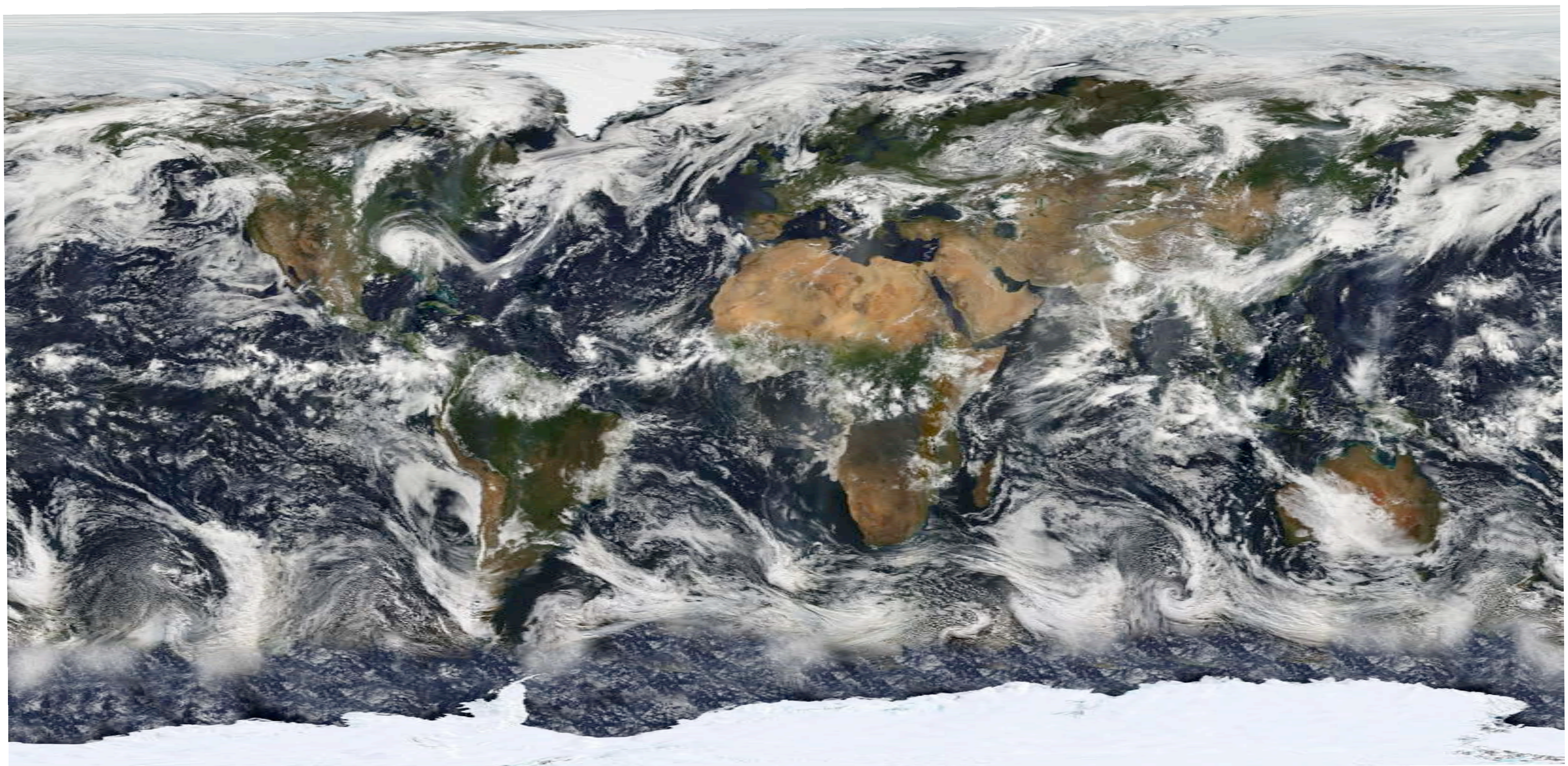
2015 NASA Carbon Cycle & Ecosystems
JOINT SCIENCE WORKSHOP

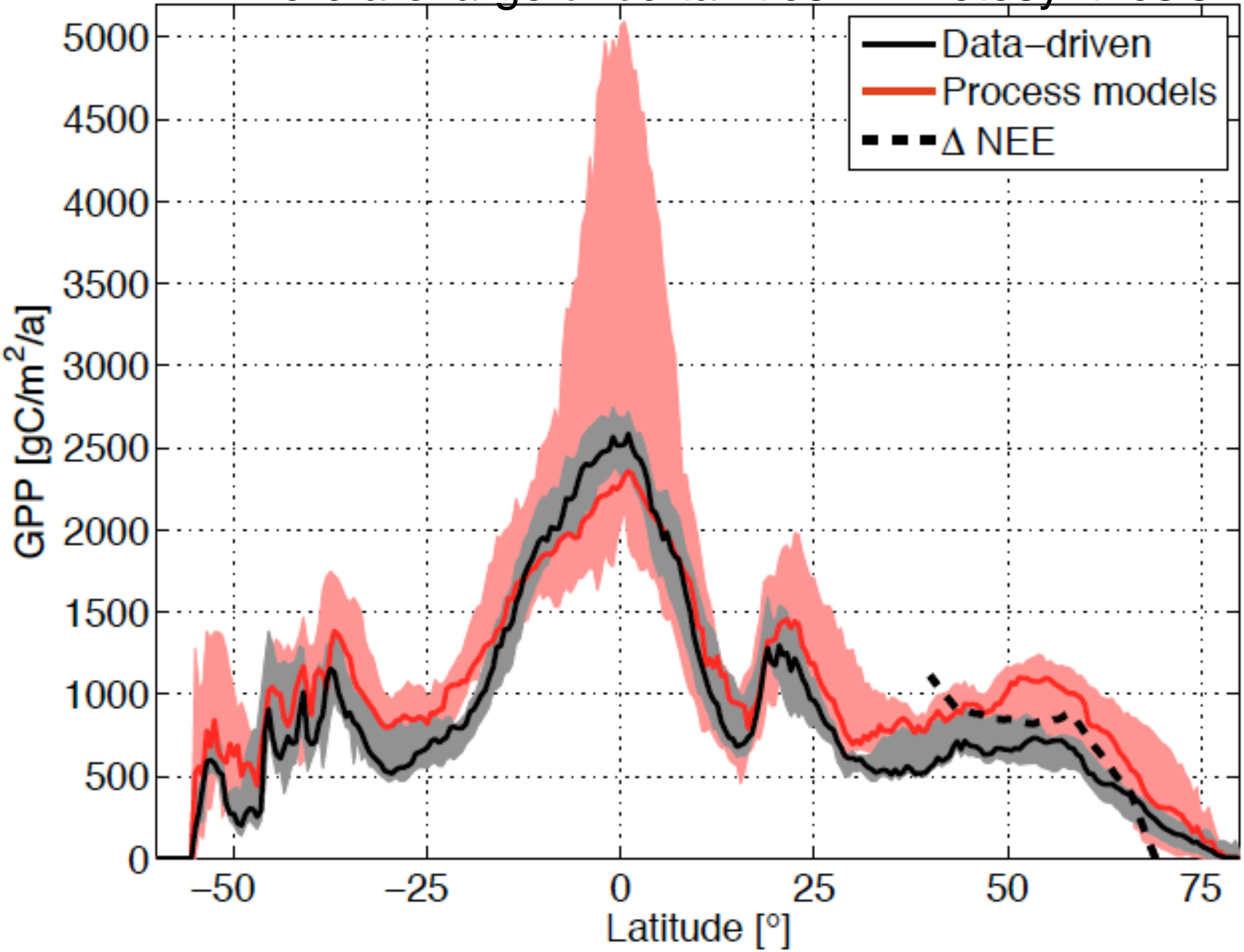
CARNEGIE INSITUTION FOR SCIENCE
DEPARTMENT OF GLOBAL ECOLOGY

Stomata to globe: How far the science has come, and how far will it go?

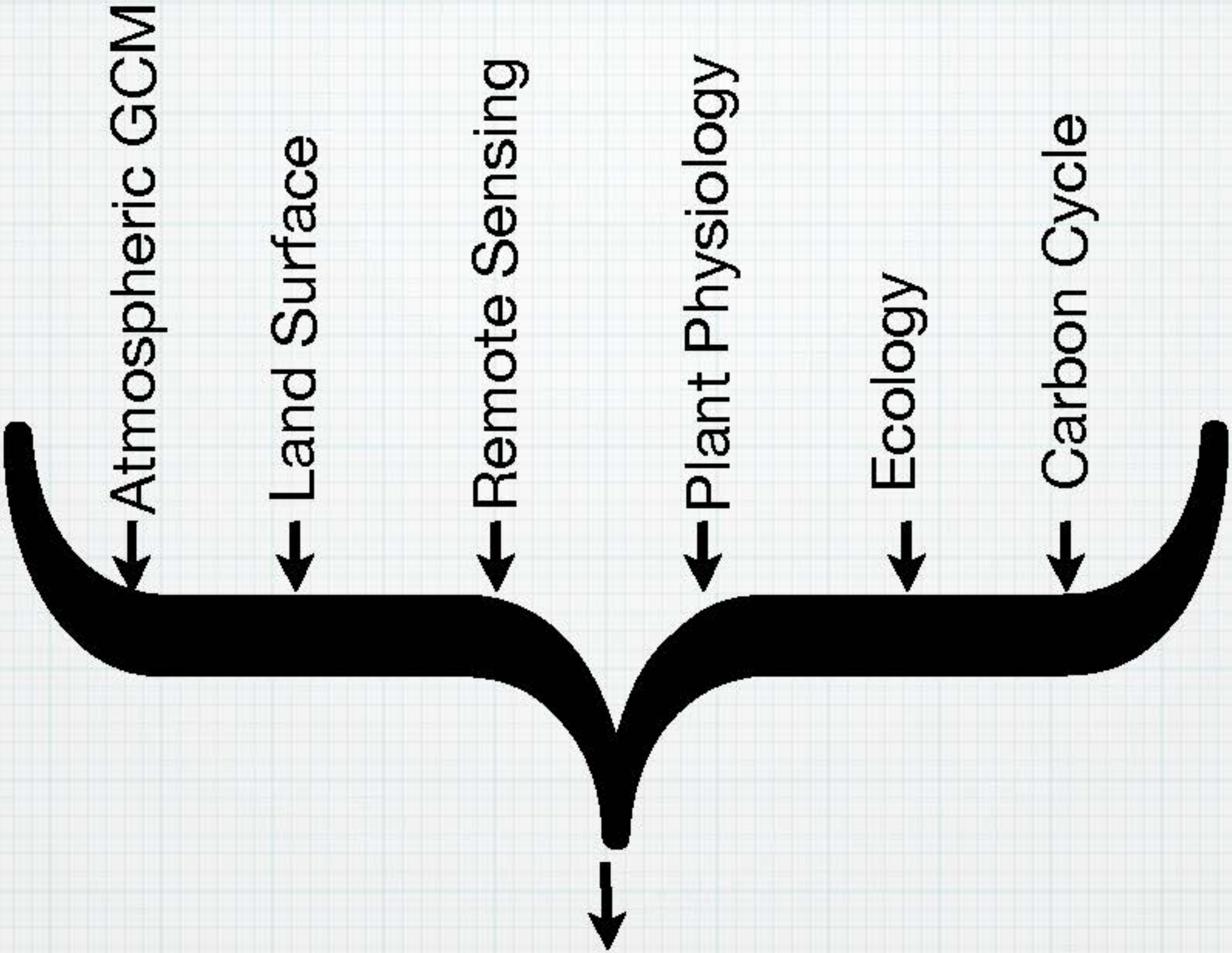
Joe Berry



There are large uncertainties in Photosynthesis



Beer, C., Reichstein, M., Tomelleri, E., Ciais, P., Jung, M., Carvalhais, N., et al. (2010). Terrestrial Gross Carbon Dioxide Uptake: Global Distribution and Covariation with Climate. SCIENCE,, 329(5993), 834–838. doi:10.1126/science.1184984



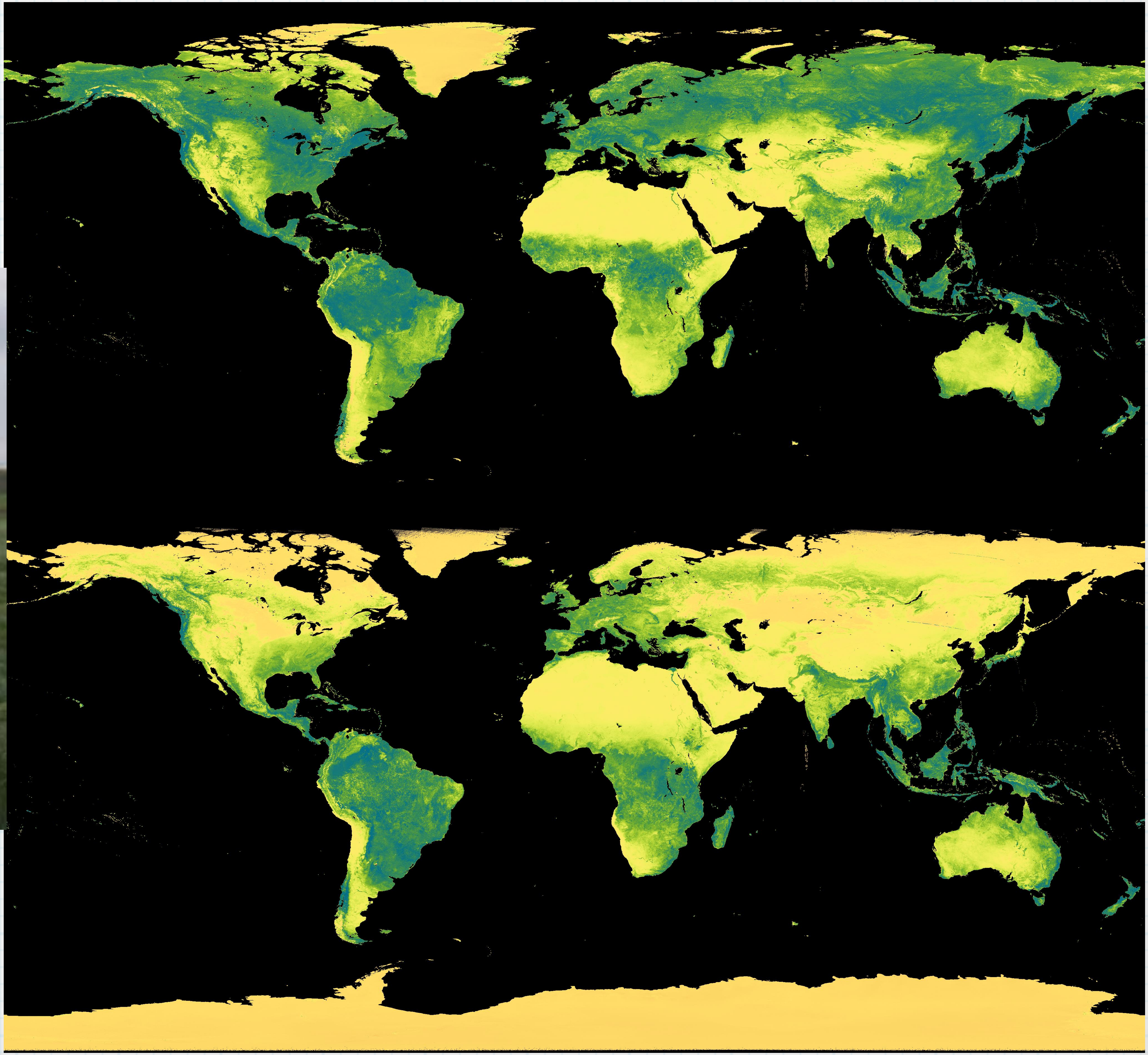
The “Greening” of the CSU-GCM
(Sellers - Mooney EOS Team)

AVHRR

and

NDVI

Jim Tucker



The Global Carbon Cycle

Inez Fung

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 88, NO. C2, PAGES 1281–1294, FEBRUARY 20, 1983

Three-Dimensional Tracer Model Study of Atmospheric CO_2: Response to Seasonal Exchanges With the Terrestrial Biosphere

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Institute for Space Studies, NASA/Goddard Space Flight Center, New York, New York 10025

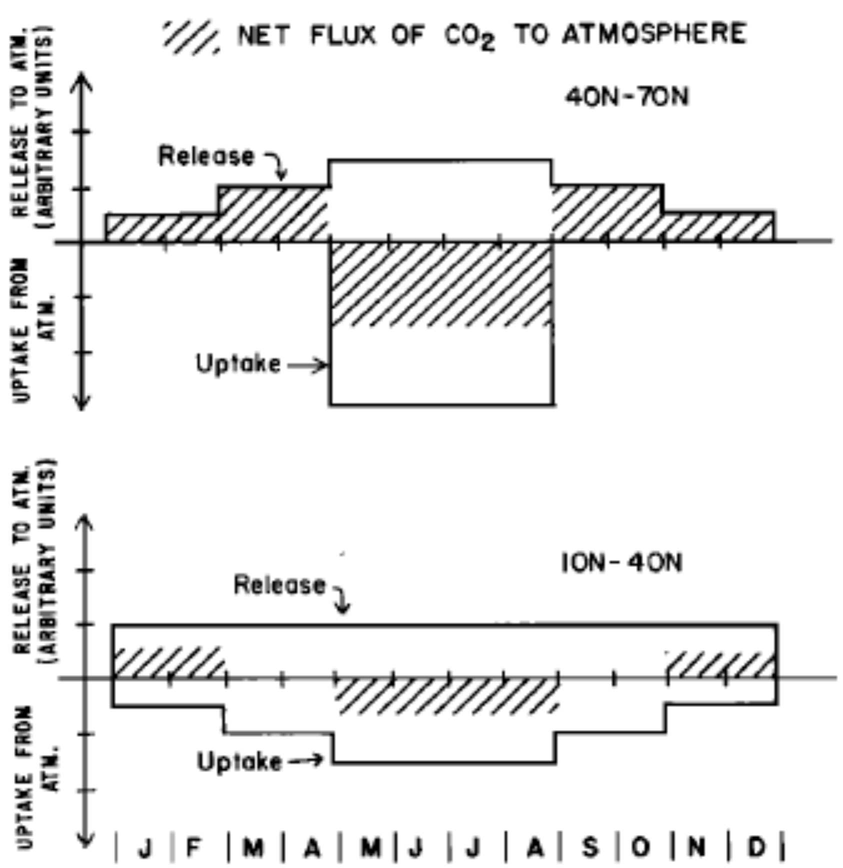


Fig. 3. Seasonality of biospheric uptake and release of CO_2 [after *Azevedo*, 1982] employed in experiment 3.

