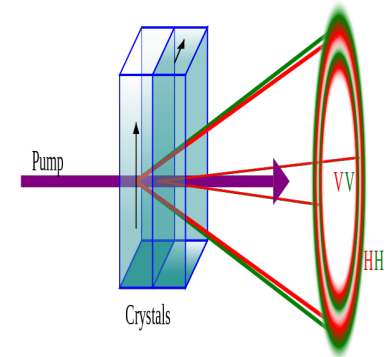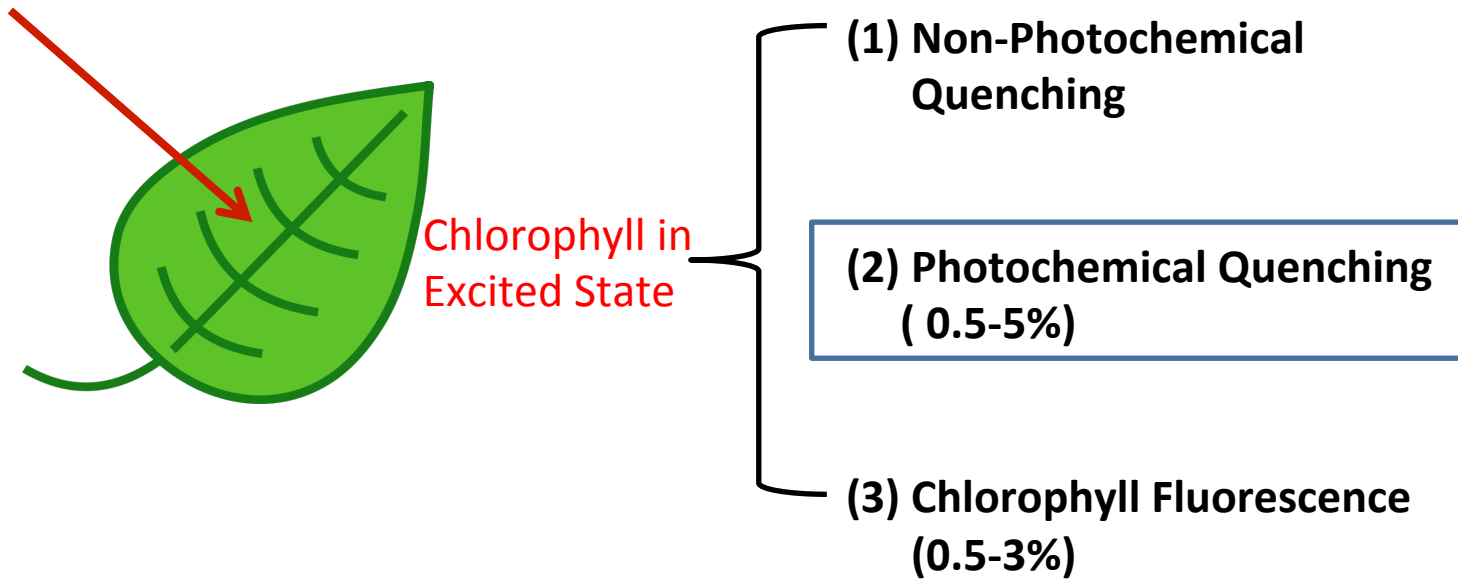# Follow the Photons

Jing M. Chen, Liming He, Ting Zheng, Gang Mo, and others
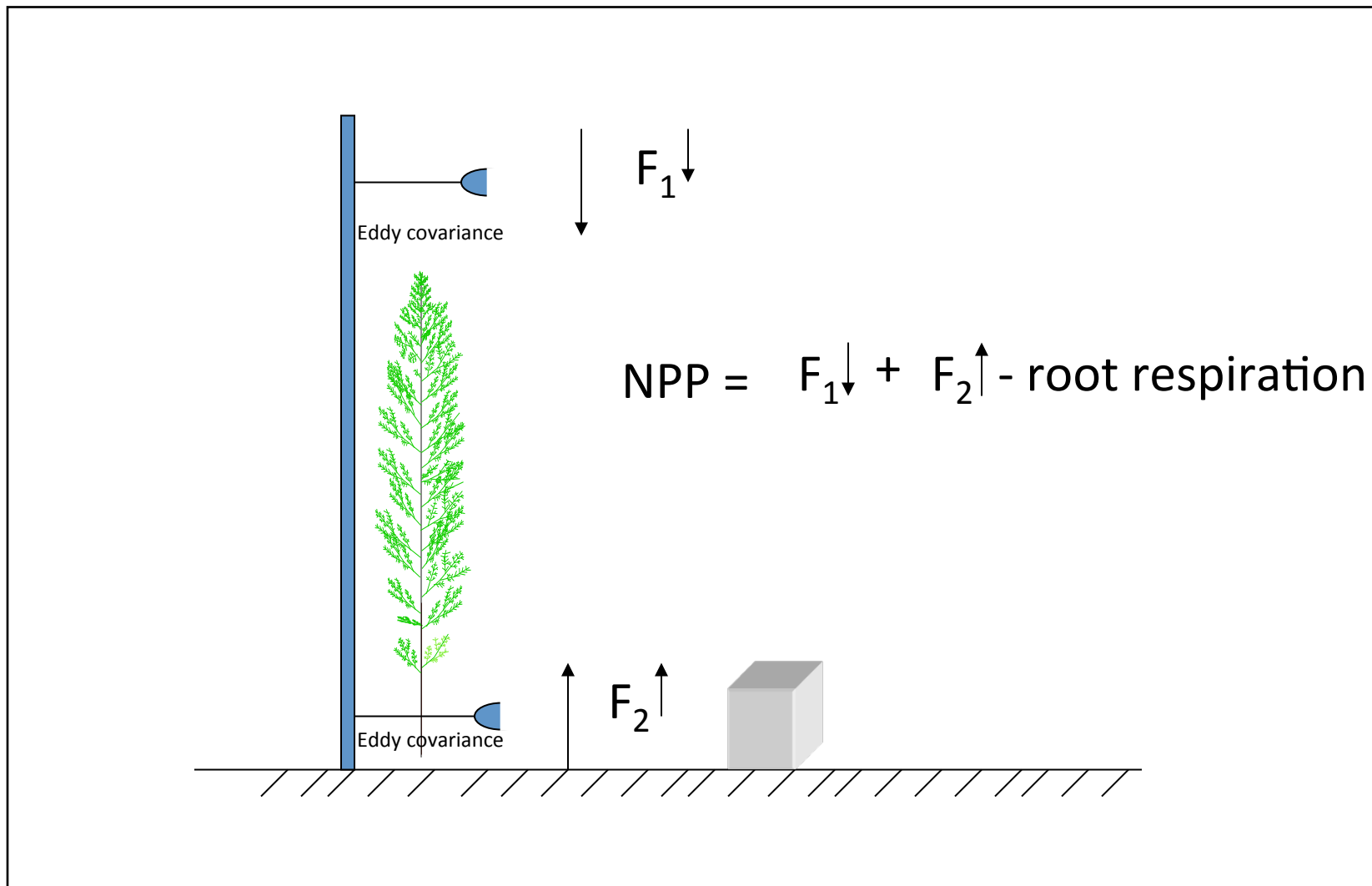
Department of Geography
University of Toronto, Canada

Where Do Photons Go in Leaves?

Chlorophyll in Excited State

(1) Non-Photochemical Quenching

(2) Photochemical Quenching (0.5-5%)
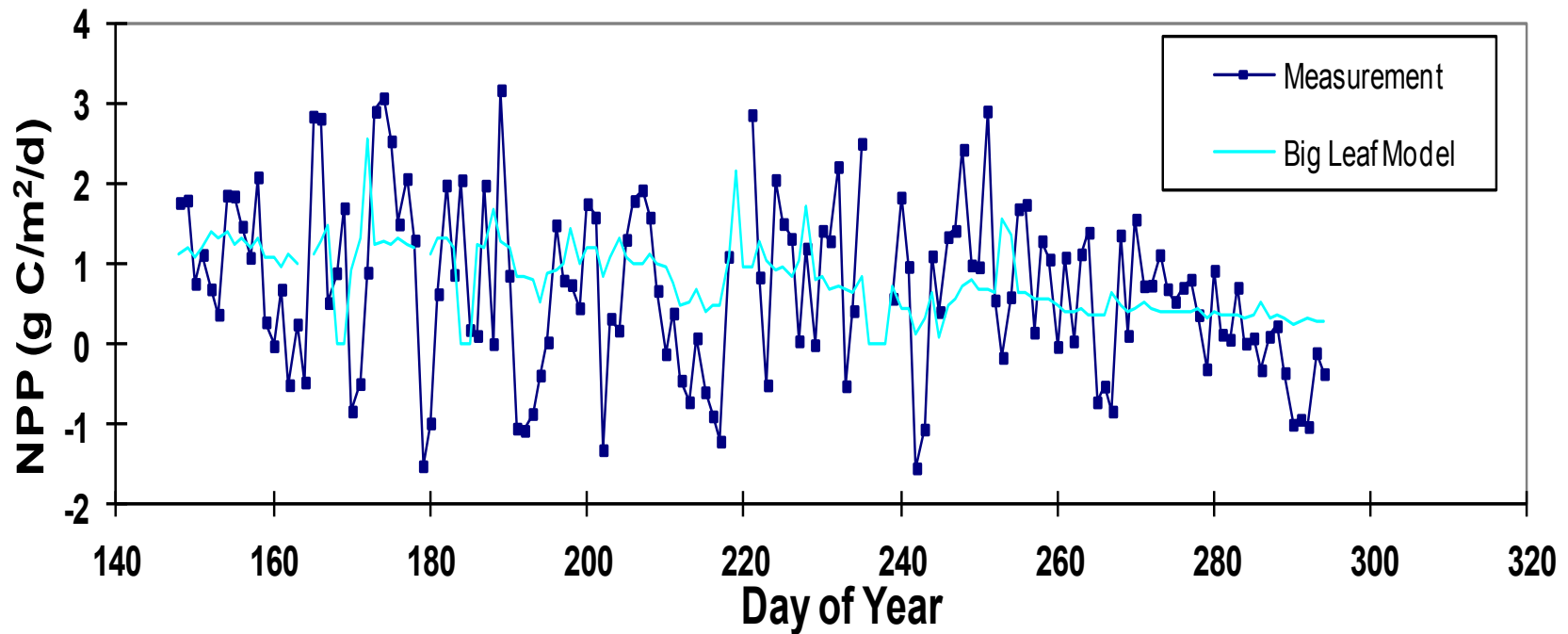
(3) Chlorophyll Fluorescence (0.5-3%)

➤ We are interested in (2);
➤ (1), (2) and (3) are inter-related;
➤ Only recently we are trying to get (2) from (1) and (3).

