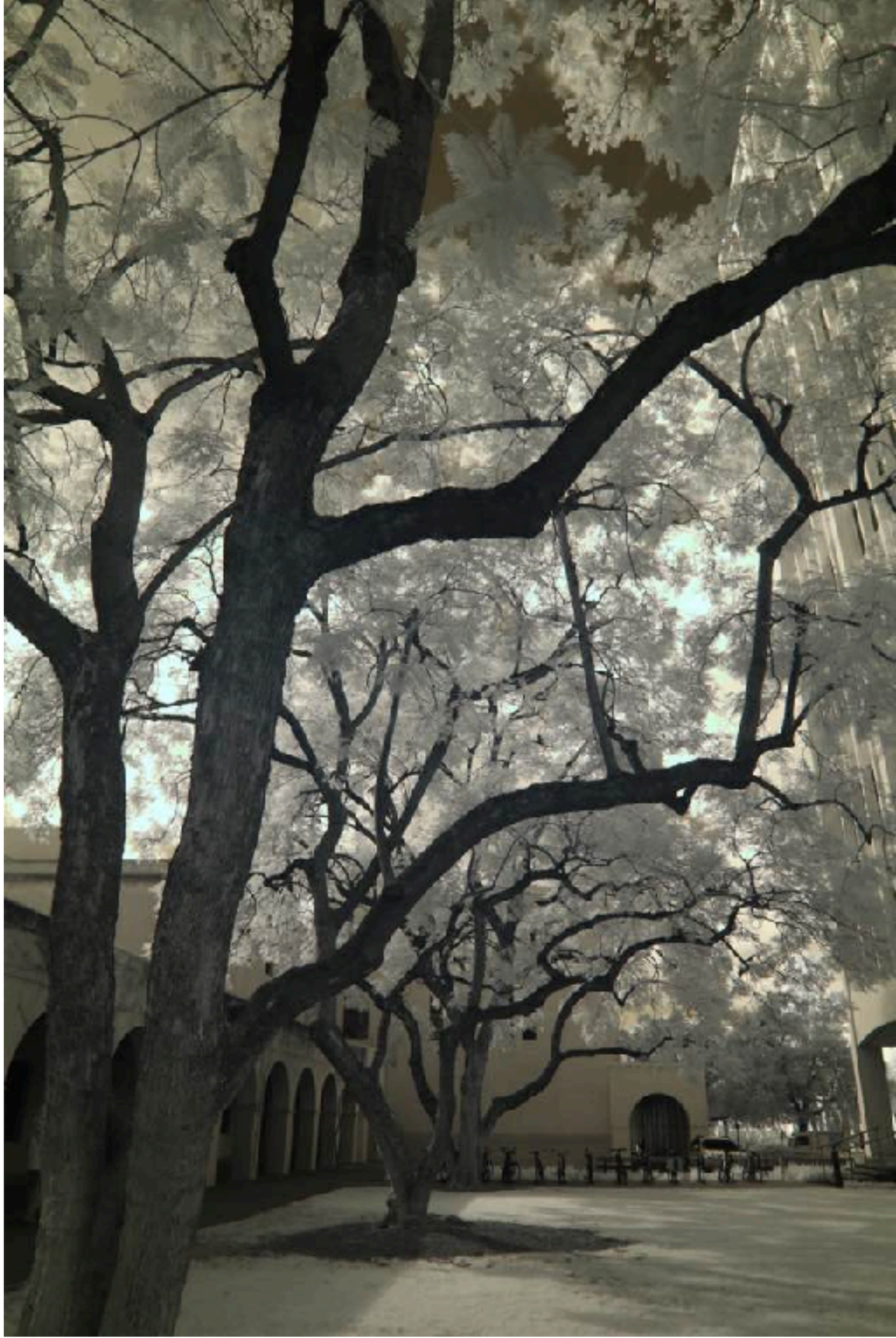
Potentials and Pitfalls for Using Chlorophyll Fluorescence on the Observational and Modeling Side to Constrain the Carbon Cycle

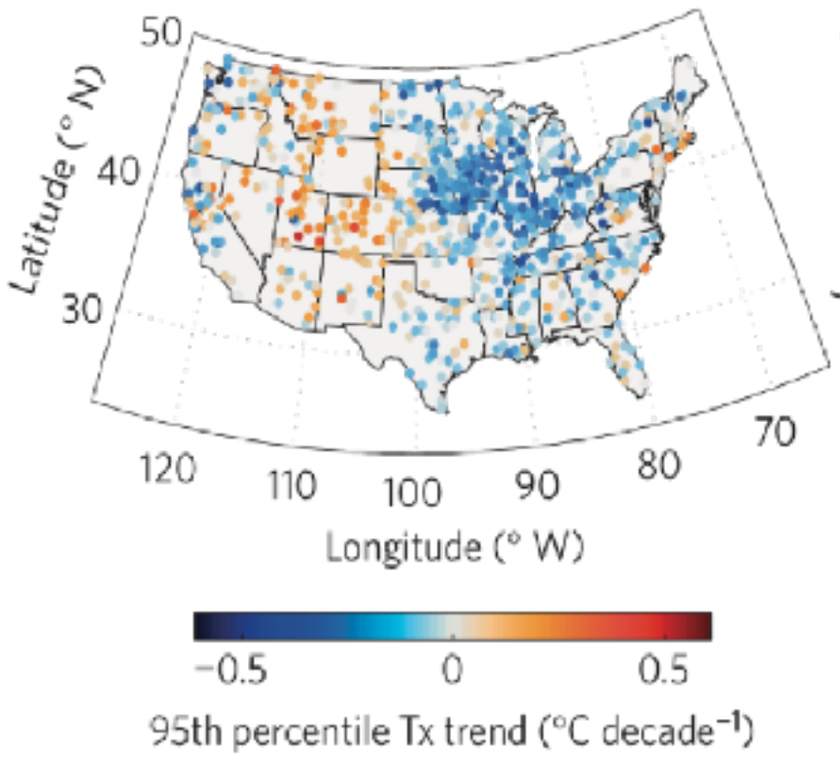
Christian Frankenberg[1,2]
(1) California Institute of Technology, Pasadena, CA, United States
(2) Jet Propulsion Laboratory / Caltech, Pasadena, CA, United States

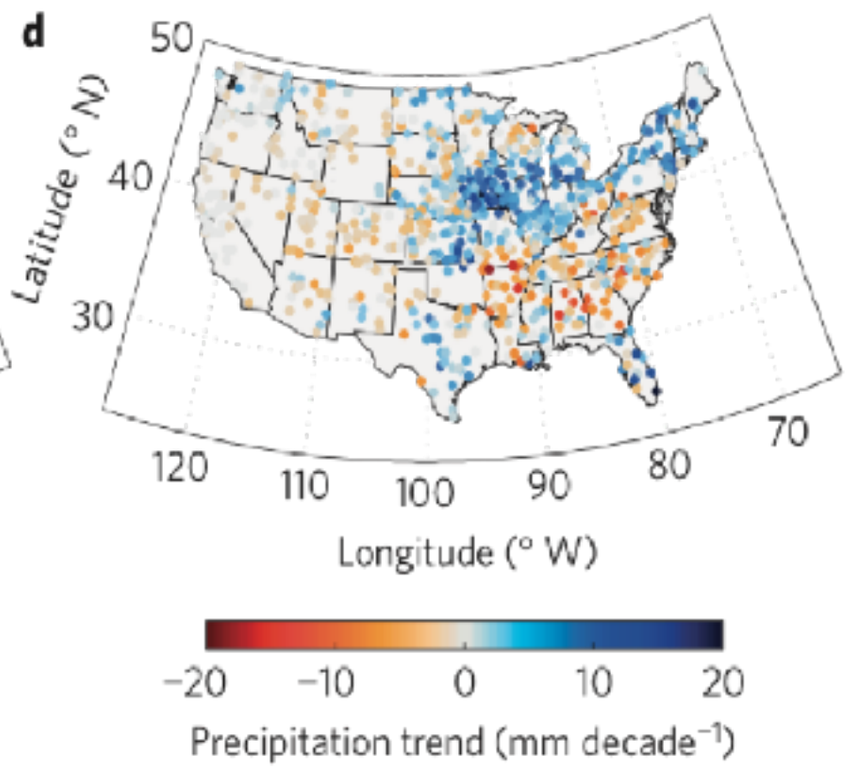
Ying Sun, Troy Magney, Philipp Koehler, Liyin He, Katja Grossmann, Jochen Stutz, CFIS team…

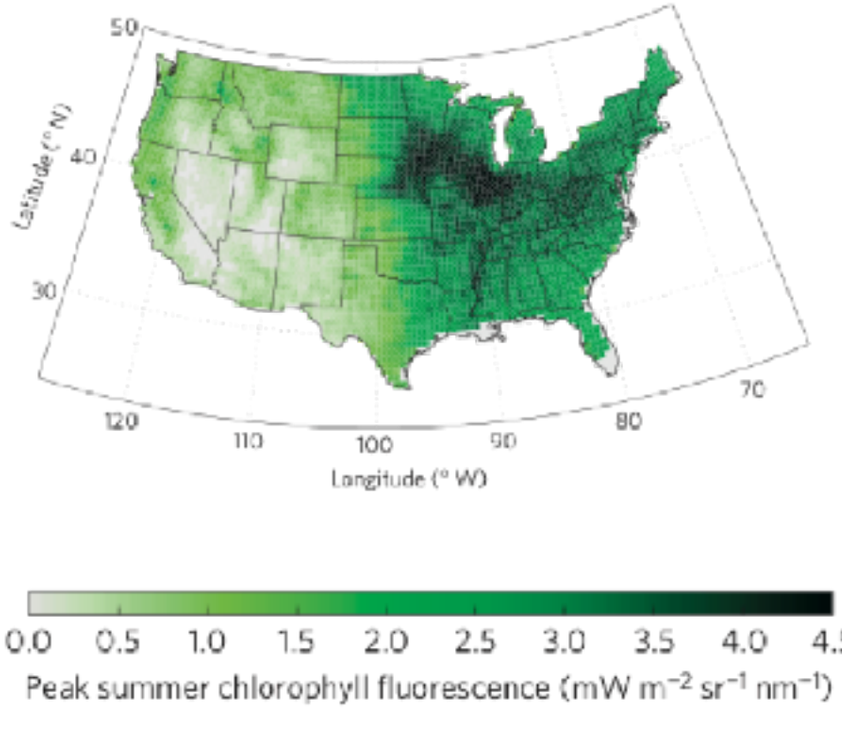


Photosynthesis is more than just about plants

(it alters the planet), Mueller et al, NatCC, 2015)