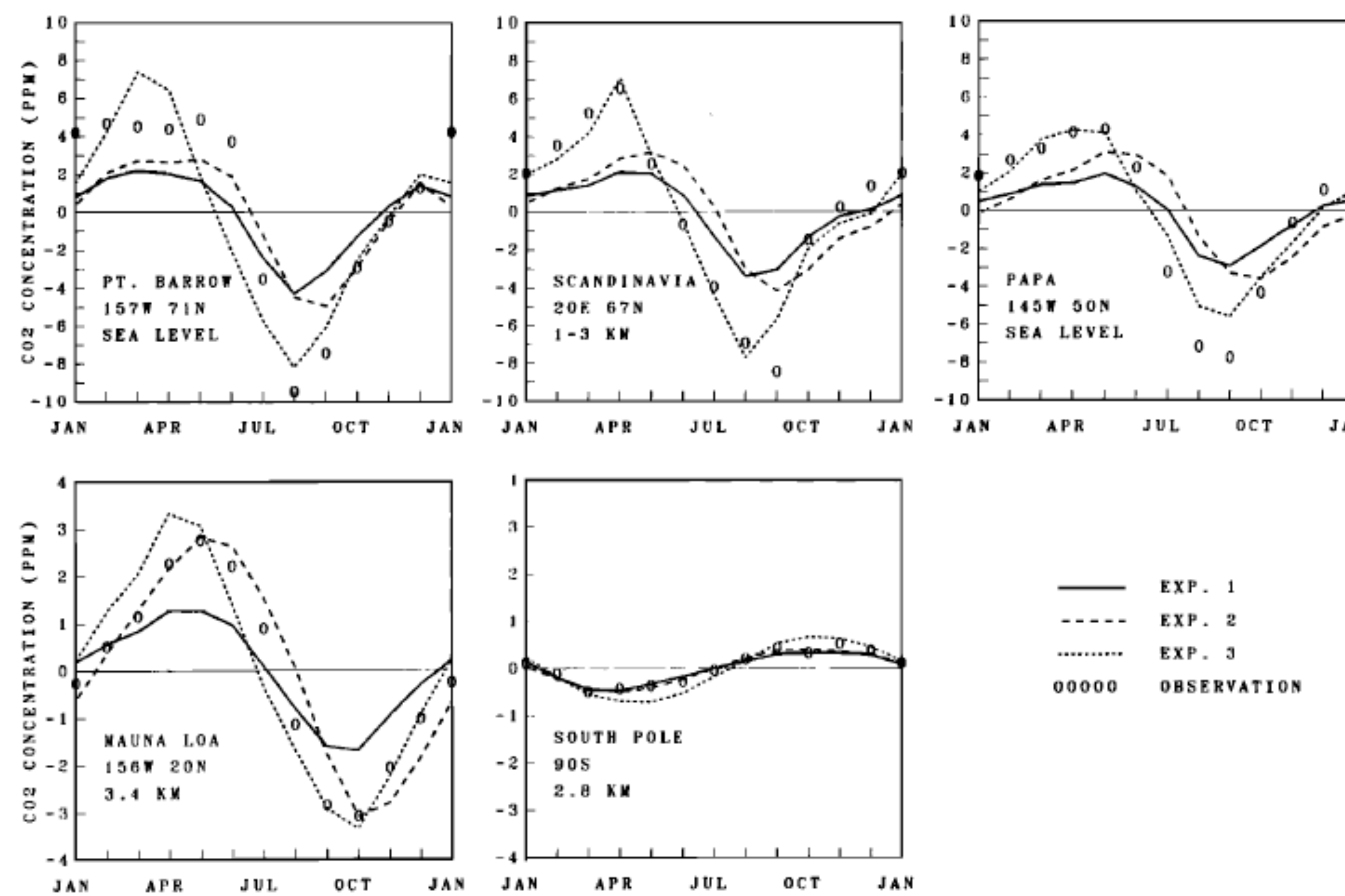
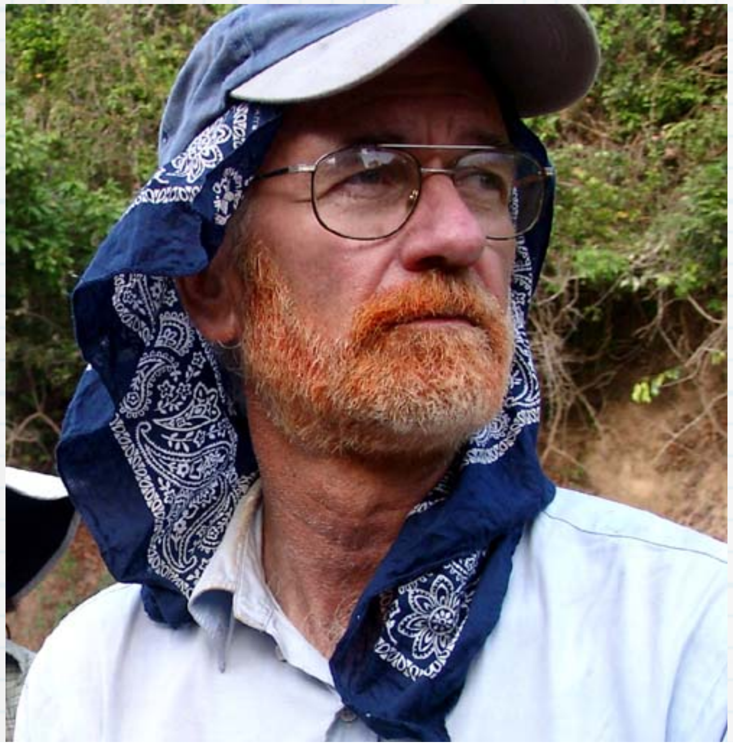


Fig. 4. Model simulated and observed annual cycles of CO_2 at five locations. Observations for Point Barrow, Papa, Mauna Loa, and the south pole are taken from *Pearman and Hyson* [1980] and that for Scandinavia from *Bolin and Bischof* [1970].

Jim Tucker

Remote Sensing



NATURE VOL. 319 16 JANUARY 1986 — ARTICLES

Relationship between atmospheric CO_2 variations and a satellite-derived vegetation index

C. J. Tucker*, I. Y. Fung†, C. D. Keeling‡ & R. H. Gammon§

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† NASA/Goddard Institute for Space Studies, New York, New York 10025, USA and Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York, New York 10964, USA
‡ Scripps Institution of Oceanography, La Jolla, California 92093, USA
§ NOAA/GMCC, Boulder, Colorado 80302, USA

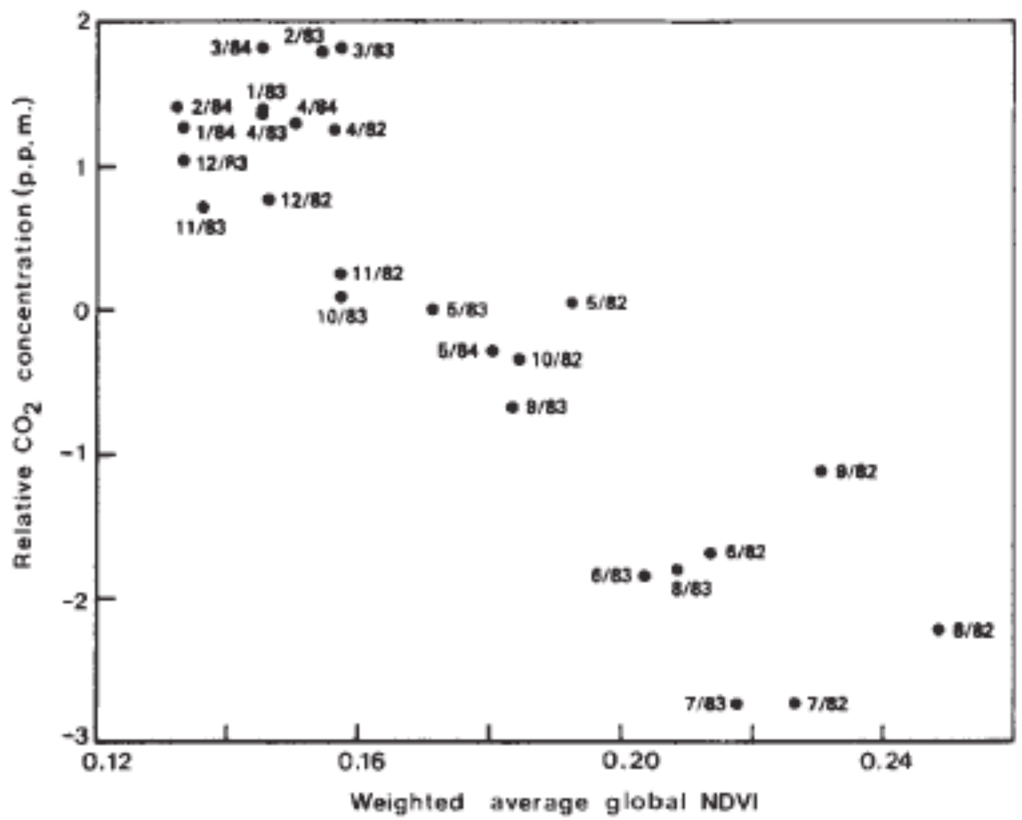


Fig. 4 The globally averaged atmospheric CO_2 concentration plotted against the globally averaged NDVI with a time lag of 1 month. The CO_2 data are from the global network of 20 NOAA/GMCC stations.

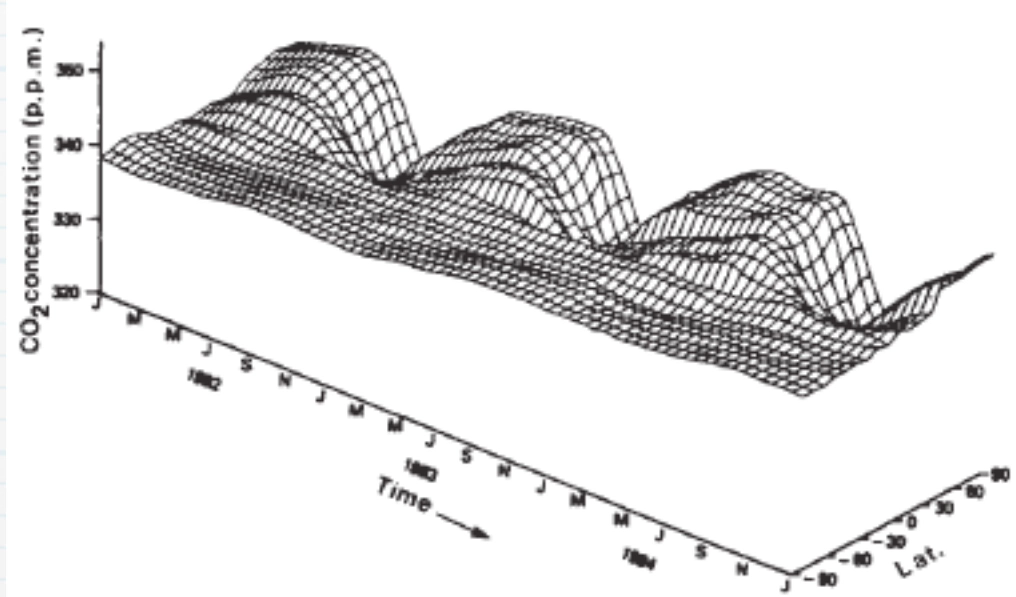
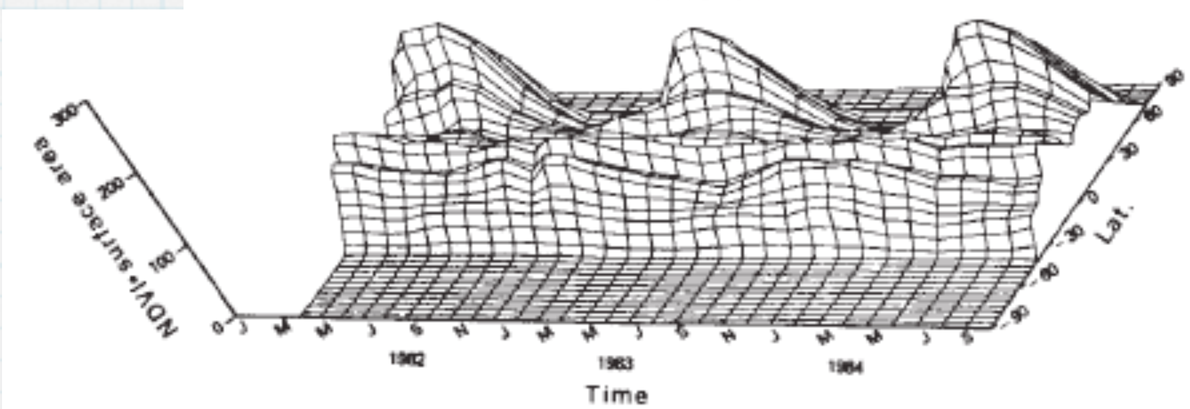


Fig. 1 Variation of global atmospheric CO_2 concentrations with latitude and time based on the NOAA/GMCC flask measurements for 1982–84.



Land-Surface Modeling

Canopy Conductance

Piers Sellers

A Simple Biosphere Model (SiB) for Use within General Circulation Models

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Dept. of Meteorology, University of Maryland, College Park, MD 20742

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Laboratory for Atmospheres, NASA/Goddard Space Flight Center, Greenbelt, MD 20771

A. DALCHER

Sigma Data Computing Corp., Rockville, MD 20850

(Manuscript received 26 February 1985, in final form 5 September 1985)

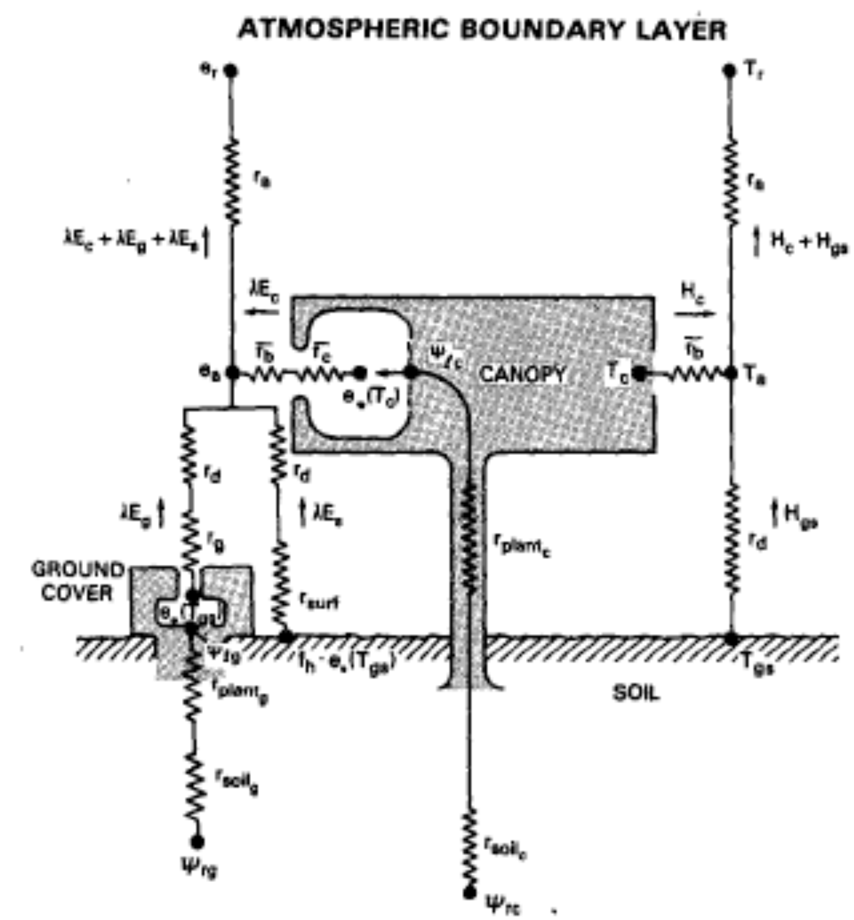
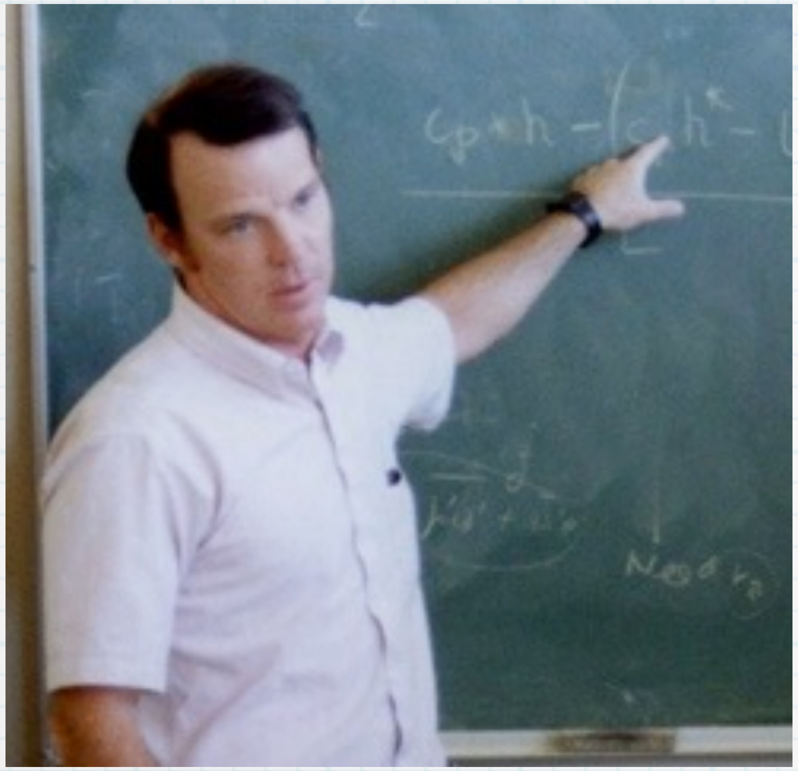


FIG. 2. Framework of the Simple Biosphere (SiB). The transfer pathways for latent and sensible heat flux are shown on the left- and right-hand sides of the diagram respectively. The treatment of radiation and intercepted water has been omitted for clarity. Symbols are defined in Table 2.

Dave Randall

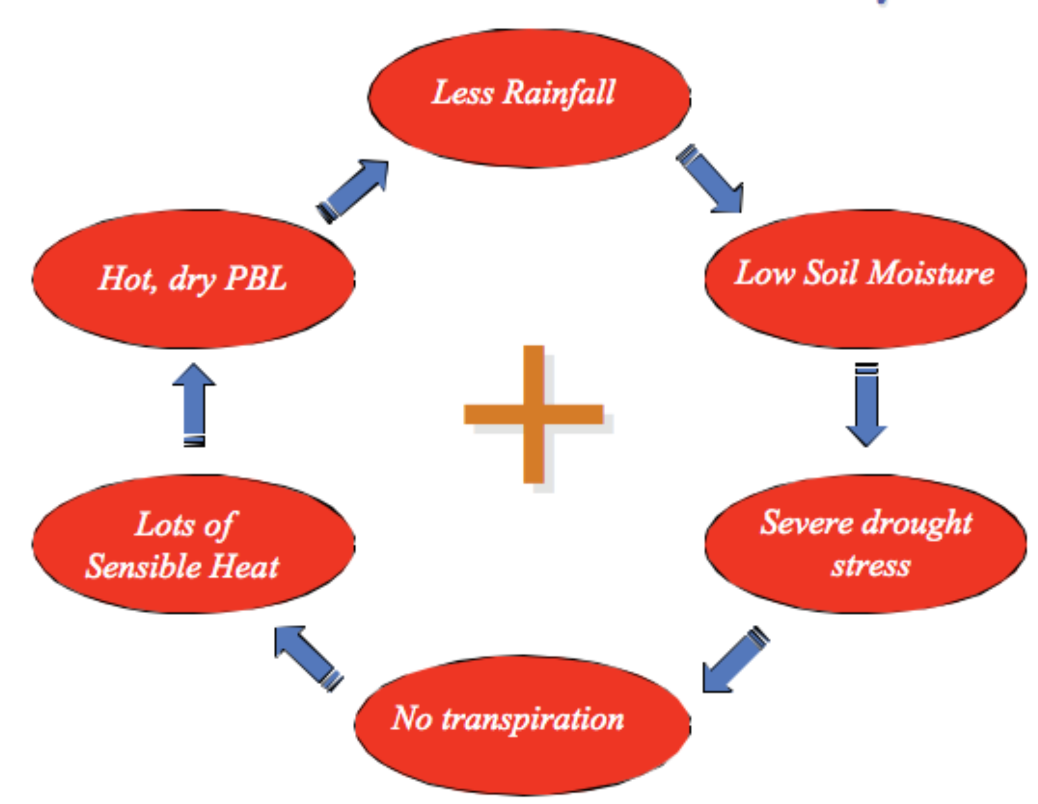
Effects of Implementing the Simple Biosphere Model in a General Circulation Model

N. SATO,* P. J. SELLERS, D. A. RANDALL,** E. K. SCHNEIDER, J. SHUKLA,
J. L. KINTER III, Y-T. HOU AND E. ALBERTAZZI



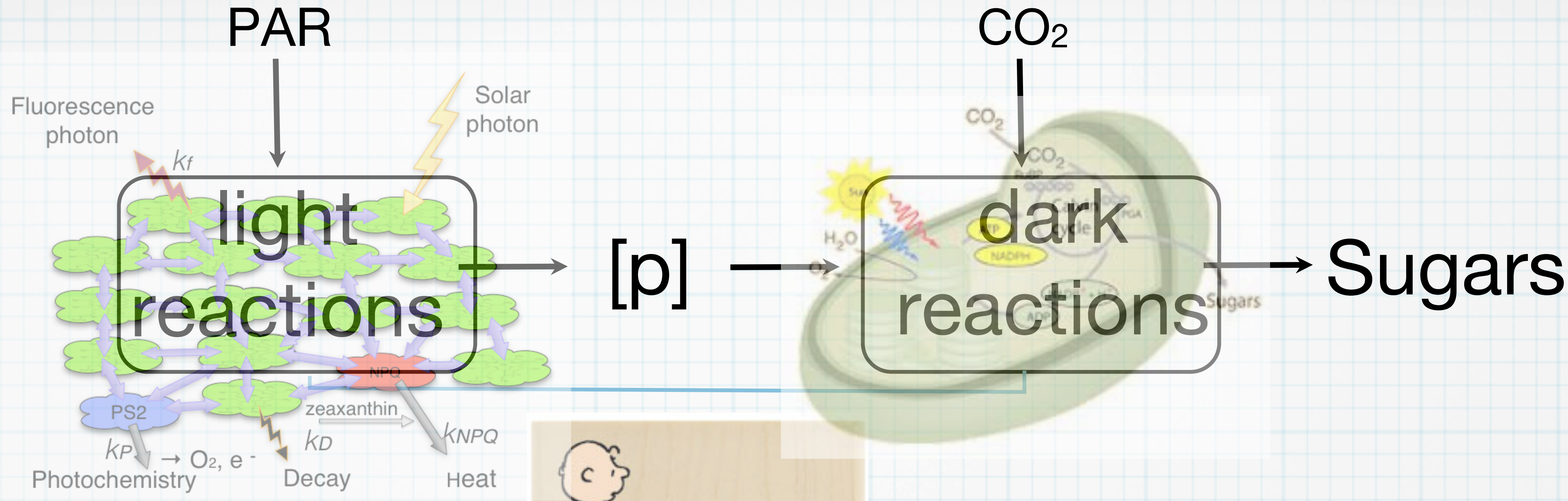
SiB worked fine when run with "prescribed" climate.
However, when it was run in the climate model, the land areas of the planet dried up and became deserts.