Two-level Flux Measurements Useful for NPP Estimation

$$NPP = F_1\downarrow + F_2\uparrow - \text{root respiration}$$

Eddy covariance

Eddy covariance

Chen et al. (1999, *EM*)

Following Photons to One Big Leaf
Old Black Spruce, BOREAS Southern Study Area
Site PI: **Paul Jarvis**

$$P = P(R_{cc}) \qquad R_{cc} = R_{sc} / LAI$$

Chen et al. (1999, *EM*)

Following Photons to Two Leaves
Old Black Spruce, BOREAS Southern Study Area
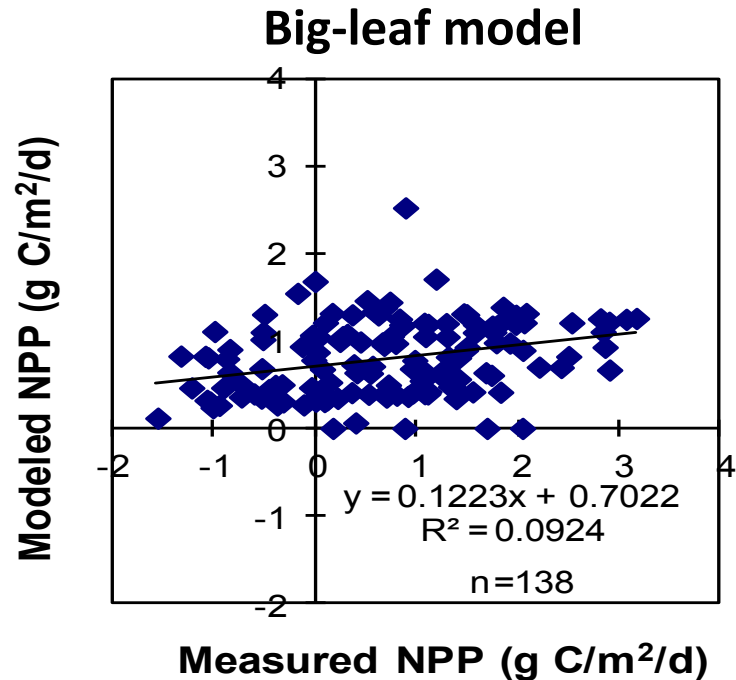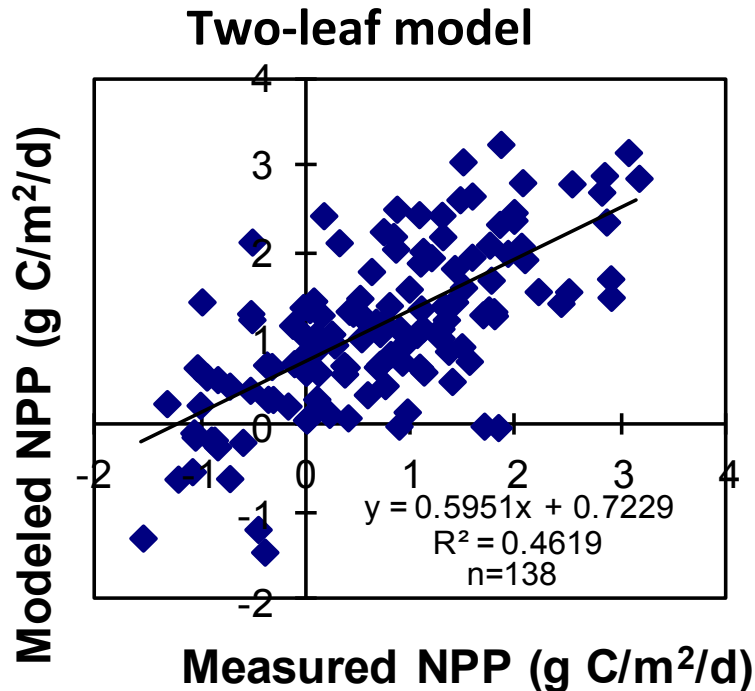## Site PIs: **Paul Jarvis and Ray Desjardins**
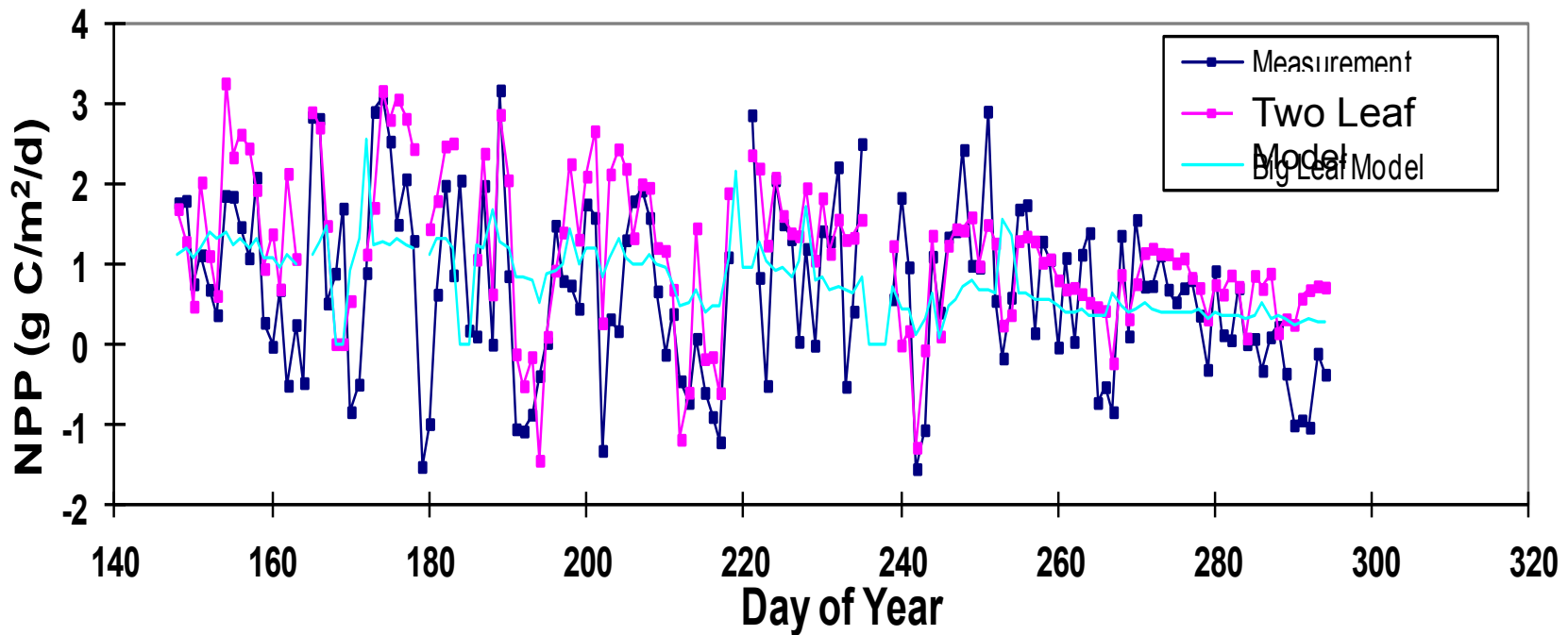
$$P = P_{sun}(R_{sc}) * L_{sun} + P_{shade}(R_{sc}) * L_{shade}$$

Norman (1993); Chen et al. (1999)

One or Two Leaves???
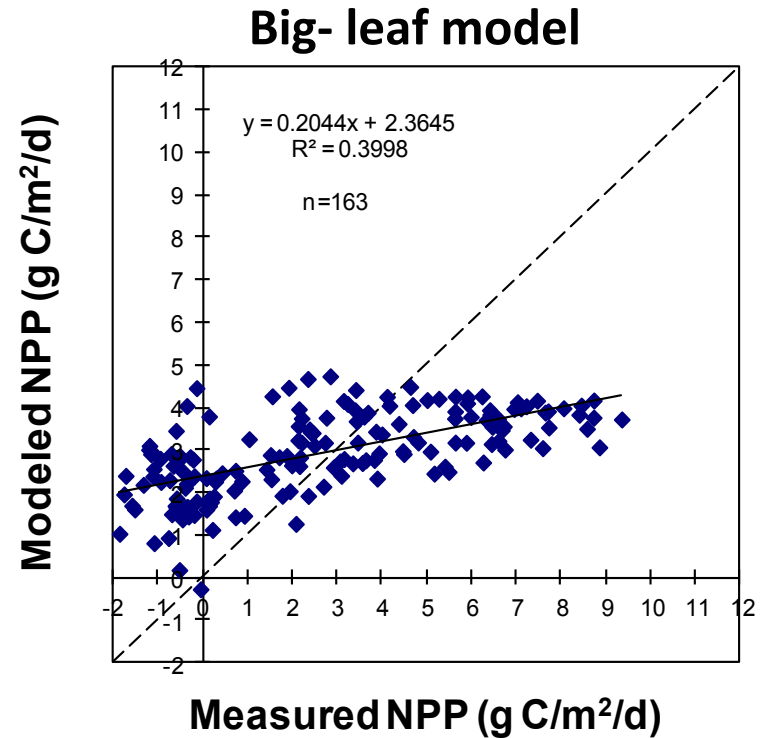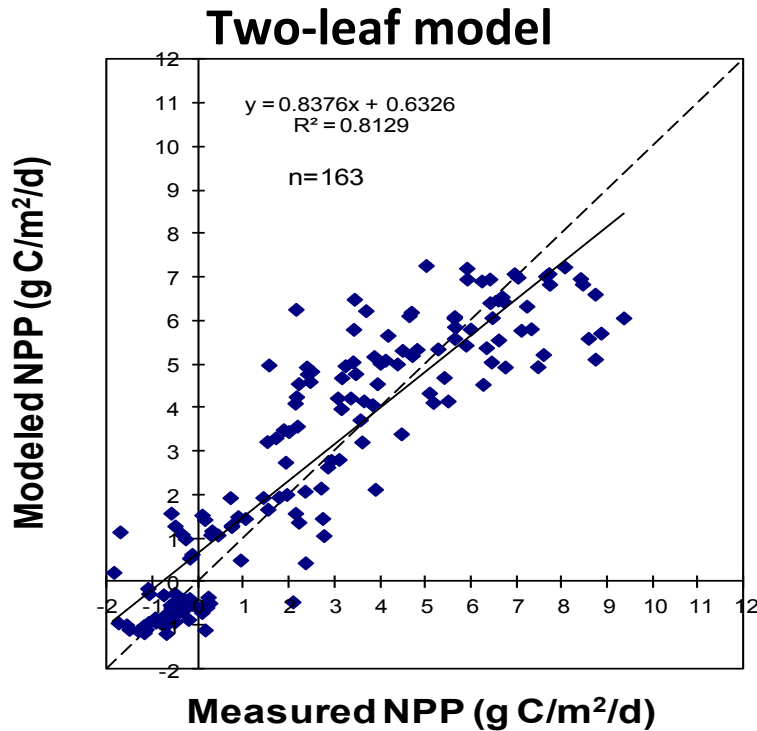## Old Black Spruce, BOREAS Southern Study Area
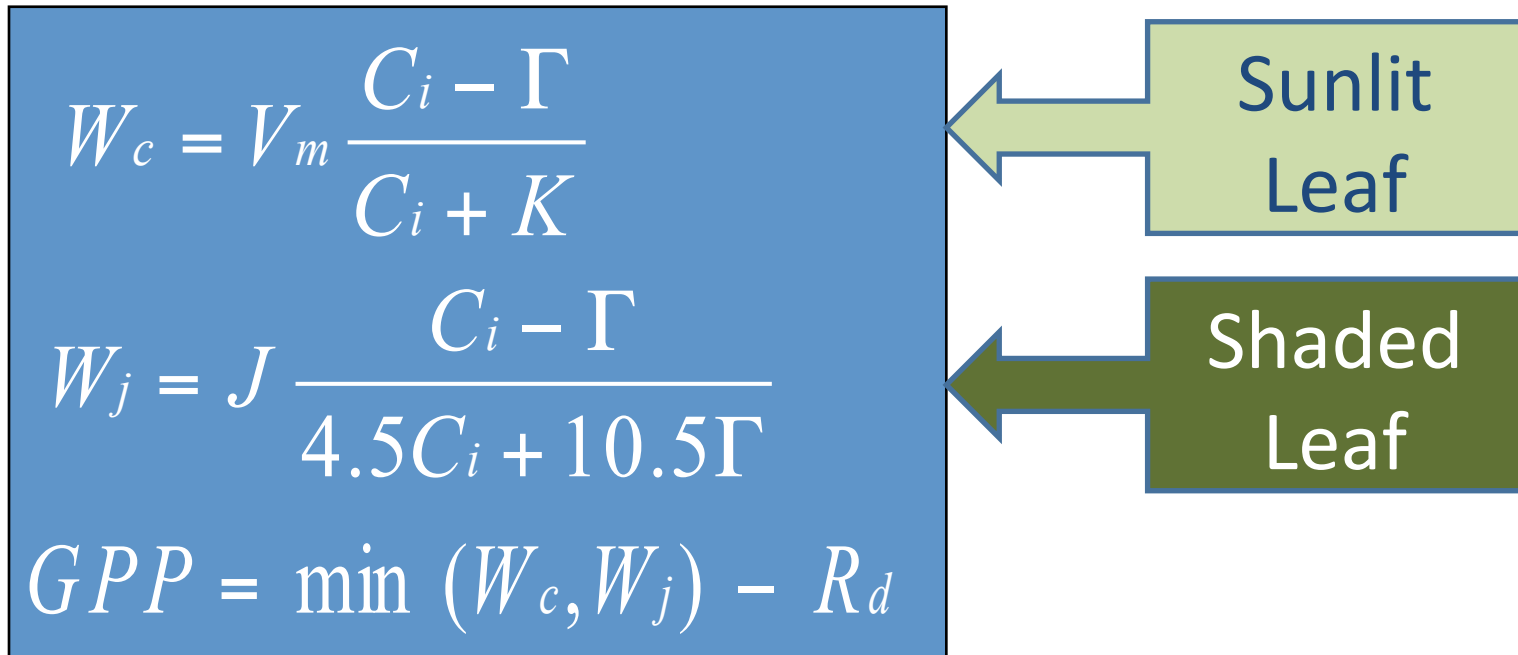## Site PI: **Paul Jarvis and Ray Desjardins**

