Multi-Angle Remote Sensing of Forest Light Use Efficiency by Observing PRI Variation with Canopy Shadow Fraction

Forrest G. Hall, Thomas Hilker, Nicholas C. Coops, T. Andrew Black

Vegetation Carbon Assimilation, Evapotranspiration and Remote Sensing

Currently A and ET cannot be measured directly from satellite.
A and ET model inputs, soil moisture & precipitation, are difficult to measure.

Carbon Assimilation Rate

A = par (satellite) x fapar (satellite) x LUE (models)

g_c = Ah/c = stomatal conductance; h = humidity, c = CO_2 concentration

Evapotranspiration

$$LE = \frac{\rho Cp\,[e^* - ea]}{\gamma}\,\frac{g_c g_a}{g_c + g_a}$$

Models compute g_c

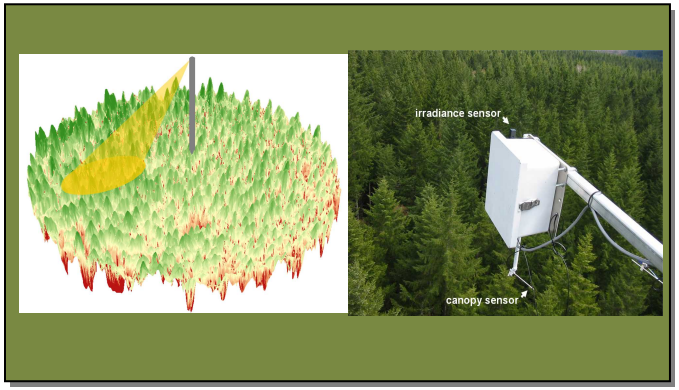
$g_c = g_c^* \times f([e^* - ea], T_a, \text{soil moisture})$ $0 \le f \le 1$

g_c^* = maximum g_c species dependent

- f is the "stress" function
- Highly non-linear function of soil moisture
- Soil moisture is difficult to model or measure
- Landscape precipitation & soil properties vary
- Soil Moisture difficult to measure in the presence of dense vegetation.

Leaf to Forest

Compute GEP from tower CO_2 flux, GEE
GEP = GEE-R
R(T) from nighttime flux
and air temperature
LUE = GEP/APAR (µmol C / µmol photons)

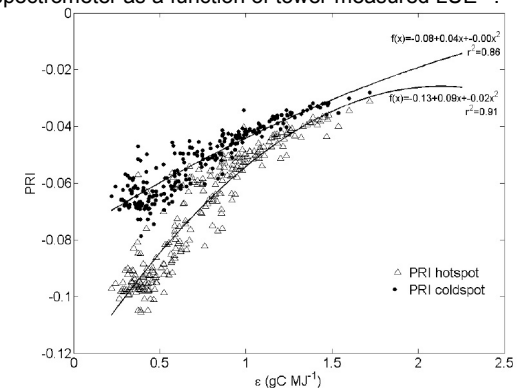


Dual channel radiometer is mounted on the DF49 Fluxnet tower with a vertical zenith angle (VZA) of 62°. A motor moves the canopy sensor 360° every 15 minutes. Data are recorded every 5 seconds, year round.

Compute LUE as a function of ∂PRI(SF)/∂SF

$$PRI = \alpha_b\, PRI_b + \alpha_d\, PRI_d$$

Measure coldspot PRI_b and hotspot PRI_d with tower spectrometer as a function of tower-measured LUE**.



Compute LUE as a function of ∂PRI/∂SF

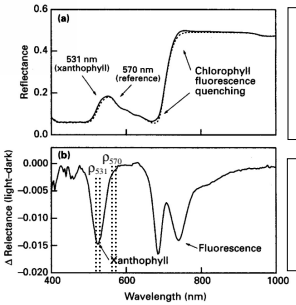
$$\partial PRI/\partial\alpha_b = PRI_b - PRI_d = 0.21 - 0.05\,LUE - 0.02\,(LUE)^2$$

LUE ≈ (∂PRI/∂SF-0.21)/0.05

Spectral Measures of Light Use Efficiency

Cell to Leaf

$$PRI = (\kappa\rho_{531} - \kappa\rho_{570})/(\kappa\rho_{531} + \kappa\rho_{570})$$



At the landscape scale ρ_{531}, ρ_{570}, κ are also sensitive to variations in other pigments and conditions other than LUE; beta-carotene, lutein, variations in soil, litter background.

These factors can affect PRI enough to overwhelm the changes due to changes in the xanthophyll cycle.

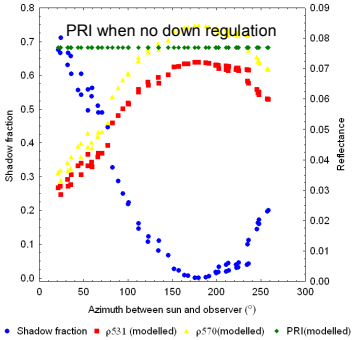
In Hall et al. 2008* we showed that *when there is no down regulation*, PRI IS INSENSITIVE to change in viewed shadow fraction. With no down regulation the reflectance in both bands *does not* differ from the sunlit to the shaded canopy leaves.

- $$\rho_{ifov}(\lambda) = \frac{[\alpha_{sh}\rho_{sh}(\lambda)F_{diff}(\lambda) + \alpha_{sun}\rho_{sun}(\lambda)F_i(\lambda)]}{F_t(\lambda)}$$
- When there is no down-regulation from light-saturation

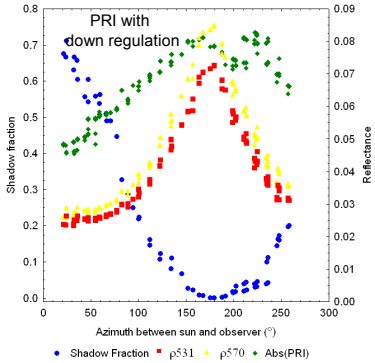
$$\rho_{sh}(\lambda) = \rho_{sun}(\lambda) = \rho(\lambda)$$

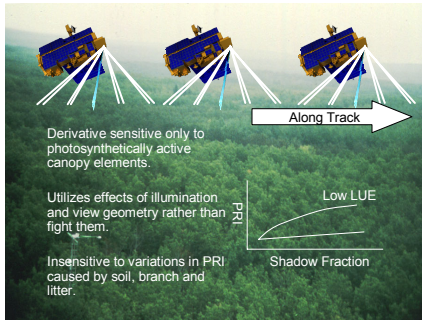
$$\rho_{ifov}(\lambda) = \rho(\lambda)[1 - \alpha_{sh}(1 - \delta_{dif}(\lambda))]$$, therefore

PRI independent of shadow fraction with no down regulation!



But, the reduction in ρ@531 nm *will* depend on the strength of the irradiance when the canopy is down regulating photosynthesis; therefore PRI *will* vary with the fraction of shadow viewed by the sensor when the canopy is down regulating photosynthesis.





Forest to Satellite

New satellite concept for the direct retrieval of xanthophyll-induced changes in light use efficiency

Measure the PRI using a multi-angle spectrometer
Retrieve shadow fraction to obtain PRI(SF). LUE can Be computed from ∂PRI/∂SF.

*Remote Sensing of Environment, 112 (2008) 3201-3211
**Remote sensing of Environment 112 (2008) 2777-2788