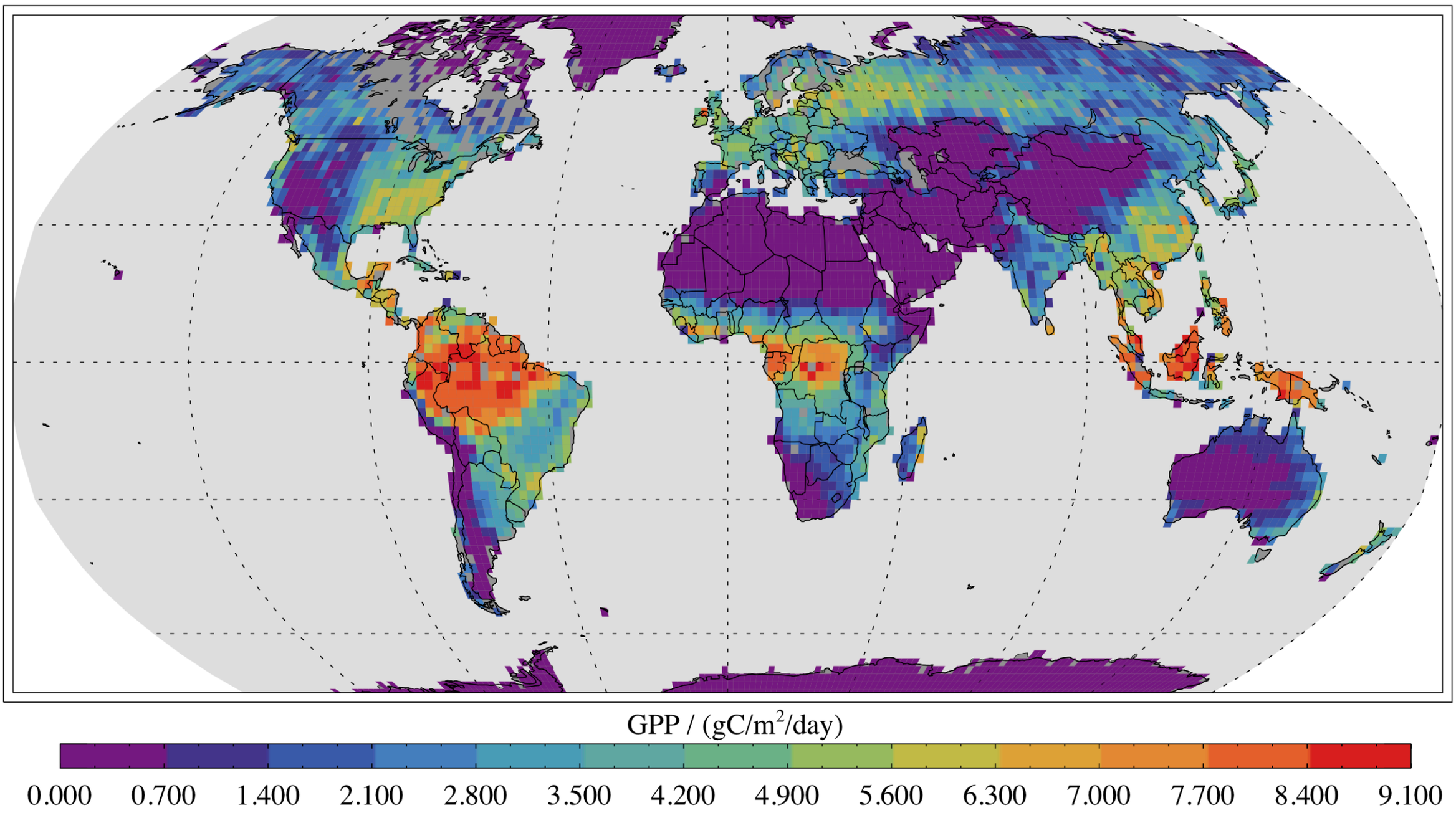






What is SIF —> Joe’s talk

Previous SIF success stories —Early days (GOSAT)



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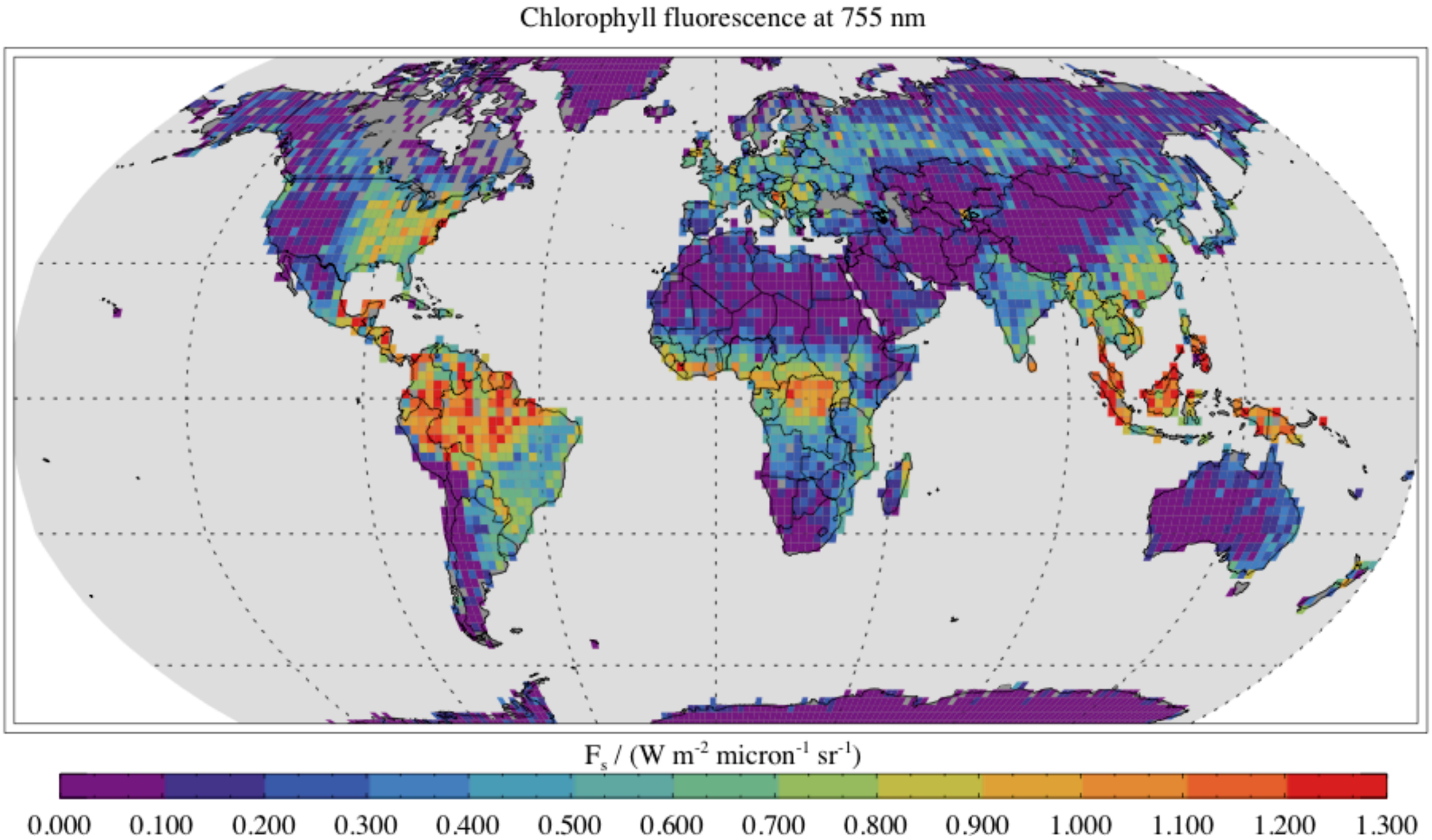
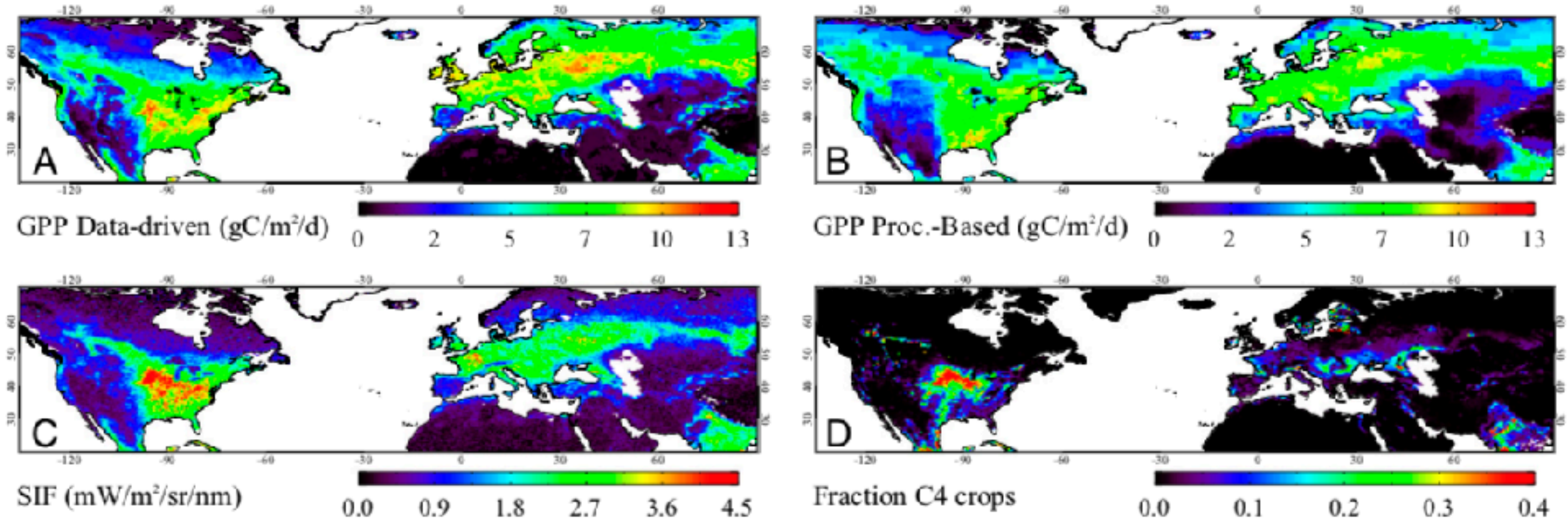
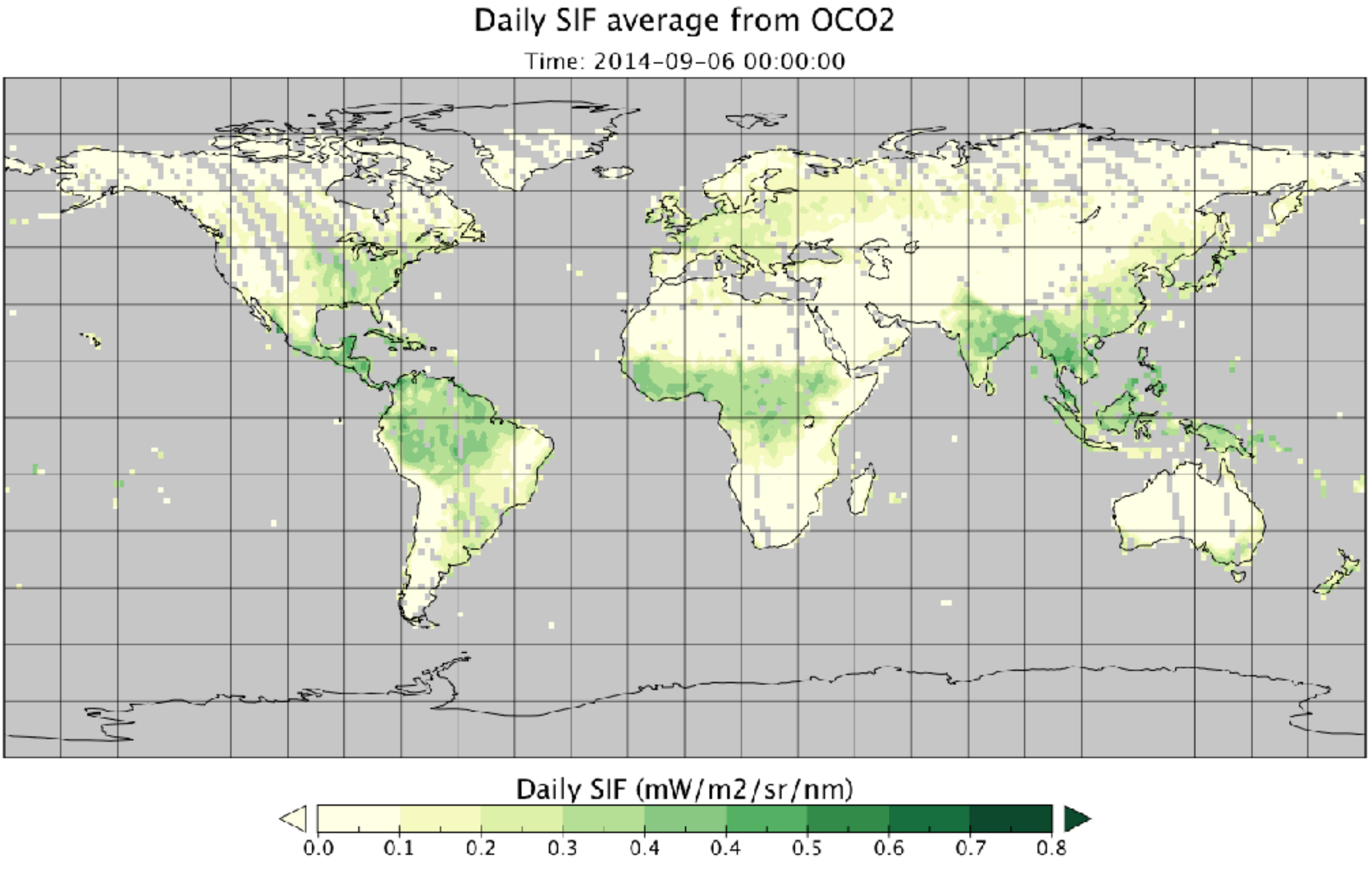


