MONITORING CANOPY STRUCTURE AND LEAF BIOCHEMISTRY USING MULTIANGLE AND HYPERSPECTRAL DATA

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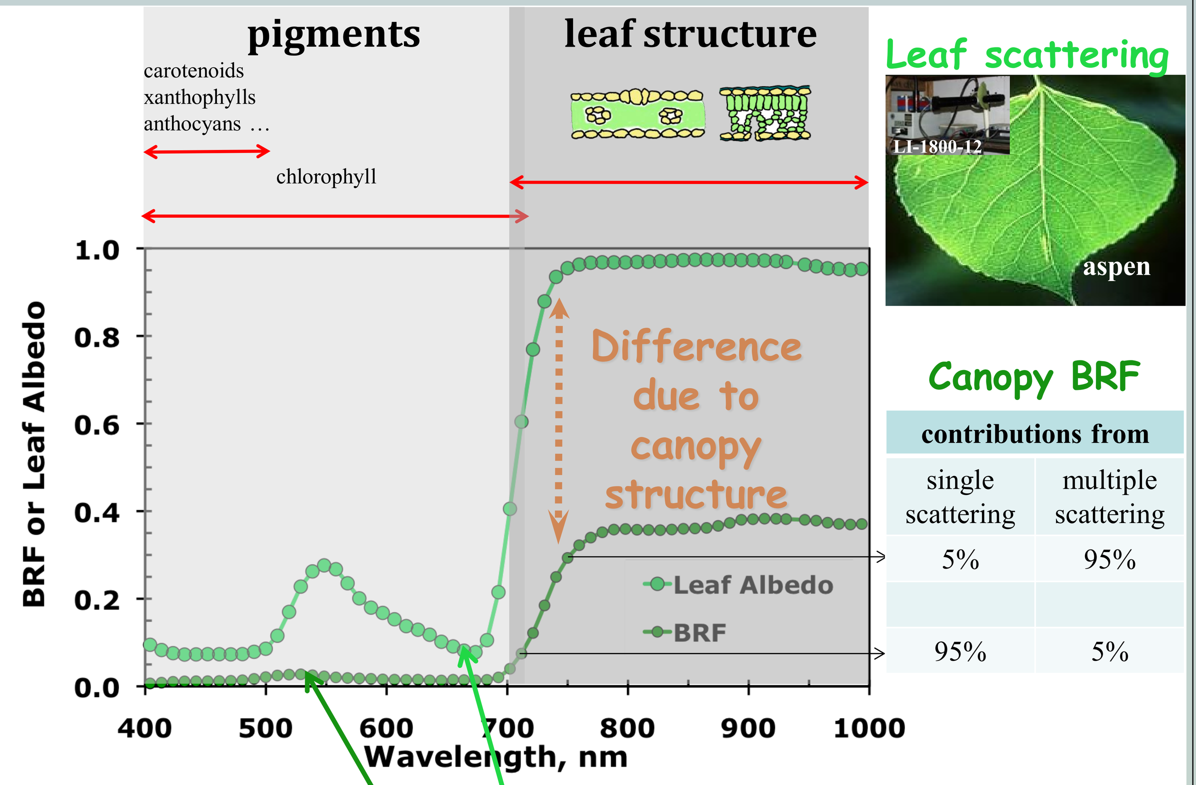
Abstract. Recent studies indicated that for temperate and boreal forests there is a strong positive correlation between the BRF at NIR wavelengths and the foliar nitrogen concentration, %N . If true, this result may offer a simple and effective approach for monitoring foliar nitrogen using broadband satellite data. However, we found that the reported correlation is an artifact resulting from variations in canopy structure rather than %N. We showed that the impact of the canopy structure can be strong enough to suppress the sensitivity of hyperspectral canopy reflectance to the leaf scattering properties, which is the only optical variable that conveys information about leaf interior, and results in spurious relationships between leaf biochemical constituents and the measured surface reflectance. We identified a new structural variable, the directional area scattering factor (DASF), which is an estimate of the fraction of leaf area inside the canopy that is visible from outside the canopy along a given direction. The DASF varies between 0 and 1, and explains variation in BRF due to variation in 3D canopy structure. In dense vegetation, it can be directly extracted from the reflectance spectrum without the use of canopy radiation models, prior knowledge, or ancillary information regarding leaf optical properties. This variable provides information critical to accounting for structural contributions to measurements of leaf biochemistry from hyperspecral data. The goal of this poster is to introduce DASF, demonstrate its critical role in retrieving leaf biochemistry and present an algorithm for retrieving DASF and leaf biochemical constituents from hyperspectral and multi-angle data.