Two-leaf model

$y = 0.5951x + 0.7229$
$R^2 = 0.4619$
$n=138$

Big-leaf model

$y = 0.1223x + 0.7022$
$R^2 = 0.0924$
$n=138$

Chen et al. (1999, *EM*)

One or Two Leaves???
Old Aspen, BOREAS Southern Study Area
Site PI: **Andy Black**

Two-leaf model

$y = 0.8376x + 0.6326$
$R^2 = 0.8129$

$n=163$

Modeled NPP (g C/m²/d)

Measured NPP (g C/m²/d)

Big- leaf model

$y = 0.2044x + 2.3645$
$R^2 = 0.3998$

$n=163$

Modeled NPP (g C/m²/d)

Measured NPP (g C/m²/d)

Chen et al. (1999, *EM*)

We known that photons are more welcome in shaded leaves

Farquhar's Model

$$W_c = V_m \frac{C_i - \Gamma}{C_i + K}$$

$$W_j = J \frac{C_i - \Gamma}{4.5C_i + 10.5\Gamma}$$
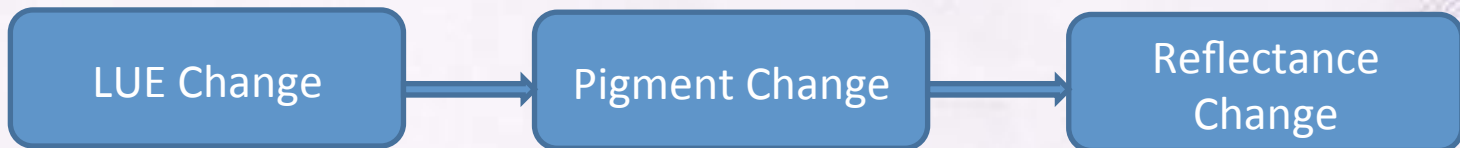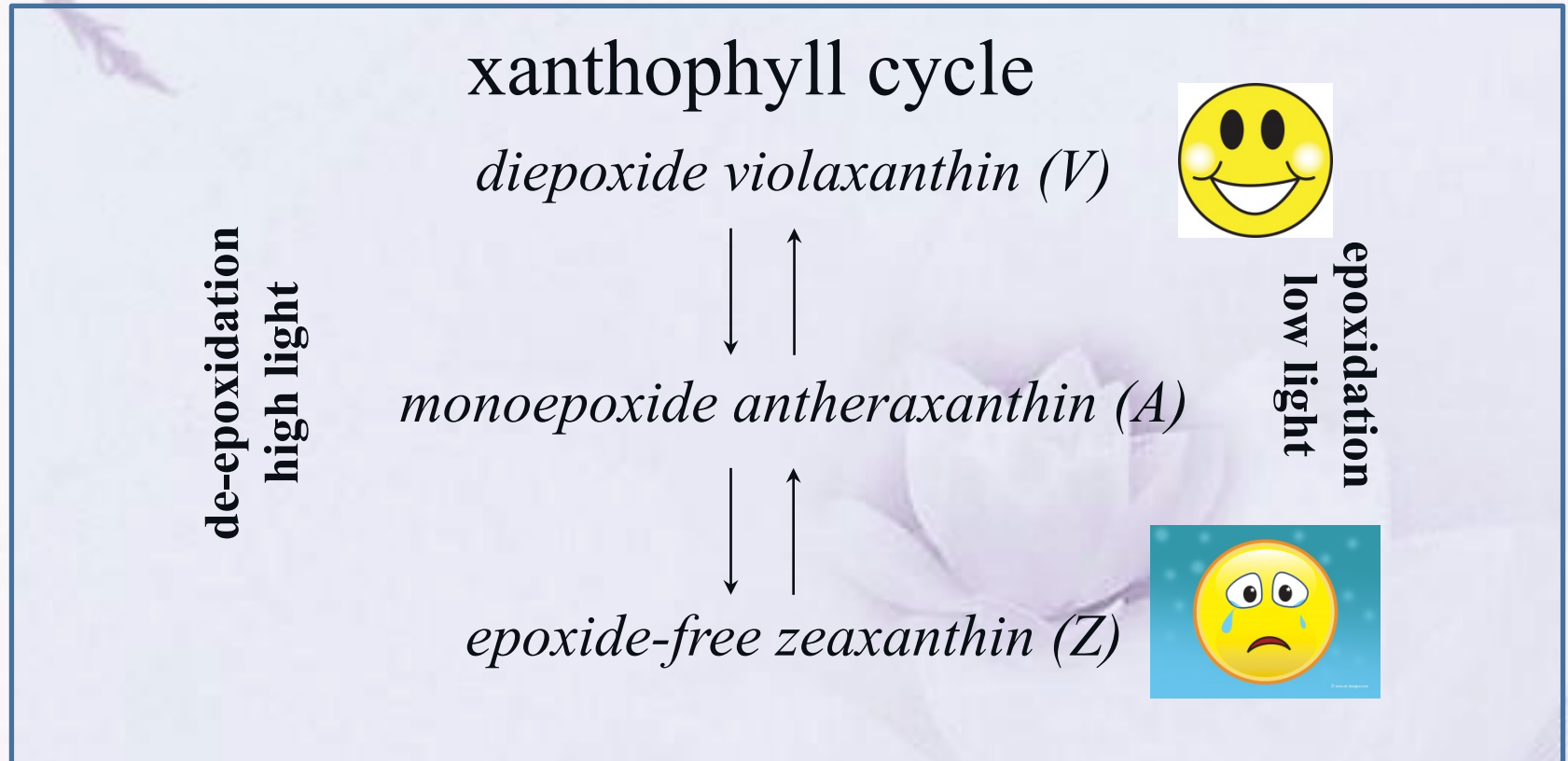
$$GPP = \min(W_c, W_j) - R_d$$

Sunlit Leaf

Shaded Leaf

W_c and W_j are temperature/nutrient-limited and light-limited gross photosynthesis rates

Can we follow photons all the way to photo systems?