Previous SIF success stories —GOME-2



Guanter et al, PNAS (2014)

Previous SIF success stories —OCO-2



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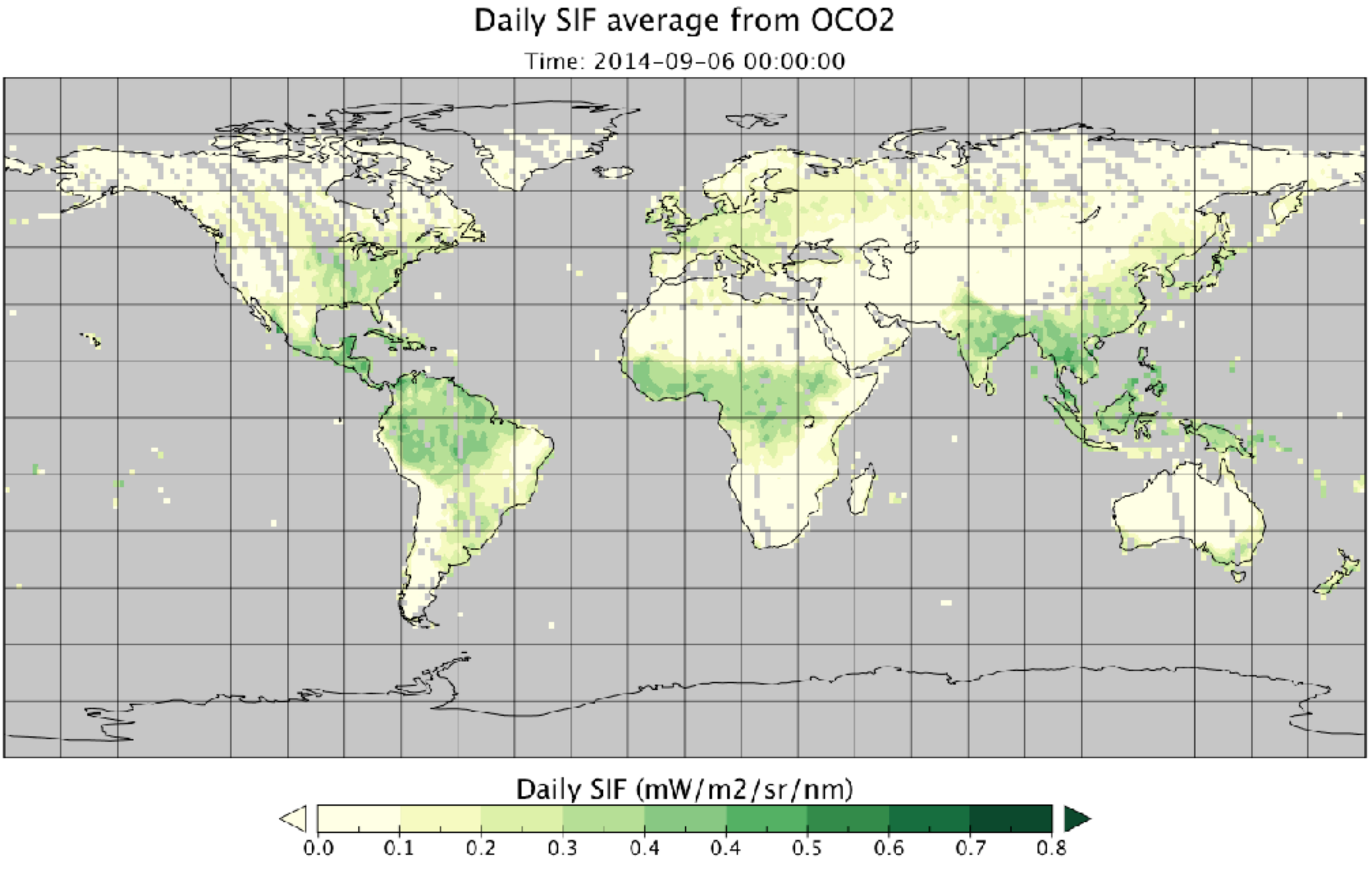

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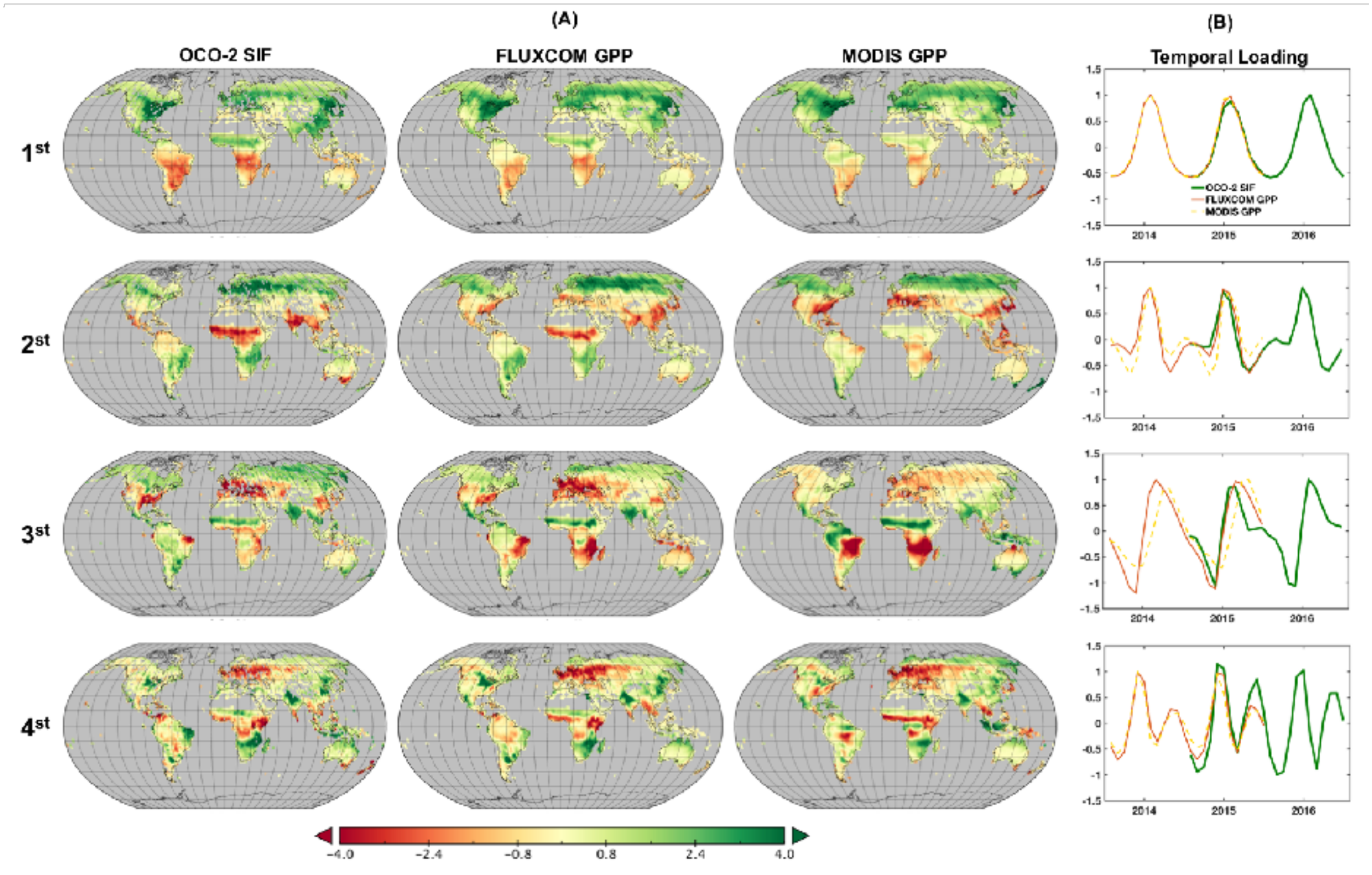
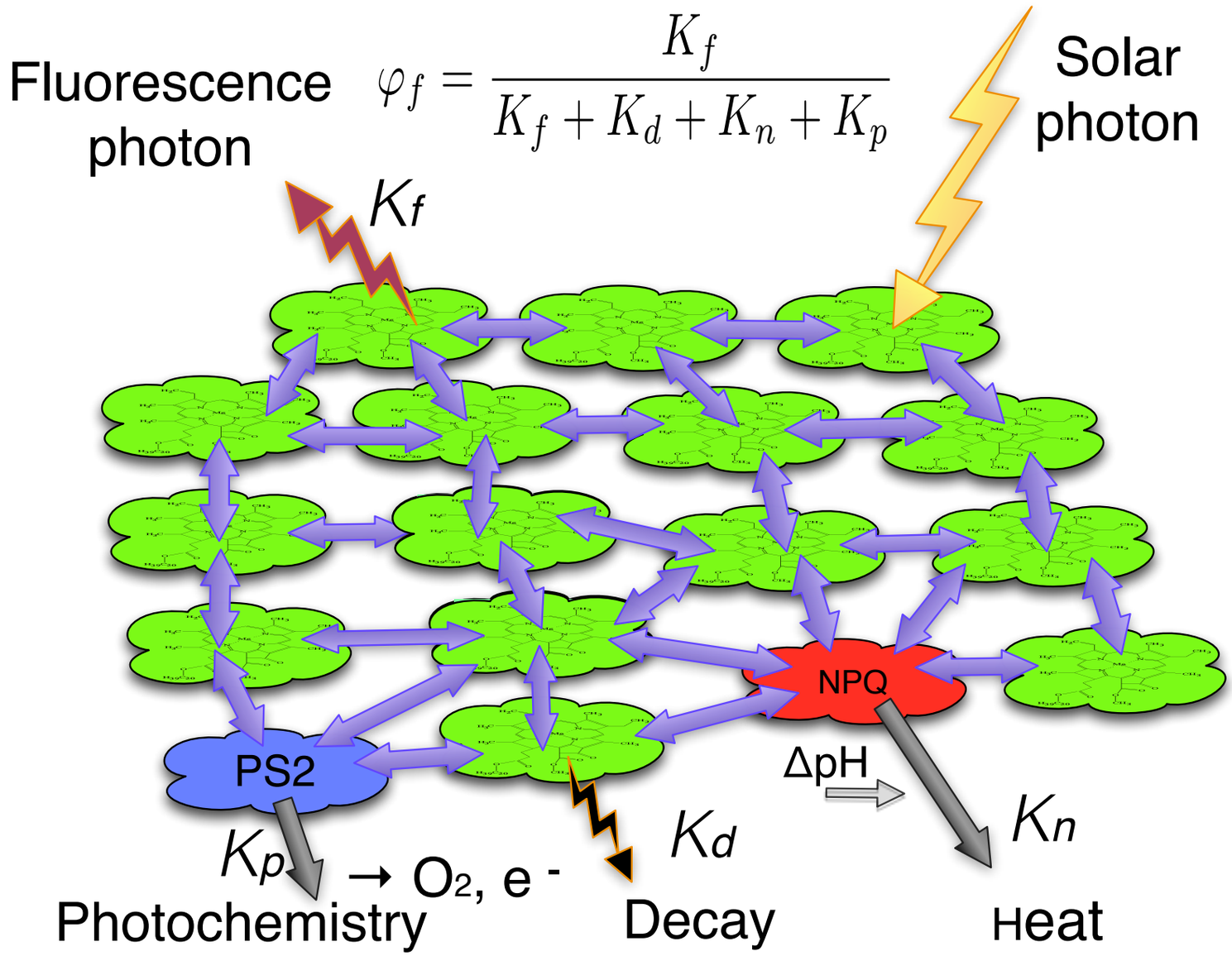
Primary GPP models, Sun, Frankenberg et al, Science special issue



Fate of absorbed photons in antenna system



Taiz and Zeiger, "Plant Physiology", 2010.