1. PHYSICAL BASIS [ref. 1]



$$\Omega\bullet\nabla I_\lambda+\sigma(r,\Omega)I_\lambda(r,\Omega)=\omega_\lambda\int_{4\pi}g(r,\Omega'\to\Omega)I_\lambda(r,\Omega')d\Omega'+F(r,\Omega)$$

canopy structure; multiply scattered photons; single scattered solar source

Figure 1. Air- and satellite-borne sensors measure solutions of the three-dimensional radiative-transfer equation. Remote sensing aims to derive ecosystem properties (σ, ω_λ, g), given these solutions. In vegetation canopies, the extinction coefficient, σ, does not depend on wavelength. A sharp increase in BRF in the 700 to 800 nm interval is due to an increase in the contribution from multiply scattered photons. A rate at which the increase occurs depends on canopy structure. Its specification is required to retrieve canopy structural information and correct BRF data for canopy structure effects. The corrected data are more directly related to leaf biochemical constituents. The 700 to 800 nm interval provides good dynamic ranges of both leaf albedo values and corresponding response of canopy BRF needed to estimate the rate [1].

- Scattering from a leaf responds differently at different wavelengths to changes in leaf properties such as pigment concentration, chemical constituents, internal structure and leaf surface properties
- The leaf albedo spectrum is the only optical variable that conveys information about leaf biochemistry
- Leaf optical properties cannot be directly measured from space because the radiation scattered from leaves and exiting the canopy in the direction to the sensor is strongly affected by 3D canopy structure
- 3D radiative-transfer equation provides the most physically consistent linkage between leaf scattering and canopy reflectance