# Non-photochemical quenching that relates to the light use efficiency

xanthophyll cycle

diepoxide violaxanthin (V)

monoepoxide antheraxanthin (A)

epoxide-free zeaxanthin (Z)

de-epoxidation high light

epoxidation low light

LUE Change → Pigment Change → Reflectance Change

Photochemical reflectance index, PRI, captures the xanthophyll cycle and hence LUE

$$PRI = \frac{\rho_{531} - \rho_{570}}{\rho_{531} + \rho_{570}}$$
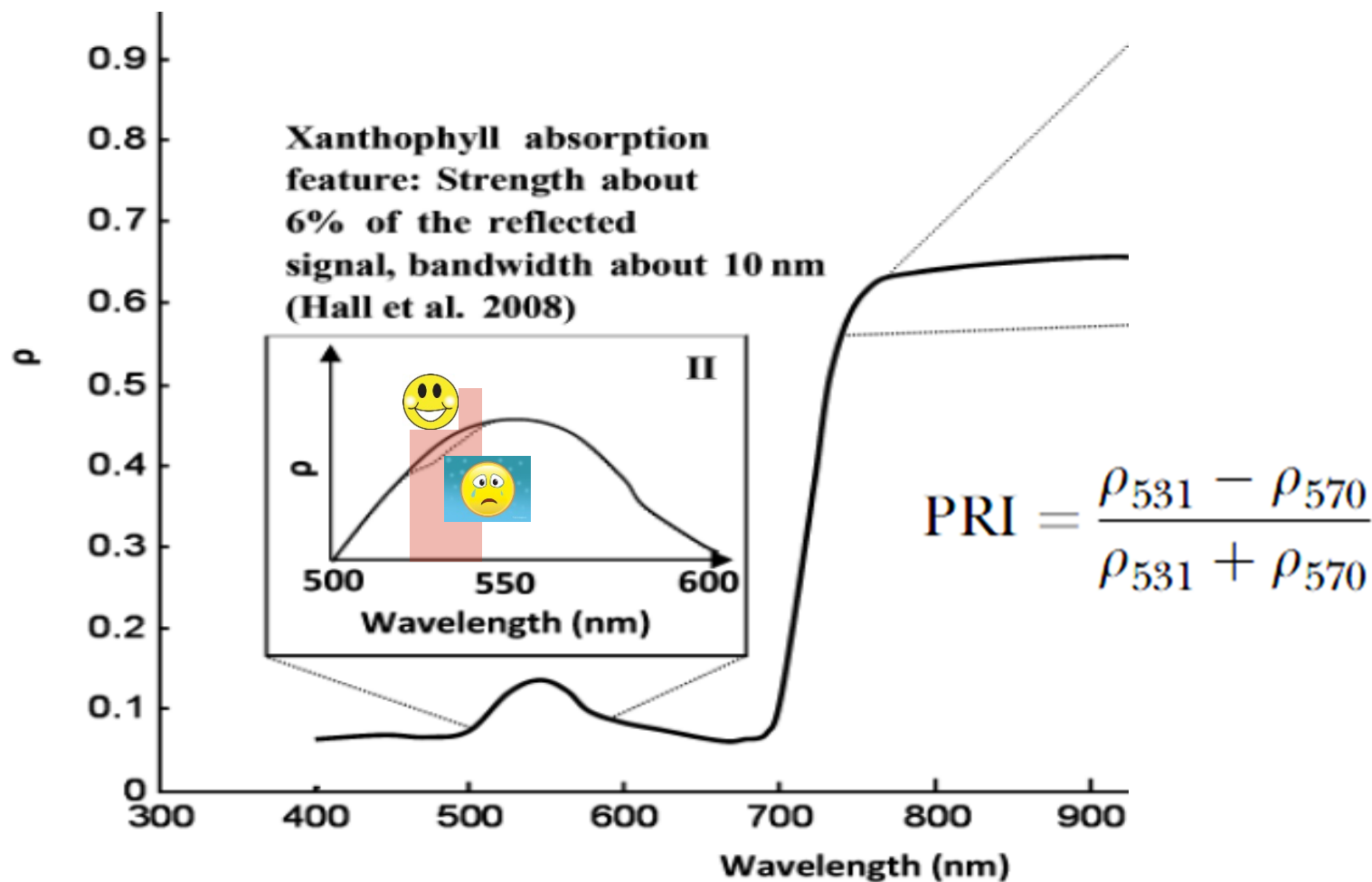
Gamon et al. (1992, RSE)

Photochemical Reflectance Index
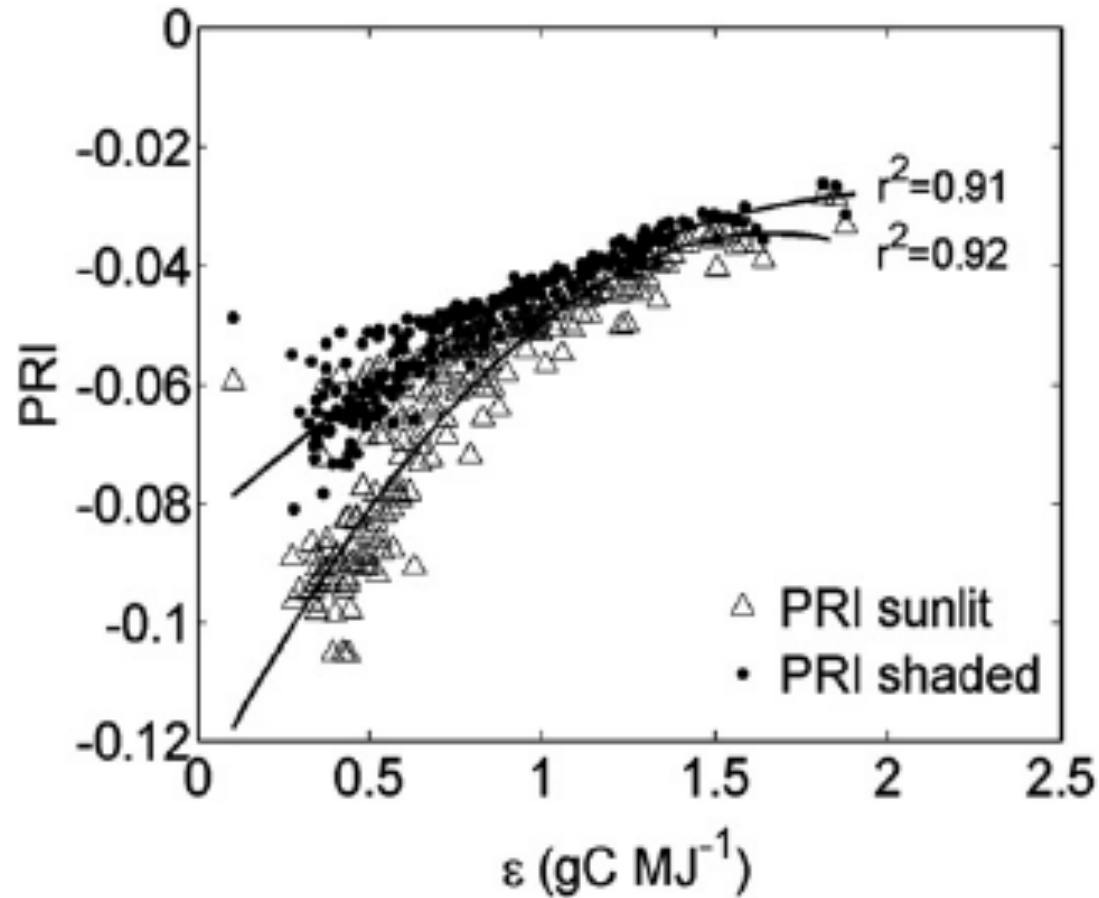
Hilker, Lyapustin, Hall, et al., 2009, RSE; Hall, Hilker, Coops, et al., 2009, RSE

Experimental Setup

A copy of the system developed by Nicholas Coops, Thomas Hilker, Forrest Hall, etc.

Site 1: White Pine Forest

Located about 12km southwest of the town of Simcoe in southern Ontario, the study site (42˚42´ 44˝ N, 80˚22´ 3˝ W) is dominated by white pine.

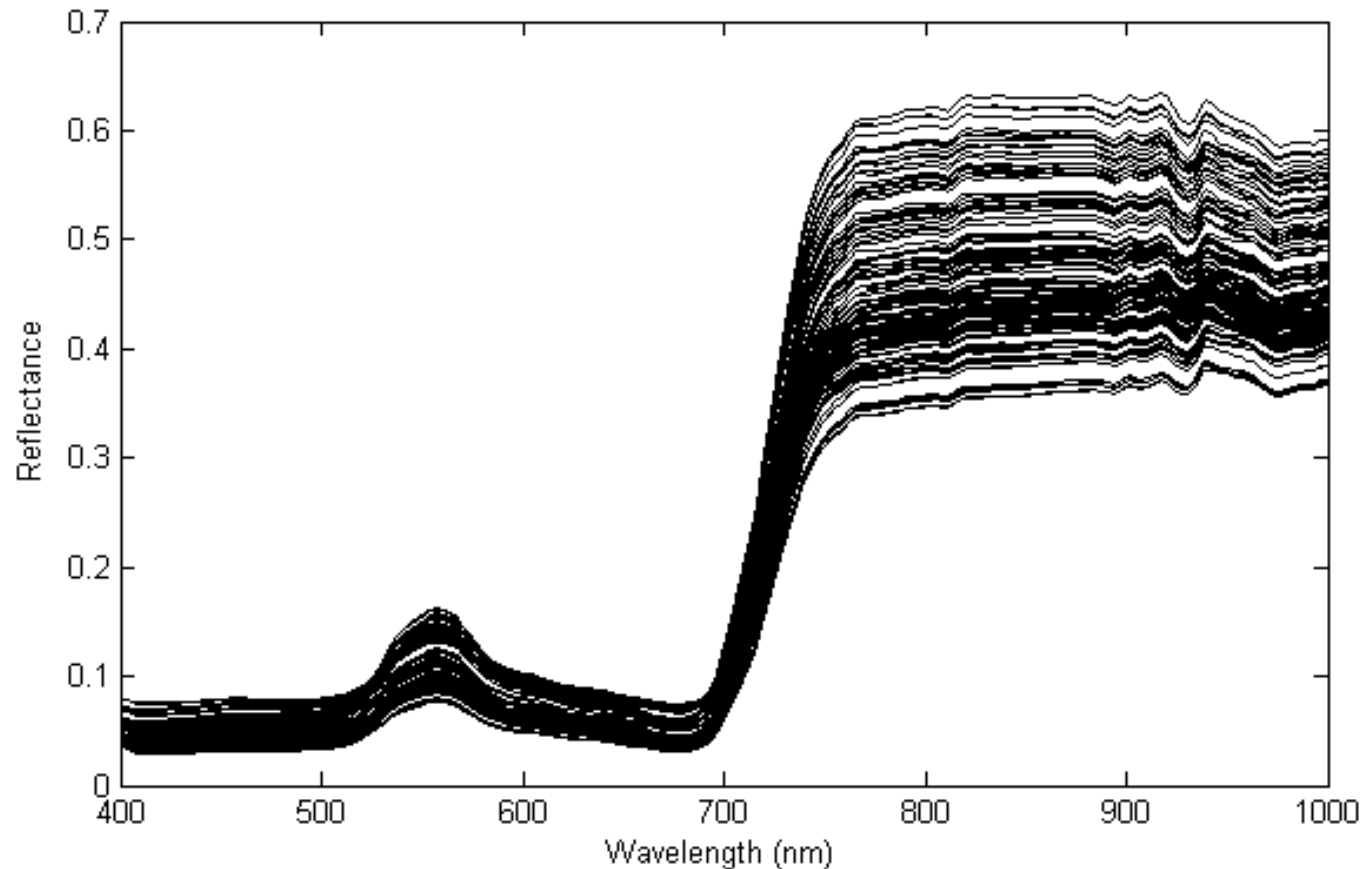A 28-m flux tower stands in the center of a 46 ha white pine stand.