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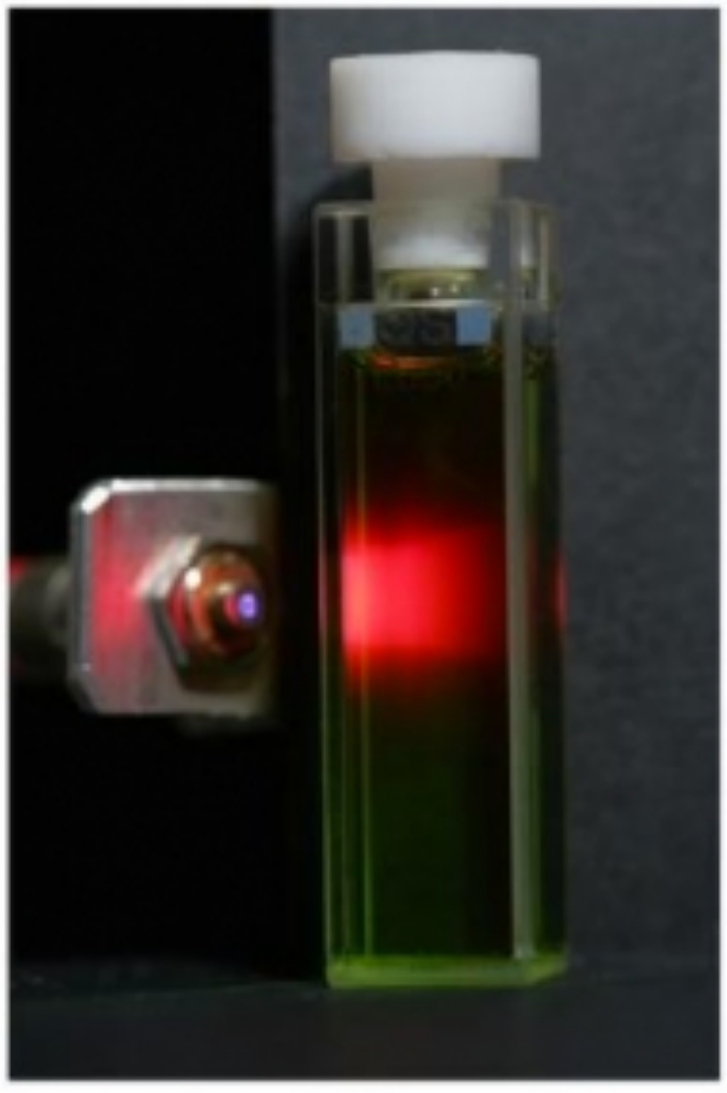
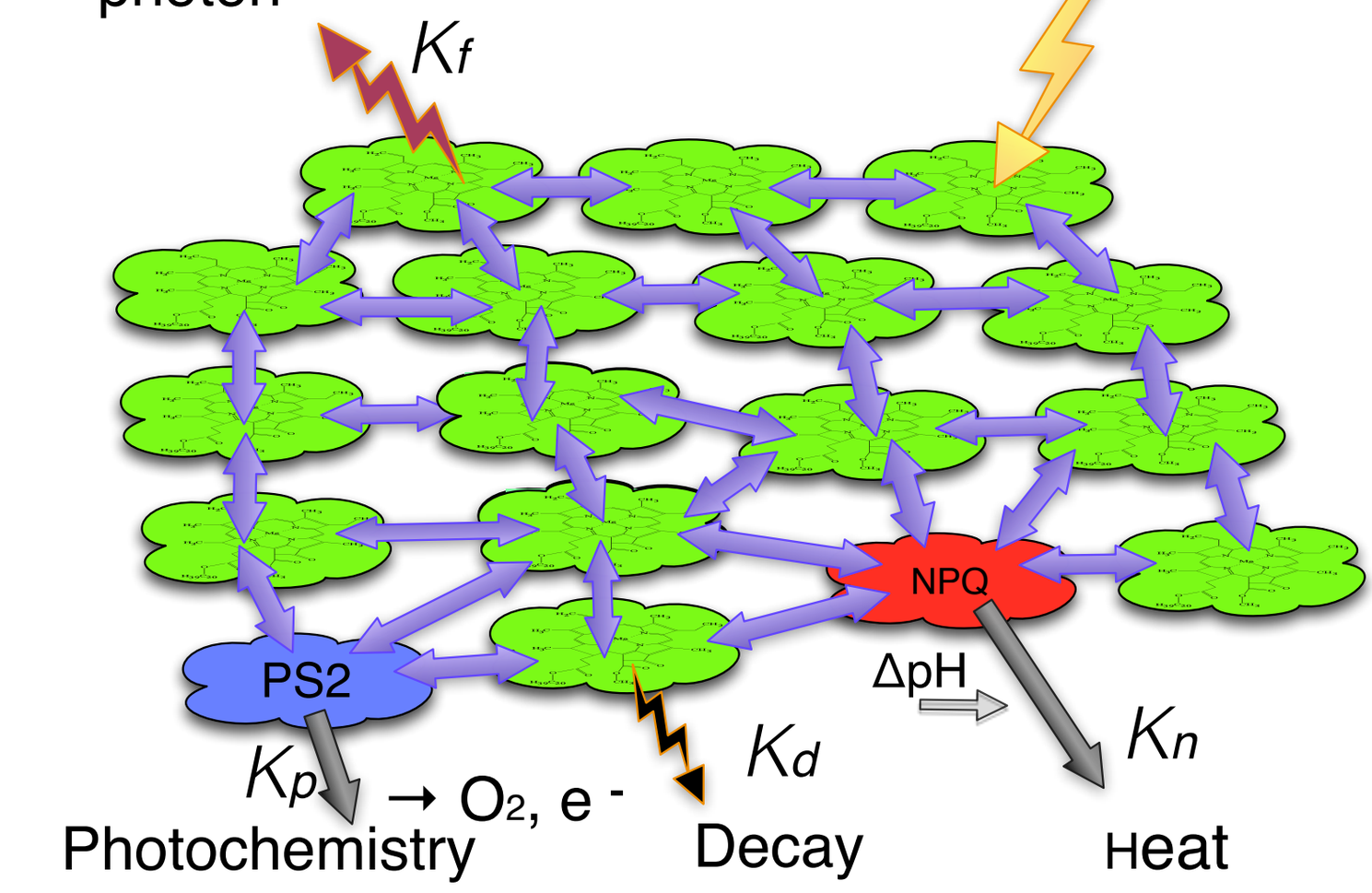


Fluorescence photon

$$\varphi_f = \frac{K_f}{K_f + K_d + K_n + K_p}$$

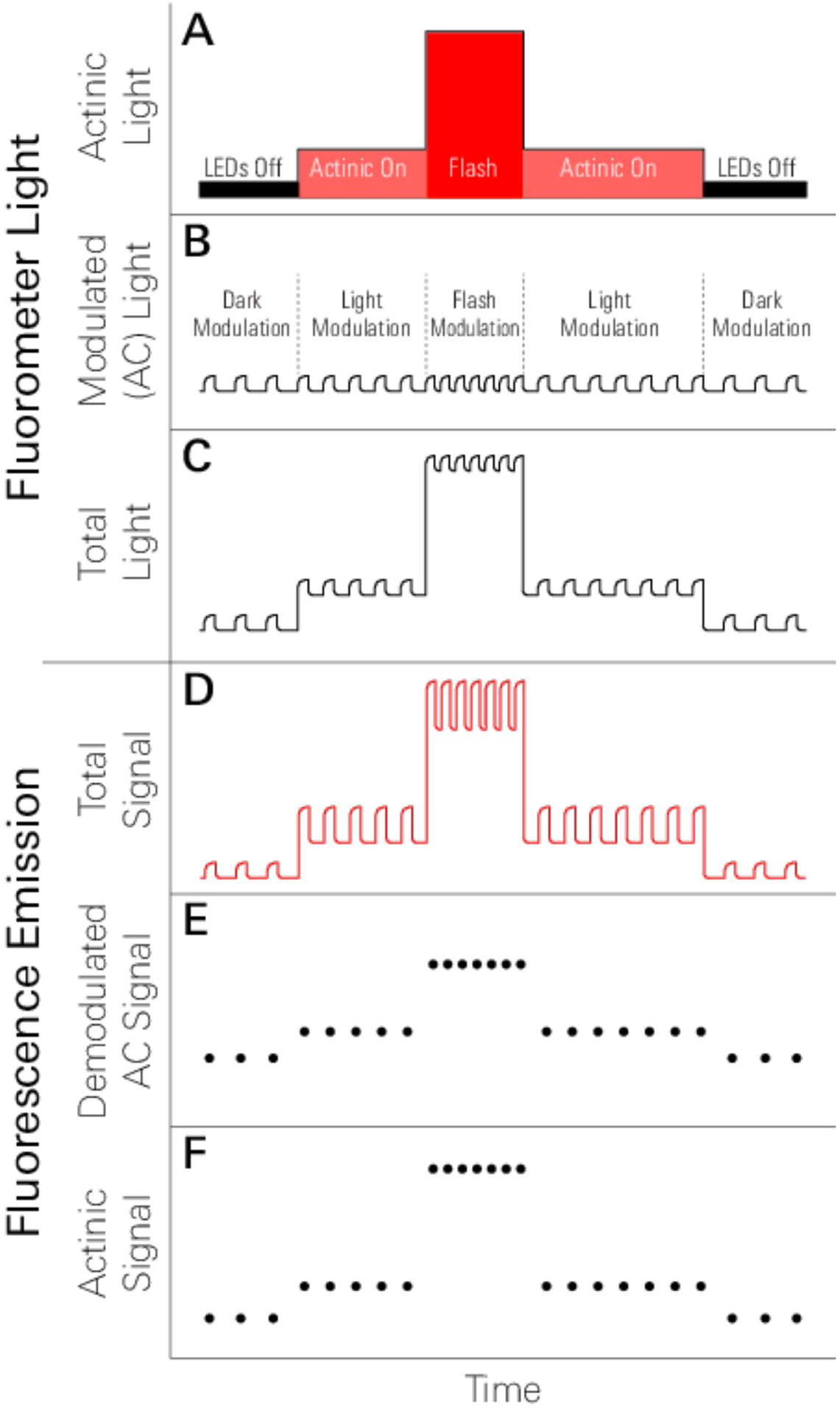
Solar photon



Pure Chlorophyll Solution —> Kp and Kn=0, fluorescence yield around 1
higher fluorescence from Chl solution than leaf already found in 1874 (Mueller)

Taiz and Zeiger, "Plant Physiology", 2010.