2. LEAF OPTICS

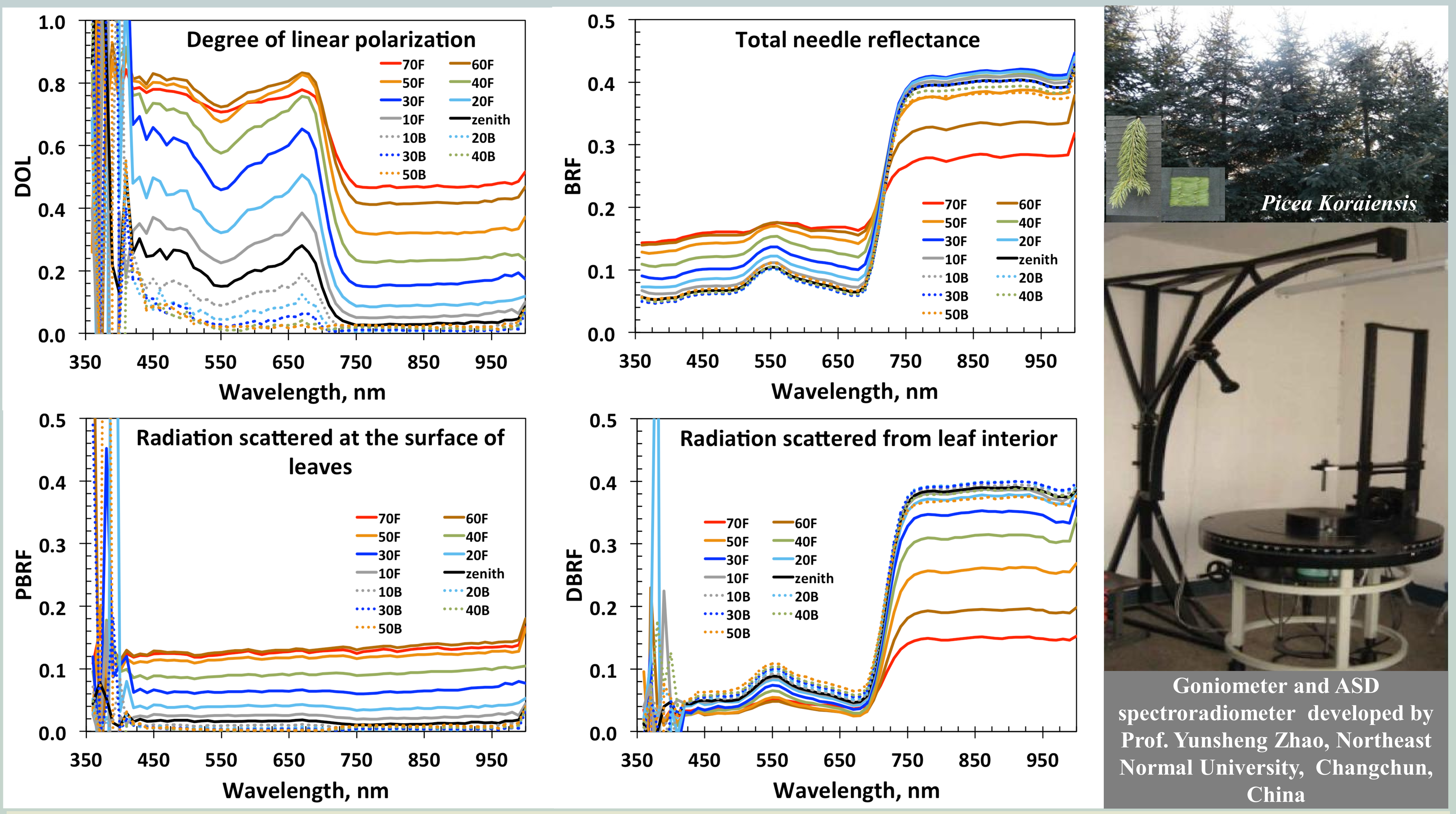
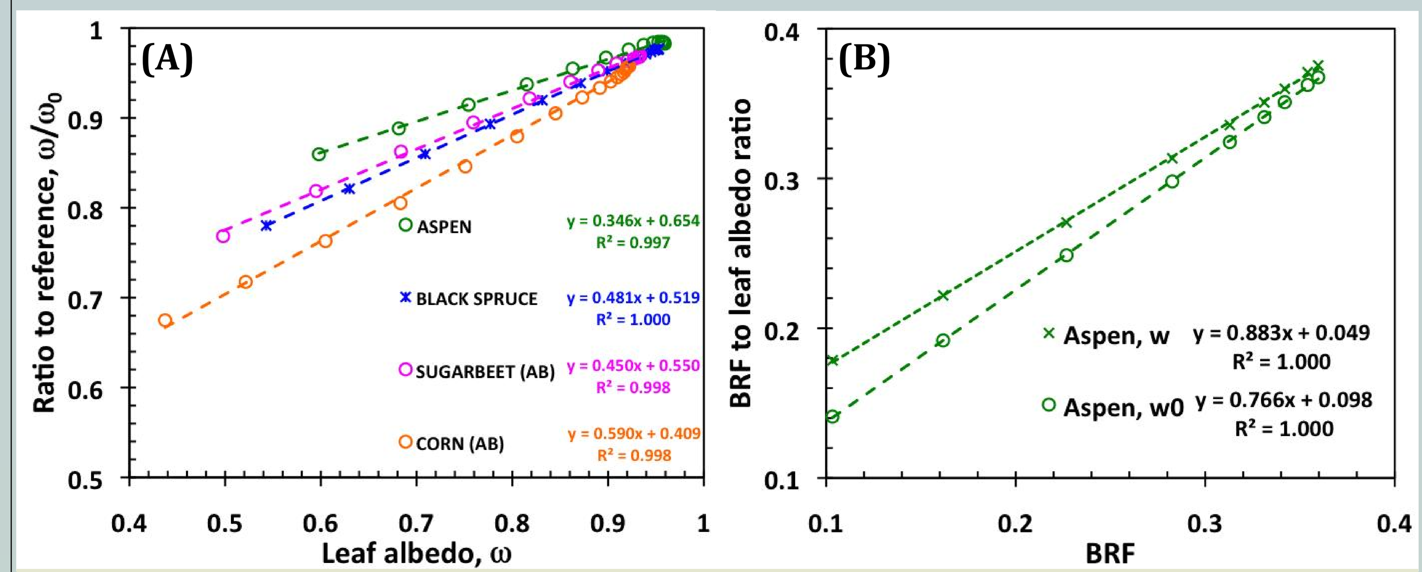