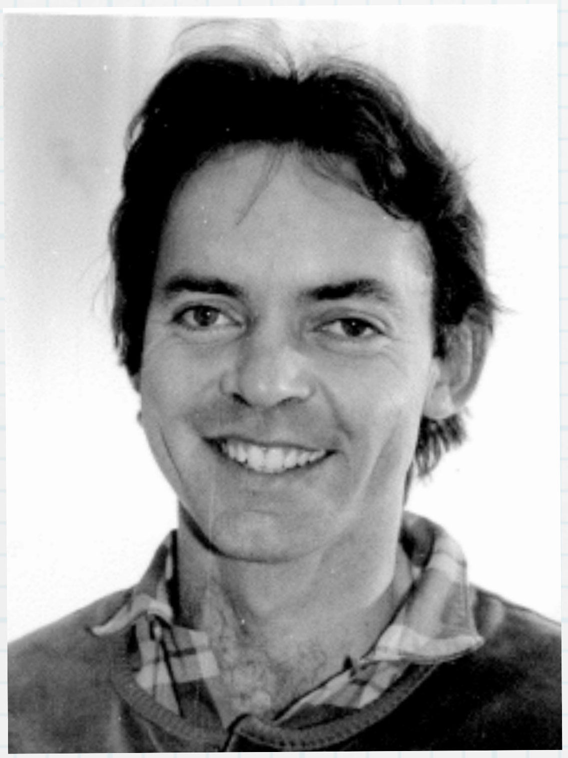
Precipitation and Ecosystem Stress:
A Positive Feedback Loop



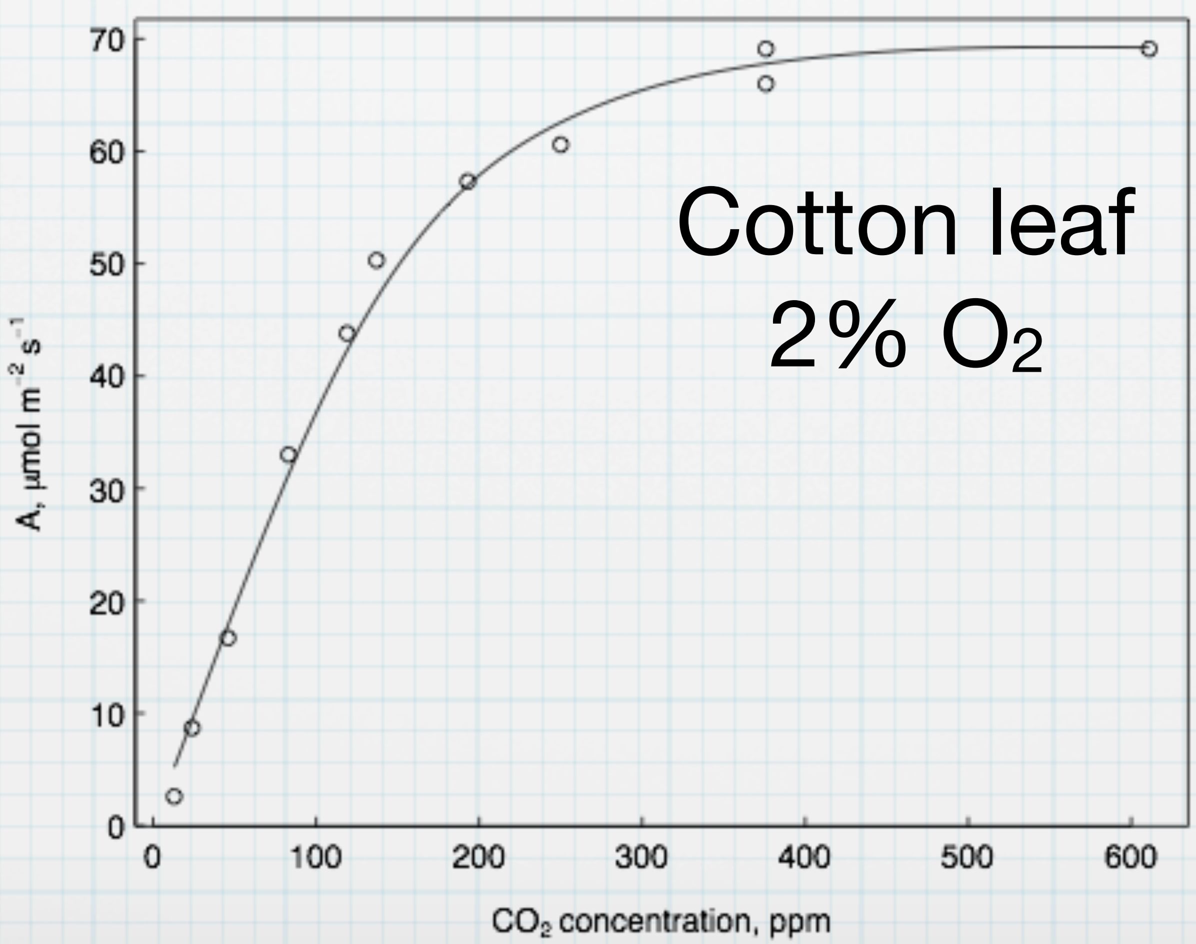
Dave referred to this as:
"Stomatal Suicide"

This gave us an opening to try to fix it with physiology.





Graham Farquhar



Susanne von Caemmerer

$$(2+1.5\beta/\alpha)V_c\left[V_{G_{max}}(1-V_c/\alpha)+\frac{V_{N_{max}}}{1+K_I/I}\right] = V_{G_{max}}\left(1-V_c/\alpha\right.$$

$$V_c^2\left(-\frac{V_{Gmax}}{\alpha}(2+1.5\beta/\alpha)\right)+V_c\left((2+1.5\beta/\alpha)\left(V_{G_{max}}+\frac{V_{N_{max}}}{1+K_I/I}\right)+\frac{V_{Gmax}}{\alpha}\right.$$

$\times$ b.s by $\frac{(1+K_I/I)}{-V_{G\,max}}$ $\quad - V_{G_{max}}\frac{V_{N_{max}}}{1+K_I/I}\;0$

$$\frac{V_c^2}{\alpha^2}(2\alpha+1.5\beta)(1+K_I/I)-\frac{V_c}{\alpha}\left[(2\alpha+1.5\beta)(1+K_I/I)+\frac{V_{N_{max}}}{V_{G\,max}}\right)+ \ldots = 0$$

$+ V_{N_{max}}$

$$\frac{V_c^2}{\alpha^2}(2\alpha+1.5\beta)(1+K_I/I)-\frac{V_c}{\alpha}\left[(2\alpha+1.5\beta)\left(1+\frac{K_I}{I}+\frac{V_{N_{max}}}{V_{G_{max}}}\right)+V_{N_{max}}\right.$$

$+ V_{N_{max}}$

$$V_0 = \frac{\beta}{\alpha}V_c$$

$$\frac{V_c}{\alpha} = \frac{\left\{\left[(2\alpha+1.5\beta)\left(1+\frac{K_I}{I}+\frac{V_{N_{max}}}{V_{G_{max}}}\right)+V_{N_{max}}\right\}\pm\sqrt{\{\ \}^2-4(2\alpha+1.5\beta)(1+\ldots}}{2(2\alpha+1.5\beta)(1+K_I/I)}$$

$I \equiv I$, $K_I \equiv I1$, $V_{N_{MAX}} \equiv N$, $V_{G_{max}} \equiv P$

$\alpha \equiv VG$, $\beta \equiv V\emptyset$

remember change 130, 140, 270

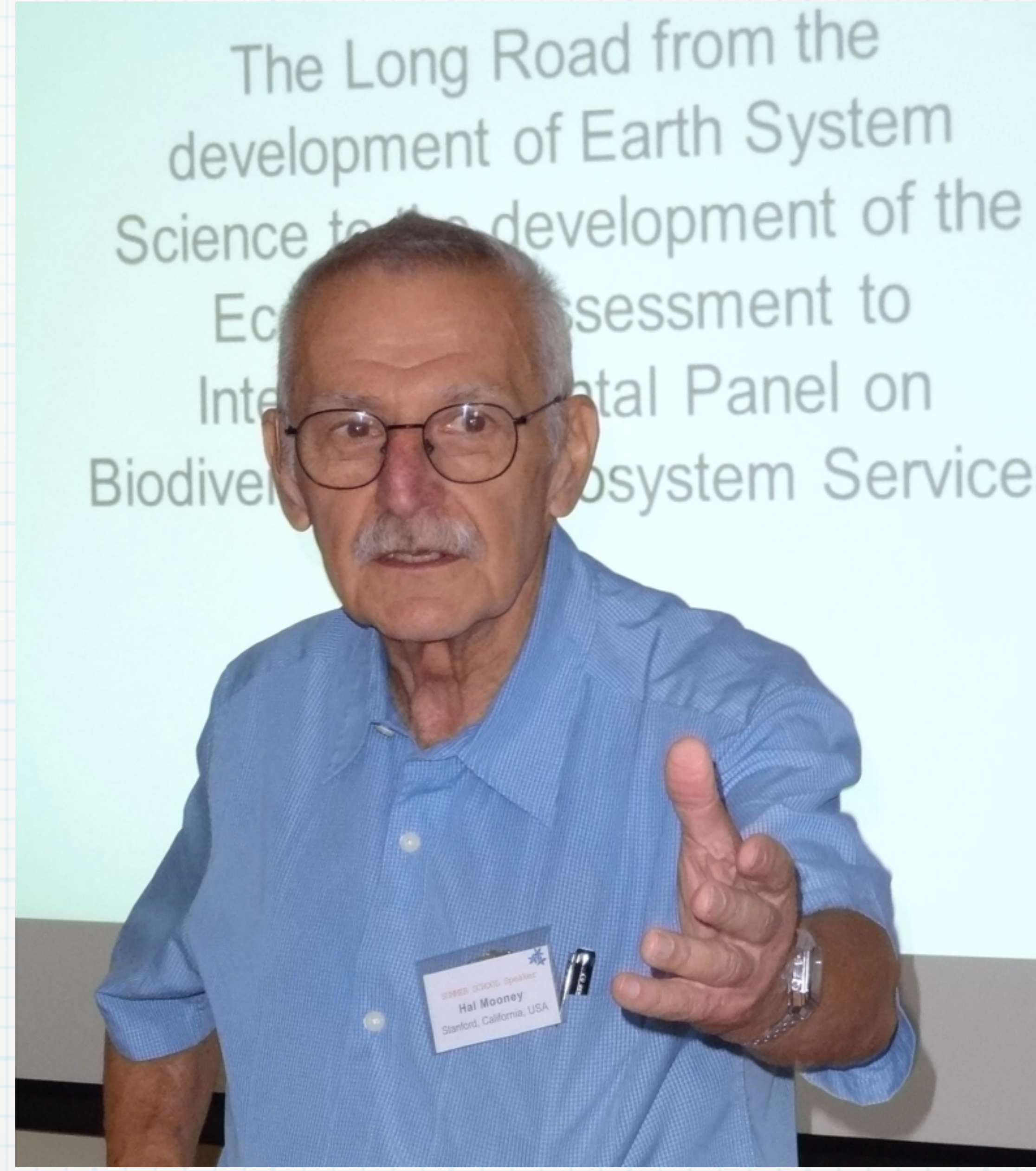
P 1629x

N 146x

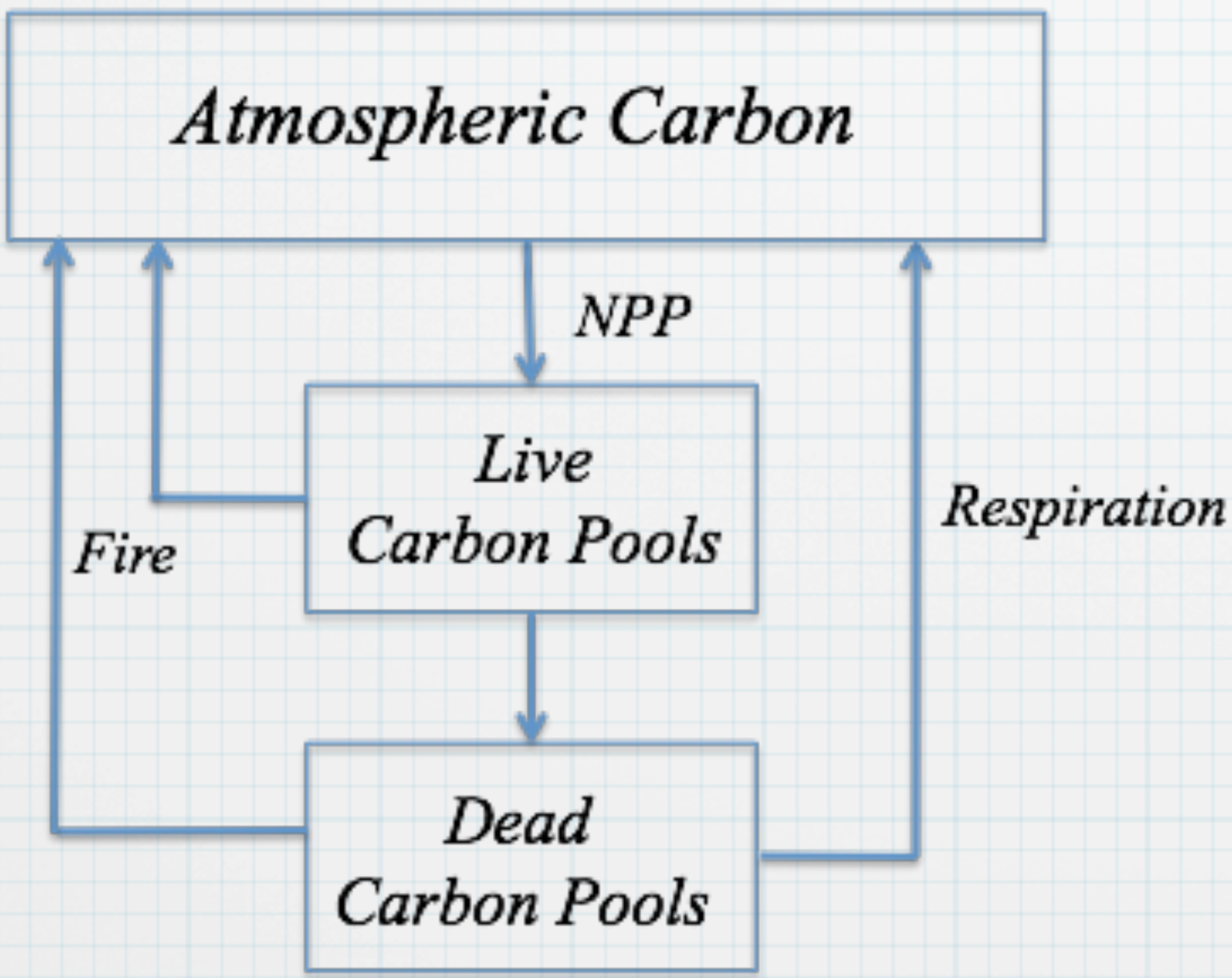
$V_c \equiv WG$, $V_0 \equiv W\emptyset$

130 I = 2000
135 I1 = 1000
140 P = 430
145 N = 39


Chris Field


The Long Road from the
development of Earth System

Hal Mooney


Atmospheric Carbon
NPP
Live
Carbon Pools
Fire
Respiration
Dead
Carbon Pools

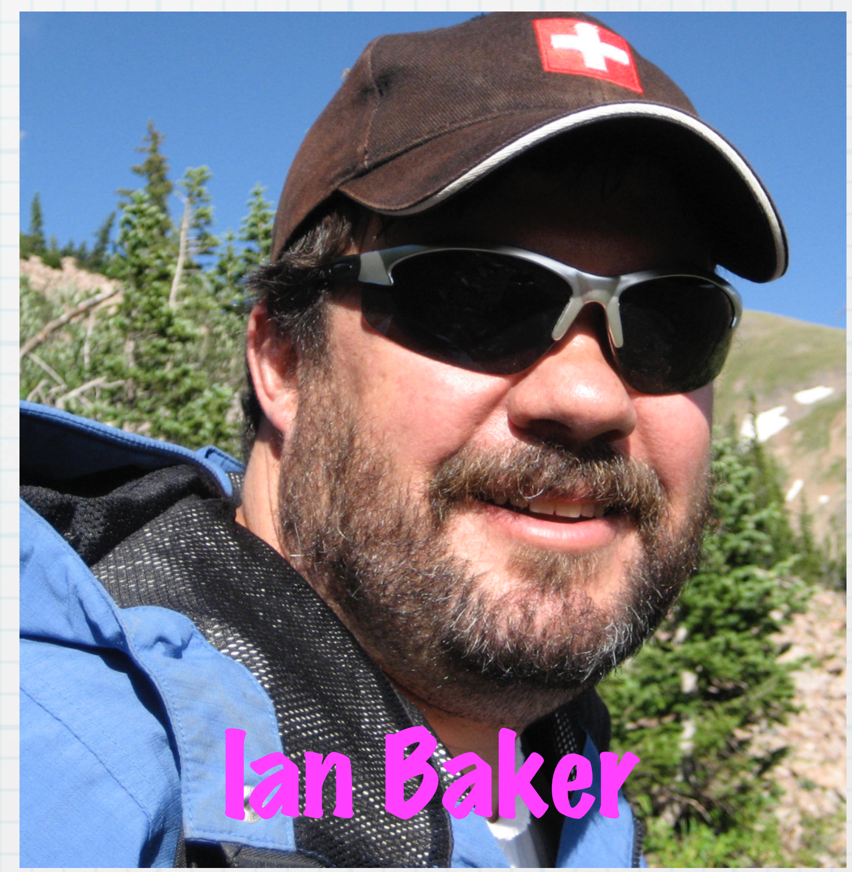

Greg Asner

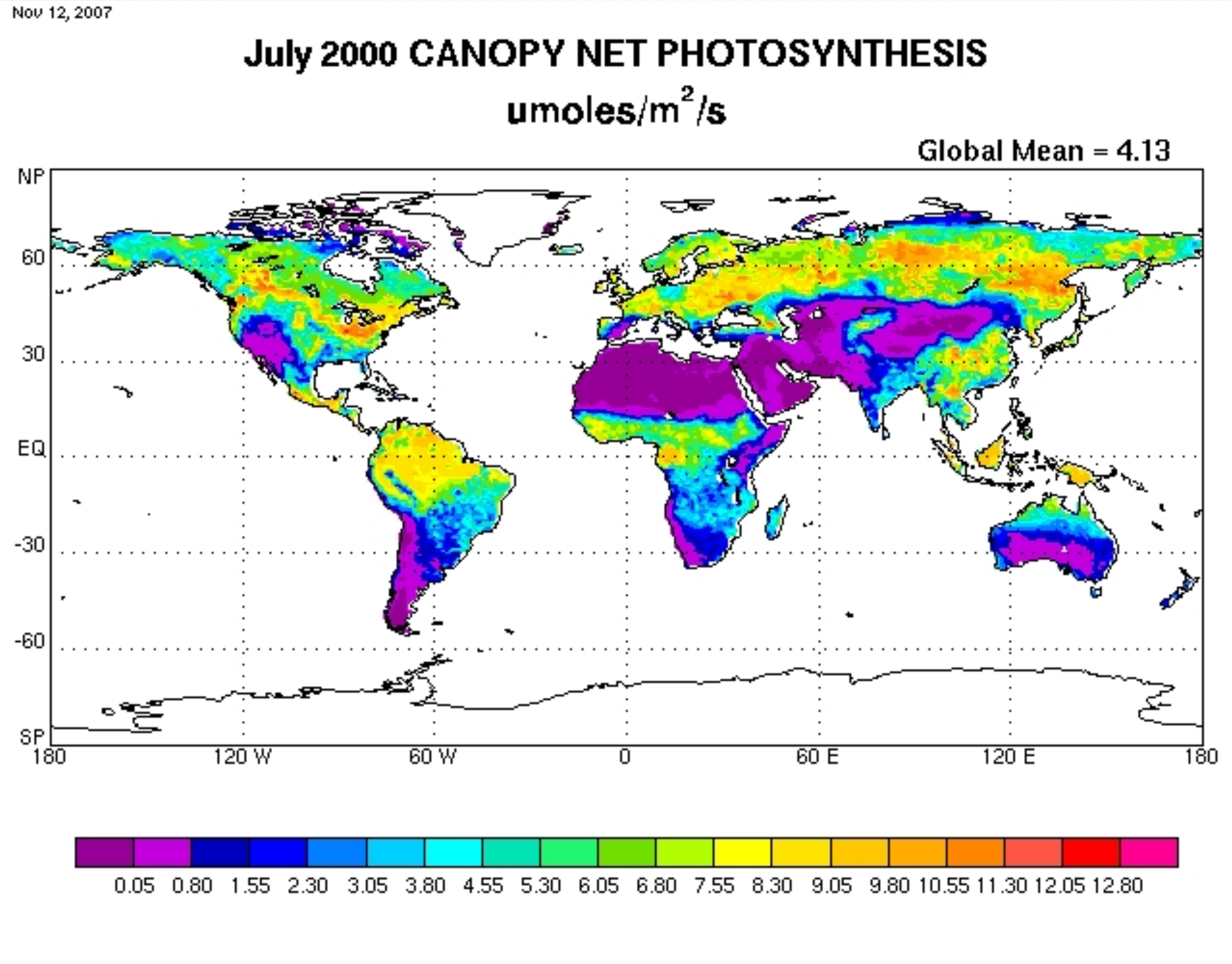

Scott Denning


Jim Randerson


Ruth de Freis


Chris Still


Ian Baker


Nov 12, 2007
July 2000 CANOPY NET PHOTOSYNTHESIS
umoles/m²/s
Global Mean = 4.13
NP
60
30
EQ
-30
-60
SP
180
120 W
60 W
0
60 E
120 E
180
0.05 0.80 1.55 2.30 3.05 3.80 4.55 5.30 6.05 6.80 7.55 8.30 9.05 9.80 10.55 11.30 12.05 12.80

To summarize:

Breakthroughs aren’t obvious until they happen.