Pulse Amplitude Modulated (PAM) fluorometry



F_s (dSIF/dAPAR)

SIF

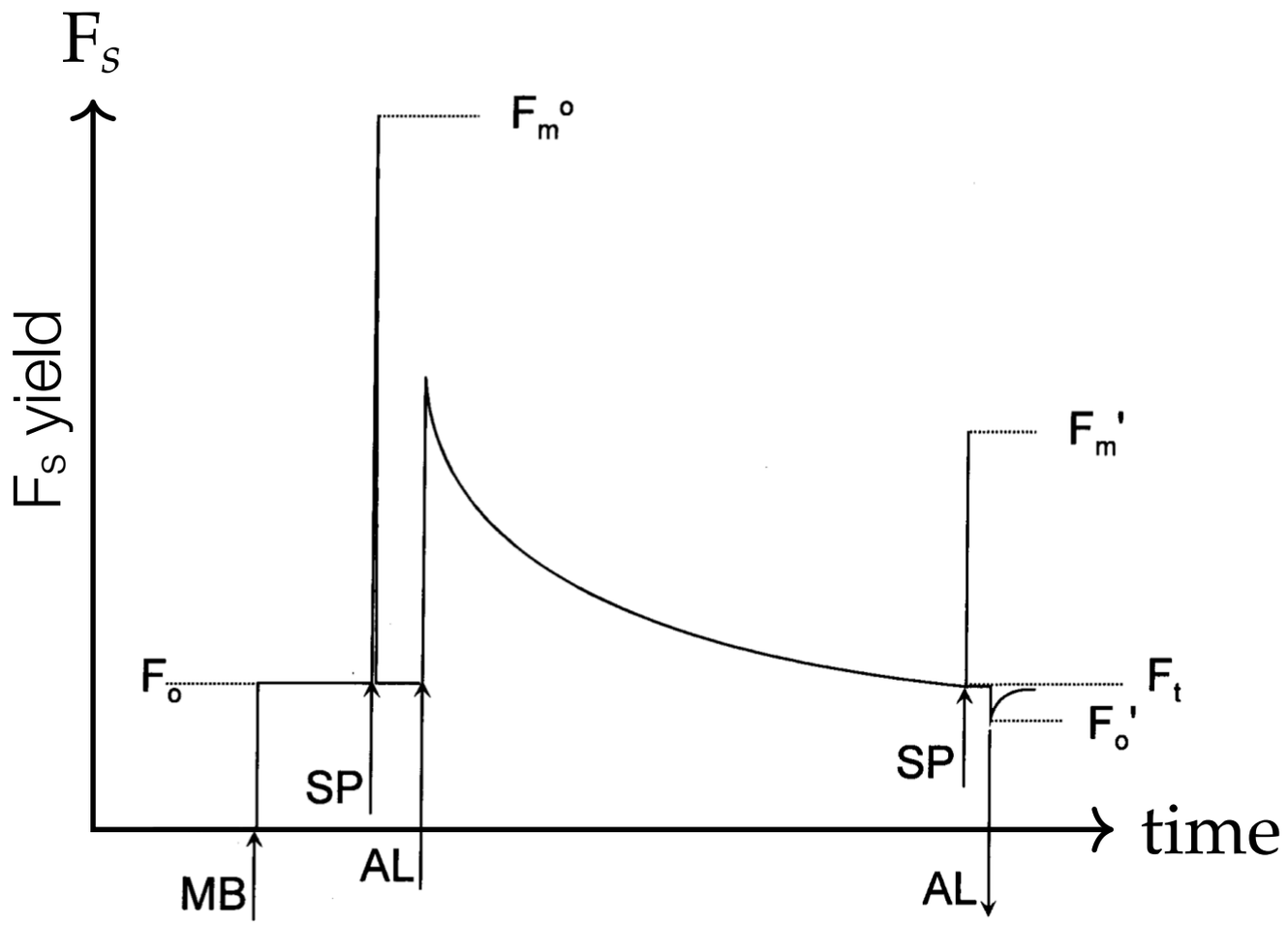
https://www.licor.com/env/help/6800/Content/theory.html

The leaf scale — Active Fluorometry

- Fluorescence yield

$$\Phi_f = \frac{K_f}{K_f + K_p + K_n}$$

- Rates for:
- Fluorescence
- Photosynthesis
- Heat quenching (NPQ)



from Maxwell & Johnson 2000

AL=Actinic Light (moderate light was turned on ↑ and off ↓)

SP = Saturating Pulse (strong pulsed light at each ↑)

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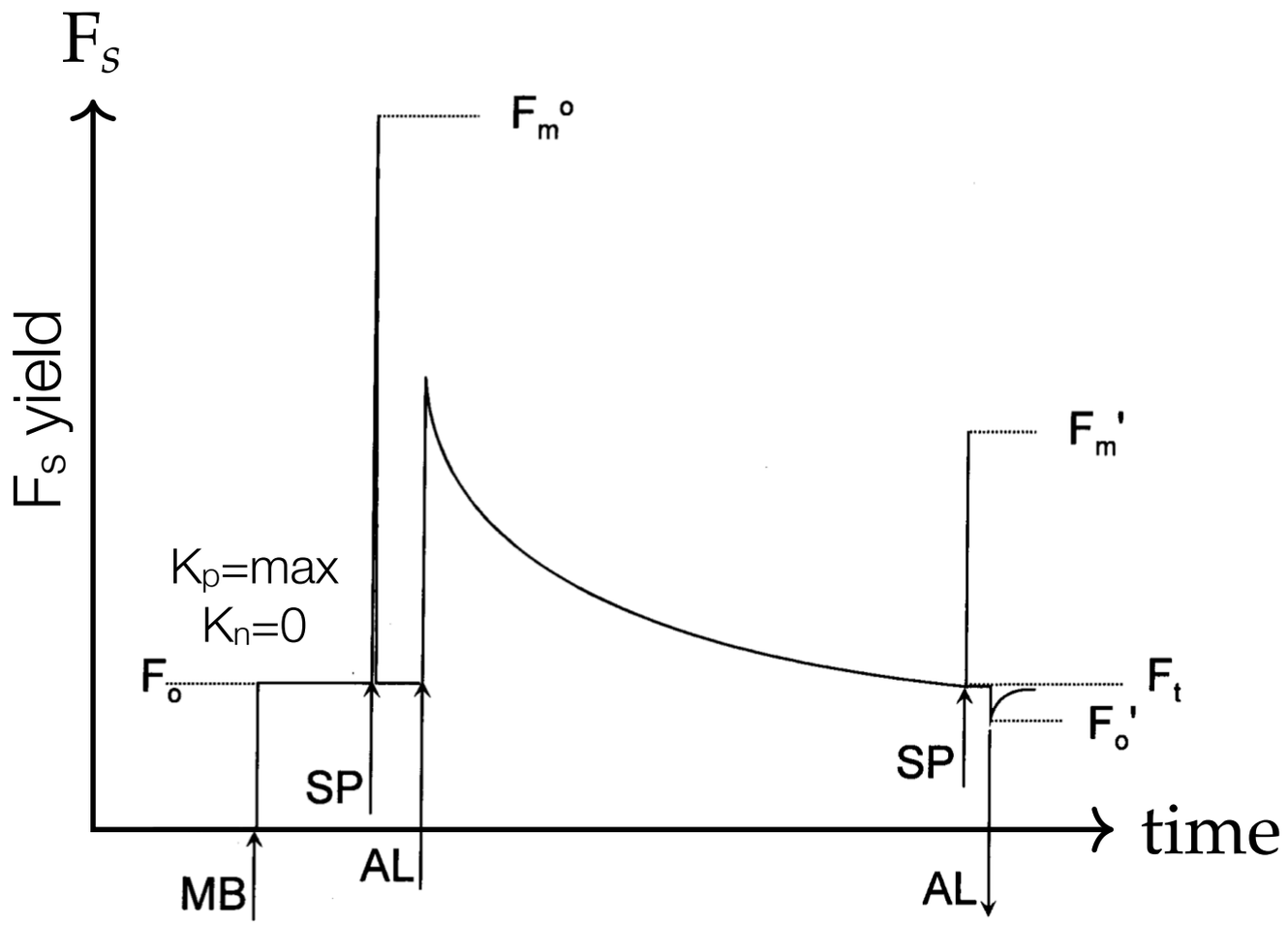

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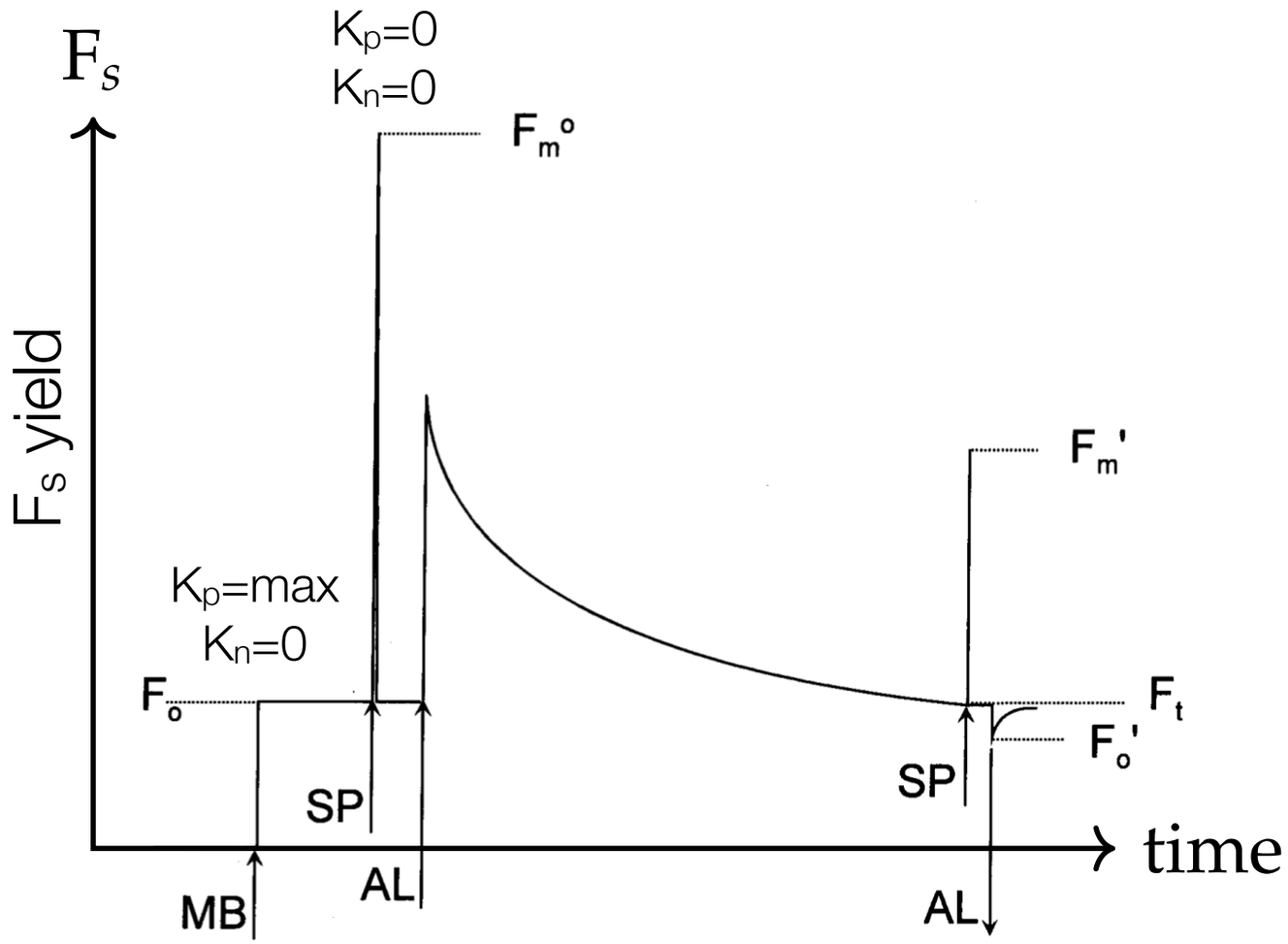