Figure 2. Several samples of coniferous shoots (*Picea Koraiensis* and *Pinus Koraiensis*) were sampled from several locations. Shoot and needle total reflectance (I) and Stokes parameters (Q , U) in the region from 350 nm to 2,500 nm at 1 nm spectral resolution were measured using an ASD (with and without polarizer) spectroradiometer mounted on a goniometer. The plots shows spectra of degree of linear polarization, total needle BRF and its polarized and diffuse components in the principle plane. Source zenith angle is 60° relative to the outward normal to the shoot. Symbols "B" and "F" indicate scattering in the forward and backward directions. The data, courtesy of Being Yang, were collected in Changchun (China) on March 8-12, 2013.

- Some radiation is scattered at the surface of leaves
- This fraction of reflected radiation does not penetrate the leaf and thus conveys no information about its interior
- This decreases the ability to remotely sense leaf biochemistry from hyperspectral data
- Polarization measurements may be useful to correct for this additional source of uncertainty because radiation reflected from the leaf surface is partly polarized whereas that from the leaf interior is not

3. DIRECTIONAL AREA SCATTERING FACTOR (DASF) [ref. 2,3]



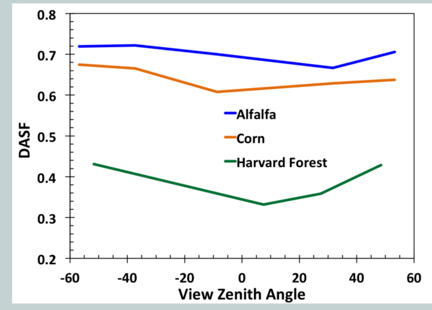
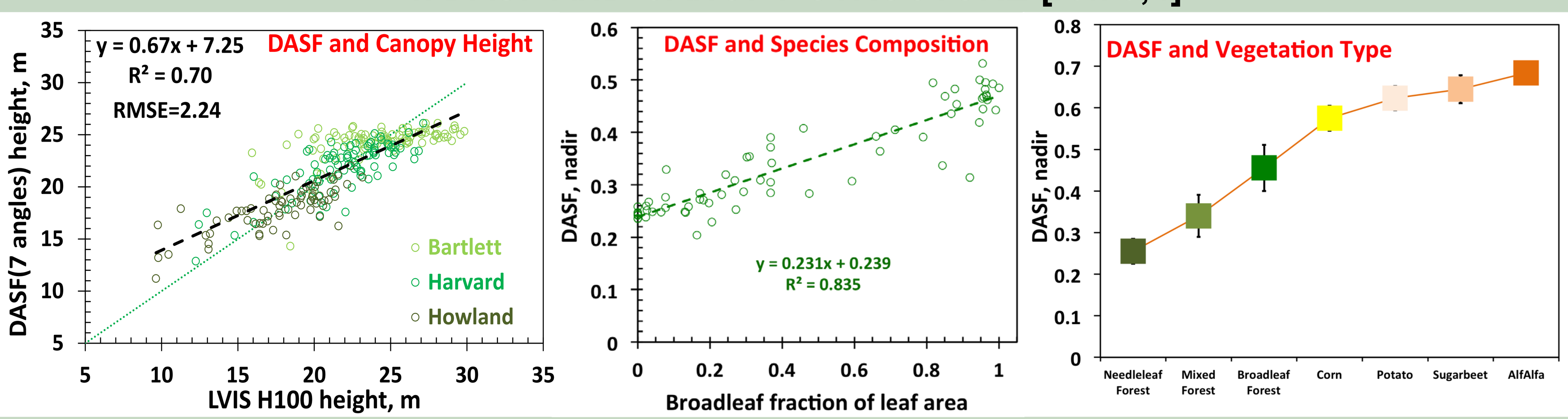