The pieces that ultimately fit together are the key to breakthroughs; we need to be *looking* for them, and we need *cultivate* them.

In light of the Decadal Survey, I’d like to make the point that the NASA centers are a tremendous resource for

this “scientific potential energy”

flipping the switches of the universe

That's how we got here. Now, where are we going?

Several speakers have already mentioned fluorescence

Key discoveries:

Plascyk, J. A. (1975). The MK II Fraunhofer Line Discriminator (FLD-II) for Airborne and Orbital Remote Sensing of Solar-Stimulated Luminescence. Optical Engineering, 14(4), 339–0. http://doi.org/10.1117/12.7971842

Perkin-Elmer & Wollops

Guanter, L., Alonso, L., Gómez-Chova, L., Amorós-López, J., Vila, J., & Moreno, J. (2007). Estimation of solar-induced vegetation fluorescence from space measurements. Geophysical Research Letters, 34(8), L08401. http://doi.org/10.1029/2007GL029289

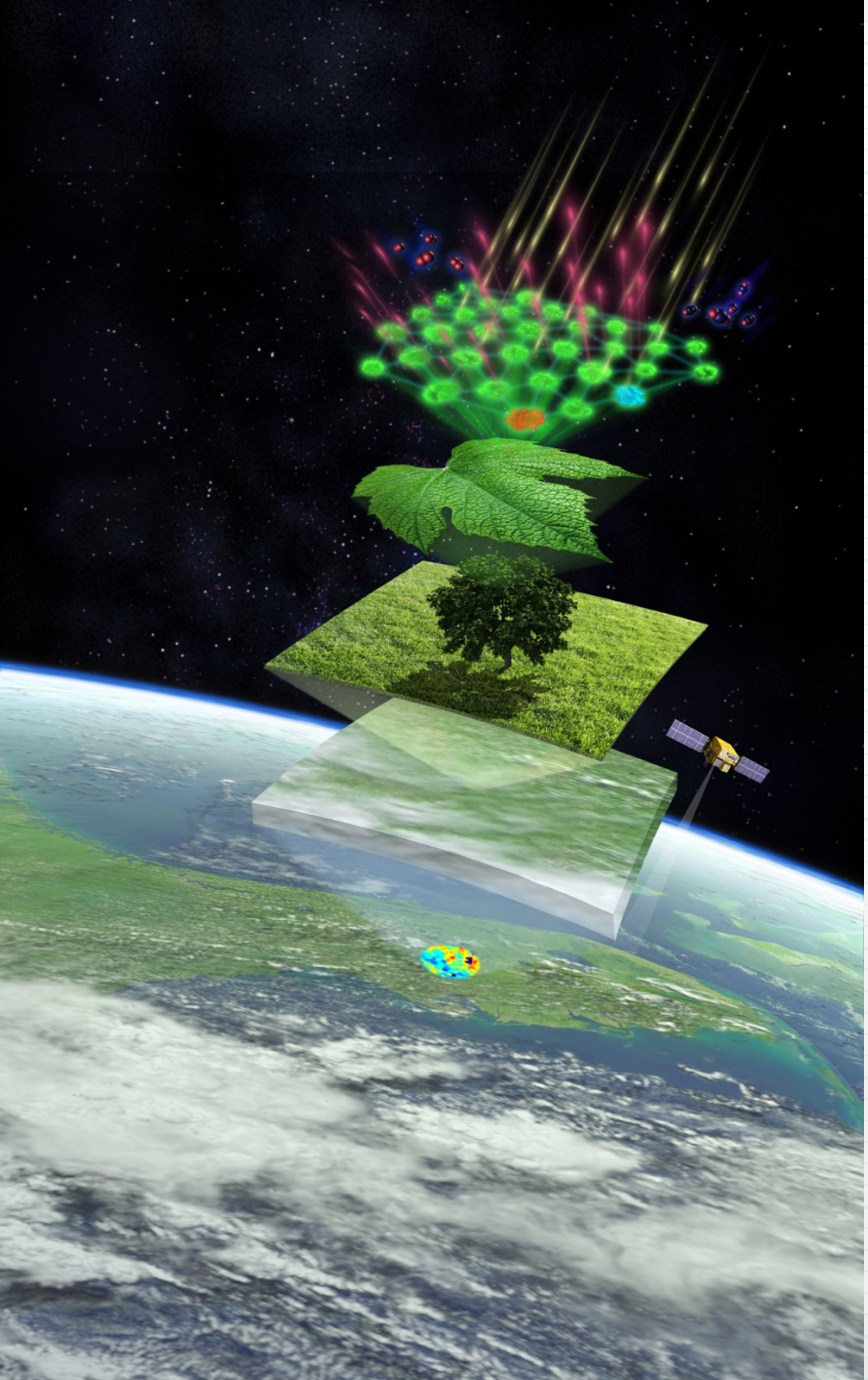
ESA

Frankenberg, C., Butz, A., & Toon, G. C. (2011). Disentangling chlorophyll fluorescence from atmospheric scattering effects in O 2A-band spectra of reflected sun-light. GEOPHYSICAL RESEARCH LETTERS, 38(3), L03801. doi: 10.1029/2010GL045896

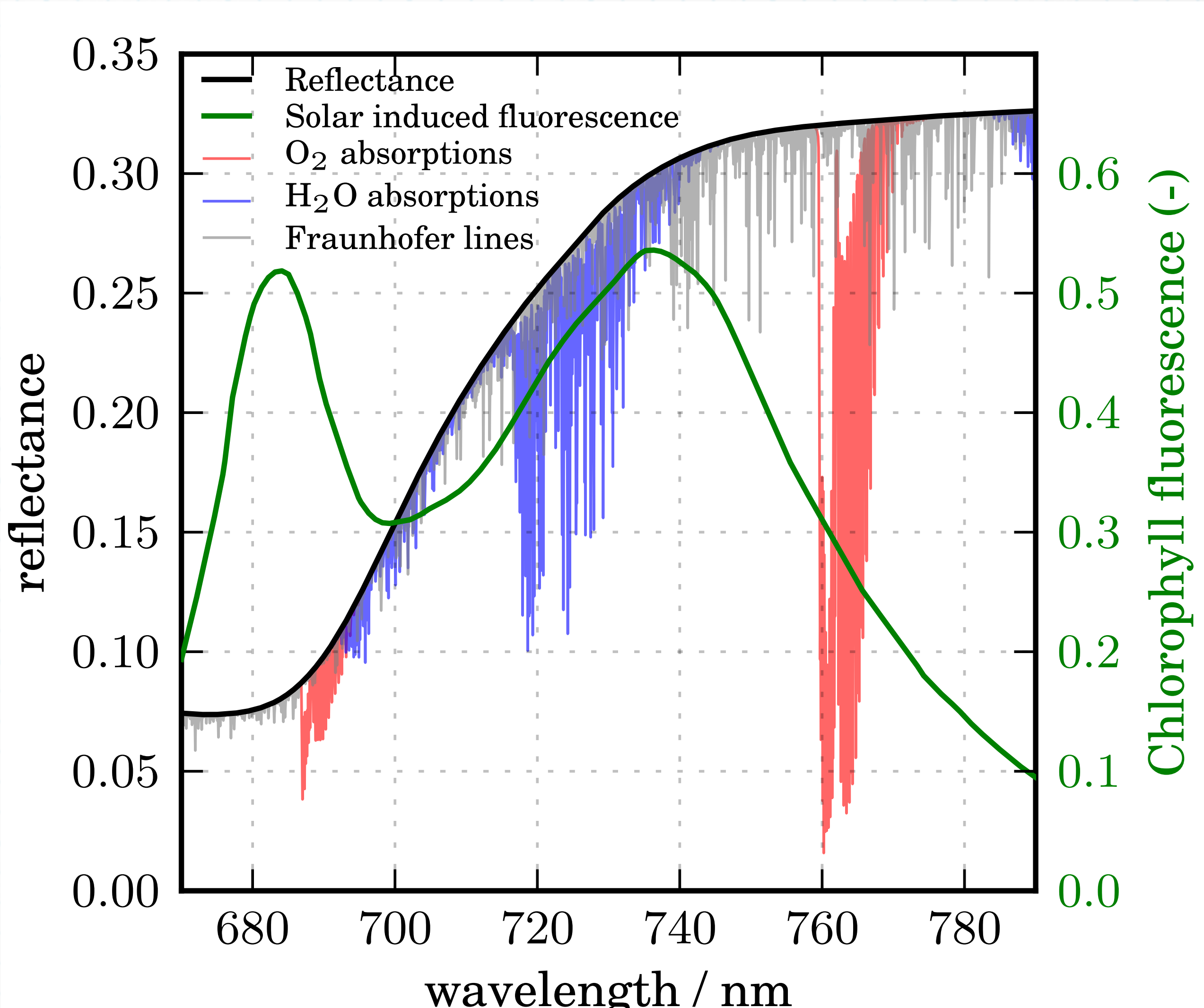
JPL

Joiner, J., Yoshida, Y., Vasilkov, A. P., Yoshida, Y., Corp, L. A., & Middleton, E. M. (2011). First observations of global and seasonal terrestrial chlorophyll fluorescence from space. Biogeosciences, 8(3), 637–651. doi:10.5194/bg-8-637-2011

GSFC

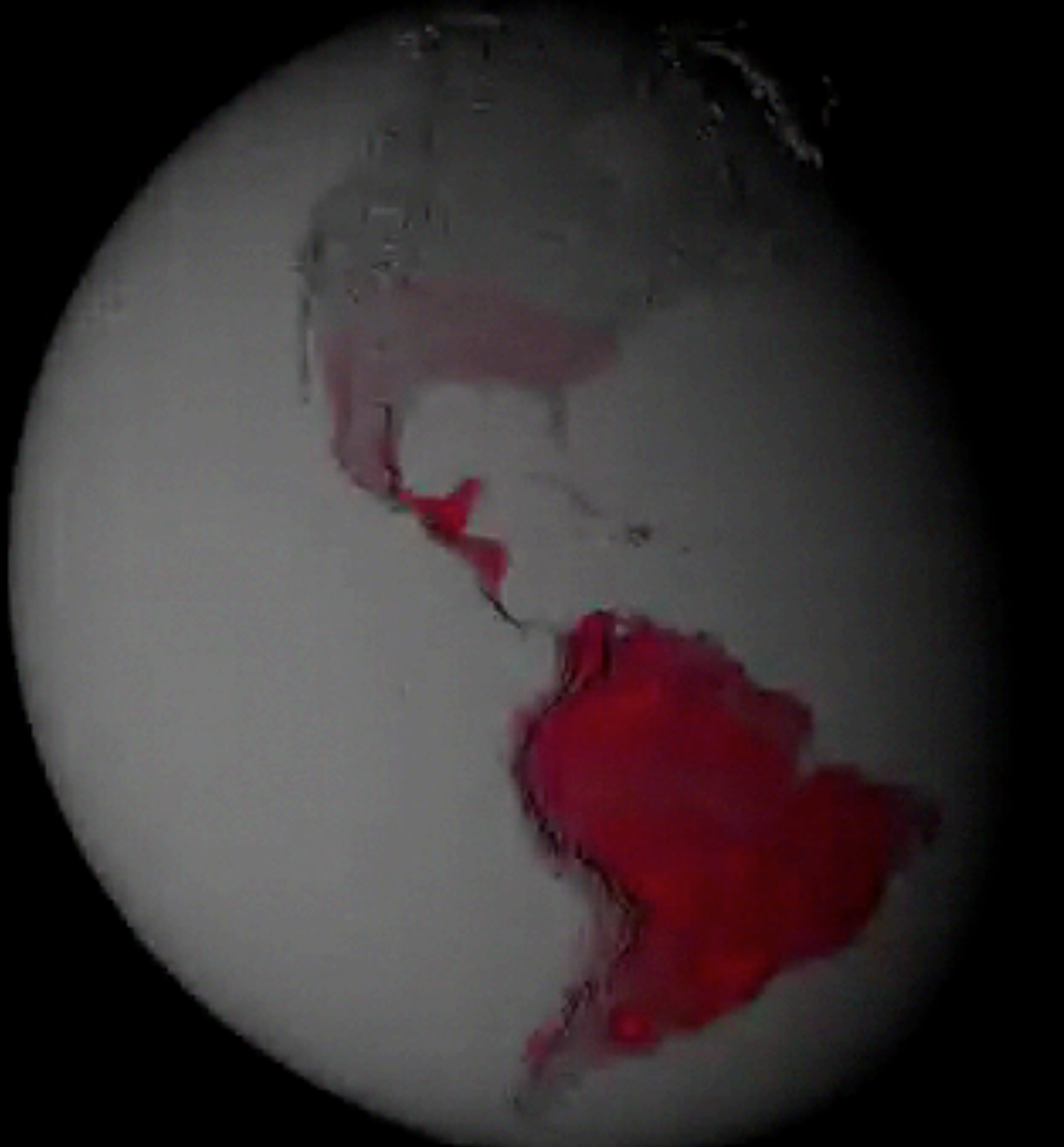


• Fluorescence from terrestrial plants is difficult to measure because it is mixed with reflected

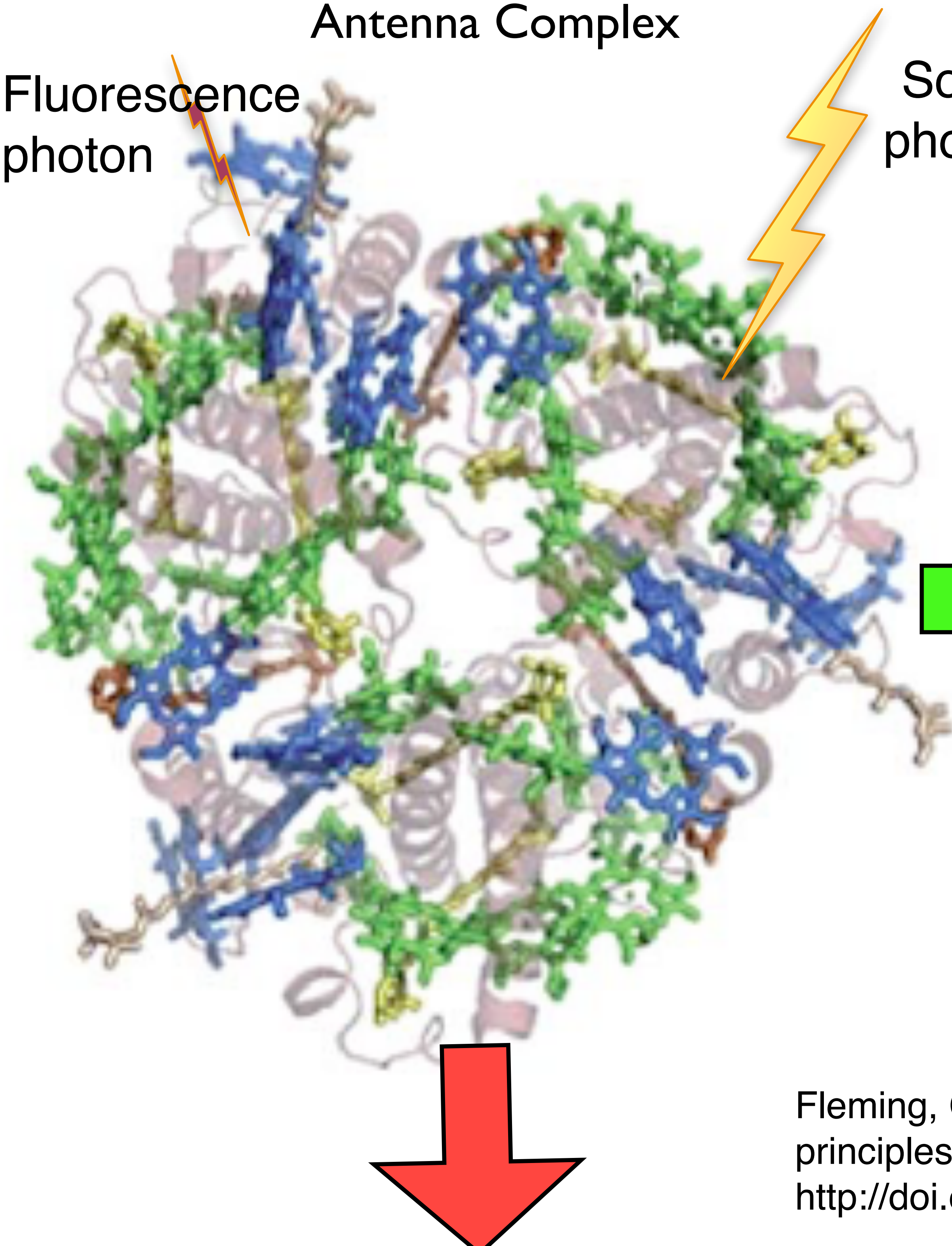


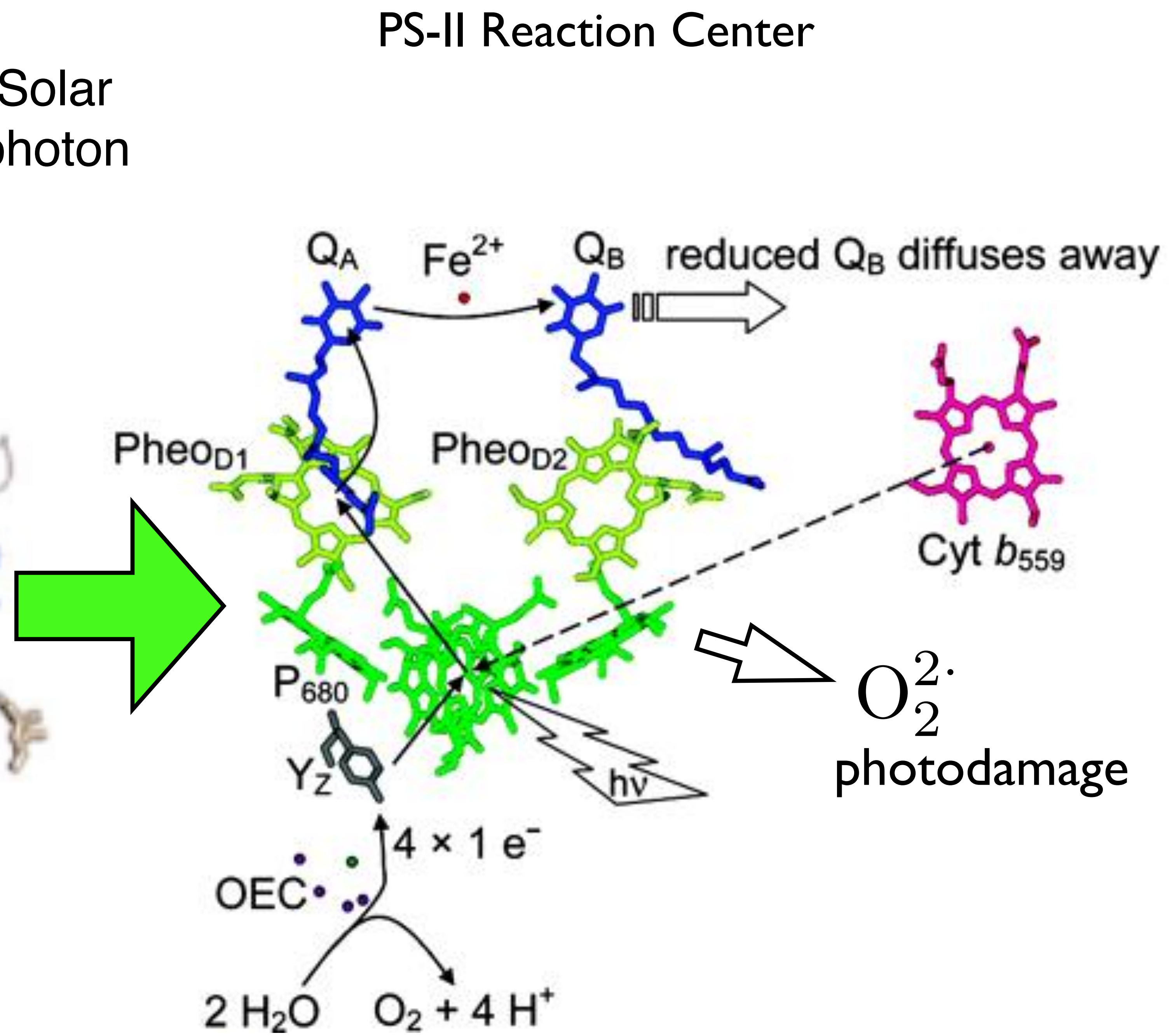
• In-filling of lines in the solar spectrum can be used to distinguish fluorescence from reflected light.