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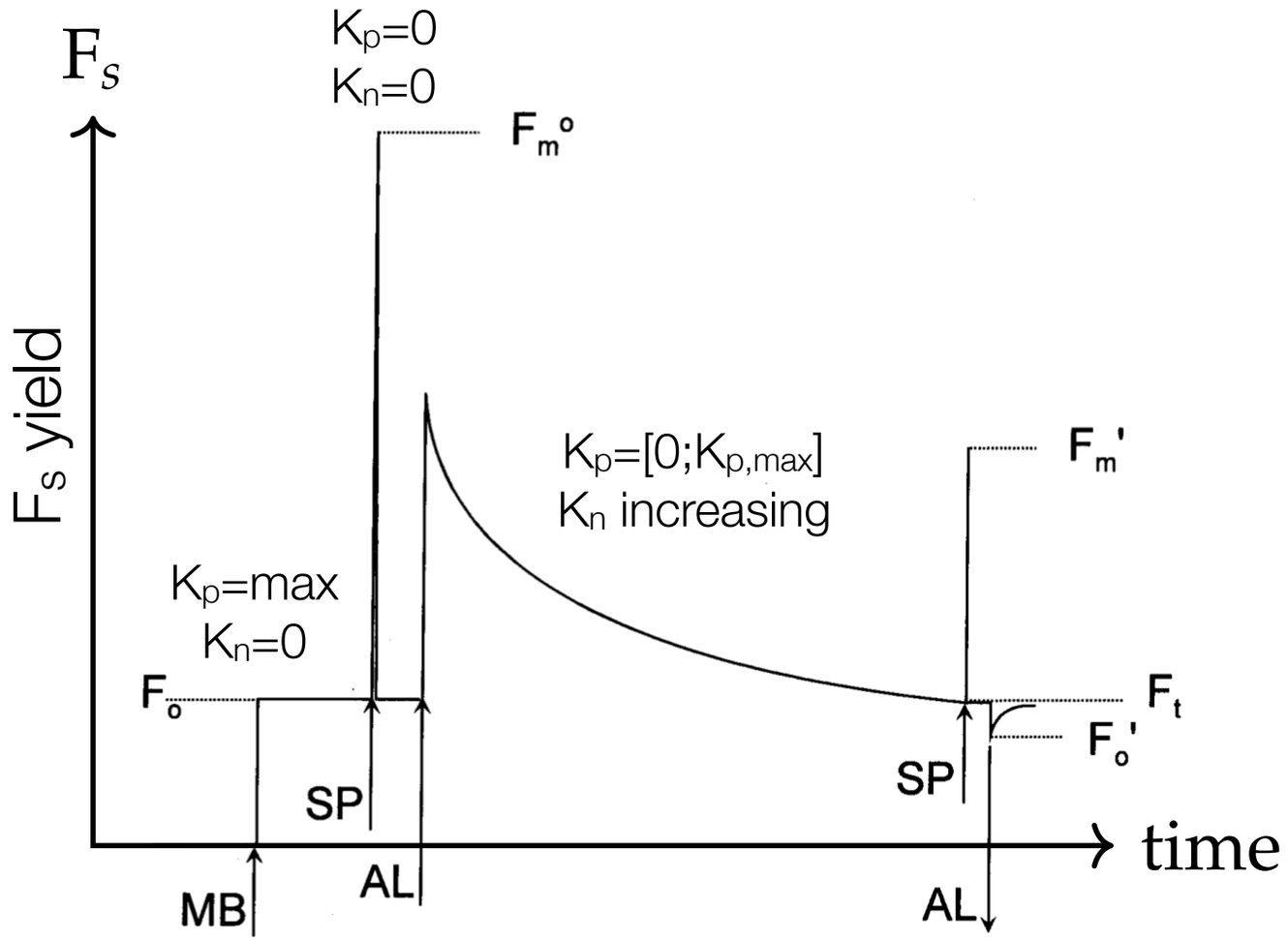

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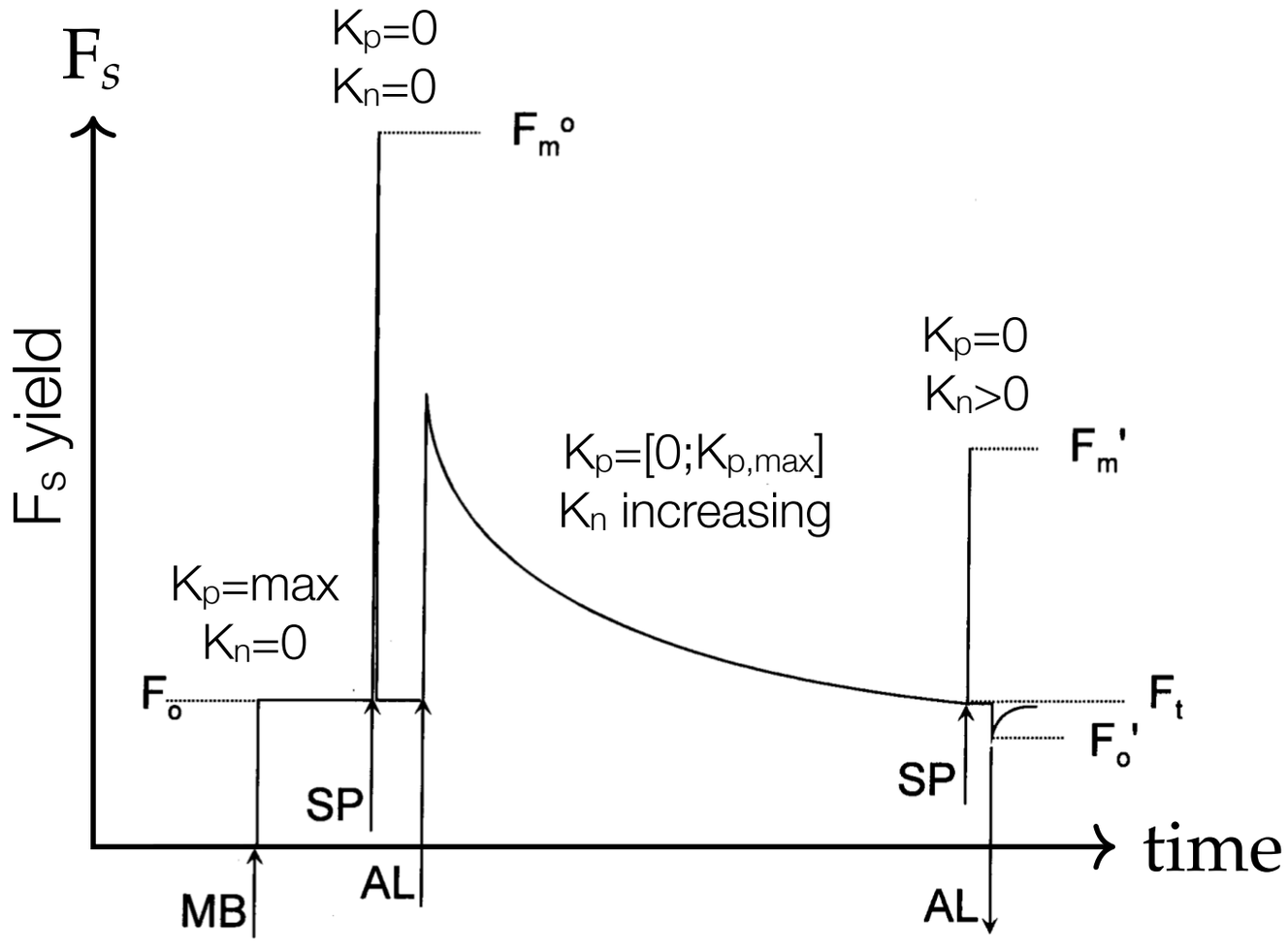

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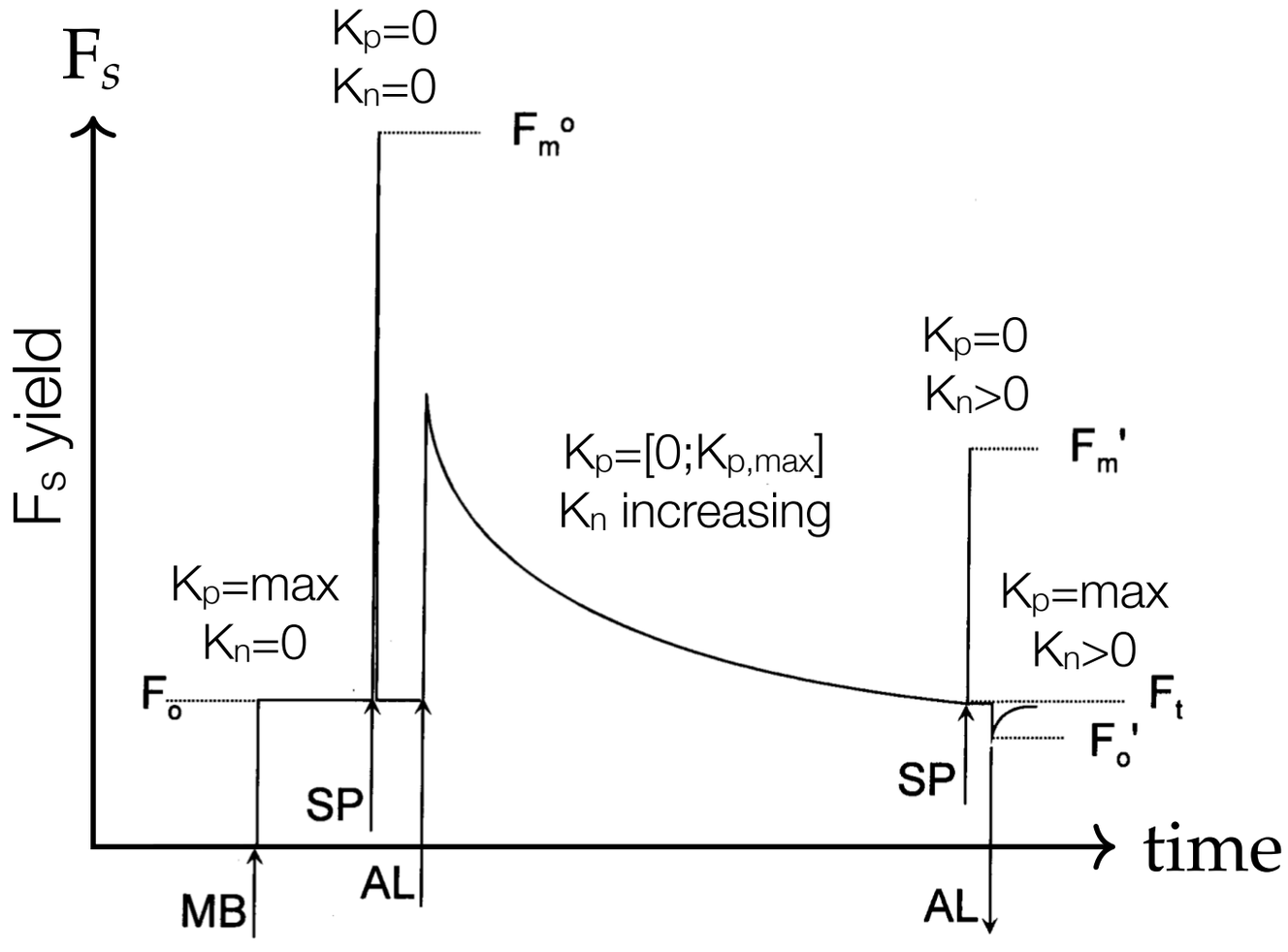

