Leaf BRDF and BTDF Measurements and Model

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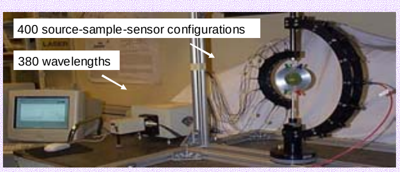
1. Introduction

• The remote estimation of plant biochemical content is based on their spectral signatures. Coupling spectral with directional measurements permits the differentiation of diffuse and specular reflections. If not quantified, specular reflection is a source of error; if understood and measured, it provides new information about leaf surface.

• Our goal is to measure leaf spectral and directional optical properties and to provide an adequate physical model based on geometric optics to be used in vegetation remote sensing, computer graphics or plant physiology.

2. Leaf BRDF and BTDF measurements in the VIS-NIR



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

• Bidirectional Reflectance or Transmittance Distribution Functions (BRDF / BTDF) are defined by Nicodemus et al. (1977). They are determined using a Spectralon reference panel:

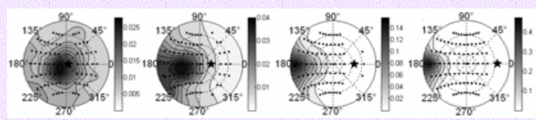
$$BRDF_{leaf} = \frac{Radiance_{leaf}}{Radiance_{Spectralon}} BRDF_{Spectralon}$$

• DHRF and DHTF are derived by summation over the upper hemisphere:

$$DHRF = \sum_i BRDF_i \cos\theta_i d\Omega_i$$

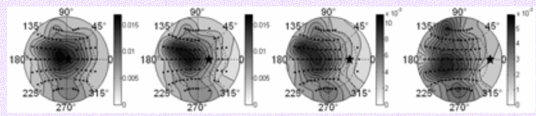
3. Measurement analysis

• BRDF are not Lambertian and their shape varies with the illumination angle



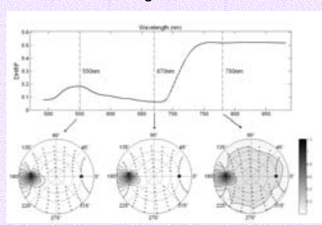
Polar plot of the BRDF (sr^{-1}) of a beech leaf adaxial face at 680 nm for four incidence angles {5°, 25°, 45°, 65°}

• BTDF are more Lambertian and their shape remains quite unchanged

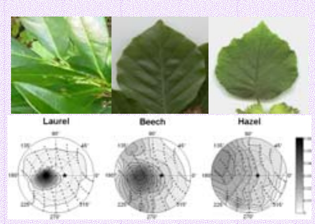


Polar plot of the BTDF (sr^{-1}) of a beech leaf adaxial face at 680 nm for four incidence angles {5°, 25°, 45°, 65°}

• Specular reflection does not vary with wavelength and strongly depends on the leaf surface roughness



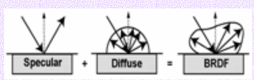
Laurel DHRF (top) and BRDF (bottom) as a function of the wavelength



Influence of surface roughness on leaf BRDF

4. BRDF modeling and inversion

• The BRDF is the sum of diffuse and specular components



Mirror-like facets on a vine leaf adaxial face

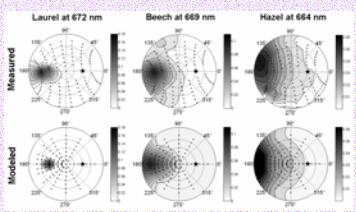
• The specular component results from Fresnel reflection on mirror-like facets (geometric optics)

$$BRDF_{spec}(\theta_s, \theta_v, \varphi_v) = \frac{Fresnel(n).GAF.D_{slope}(\sigma)}{2\pi^2 \cos\theta_s \cos\theta_v}$$

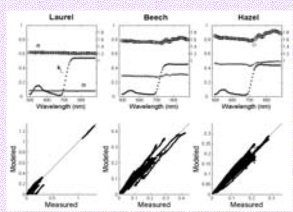
• The diffuse component is Lambertian

$$BRDF_{diff} = \frac{k_l}{\pi}$$

n: refractive index
σ: surface roughness
k_l: Lambert coefficient



Measured and modeled BRDF at minimum reflection

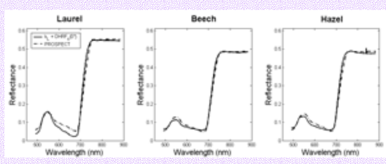


Parameter values after inversion (top). Measured vs modeled BRDF (bottom)

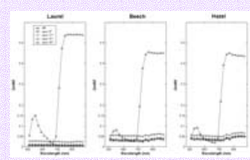
Inversion at each wavelength

• (+) Shows that the model can fit the measured BRDF
• (+) Confirms the spectral invariance of the specular component
• (+) Permits to evaluate of the amount of light that did not penetrate into the leaf
• (+) Permits to estimate the effective surface refractive index and roughness
• (-) Leads to 3 wavelength dependent parameters

5. Derivation of hemispherical quantities



Modeled DHRF(0°) (solid line) and fit with the Prospect model (dashed line)



Modeled diffuse and specular DHRF for various illumination angles

6. Towards a validated leaf optical properties model

• From previous work, BRDF and BTDF (the latter being assumed Lambertian) may be written:

$$BRDF = k_{l1}(\lambda)/\pi + BRDF_{spec}(n,\sigma) \quad \text{and} \quad BTDF = k_{l2}(\lambda)/\pi$$

• Lambert parameters $k_{l1}(\lambda)$ and $k_{l2}(\lambda)$ will be determined with the Prospect model which accounts for volume absorption and scattering

7. Conclusion

• Leaf BRDF are not Lambertian contrary to BTDF. They result from diffuse and specular reflections, the spectral behaviours of which are totally different.

• We propose a simple physical model to capture the main directional features of the measured BRDF with two parameters (surface refractive index and roughness).

• Further work will focus on a leaf spectral and directional optical properties model based on Prospect. Validation relies on simultaneous measurements of leaf optical properties, biochemistry and anatomy (work in progress). Anatomical measurements will also be used for ray tracing simulations on a realistic leaf 3D model.

Acknowledgements

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