• It takes a special high resolution spectrometer. So far it has been accomplished with 5 satellites



Fluorescence in Photosynthesis Research

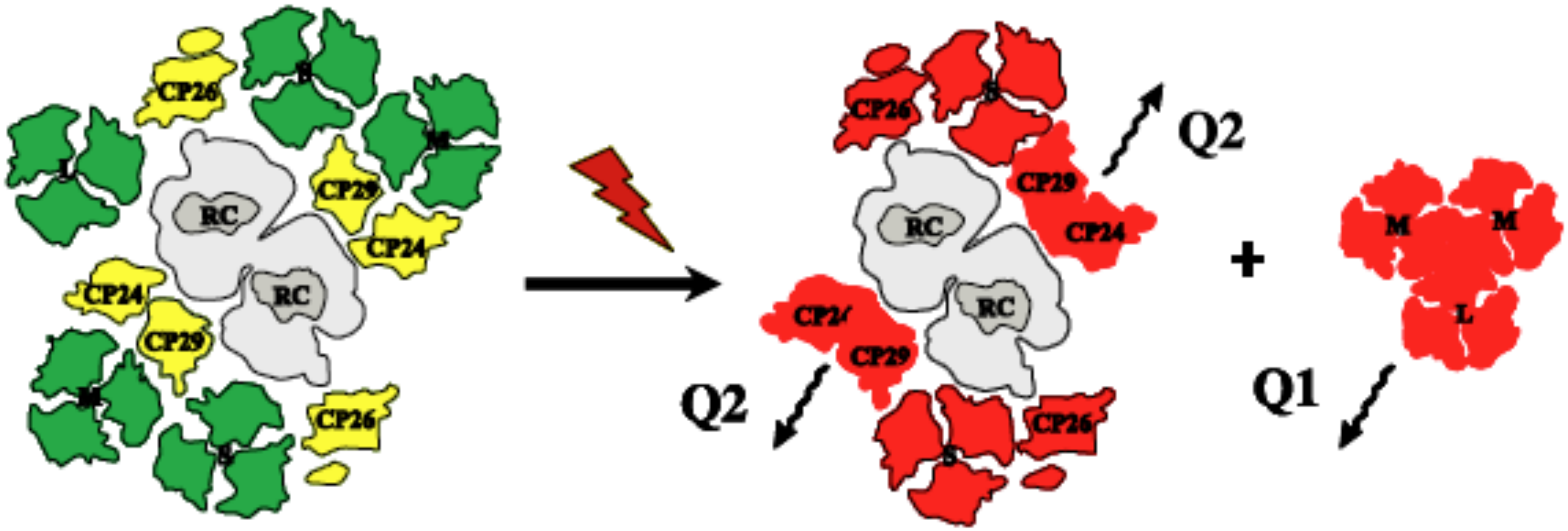


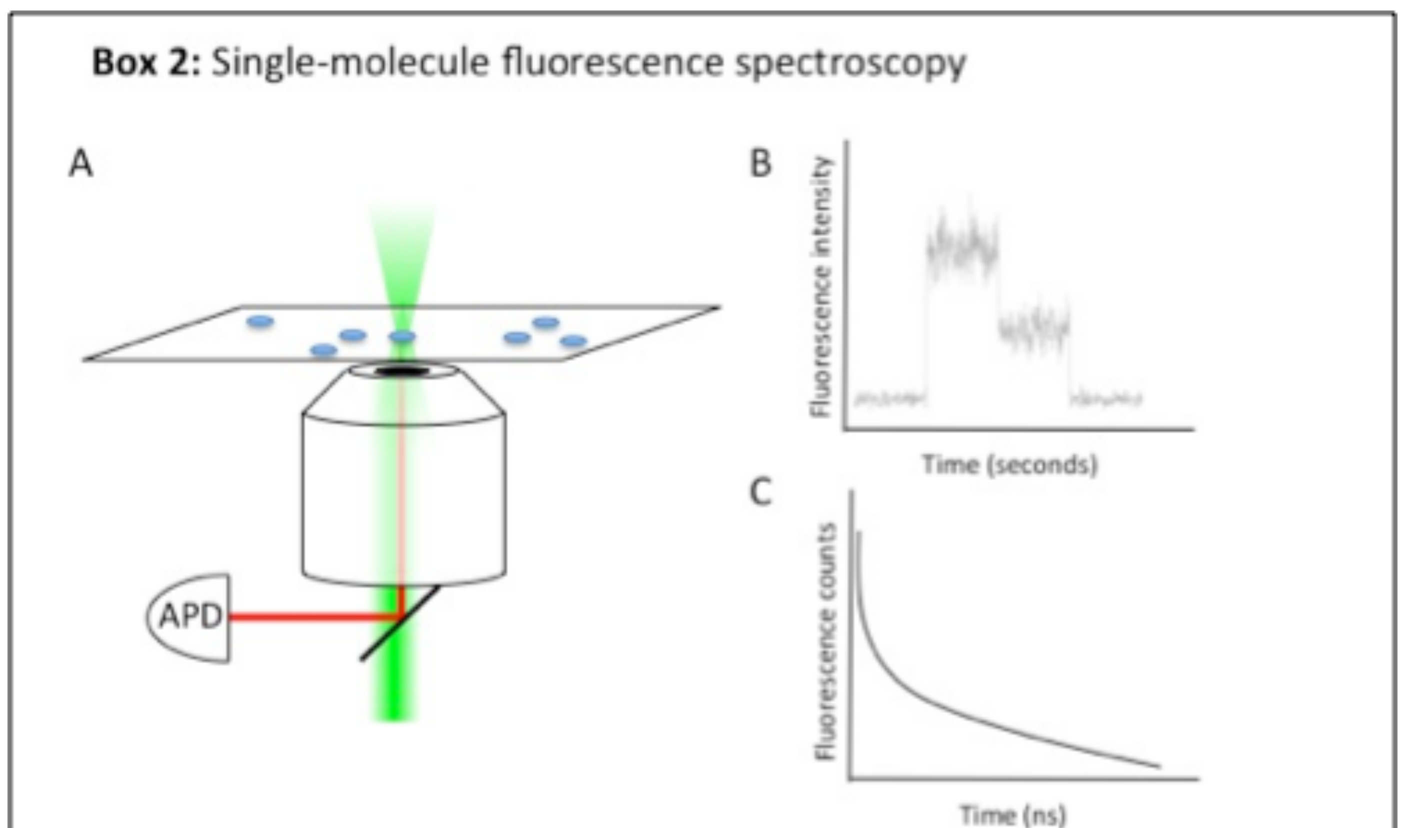


Fleming, G. R., Schlau-Cohen, G. S., Amarnath, K., & Zaks, J. (2012). Design principles of photosynthetic light-harvesting. Faraday Discussions, 155, 27. http://doi.org/10.1039/c1fd00078k

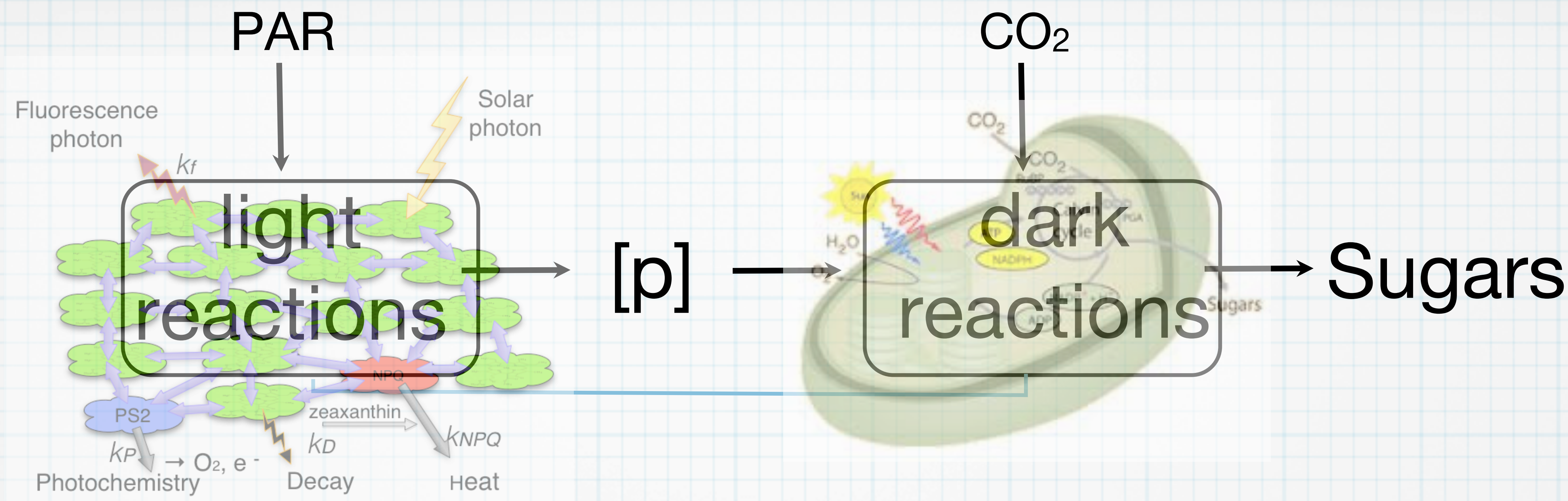
Non-photochemical Quenching

Non Photochemical Quenching

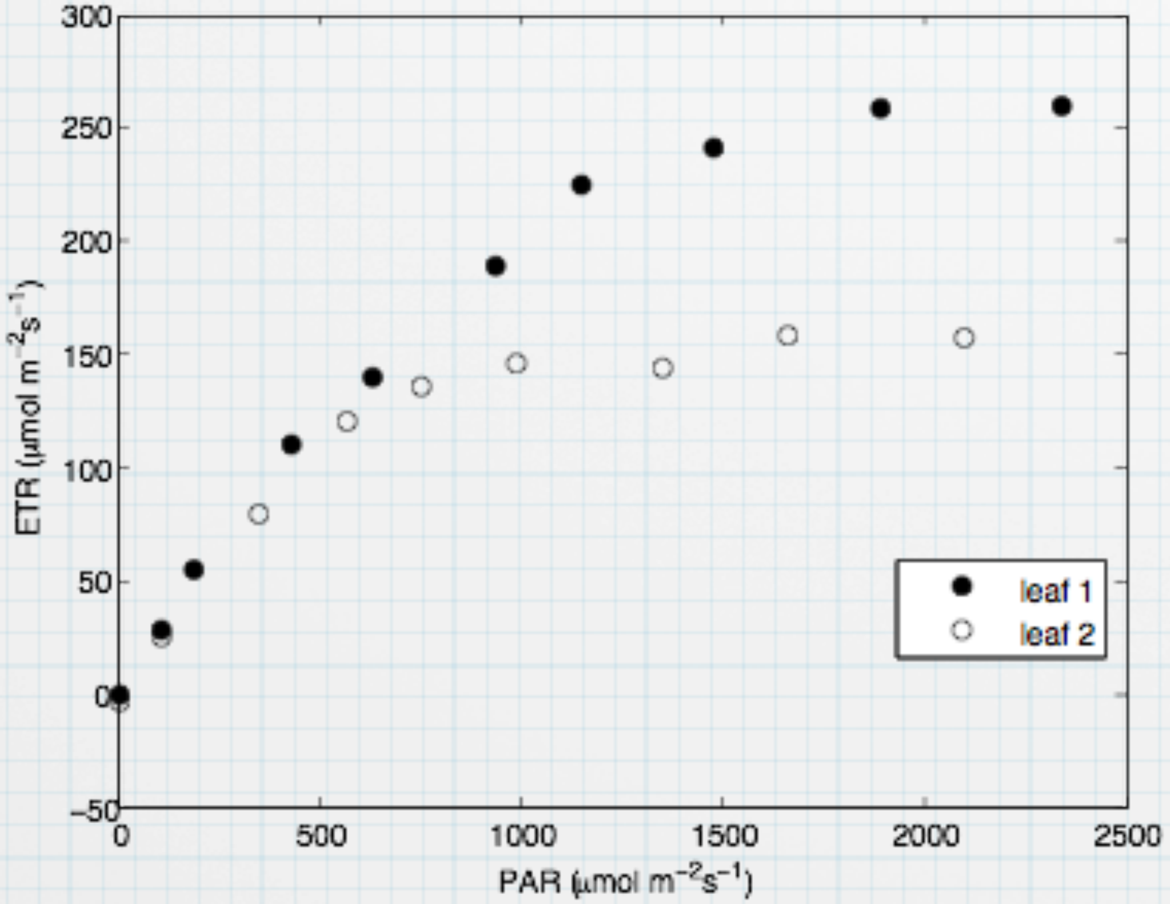


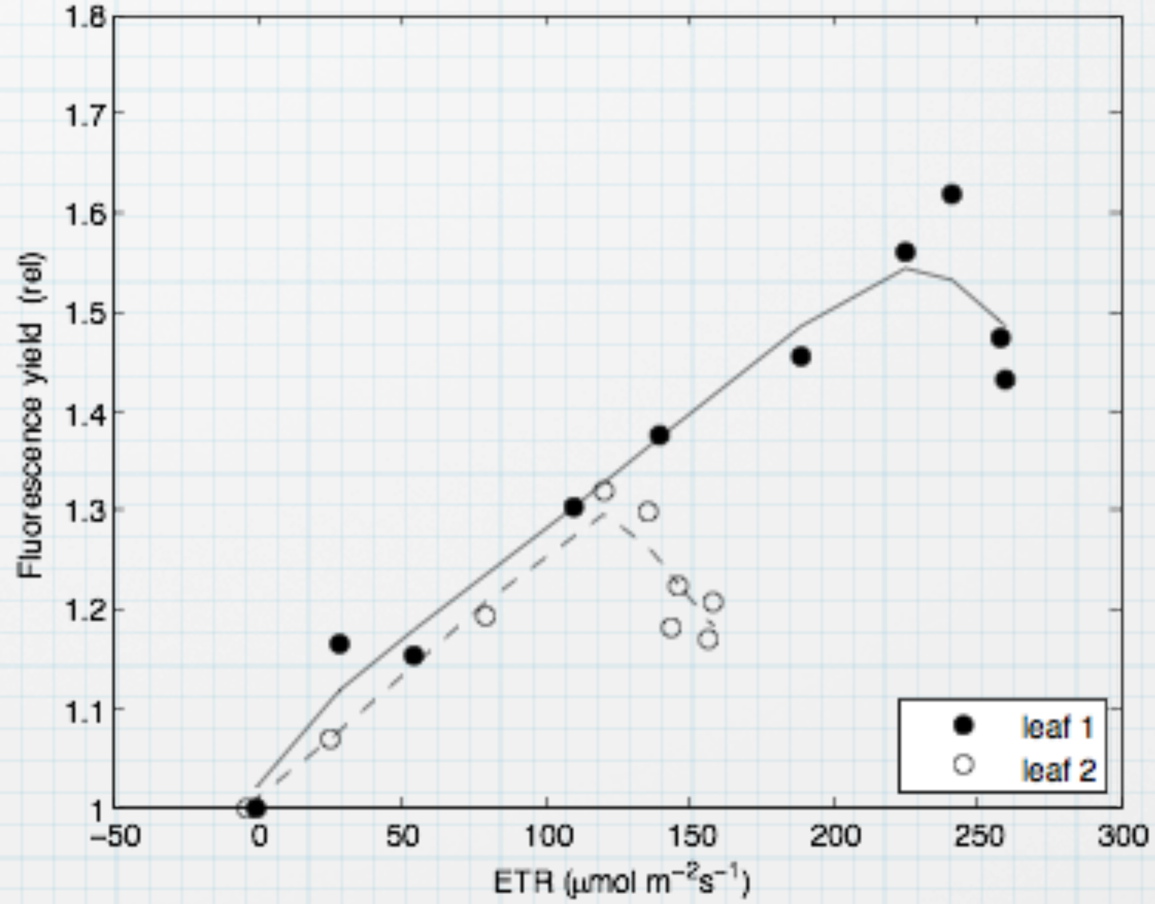


Schlau-Cohen, G. S., Bockenhauer, S., Wang, Q., & Moerner, W. E. (2014). Single-molecule spectroscopy of photosynthetic proteins in solution: exploration of structure–function relationships. Chemical Science, 5(8), 2933. http://doi.org/10.1039/c4sc00582a

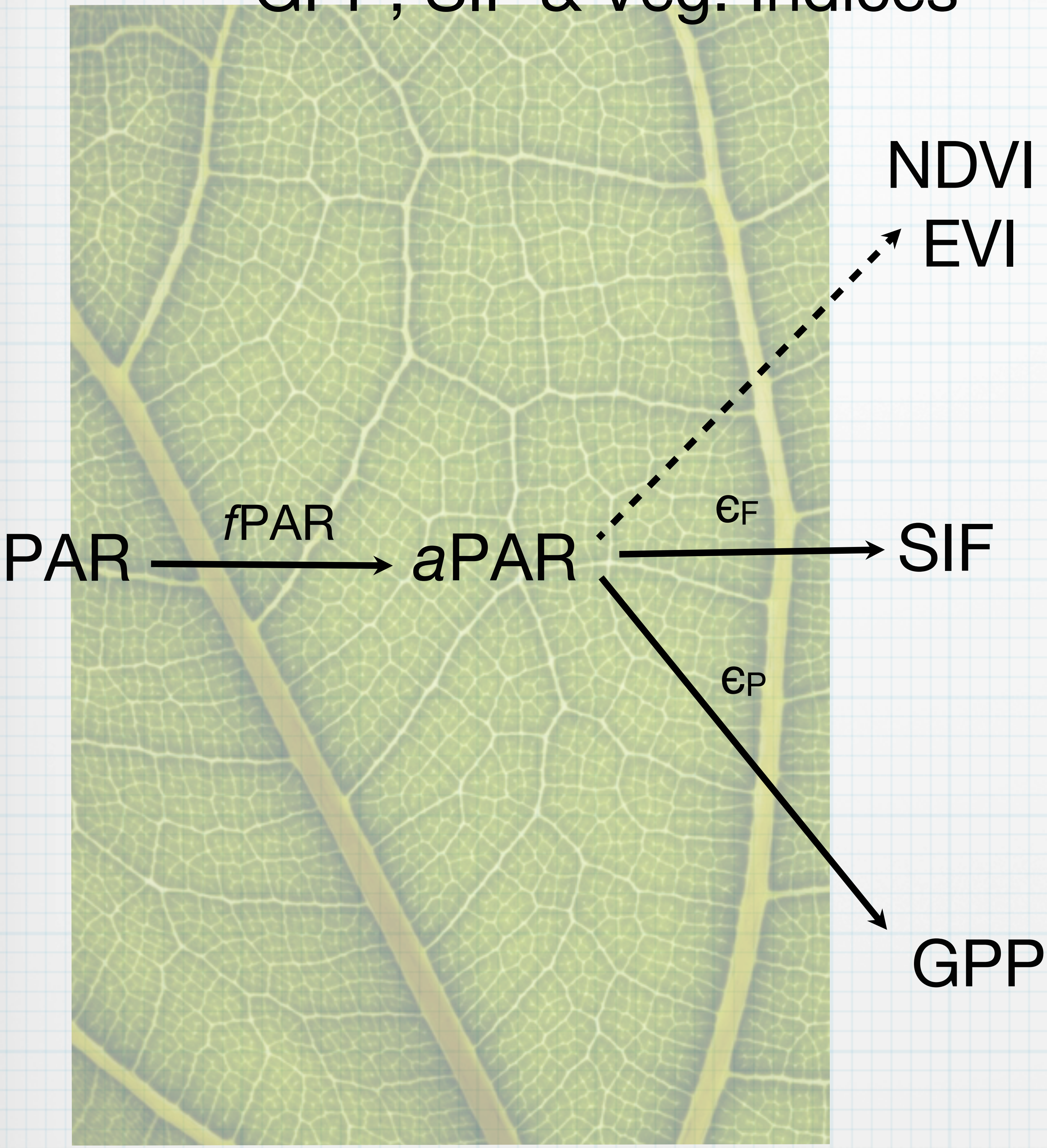


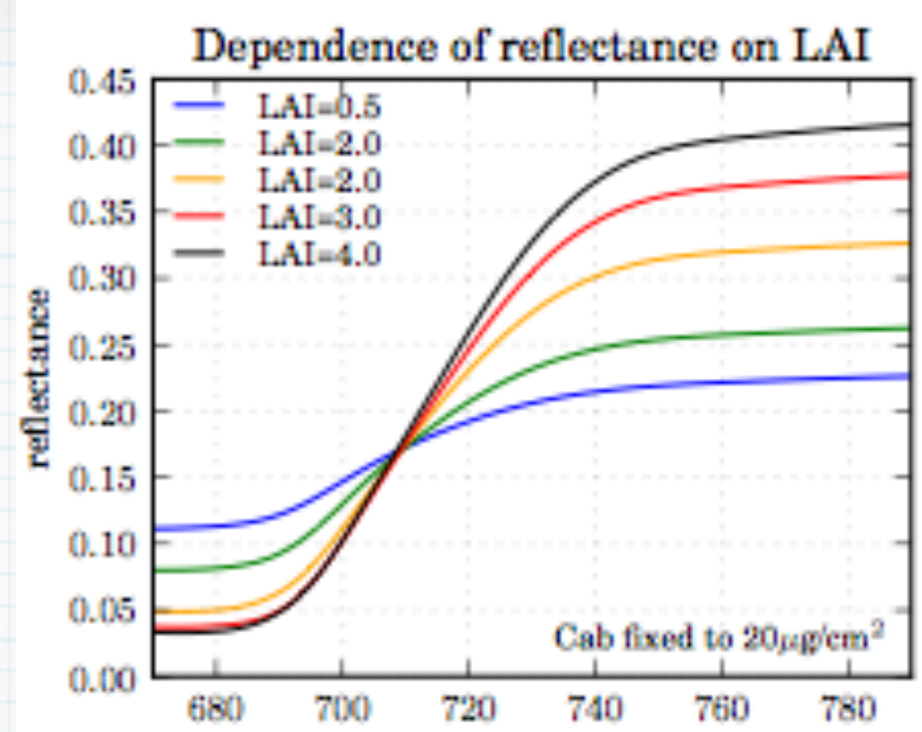
Fluorescence *vs.* the electron transport rate (ETR)