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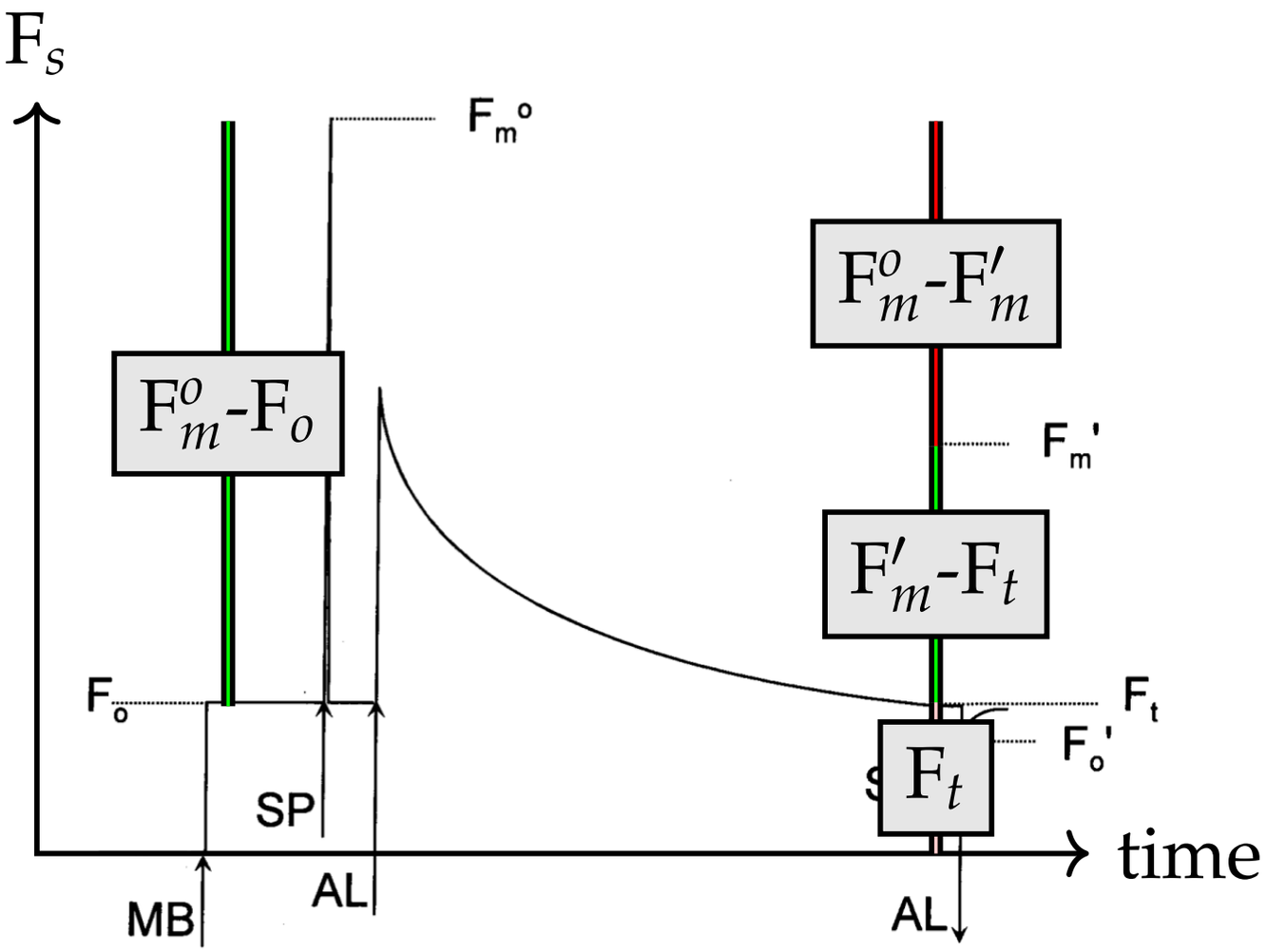
THE POWER OF ACTIVE FLUOROMETRY

- NPQ = $(F_m^o - F'_m)/F'_m$
- $\Phi_{PSII} = (F'_m - F_t)/F'_m$

  Genty, Briantais, Baker (1988), >5000 citations

- maximum PSII yield = $(F_m - F_o)/F_m$
- steady state fluorescence F_t
- F_t * APAR is the only thing we can measure from space



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The potential and pitfalls of SIF

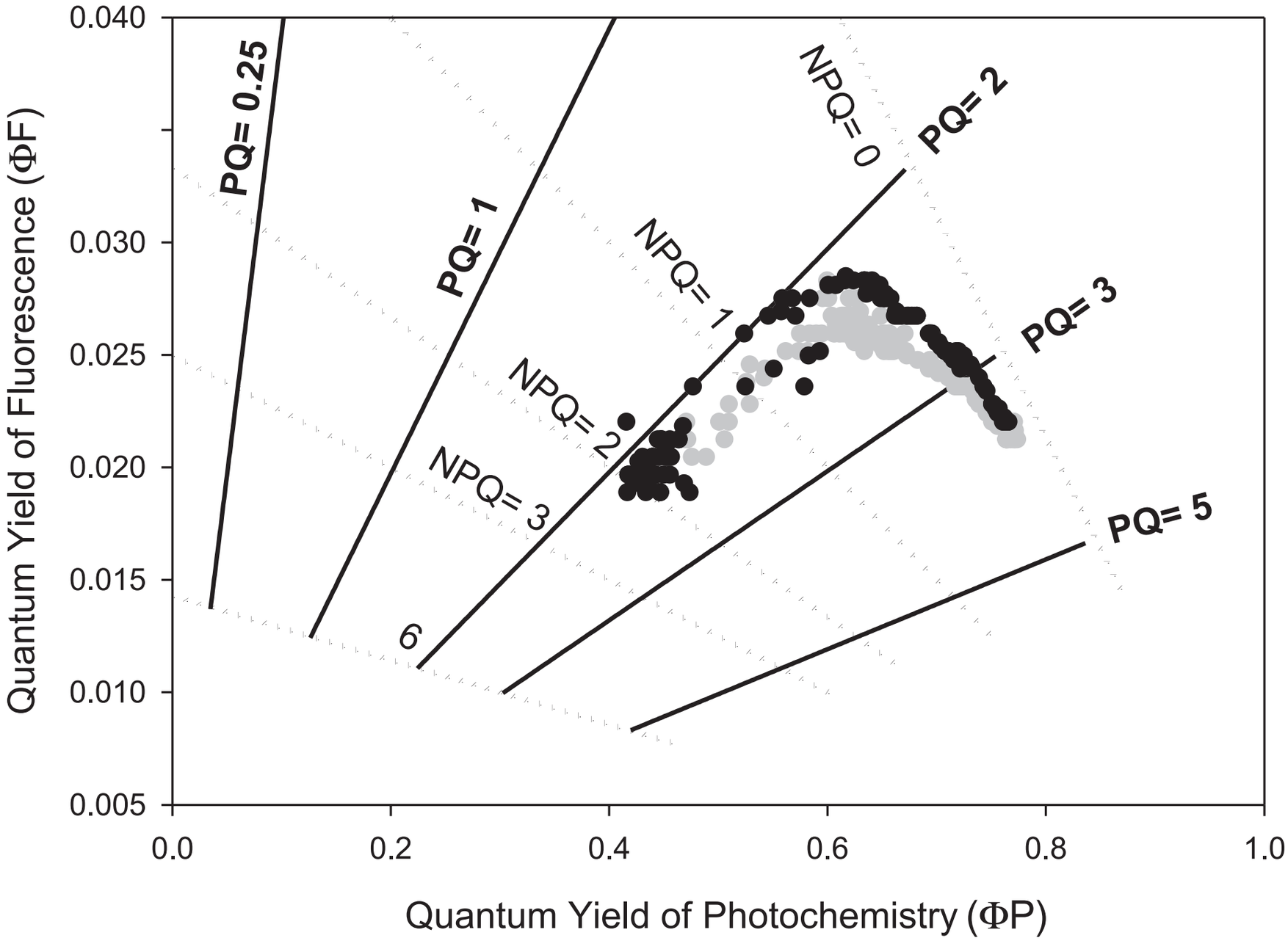
Potential

- SIF is the first remote sensing metric to excite plant physiologists (as opposed to greenness indices)
- SIF is related to APAR and/or changes in efficiencies
- Far less affected by atmospheric effects (unlike NDVI/EVI/LAI)
- “easy” to implement in Earth System Model

Pitfall

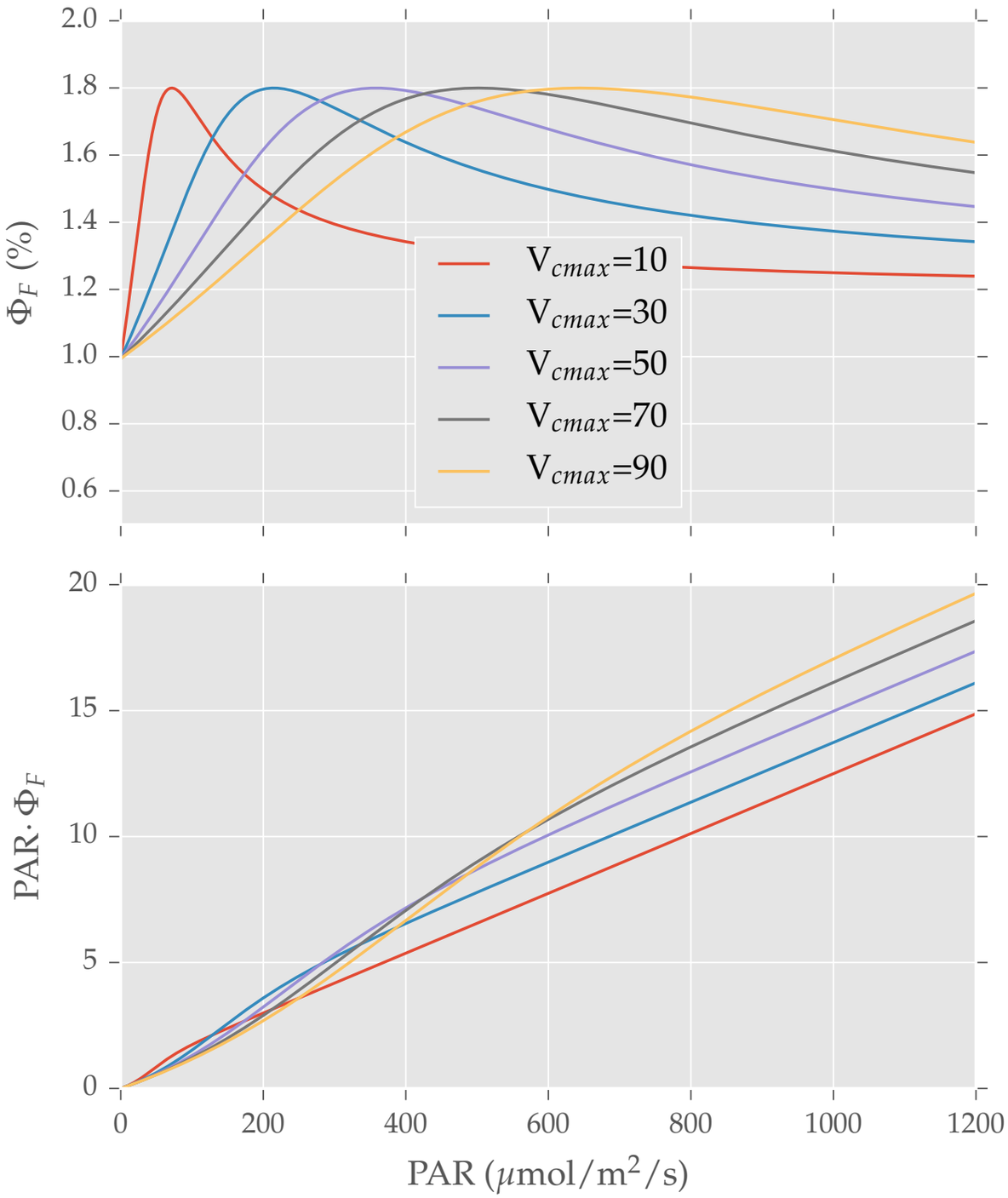
- We only measure absolute fluorescence, not yields (unlike PAM), requires some re-thinking of physiologists
- With SIF alone, it is hard to differentiate changes in APAR from changes in efficiencies and structure.

