitivity to peak ratio

Backward

Forward

- PSI / PSII = 2
- PSI / PSII = 1
- PS1 / PSII = 0.5

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Leaf level: sensitivity to PROSPECT parameters

In this case other PROSPECT parameters (Cs, N, Cdm) were also varied.

Yet the relation between Fb and leaf absorption remains quite strong.
Leaf level: sensitivity to Chlorophyll concentration

Backward

Forward
Canopy level: radiative transfer modelling

4-stream radiative transfer:

direct radiation, diffuse upward, diffuse downward, in observation direction

Sunlit leaves:

\[ P(\text{viewing sunlit-side} \mid \text{sunlit}) \ast \text{direct radiance} \ast \text{Matrixb} \]

\[ P(\text{viewing ‘back’-side} \mid \text{sunlit}) \ast \text{direct irradiance} \ast \text{Matrixf} \]

Shaded leaves:

\[ P(\text{viewing backside}) \ast \text{diffuse upward irradiance} \ast \text{Matrixf} \]

\[ P(\text{viewing frontside}) \ast \text{diffuse upward irradiance} \ast \text{Matrixfb} \]

\[ P(\text{viewing backside}) \ast \text{diffuse downward irradiance} \ast \text{Matrixf} \]

\[ P(\text{viewing frontside}) \ast \text{diffuse downward irradiance} \ast \text{Matrixb} \]

\[ \text{--------------------------------------------- +} \]

\[ \text{total F in viewing direction} \]
What do we see at TOC?
For 3 wavelengths (BRDF and the two peaks: 685 and 730, and 755 nm)

For LAI = 2, Cab = 60, $R_{in} = 600 \text{ W m}^{-2}$

Fluorescence directionality is different from BRDF

We see mainly the back of sunlit leaves
Canopy level: sensitivity to Chlorophyll concentration and LAI

- Increase
- Saturation
- Spectral changes

Cab = 5 µg cm²

Cab = 10 µg cm²

Cab = 40 µg cm²

Cab = 80 µg cm²
Canopy level: and what about EVI and aPAR?
Canopy level: fluorescence versus EVI and aPAR

- Increasing Chlorophyll
- Increasing LAI
What about photosynthesis?

From low to high Cab concentrations…

Increasing Cab -> more photosynthesis in upper leaves, but less in lower leaves. Net effect: photosynthesis not very sensitive to Chlorophyll (if Vcmax etc. are constant!)

![Graph showing the relationship between aPAR and A]
… thus canopy photosynthesis does not seem sensitive to chlorophyll.

**But: In the model leaves are not shade or sun adapted**
Weather conditions, $V_{\text{cmax}}$ and stomatal conductance

Look-Up table with $4^6 = 4096$ elements, regular grid.

- $R = [50, 100, 400, 800]$ W m$^{-2}$
- $e_a = (5:5:20)$ hPa
- $C_a = (20:20:80)$ ug cm$^{-2}$
- $V_{\text{cmax}} = (20:50:170)$ umol m$^{-2}$ s$^{-1}$
- $\lambda = (250:250:1000)$ mol H$_2$O (mol CO$_2$)$^{-1}$
F is closer related to photosynthesis than EVI or aPAR.
Same data, but different colors specify values of variables

Chlorophyll seems to spoil the 1:1 relation, if it is known the parameter space can be reduced
Averages over all parameters but one sensitivity to one parameter at the time

- weather data
- C isotope discrimination?
- PRI?

Can be retrieved from reflectance spectra
Farquhar, Von Caemmerer and Berry (1980)

However, there are two key parameters which, although often correlated in vivo, show important genotypic and phenotypic variation. These are the RuP₂ carboxylase capacity of the leaf \( (V_{c\text{max}} = \rho k_c E_t) \) and the electron transport capacity \( (J_{\text{max}} = \rho j_{\text{max}}) \). The way in which these two capacities vary, absolutely, and in ratio may well be a key to our understanding of the ecophysiology of plants.