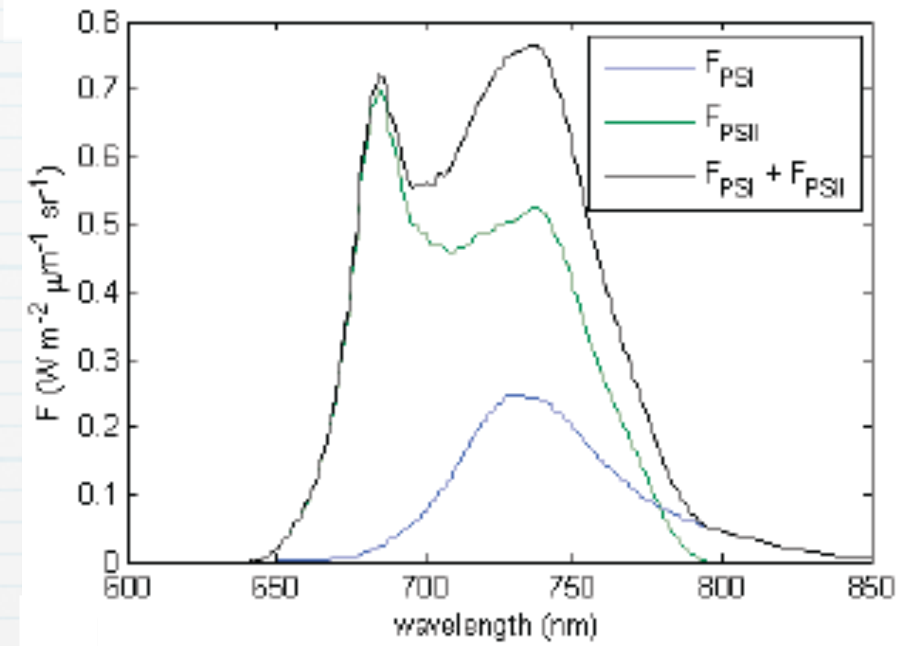




GPP, SIF & Veg. Indices







GPP and Solar Induced Fluorescence (SIF)

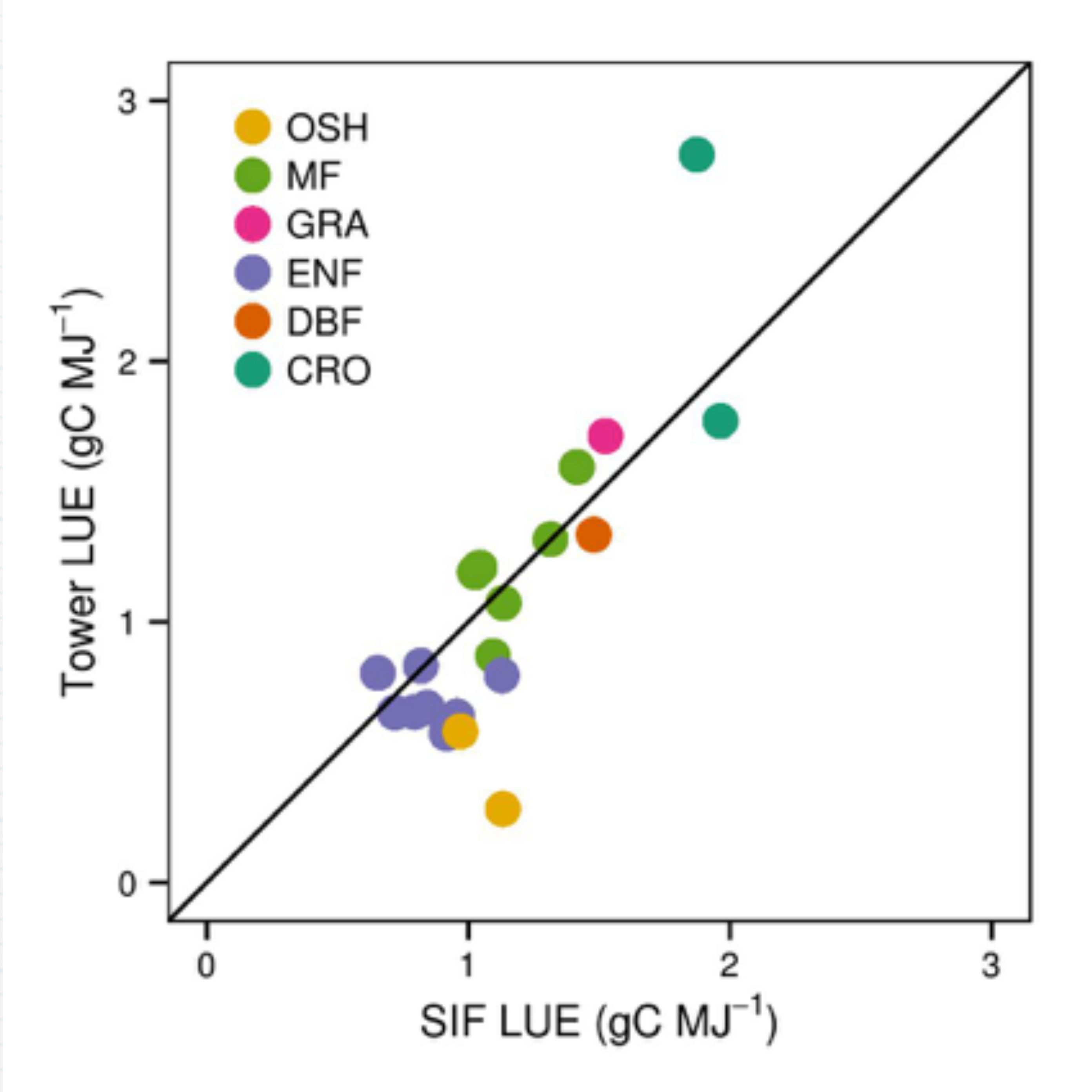
$$aPAR = f(\mathrm{NDVI}) \times \mathrm{PAR}$$

$$\mathrm{GPP} = a\mathrm{PAR} \times \epsilon_P$$

$$\mathrm{SIF} = a\mathrm{PAR} \times \epsilon_F$$

$$\mathrm{GPP} = \mathrm{SIF} \times \frac{\epsilon_P}{\epsilon_F}$$

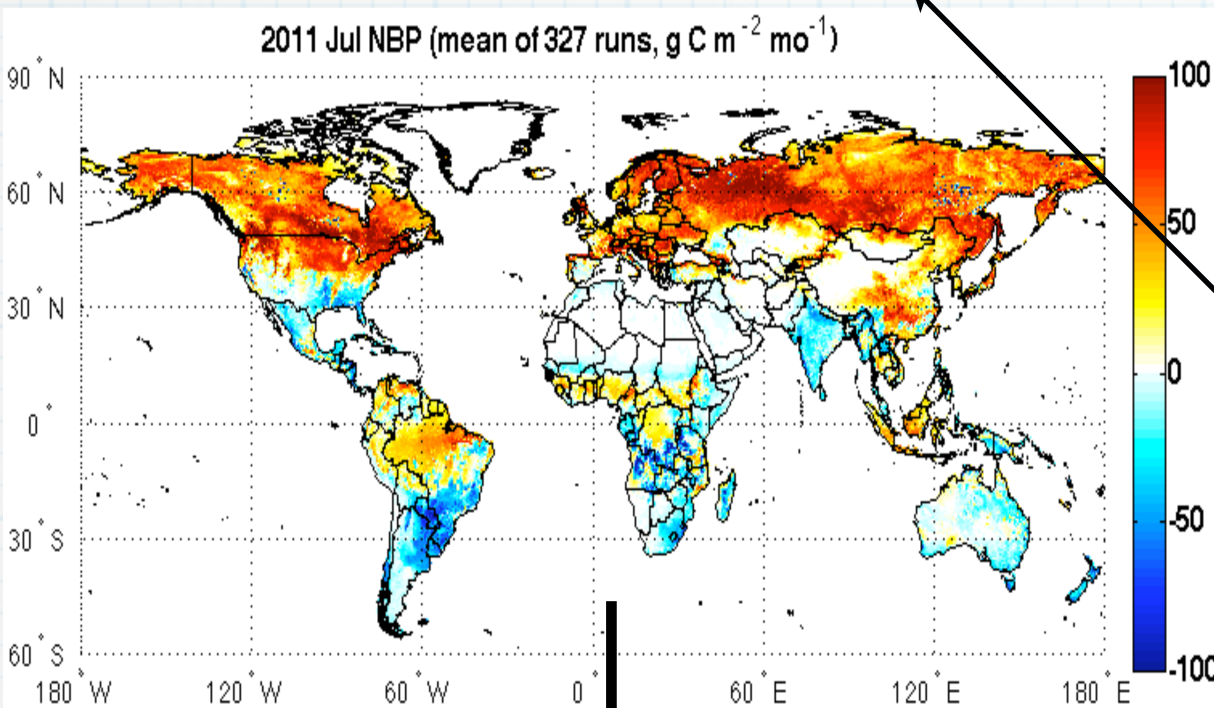
ε_P vs. ε_F at Flux Towers



Grayson Badgley, John Kimball et al.

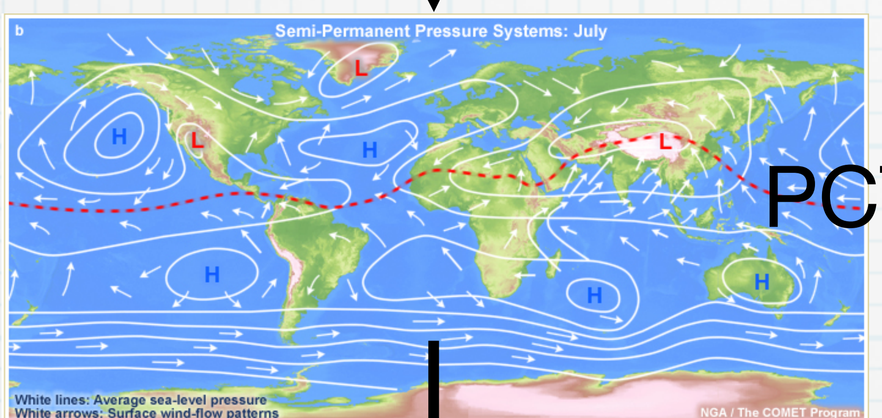
CASA, carbon cycle model

G. James Collatz, Joanna Joiner, Stephan R Kawa et al.

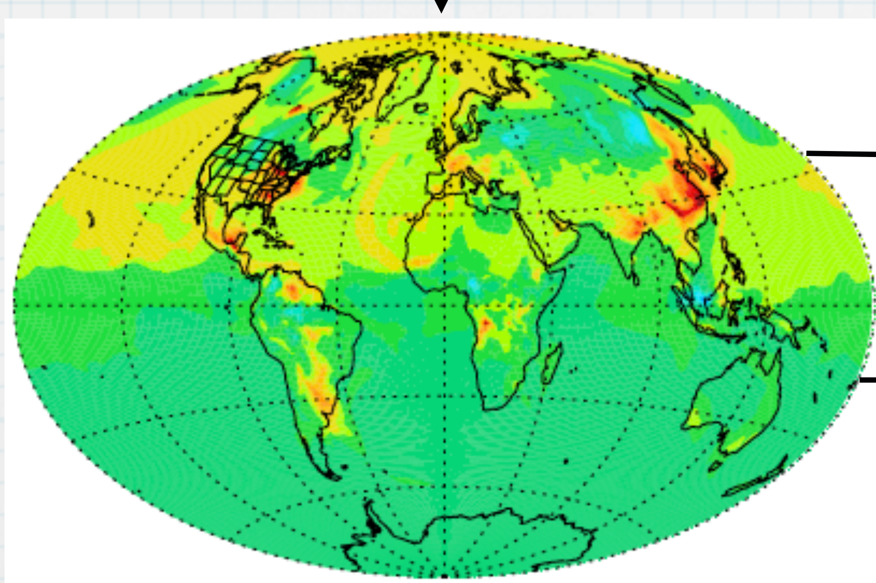


$$\left\{\begin{array}{l} \mathrm{NPP} = \mathrm{PAR}\cdot\mathrm{FPAR}\cdot\mathrm{LUE} \\ \qquad \text{where} \quad \mathrm{LUE} = f(\mathrm{T}, \mathrm{P/PET}) \\ \\ \mathrm{NPP} = k\cdot\mathrm{SIF} \end{array}\right.$$

$$\text{where}: \quad k = \frac{\overline{\mathrm{NPP}}_{max}}{\overline{\mathrm{SIF}}_{max}}$$

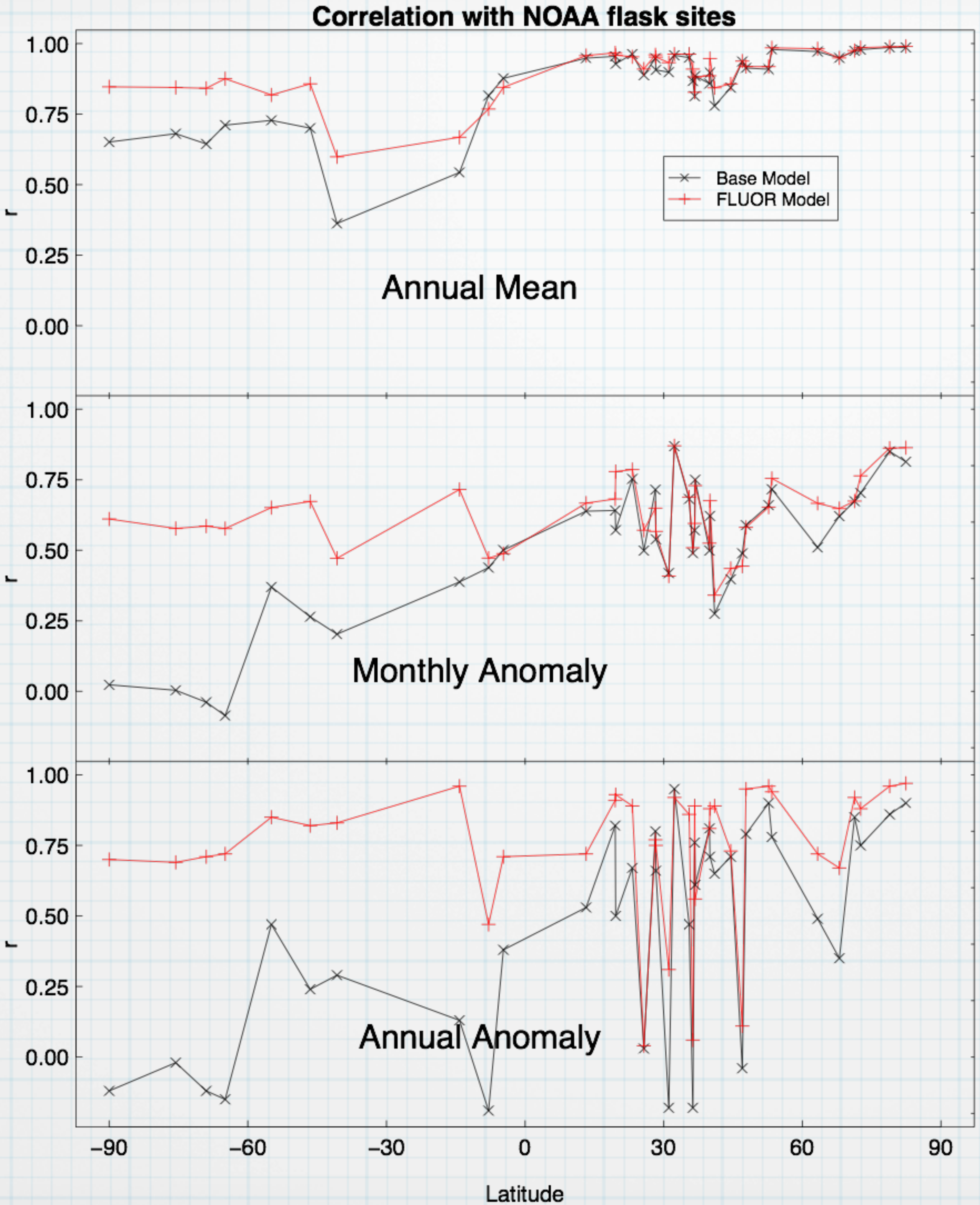


PCTM, atmos. transport model



Baseline model $[CO2]_{i,j}$

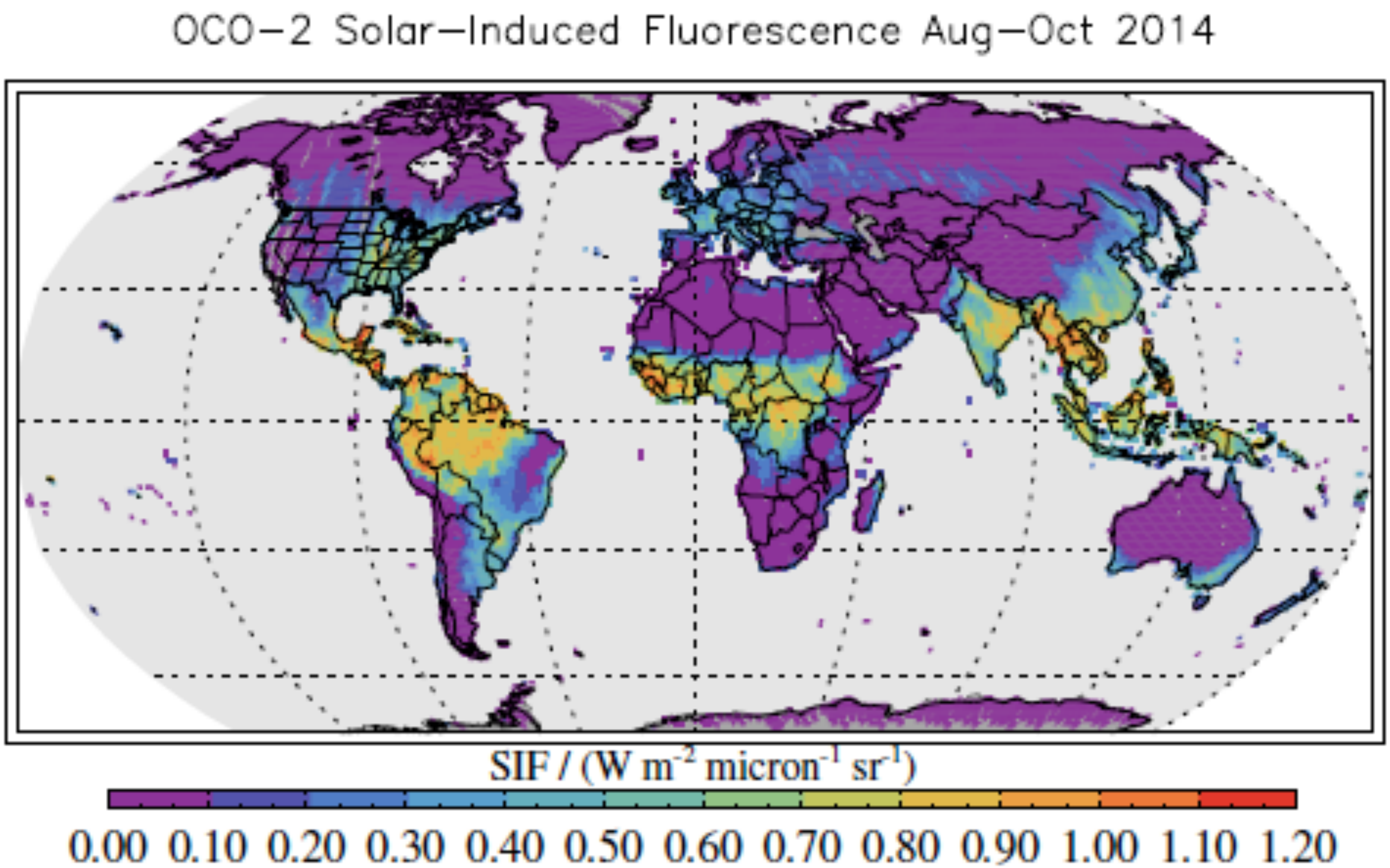
Flour. model $[CO2]_{i,j}$



Correlation with NOAA flask sites
Base Model
FLUOR Model
Annual Mean
Monthly Anomaly
Annual Anomaly
r
Latitude
1.00
0.75
0.50
0.25
0.00
-90
-60
-30
0
30
60
90