Site 2: Deciduous Forest

Located in Haliburton Forest (on the southwest of Algonquin Park), the tower is 33m high.
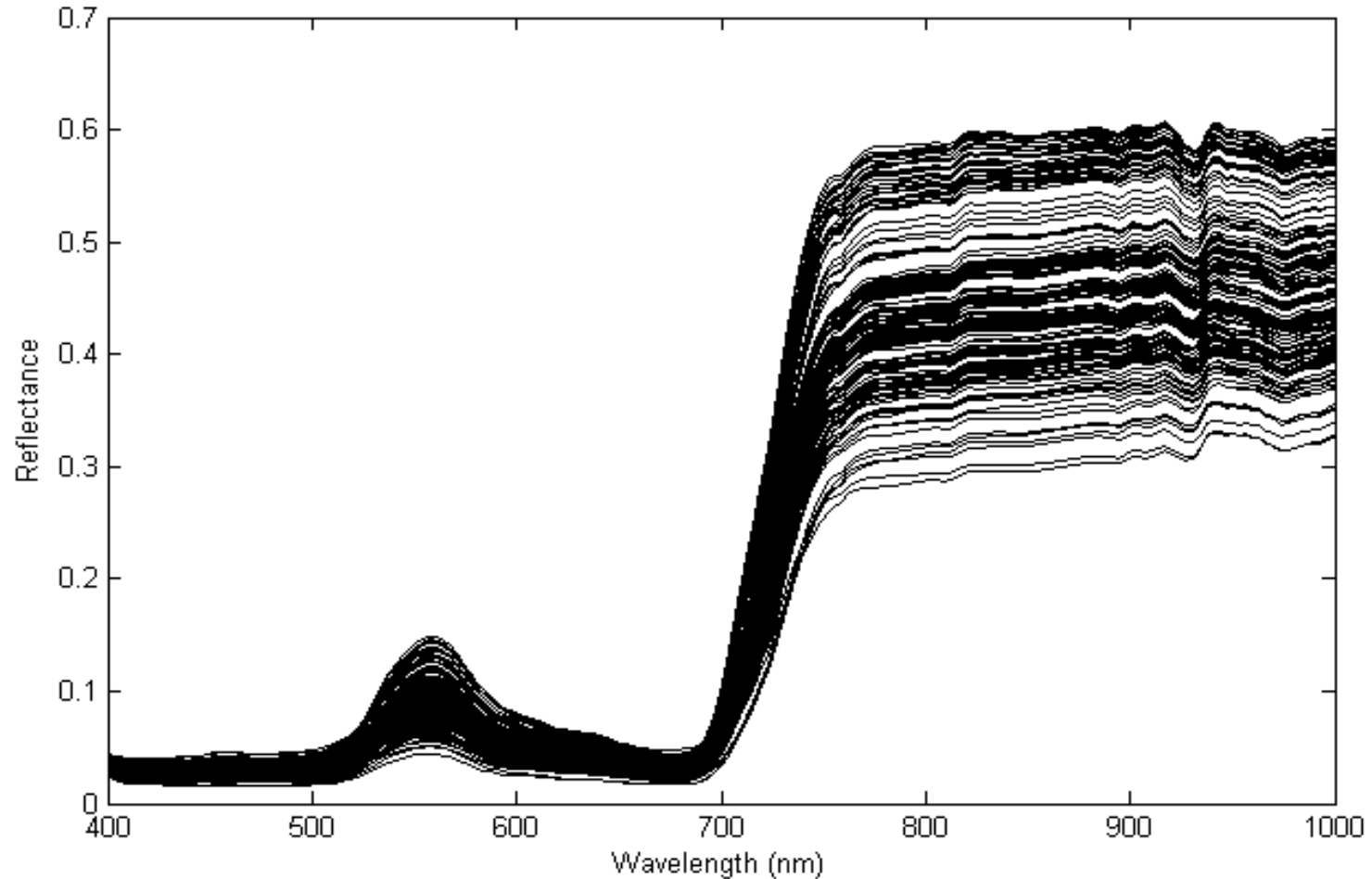

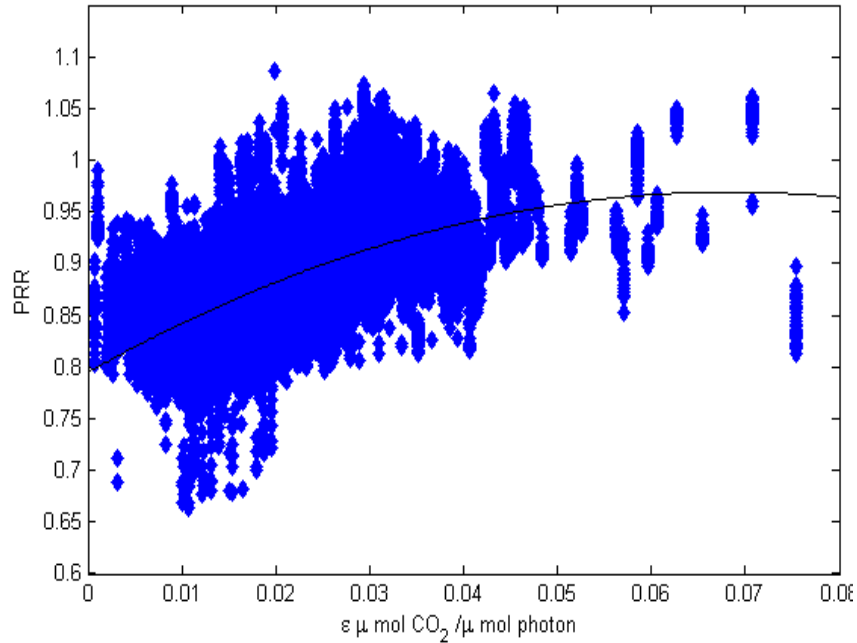**Sugar maple is the dominant species in this forest**

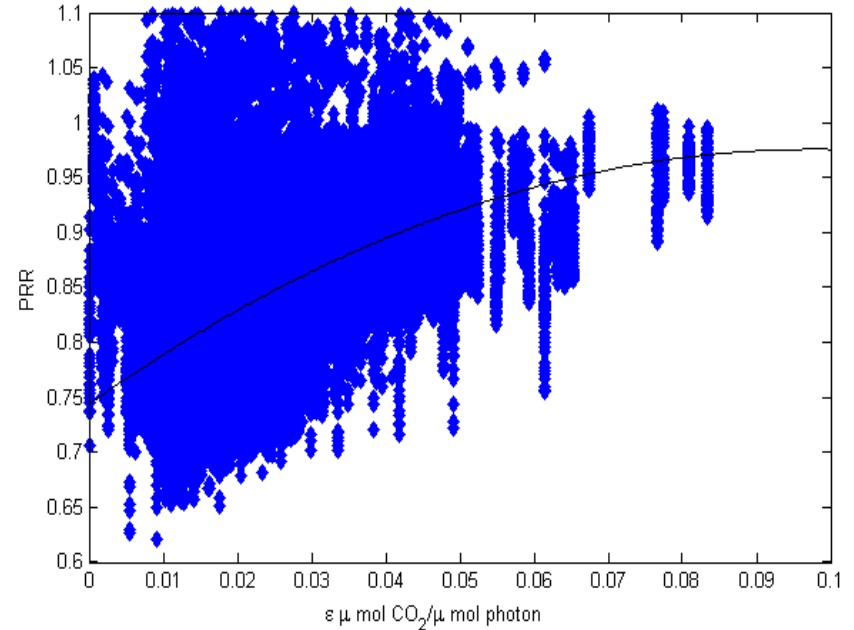# Multi-angle Spectral Measurements above a White Pine Forest