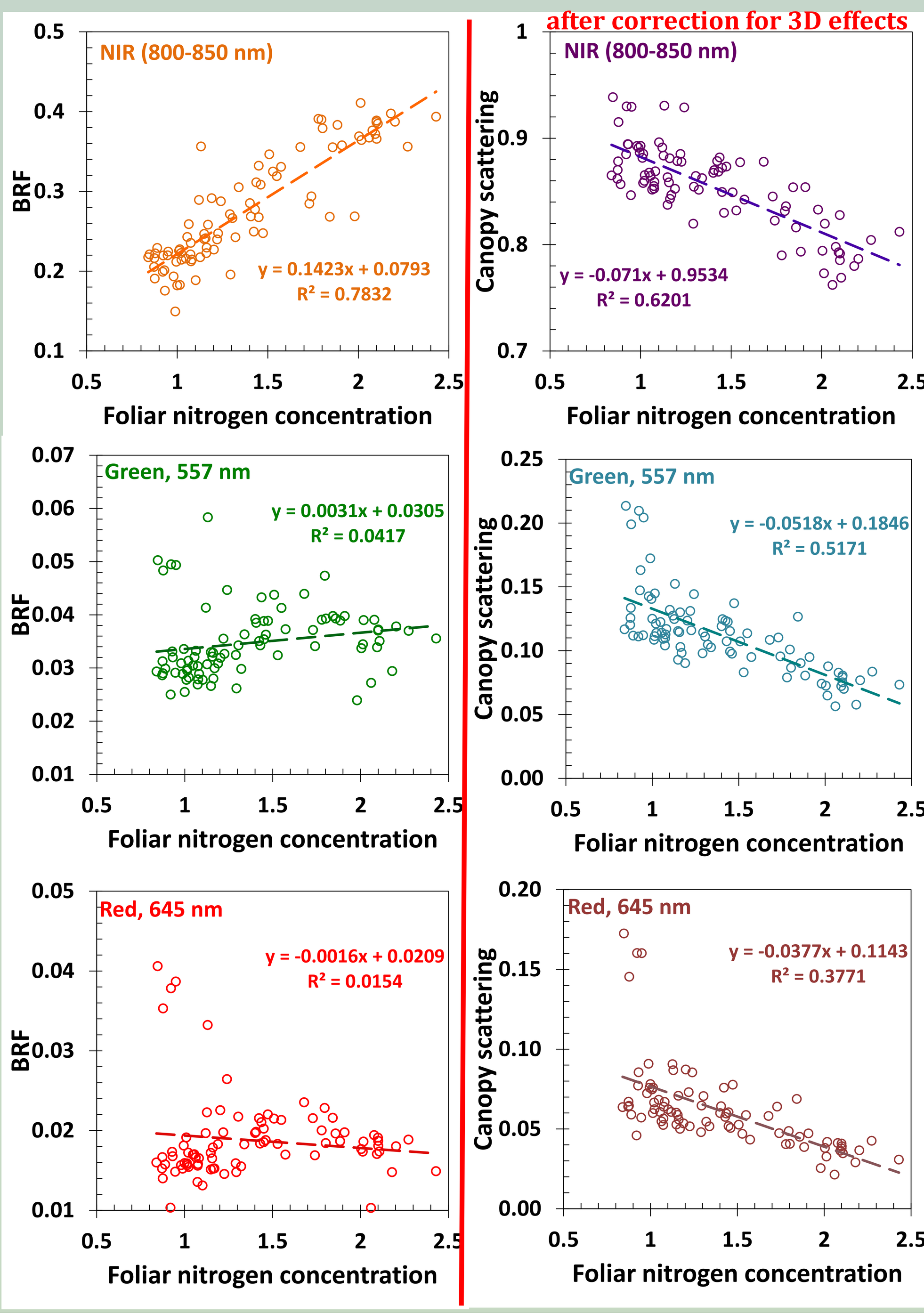
Figure 3. Leaf albedo and BRF spectra follow spectrally invariant relationships. Panel A: By plotting the ratio ratio $\omega_\lambda/\omega_{0\lambda}$ versus ω_λ for the 710- to 790nm spectral interval, a linear relationship is obtained. Here ω_λ represents measured leaf albedo spectra of black spruce needle, sugar beet, aspen and corn leaves; $\omega_{0\lambda}$ is the fixed reference spectrum. Panel B: BRF to leaf albedo ratio, BRF/ω, versus BRF linear relationship in the spectral interval [710, 790 nm] for a 90m by 90 m dense patch of aspen. The BRF spectrum is derived from AVIRIS data. The first relationship ("Aspen, w") is obtained using albedo of an aspen leaf. The reference spectrum $\omega_{0\lambda}$ is used in the second relationship ("Aspen, w0"). The use of the reference spectrum in place of the true aspen leaf spectrum does not violate the linear relationship, although it impacts the slope (k) and intercept (b). In both cases the ratio $b/(1-k)$, which gives the DASF is the same [2,3].