Jim Collatz

3–month OCO–2 average (all modes)

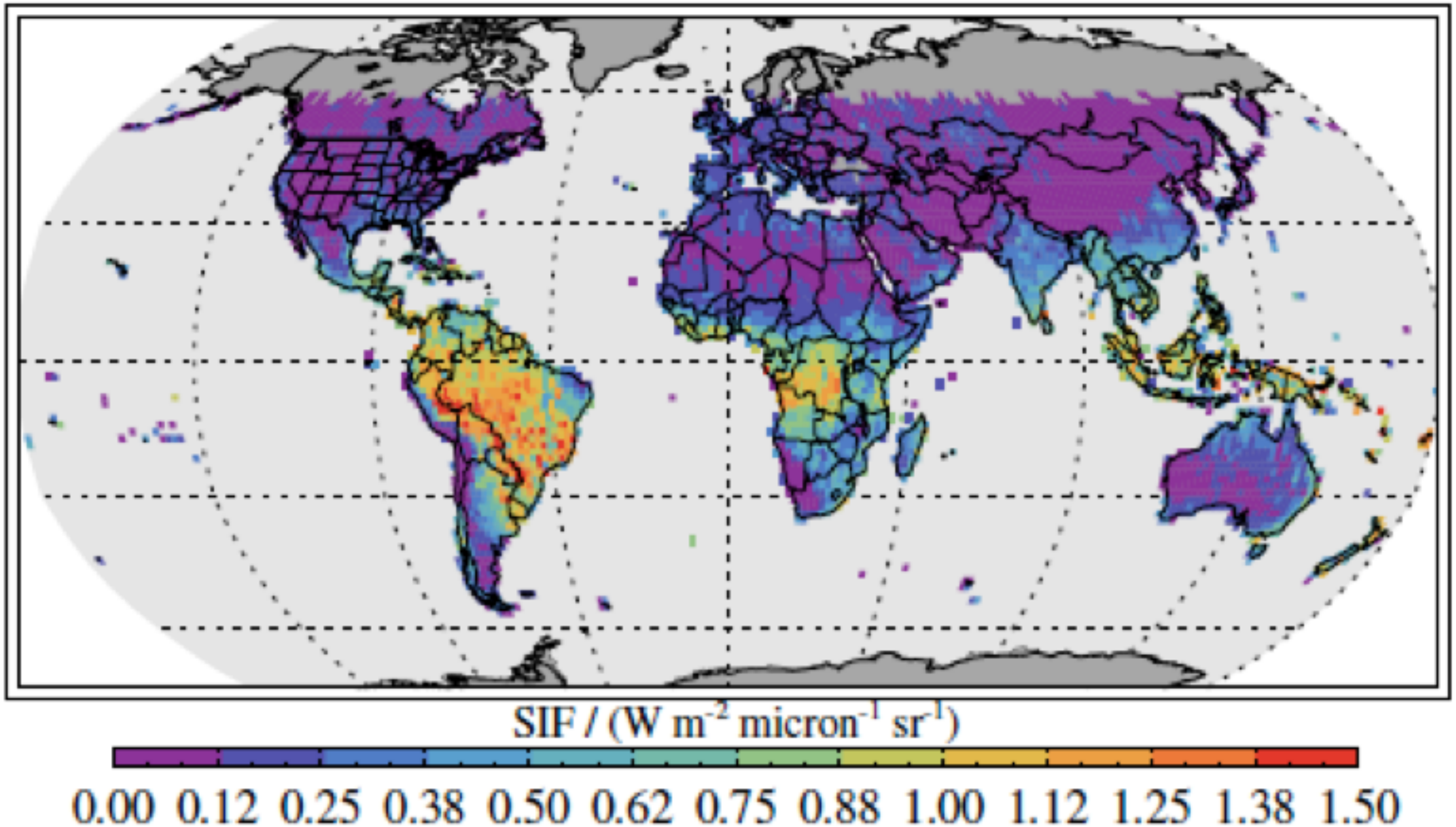


still tentative. . .

Christian Frankenberg

Latest B5000 dataset (Nov / Dec. 2014)

OCO2 B5000x4

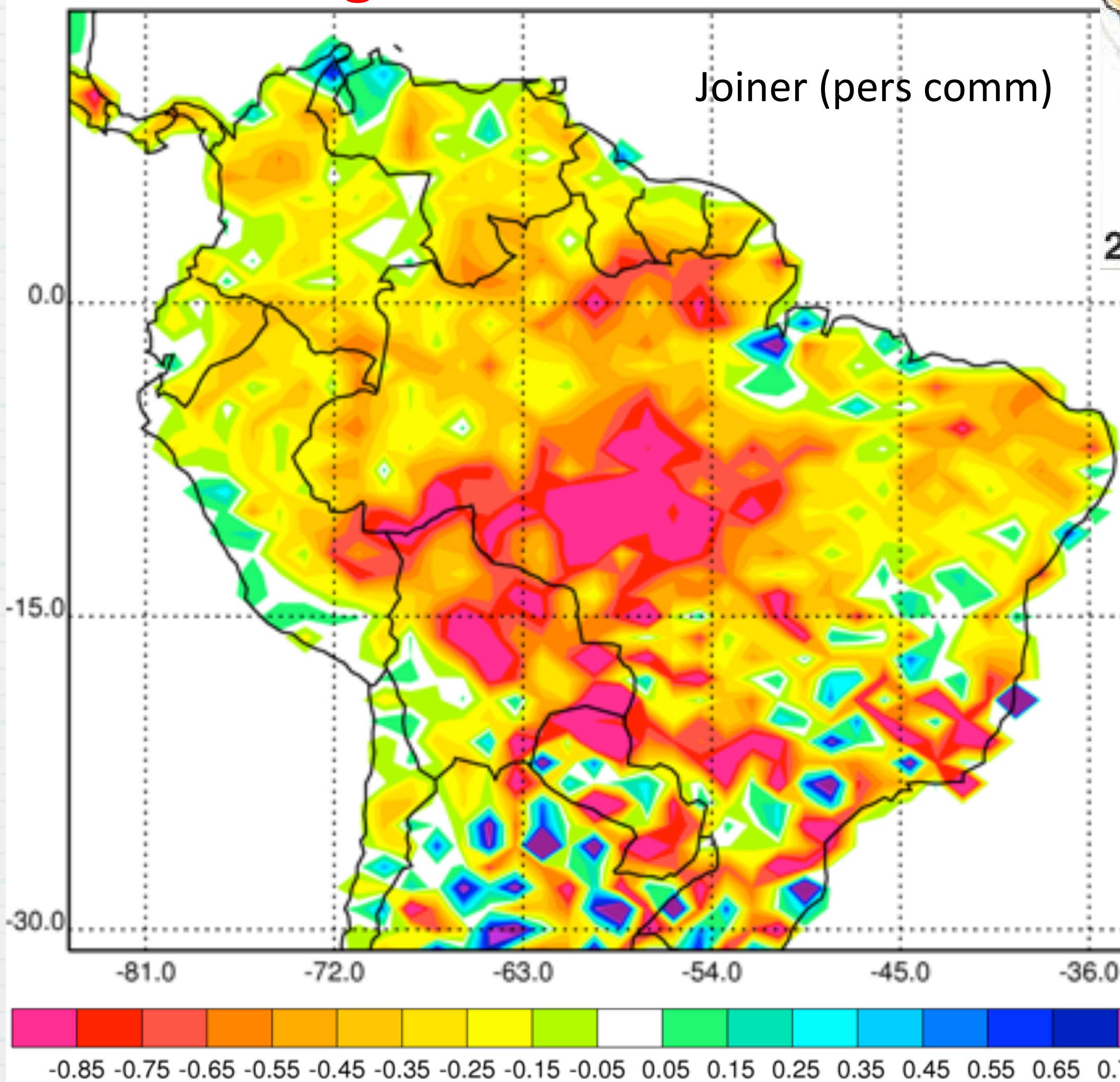


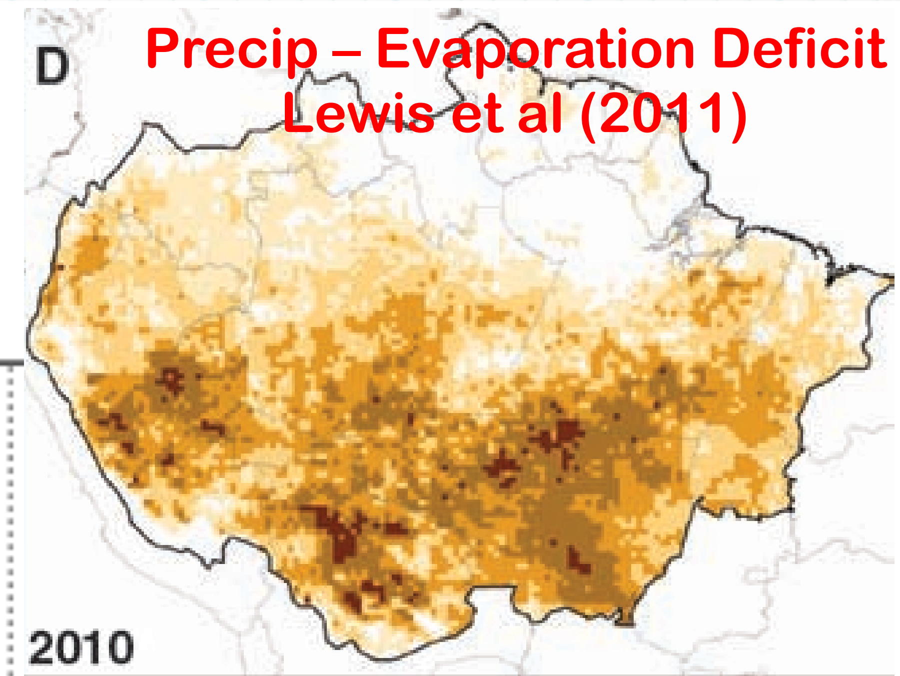
still tentative. . .

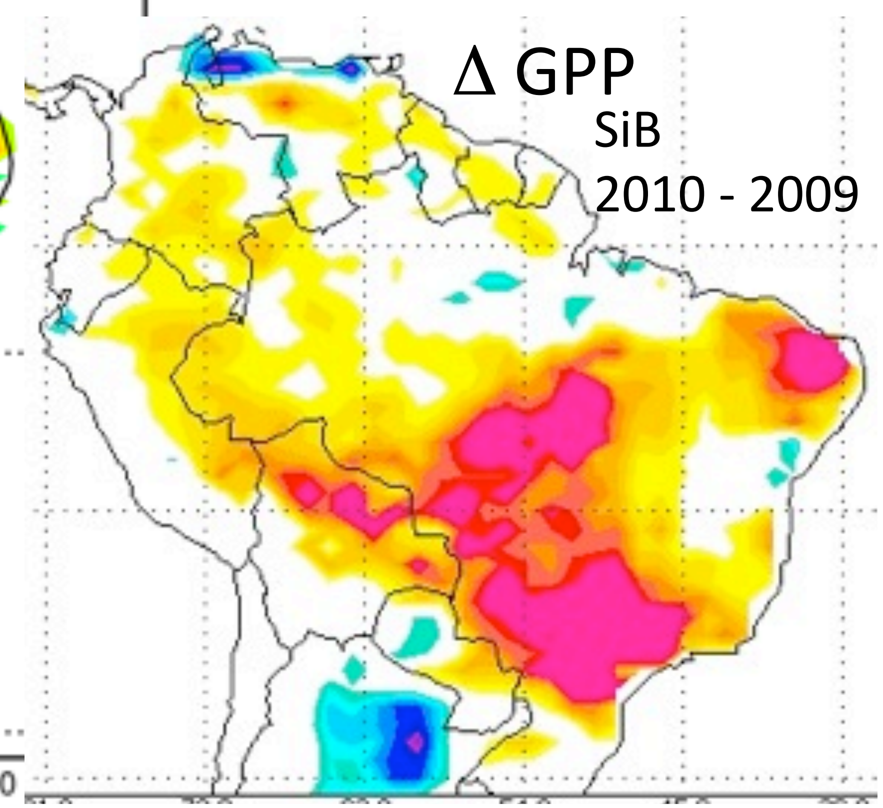
Fluorescence Responds to Drought

2010 Amazon Drought

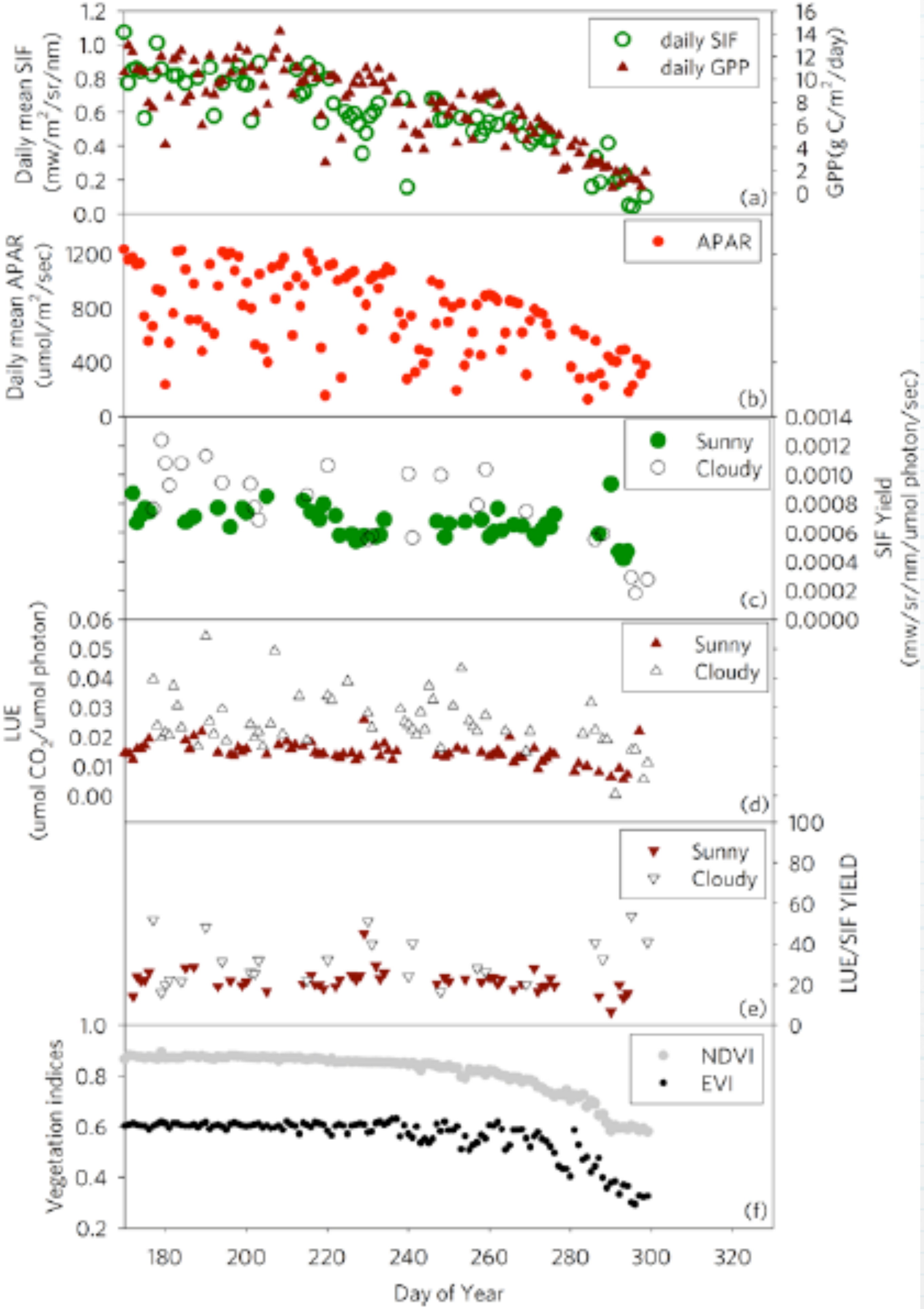
Change in SIF 2010 - 2009





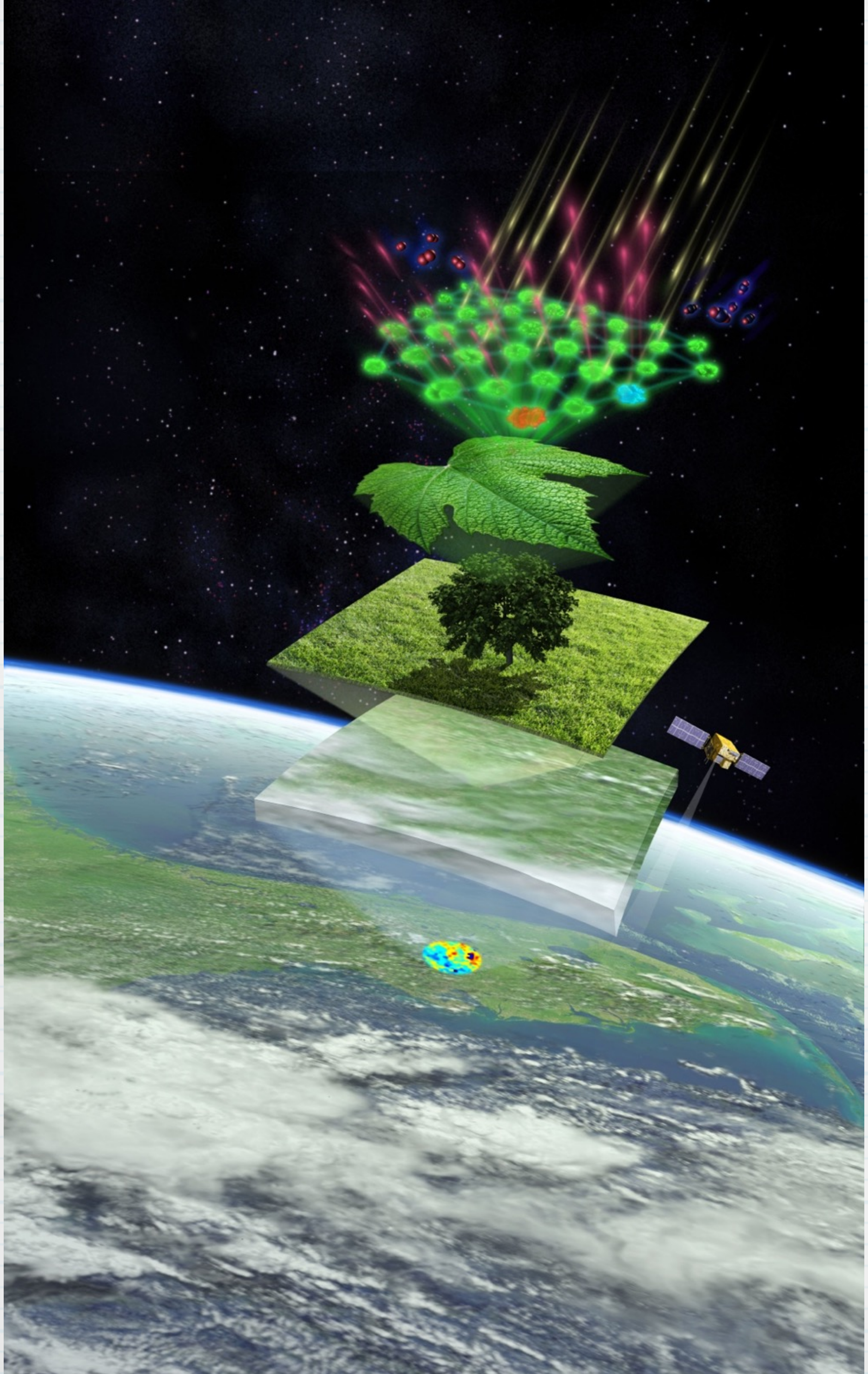


Ian Baker, Joanna Joiner & Scott Denning



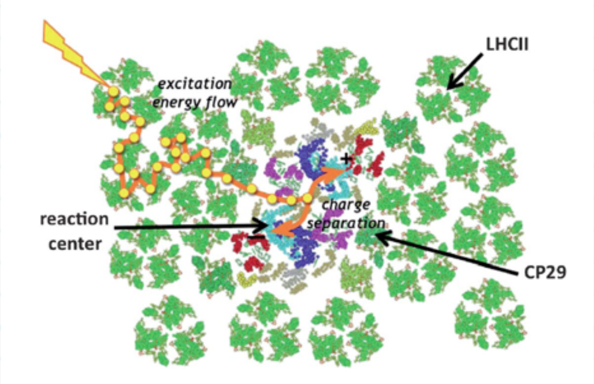
Studies of fluorescence (SIF) at HF flux tower.