Multi-angle Spectral Measurements Above a Maple Forest
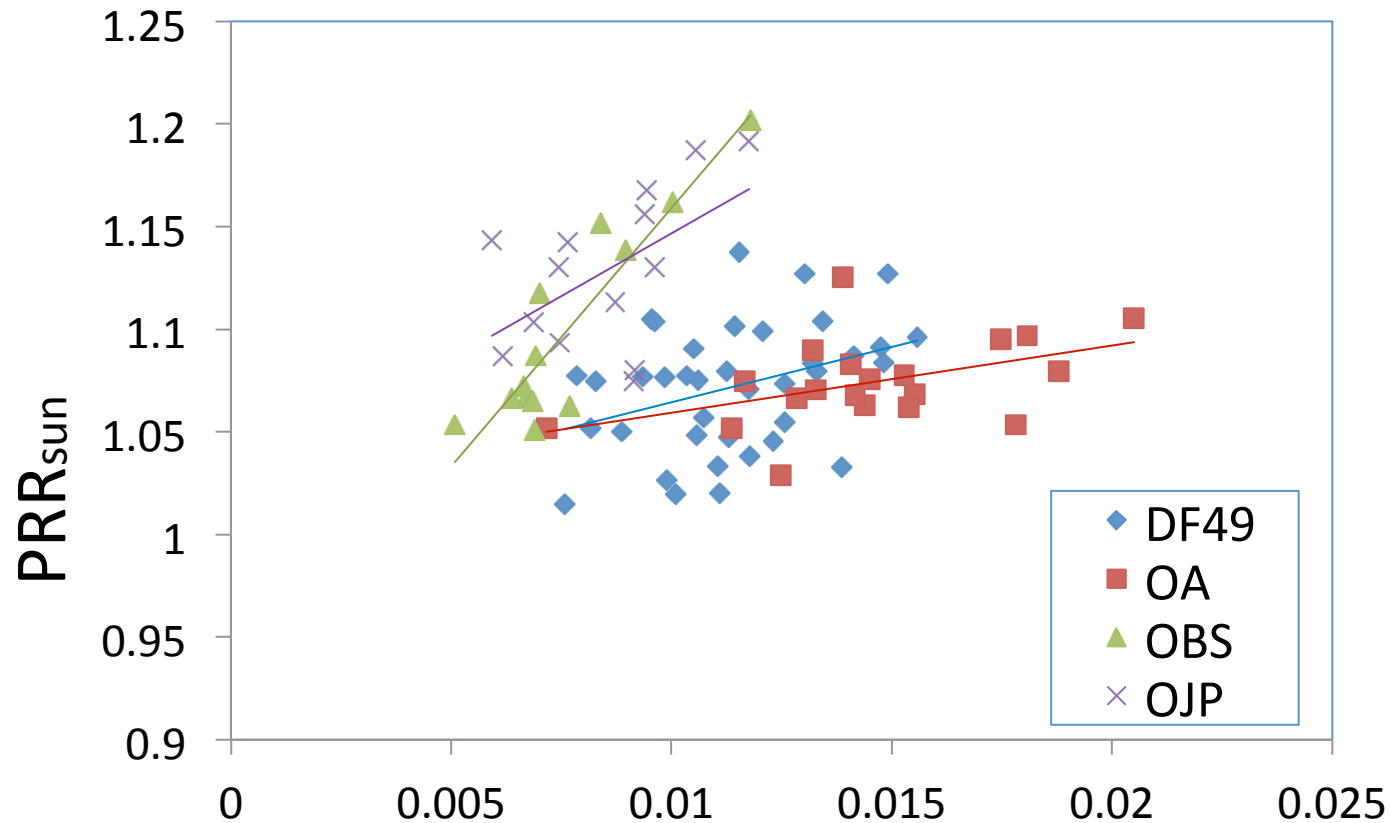
Canopy-level PRI and LUE
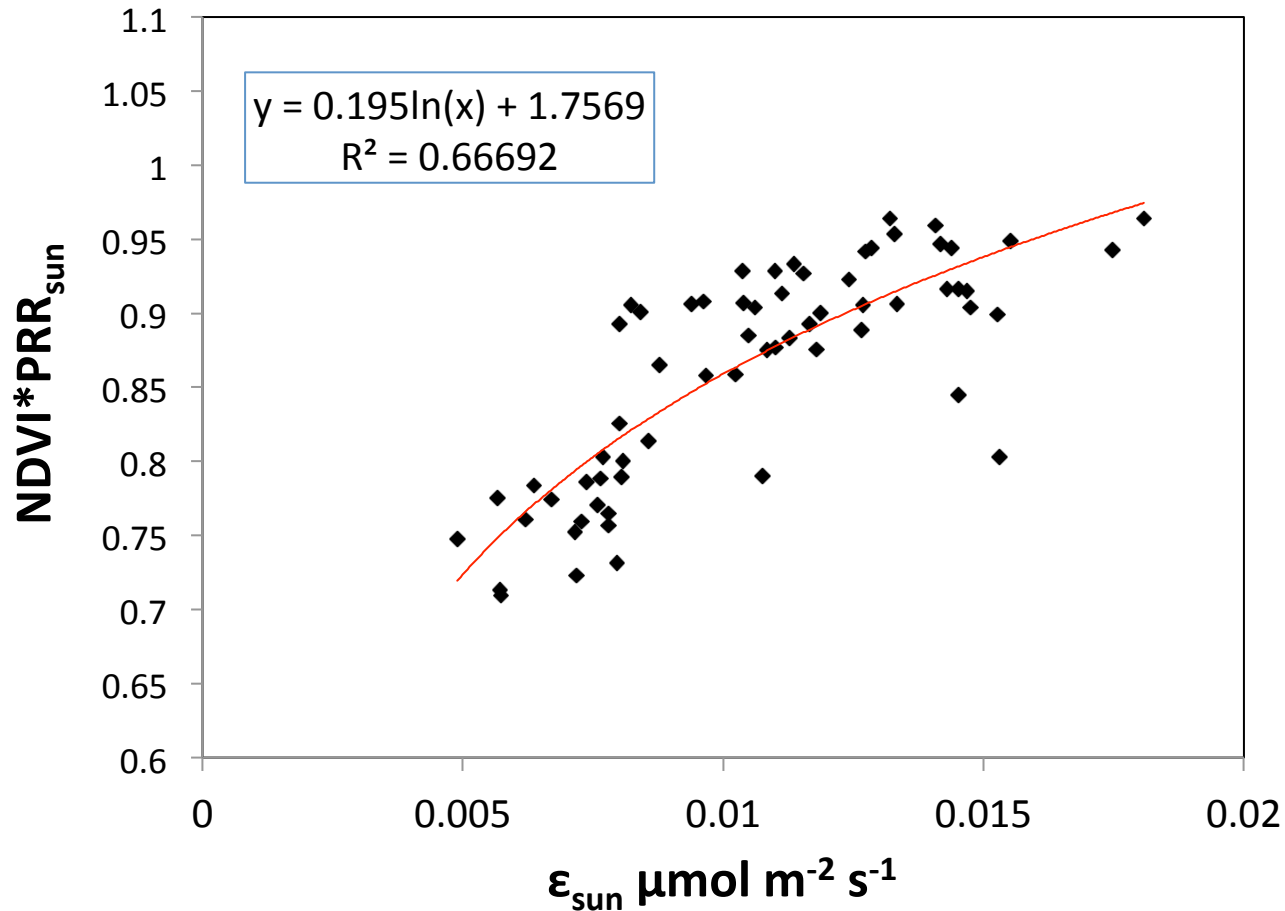

White Pine, Ontario, Canada

Sugar Maple, Ontario, Canada

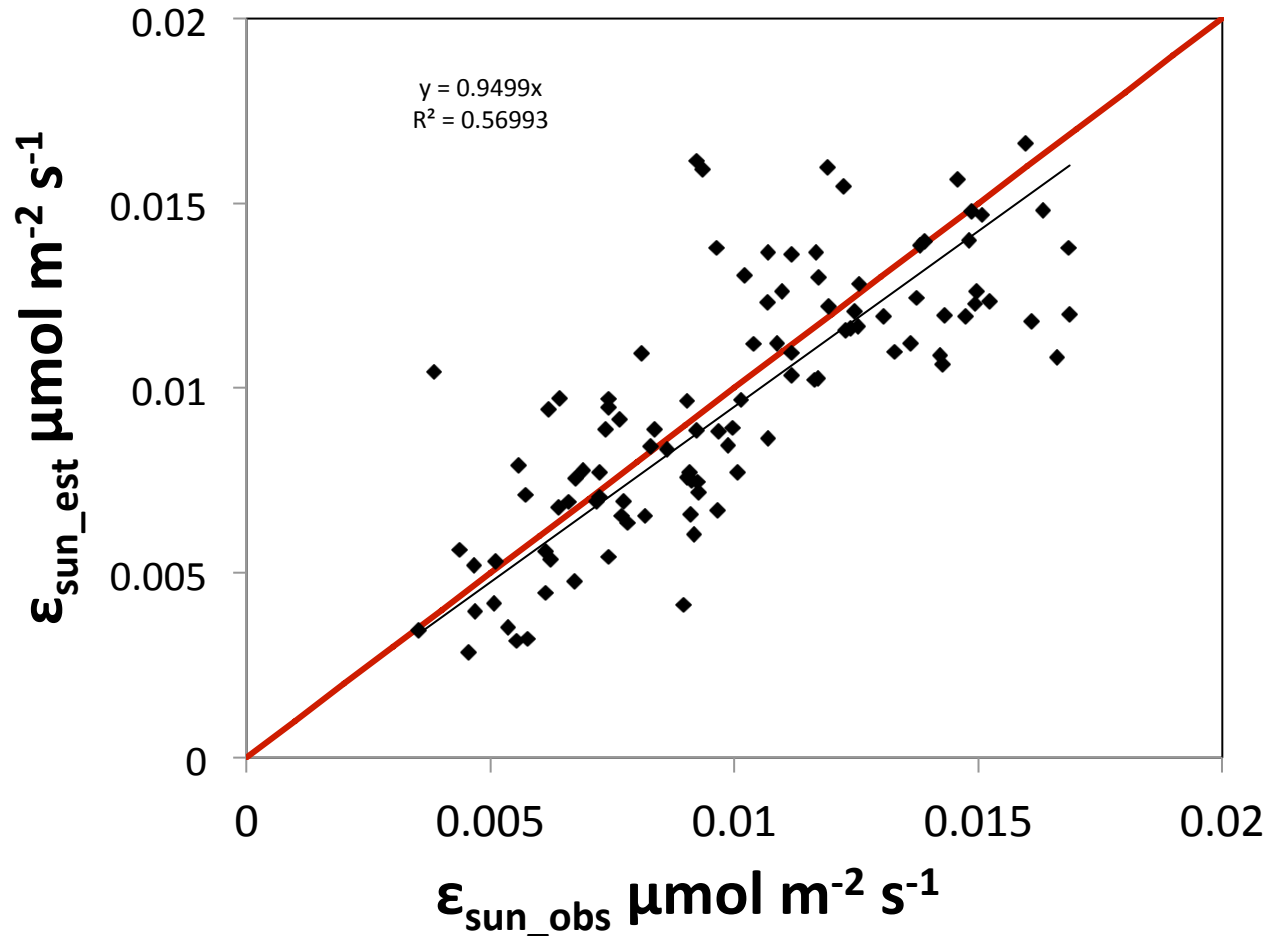# Relationships between PRR and LUE derived from tower flux data

$$PRR = \rho_{531} / \rho_{570}$$

Data from Nicholas Coops and Thomas Hilker   Zhang, Chen et al. In preparation

Relationships between NDVI*PRR and LUE derived from tower flux data

Zhang, Chen et al. In preparation

Sunlit LUE estimated using the relationship between NDVI*PRR$_{sun}$ and LUE$_{sun}$
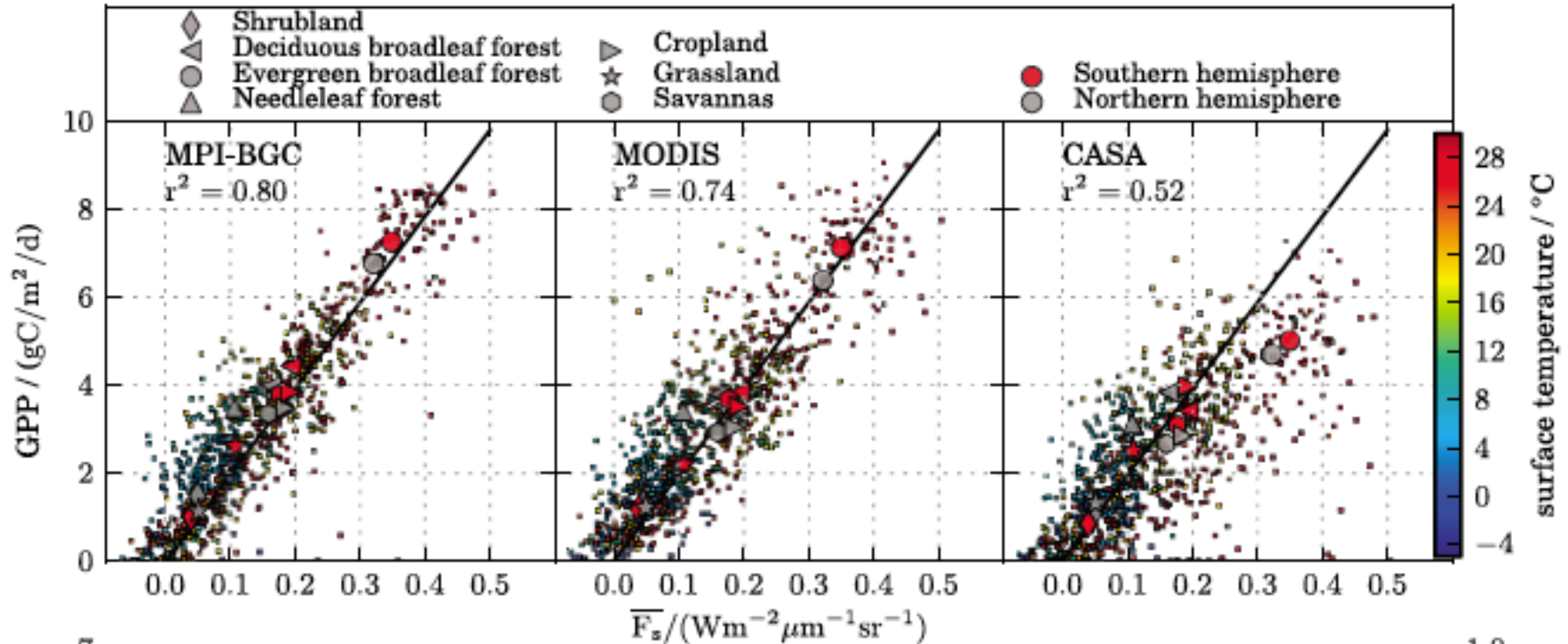

Zhang, Chen et al. In preparation

What is Sun-induced Chl Fluorescence (SIF)?

