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Multispectral and multiangular measurement and modeling of leaf reflectance and transmittance

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1. Introduction

• Radiative transfer models are useful to non-destructive estimation of vegetation biochemical content at leaf and canopy levels. They generally consider the leaf as a plane parallel absorbing and scattering medium, the absorption coefficients of which are estimated by model inversion.

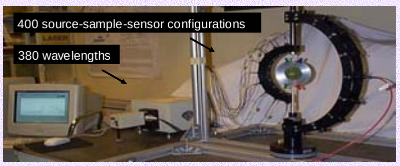
• This study aims at simulating the optical properties of a typical dicotyledon leaf described by a 3-D geometric model. The absorption coefficients used are compared to those published in the literature. Results are compared to measurements.

• It is focused on a beech (*Fagus sylvatica*) leaf picked in July 2005. Optical and anatomical measurements are performed in the laboratory and radiative transfer simulations are made with the 3-D Monte-Carlo ray-tracing model RAYTRAN.

2. Measurement of leaf optical and anatomical properties

- **Bidirectional reflectance and transmittance.** The leaf is placed in a spectro-photo-goniometer to measure its Bidirectional Reflectance and Transmittance Distribution Functions (BRDF and BTDF respectively). These functions can be determined using a Spectralon® reference panel and accounting for its deviation from Lambertian behaviour.

$$BRDF_{leaf} = \frac{Radiance_{leaf}}{Radiance_{Spectralon}} BRDF_{Spectralon}$$



Spectro-photo-goniometer measuring reflected and transmitted light at 4 incidence angles, 98 observation angles, and 381 wavelengths from 500 to 880 nm

- **Biochemistry and anatomical structure.** Three pieces of the leaf blade are taken: one for chlorophyll content, one for water and dry matter content and one for leaf cross-section.

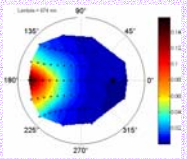
Water content $(g.cm^{-2})$	6.2×10^{-3}
Dry matter content $(g.cm^{-2})$	5.8×10^{-3}
Chlorophyll content $(g.cm^{-2})$	4.2×10^{-5}

Biochemical content of the beech leaf measured in the laboratory by destructive methods

Cross-section of the beech leaf

3. Estimation of leaf hemispherical optical properties

- Assuming the leaf BRDF is the sum of diffuse and specular components and the leaf BTDF is diffuse, the approach of Bousquet *et al.* (2005) can be used to estimate the Directional Hemispherical Reflection and Transmittance Factors (DHRF and DHTF respectively).

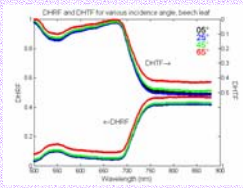


Measured BRDF

BRDF Model inversion

$$\boxed{\begin{gathered} refractive\,index = 1.42 \\ roughness\ parameter = 0.32 \\ Lambert\,coefficient = f(\lambda) \end{gathered}}$$

Numerical estimation



DHRF and DHTF calculated from measurement at various incidence angles

$$DHRF(\lambda) = \int BRDF(\lambda)\cos\theta\, d\Omega$$

- The relative error tolerance in numerical estimation is 1x10^{-4}. However the lack of data at high viewing angles and in the specular peak may cause greater errors.

4. Construction of the leaf model

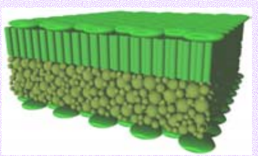
- The cell shapes and tissue thicknesses were set to fit the measurements of leaf anatomy and biochemistry.
- The refractive index and the linear absorption coefficient of leaf constituents are needed.

	Water	Dry matter	Chlorophyll
Content $(g\,cm^{-2})$	3.7×10^{-3}	5.8×10^{-3}	4.2×10^{-5}
Density $(g\,cm^{-3})$	1	1.5 Jacquemoud et al.1996	0.047 Fukshansky et al 1993
Refractive index	1.33 *at* 700 *nm* Segelstein 1981	1.52 (VIS) Kumar and Silva 1973	1.42 (VIS) Kumar and Silva 1973
Linear absorption coefficient	Segelstein 1981	from Prospect	cf figure

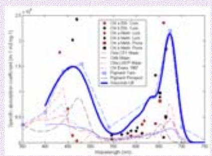
Beech leaf model parameters

$$Linear\,absorption\,coefficient = specific\,absorption\,coefficient \times density$$

$$Volume = mass / density$$



Beech leaf model



Specific absorption coefficient of chlorophyll

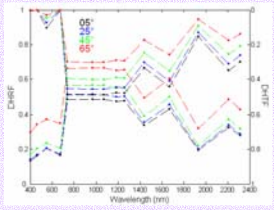
5. Simulation of the 3-D radiative transfer

- The 3-D MonteCarlo ray-tracing model RAYTRAN was used in accordance with the approach of Govaerts *et al.* (1996).

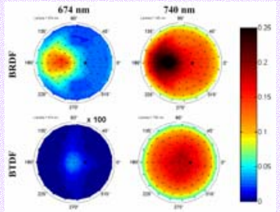
- Simulated DHRF and DHTF reproduce typical leaf spectra at small incidence angles. However the leaf model overestimates the reflectance at high incidence angles.

- Reflection is overestimated due to the high refractive index of dry matter and to the air spaces between the epidermis and the palisade layer.

- The BRDF show a strong specular reflection while the BTDF are almost Lambertian, whatever the wavelength.



Simulated DHRF and DHTF at various incidence angles



Simulated BRDF and BTDF at 25° incidence angle

6. Conclusion and perspectives

- A 3-D model was built in close agreement with a real beech leaf.
- Radiative transfer simulations compare well with experiment.
- Results will be used to improve 1-D radiative transfer model of the leaf.

References

Bousquet, L., S. Lachérade, et al. (2005). "Leaf BRDF measurements and model for specular and diffuse components differentiation." Remote Sensing of Environment 98: 201-211.

Govaerts, Y., S. Jacquemoud, et al. (1996). "Three-dimensional radiation transfer modeling in a dicotyledon leaf." Applied Optics 35(33): 6585-6598.

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