- An estimate of the fraction of leaf area inside the canopy that is visible from outside the canopy along a given direction
- Obtainable from multiangle hyper-spectral data without the use of canopy-reflectance model, prior knowledge, or ancillary information regarding leaf optics

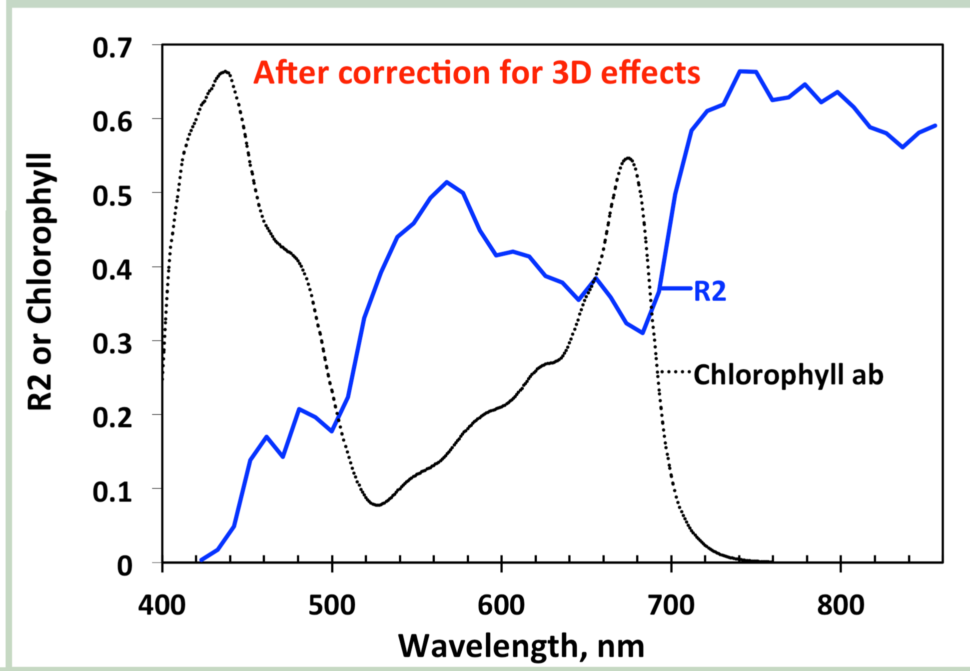
4. DASF AND CANOPY STRUCTURE [ref. 3,4]



5. DASF AND LEAF BIOCHEMISTRY [ref. 3]



- DASF provides information critical to accounting for structural contributions to measurements of leaf biochemistry from remote sensing
- Whereas the BRF exhibits either positive or no relation with foliar N, its structure-corrected counterpart is negatively correlated with N in the 423- to 855 nm interval



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