Part (~1%) of photosynthetically active radiation absorbed by leaf chlorophyll is emitted in longer wavelengths as SIF.

Colombo et al., 2016, *Annali Di Botanica*
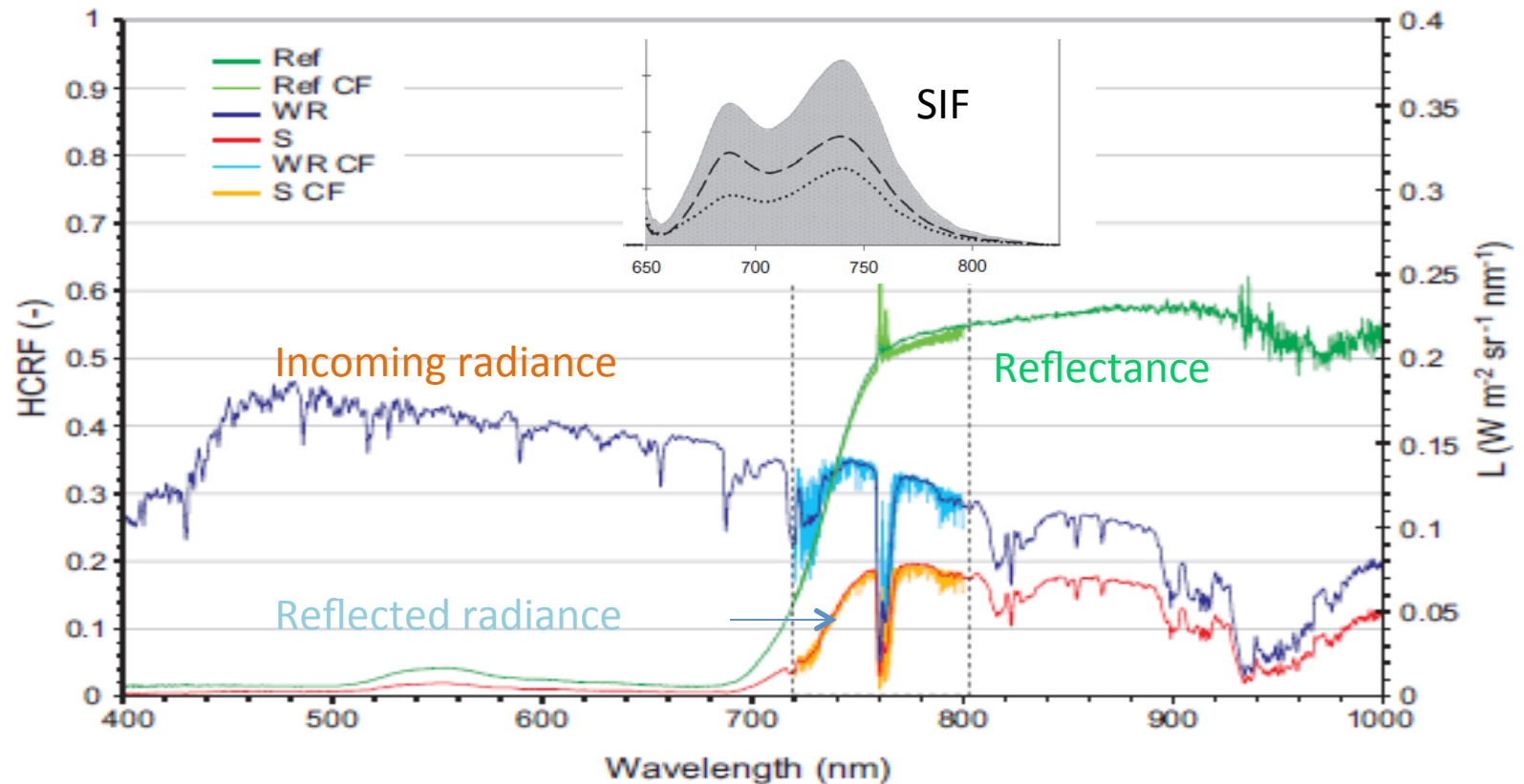
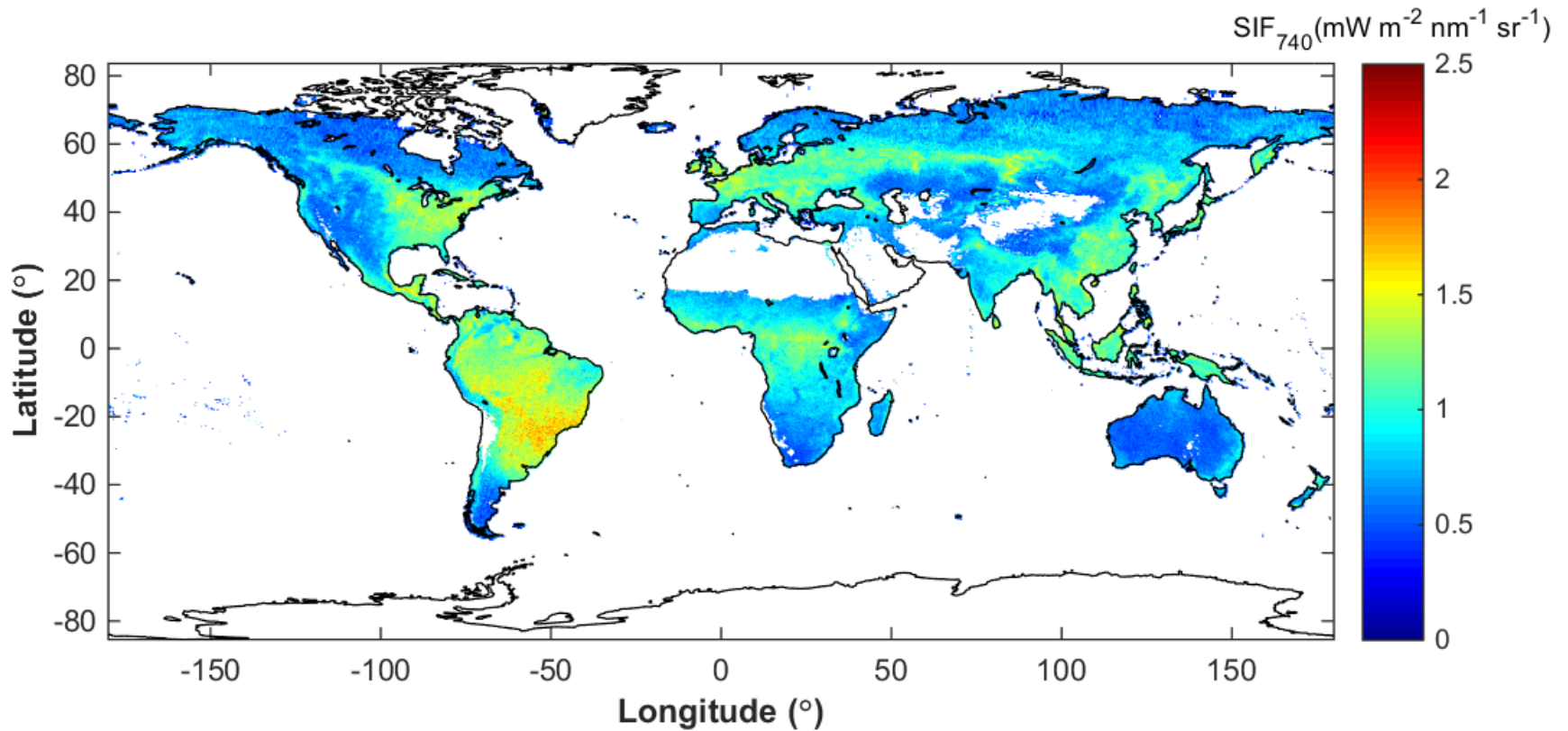# Correlation Between Chlorophyll Fluorescence and GPP

GOSAT, 2009, Annual Total, Spatial Correlation

$$\overline{F_s} = F_s / \cos(SZA(t_0)) \cdot \int_{t=t_0}^{t=t_0+1} \cos(SZA(t))dt$$