Yang, X., Tang, J., Mustard, J. F., Lee, J.-E., Rossini, M., Joiner, J., et al. (2015). Solar-induced chlorophyll fluorescence correlates with canopy photosynthesis on diurnal and seasonal scales in a temperate deciduous forest. Geophysical Research Letters, n/a–n/a. http://doi.org/10.1002/2015GL063201

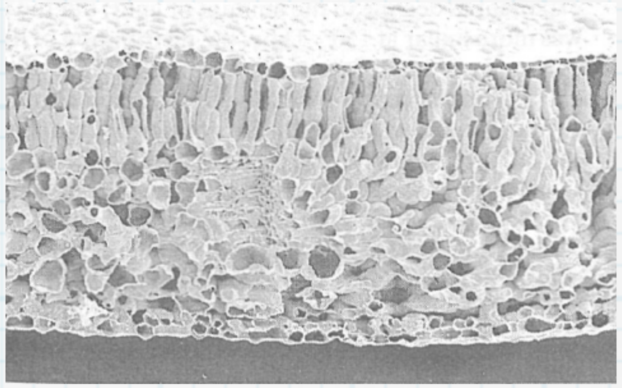


SIF

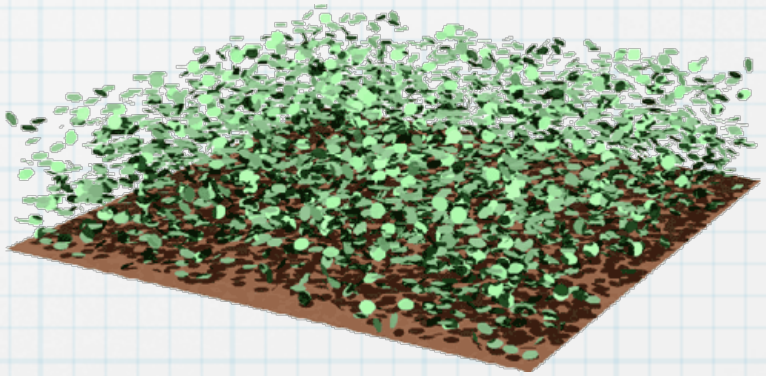
We need to consider hierarchy of scales



chloroplast membrane



leaf

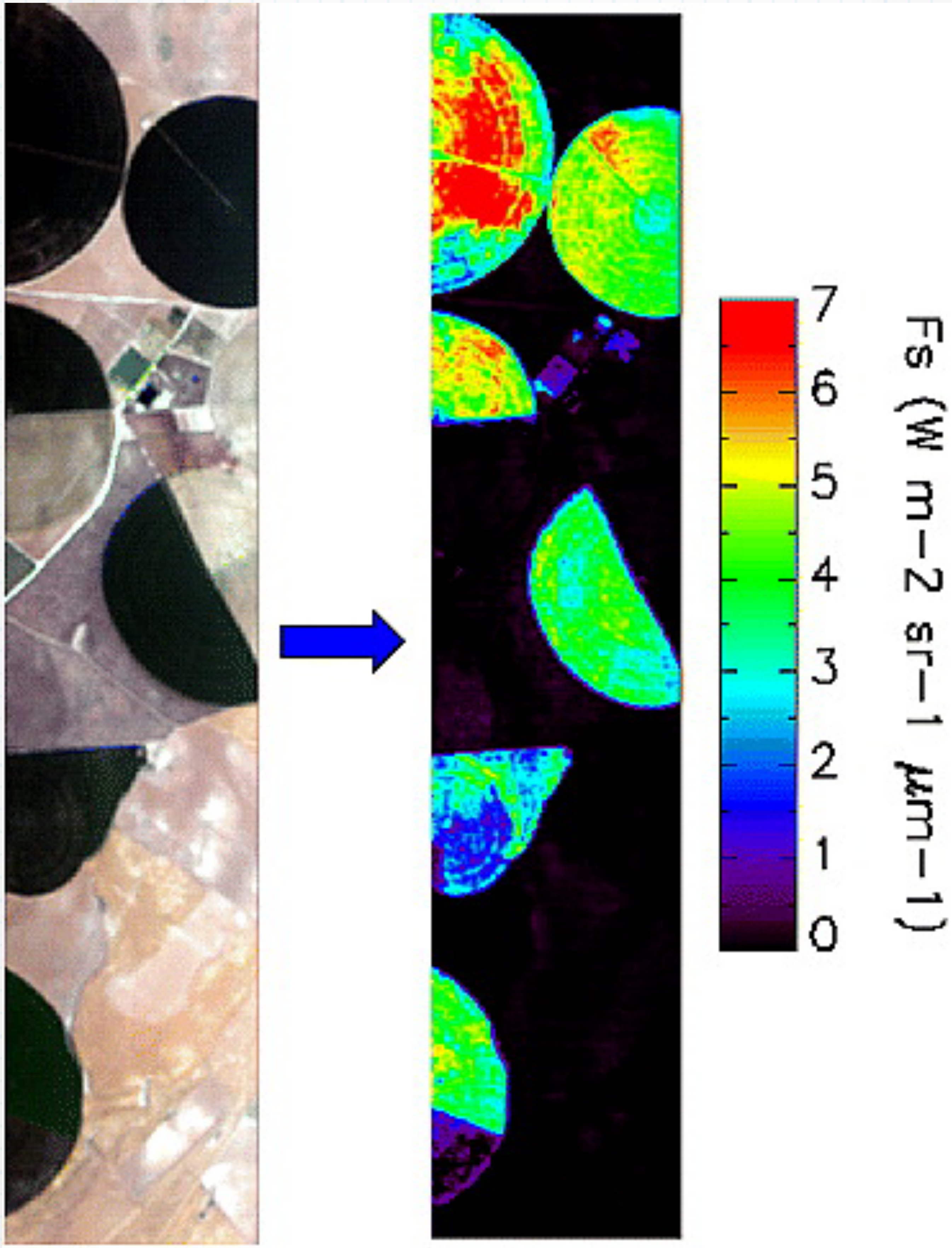


canopy

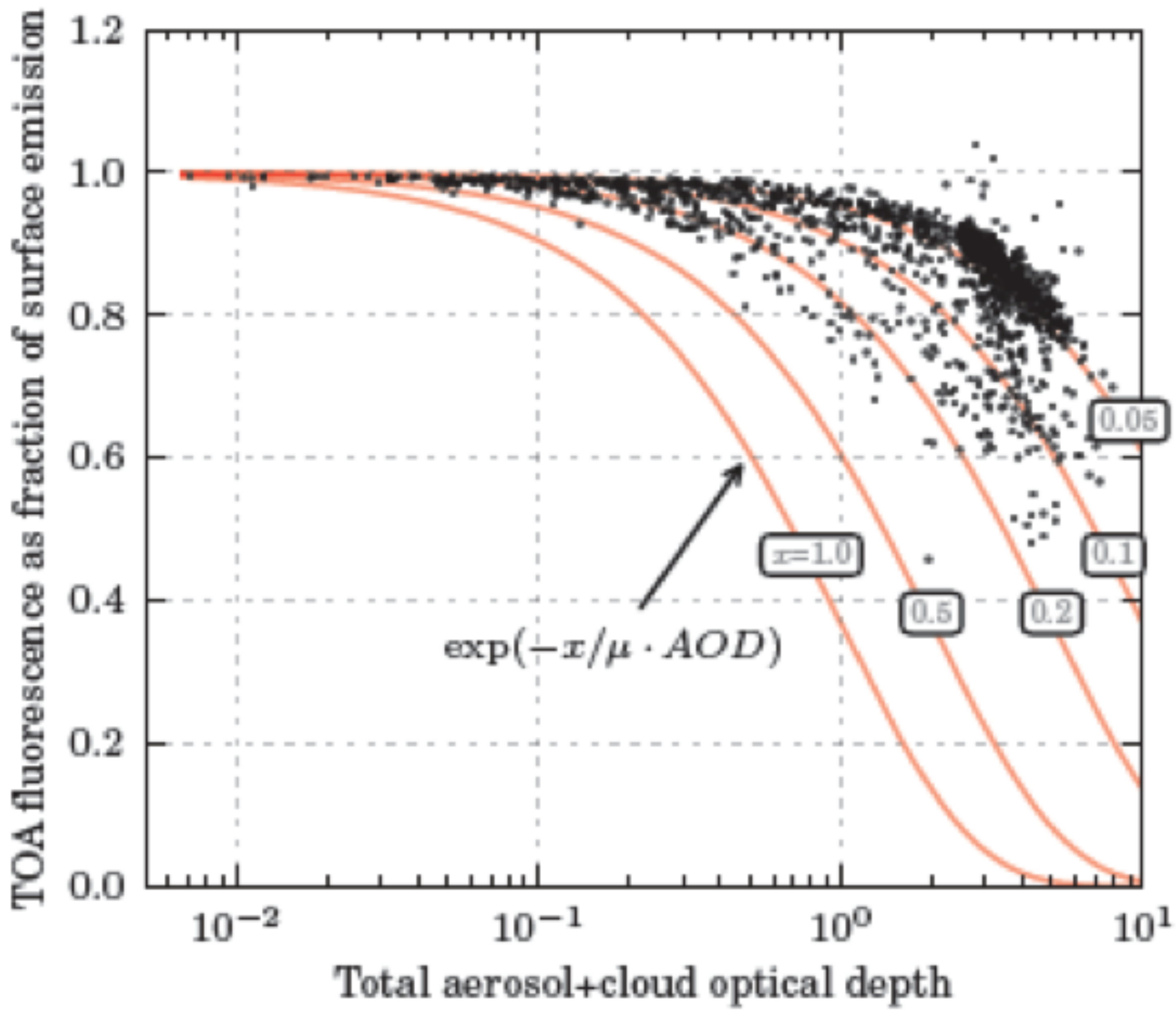
but understanding the mechanism is a critical first step.

Final Thoughts:

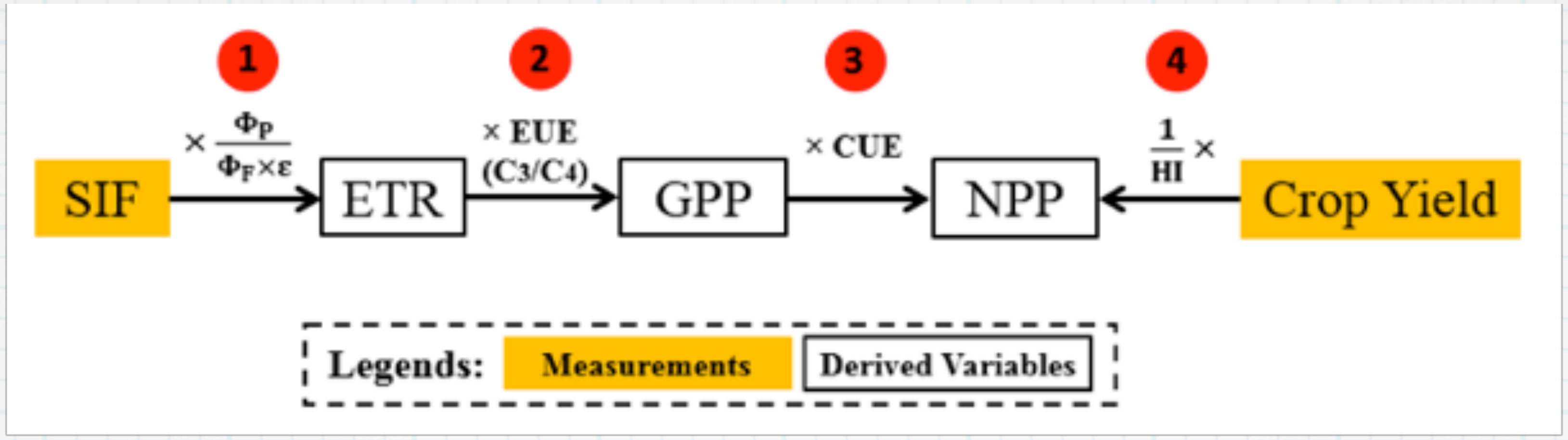
- SIF is turning out to be surprisingly useful:
  - Seems to be proportional to GPP;
  - Indicates drought;
  - Indicates beginning and end of growing season.
- It is also a hot topic in fundamental research on photosynthesis.
- There are still a lot to learn about fluorescence from canopies.
- Fluorescence is a product of photosynthesis which can be modeled and measured over the globe. If we model SIF correctly does it mean that we have modeled GPP correctly?


7
6
5
4
3
2
1
0
Fs (W m-2 sr-1 μm-1)

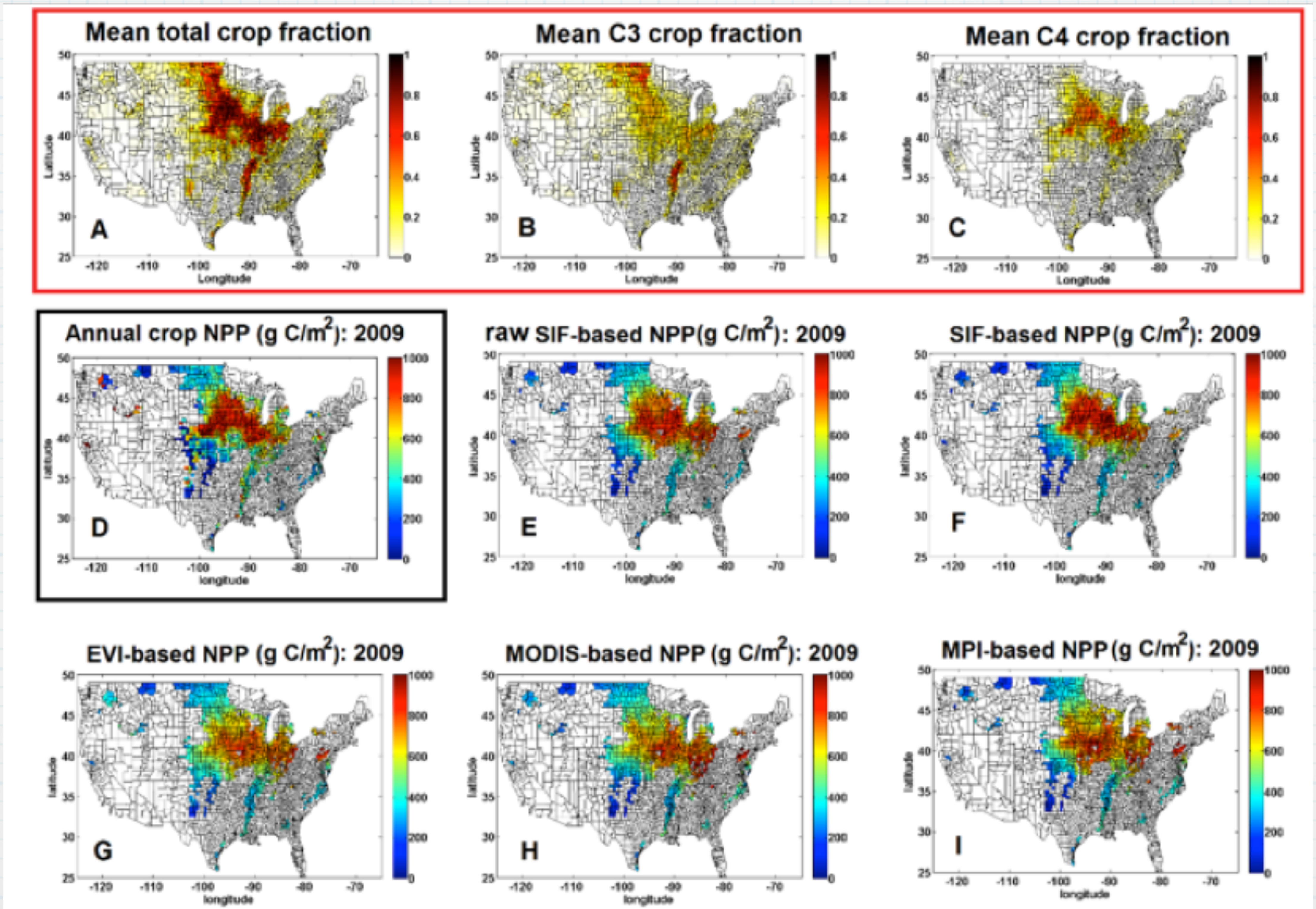
THE SCATTERING IMPACT, ADDED ADVANTAGE OF FLUORESCENCE (ESP. IN TROPICS)



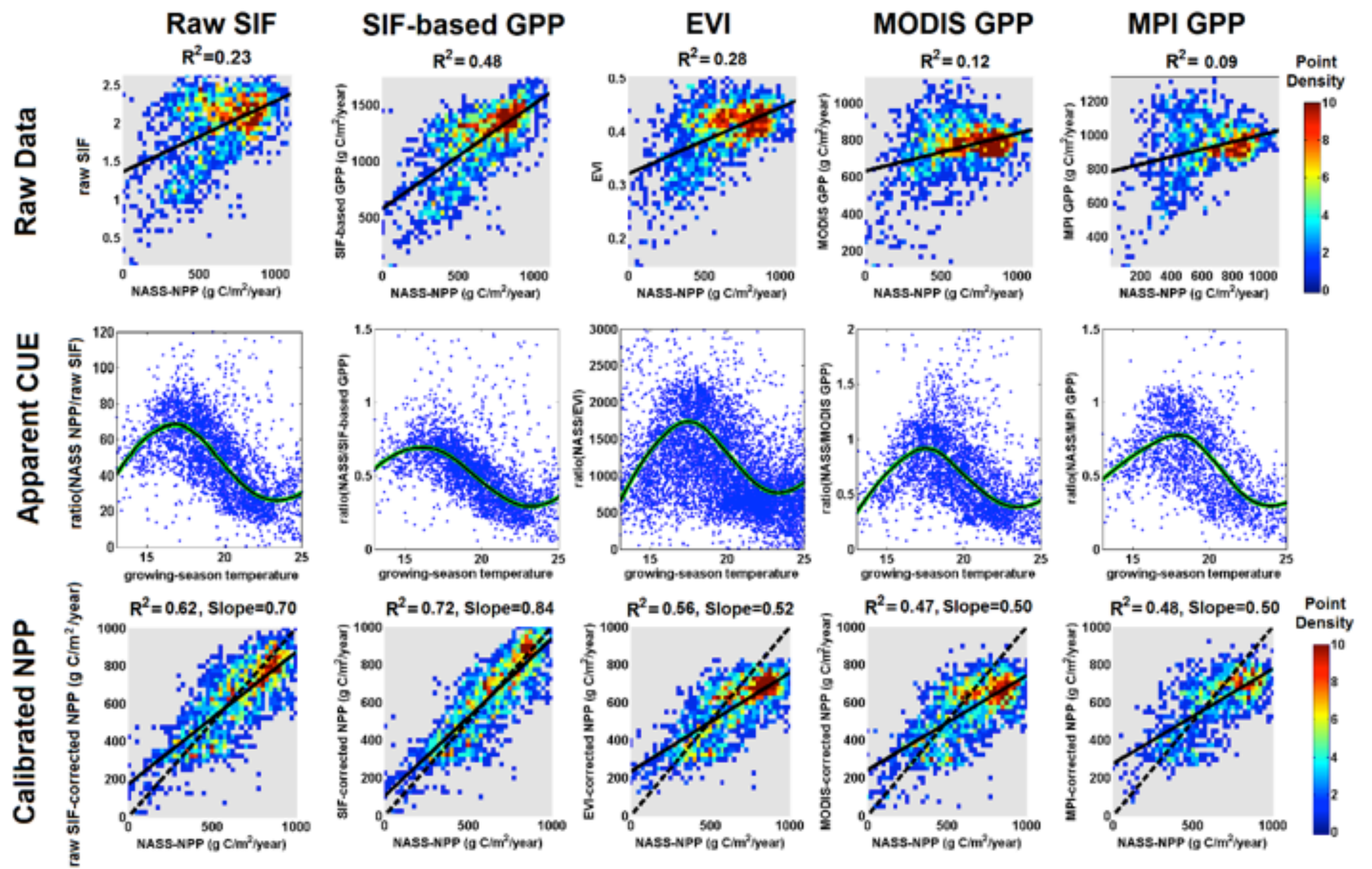
Frankenberg et al, AMT (2012)



1
2
3
4
× Φ_P / (Φ_F × ε)
× EUE (C3/C4)
× CUE
1/HI ×
SIF
ETR
GPP
NPP
Crop Yield
Legends:
Measurements
Derived Variables



Mean total crop fraction
Mean C3 crop fraction
Mean C4 crop fraction
A
B
C
Latitude
Longitude
Annual crop NPP (g C/m2): 2009
raw SIF-based NPP(g C/m2): 2009
SIF-based NPP(g C/m2): 2009
D
E
F
EVI-based NPP (g C/m2): 2009
MODIS-based NPP (g C/m2): 2009
MPI-based NPP(g C/m2): 2009
G
H
I
latitude
longitude


Raw SIF
SIF-based GPP
EVI
MODIS GPP
MPI GPP
Raw Data
Apparent CUE
Calibrated NPP
R2=0.23
R2= 0.48
R2= 0.28
R2= 0.12
R2= 0.09
Point Density
raw SIF
SIF-based GPP (g C/m2/year)
EVI
MODIS GPP (g C/m2/year)
MPI GPP (g C/m2/year)
NASS-NPP (g C/m2/year)
ratio(NASS NPP/raw SIF)
ratio(NASS/SIF-based GPP)
ratio(NASS/EVI)
ratio(NASS/MODIS GPP)
ratio(NASS/MPI GPP)
growing-season temperature
R2=0.62, Slope=0.70
R2=0.72, Slope=0.84
R2=0.56, Slope=0.52
R2=0.47, Slope=0.50
R2=0.48, Slope=0.50
raw SIF-corrected NPP (g C/m2/year)
SIF-corrected NPP (g C/m2/year)
EVI-corrected NPP (g C/m2/year)
MODIS-corrected NPP (g C/m2/year)
MPI-corrected NPP (g C/m2/year)