Frankenberg et al. 2011, *GRL*

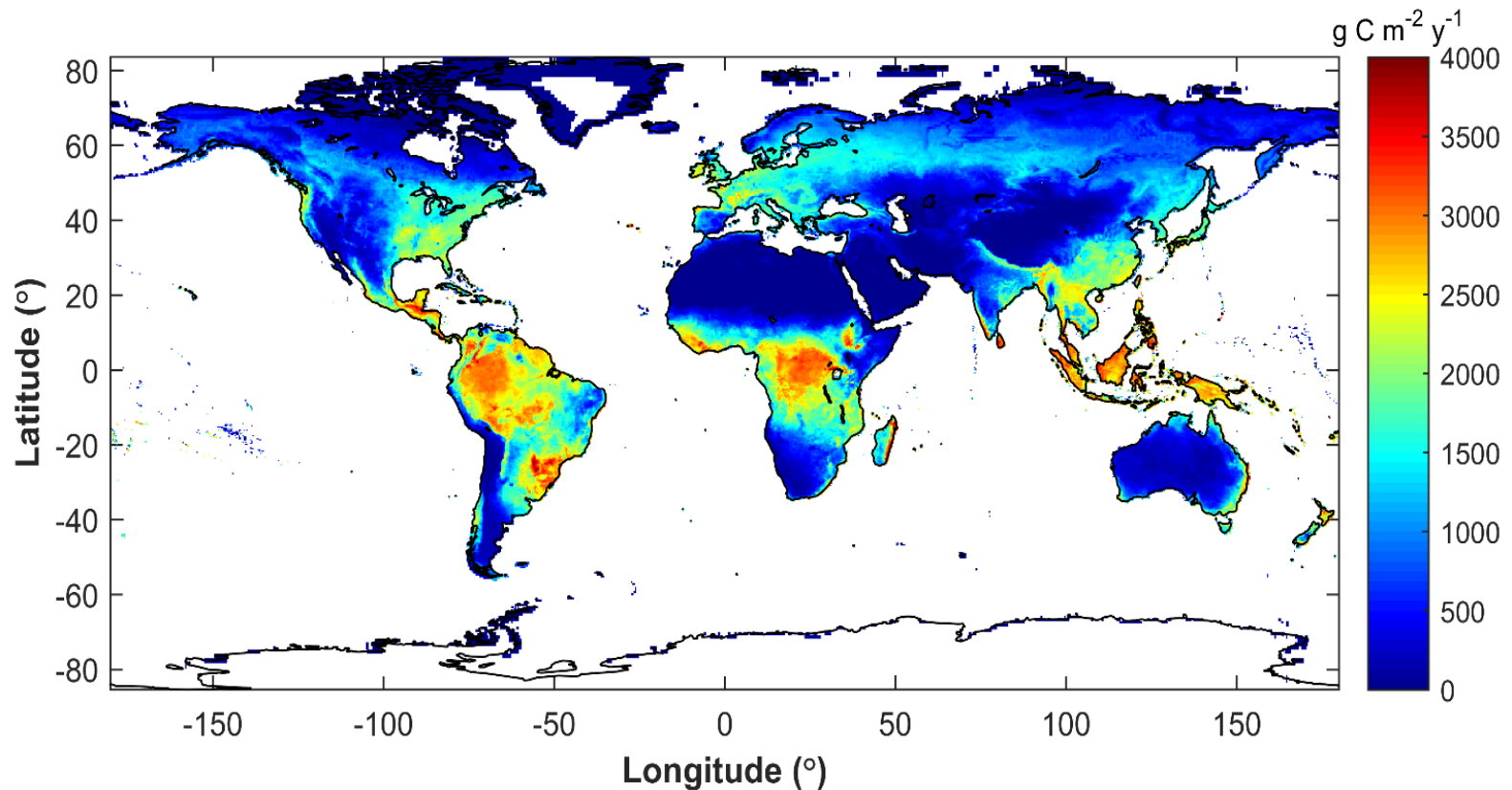# Annual Average SIF

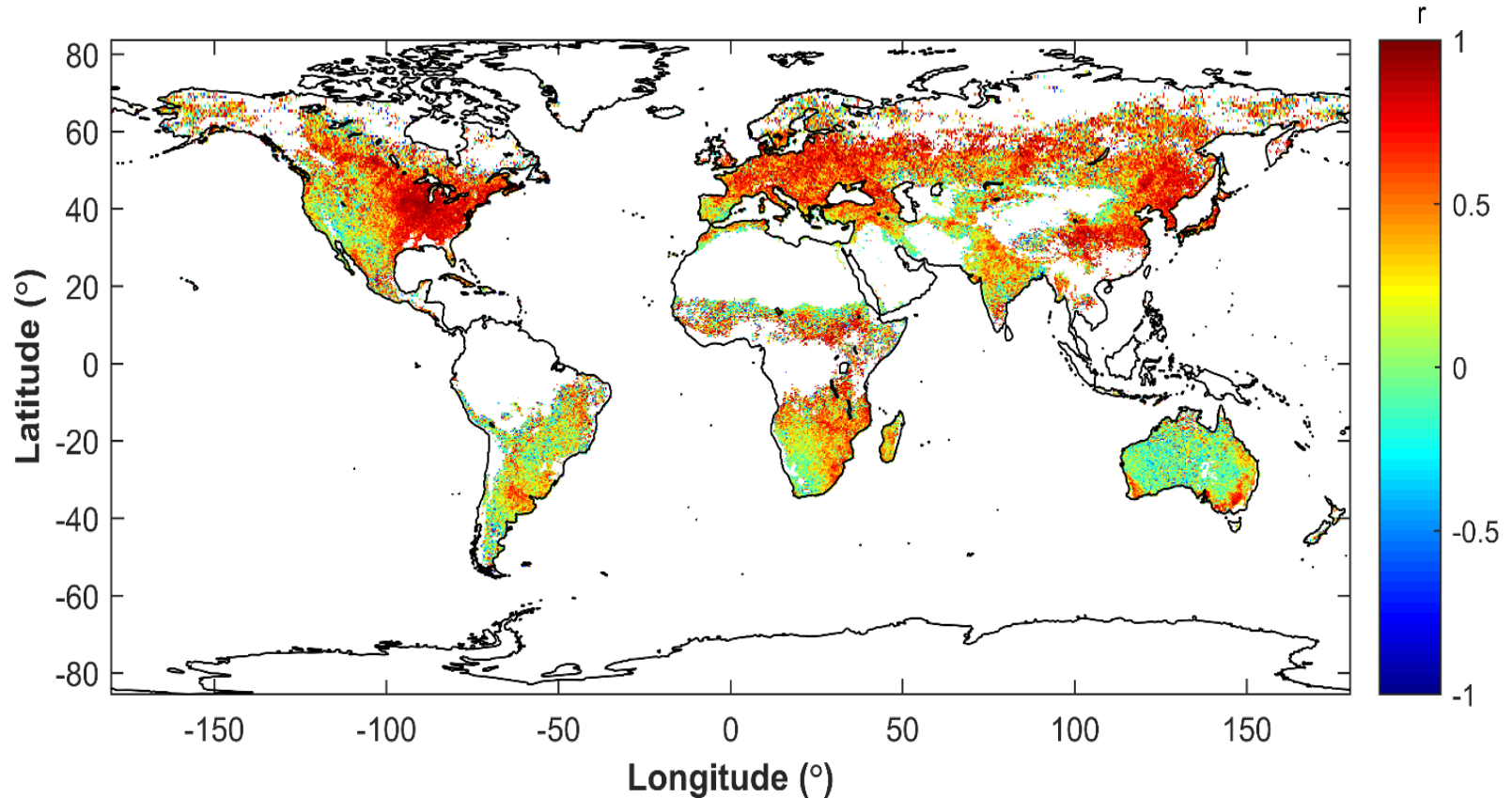## GOME-2, 2015

Data from Joan Joiner et al.

Global Gross Primary Productivity (GPP)

2015, Boreal Ecosystem Productivity Simulator, 1 km resolution

Correlation Coefficient (r) between GPP and SIF

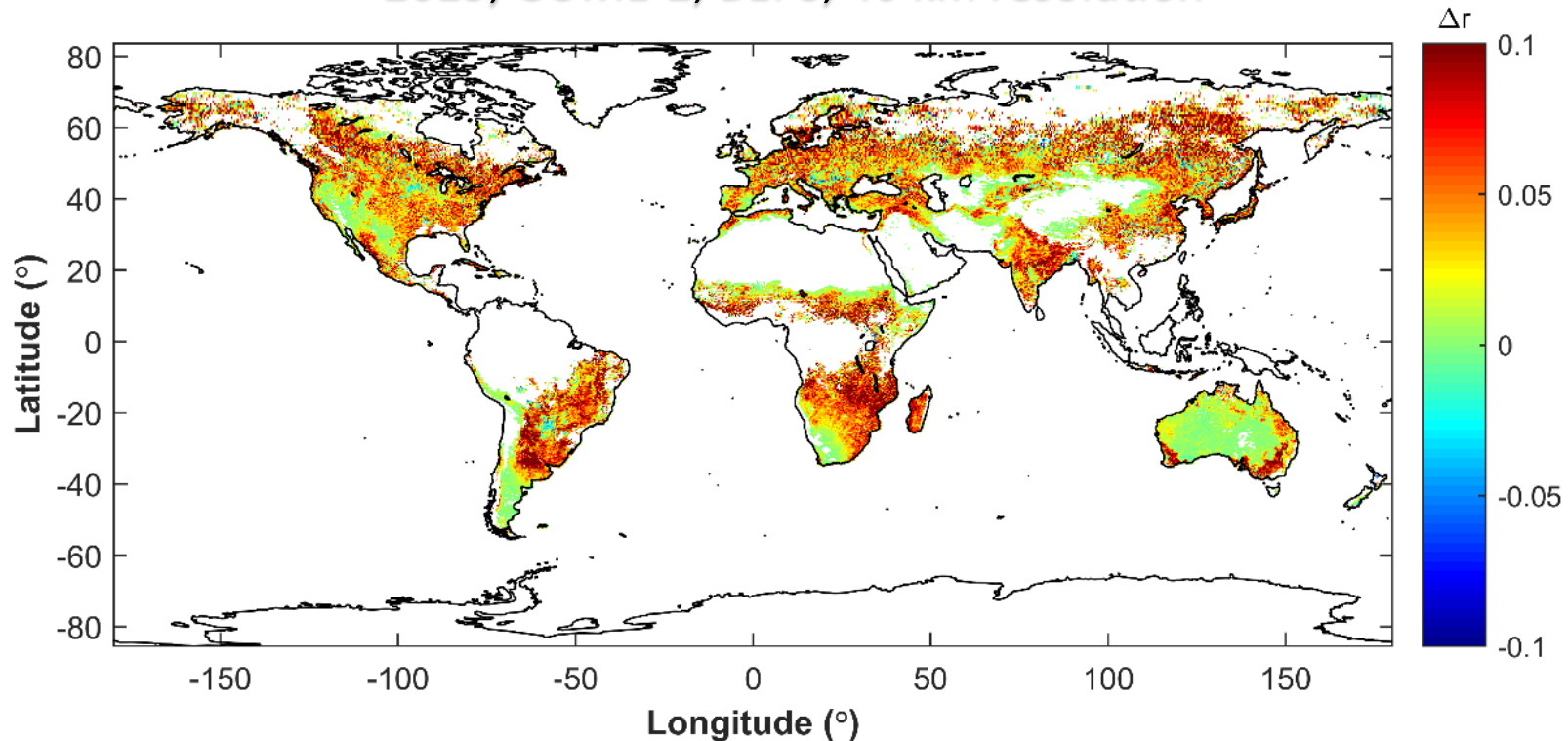## 2015, GOME-2, BEPS, 40 km resolution

Data from Joan Joiner et al.

He, Chen et al., in preparation

Improvement of the Correlation between GPP and SIF Through Separating SIF for Sunlit and Shaded Leaves

2015, GOME-2, BEPS, 40 km resolution

$$\Delta r = r(GPP, SIF_t) - r(GPP, SIF)$$

$$SIF_t = SIF_h + SIF_{sh} \cdot \left(L - L_{sun} \right)$$

He, Chen et al., in preparation
This work benefitted from discussions with Joe Berry

Conclusion

During and after BOREAS, we started following the photons in various ways (with a lot of sweat!) and learned a few things:

➤ The mechanistic Farquhar's photosynthesis model requires us to follow photons to at least two leaves, sunlit and shaded;

➤ The interpretation of remotely sensed PRI and SIF also requires us to do the same!

Annual Average SIF Normalized to Hotspot

GOME-2, 2015