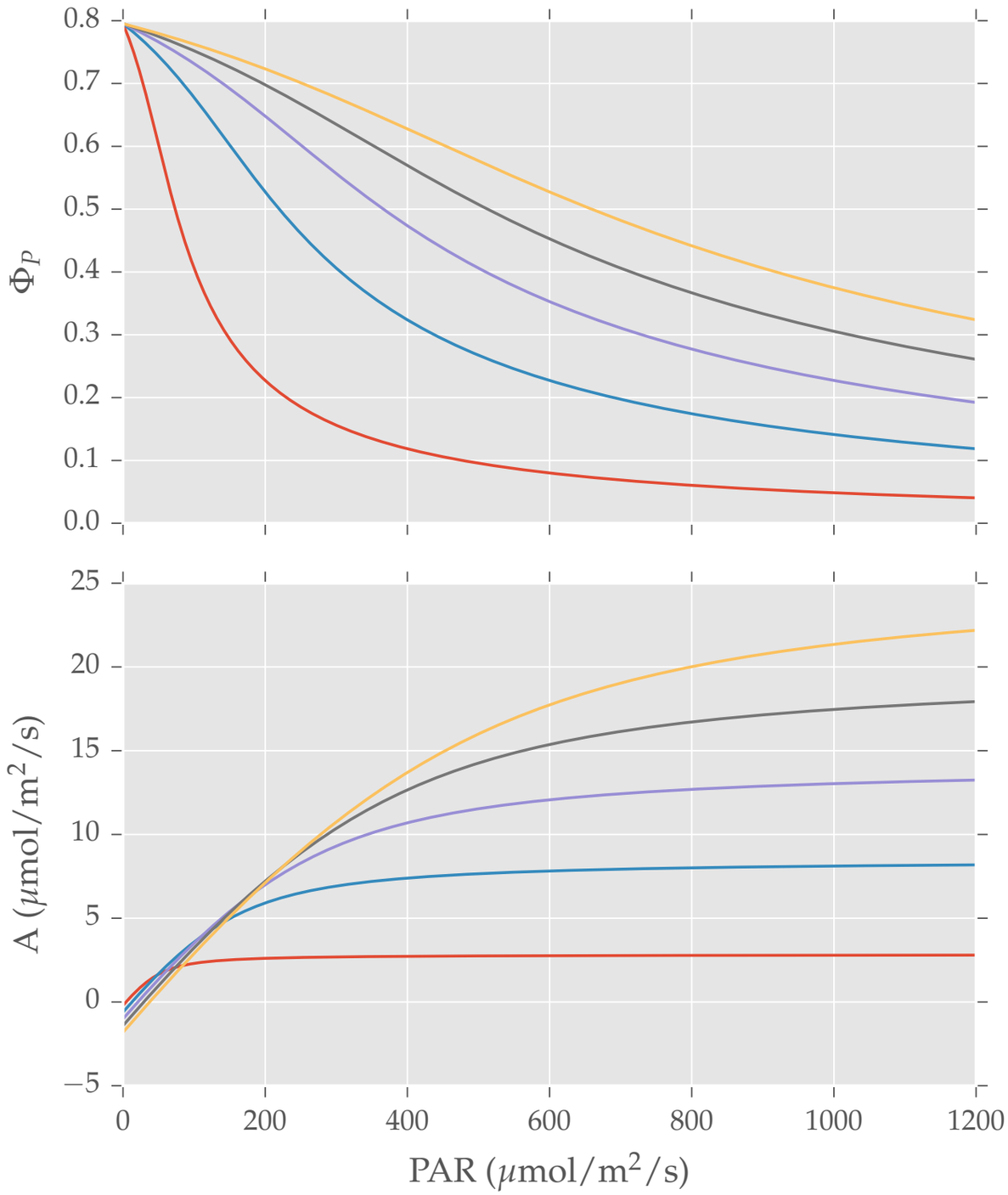
“Easy to model”: General yield relationship
—> not all models expose effective PSII yield



from Porcar-Castell et al (2014)

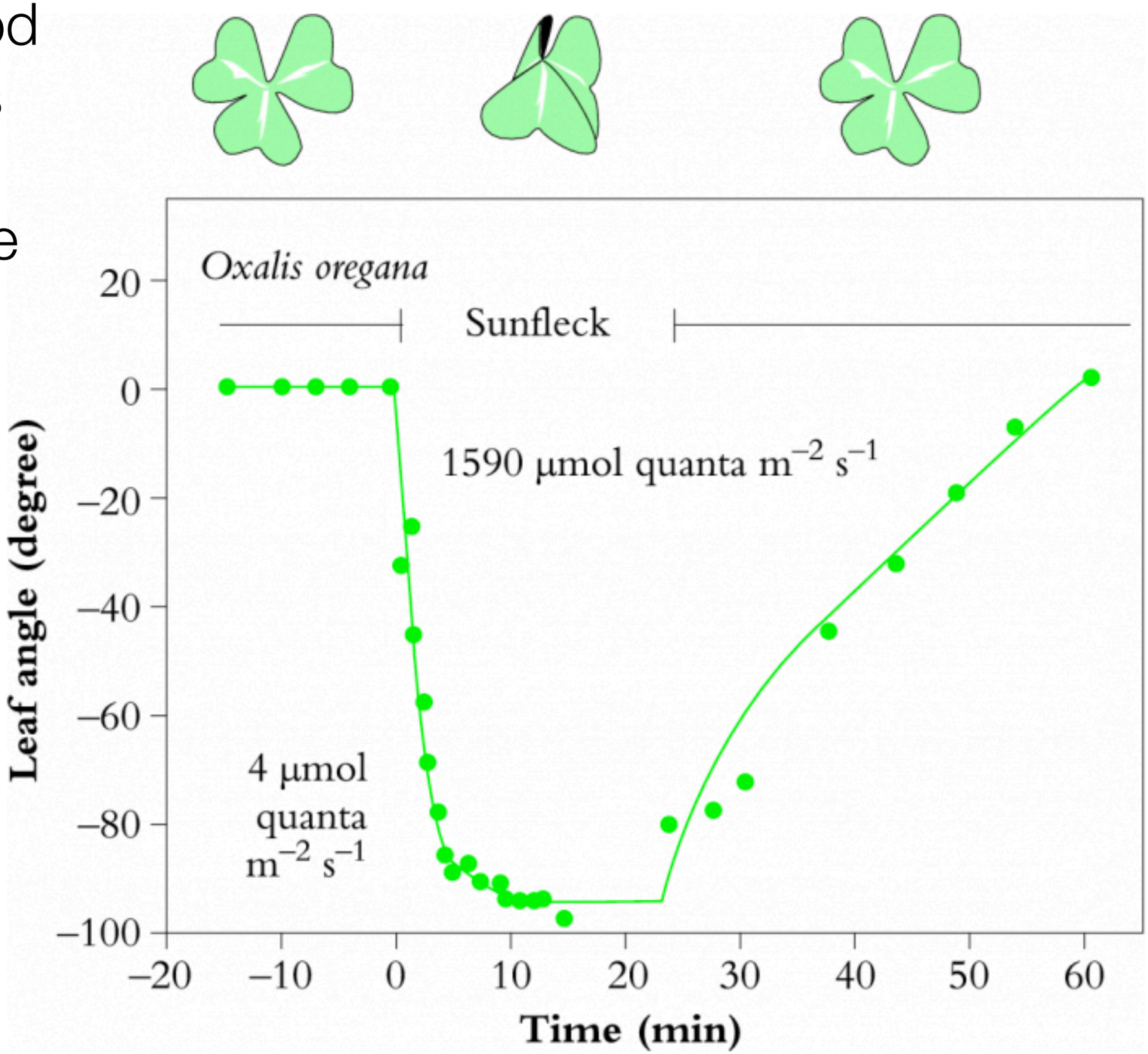
Leaf-level yields (Top) and absolute (Bottom) SIF and Photosynthesis for C3 (from SCOPE model)





What if plants use an alternative method to avoid excess light? Avoid absorption in the first place

— Leaf orientation



http://plantsinaction.science.uq.edu.au/

Alternative method: Avoid absorption in the first place

— Chloroplast movements

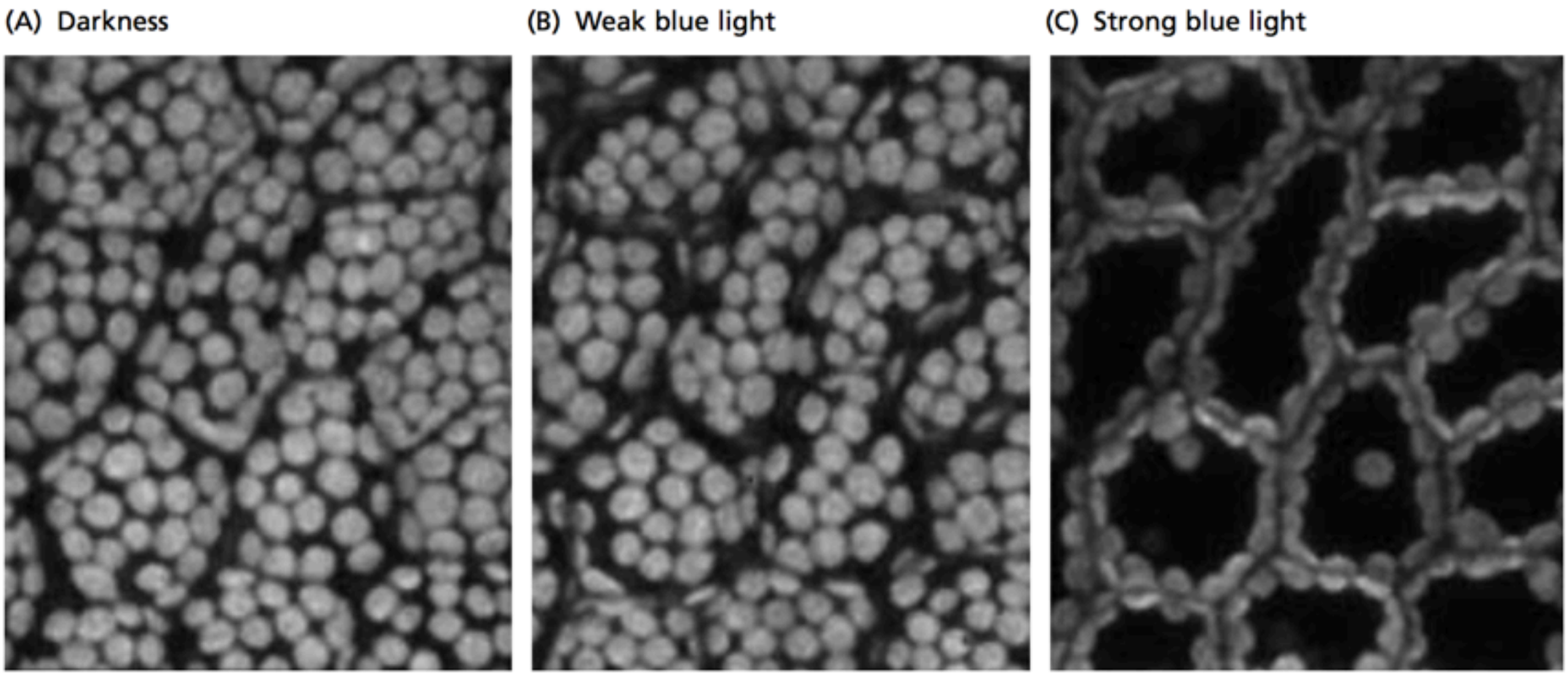


FIGURE 9.5 Chloroplast distribution in photosynthesizing cells of the duckweed *Lemna*. These surface views show the same cells under three conditions: (A) darkness, (B) weak blue light, and (C) strong blue light. In A and B, chloroplasts are positioned near the upper surface of the cells, where they can absorb maximum amounts of light. When the cells were irradiated with strong blue light (C), the chloroplasts move to the side walls, where they shade each other, thus minimizing the absorption of excess light. (Micrographs courtesy of M. Tlalka and M. D. Fricker.)

Taiz and Zeiger, "Plant Physiology", 2010.

Carbon - Water coupling (Flexas et al)

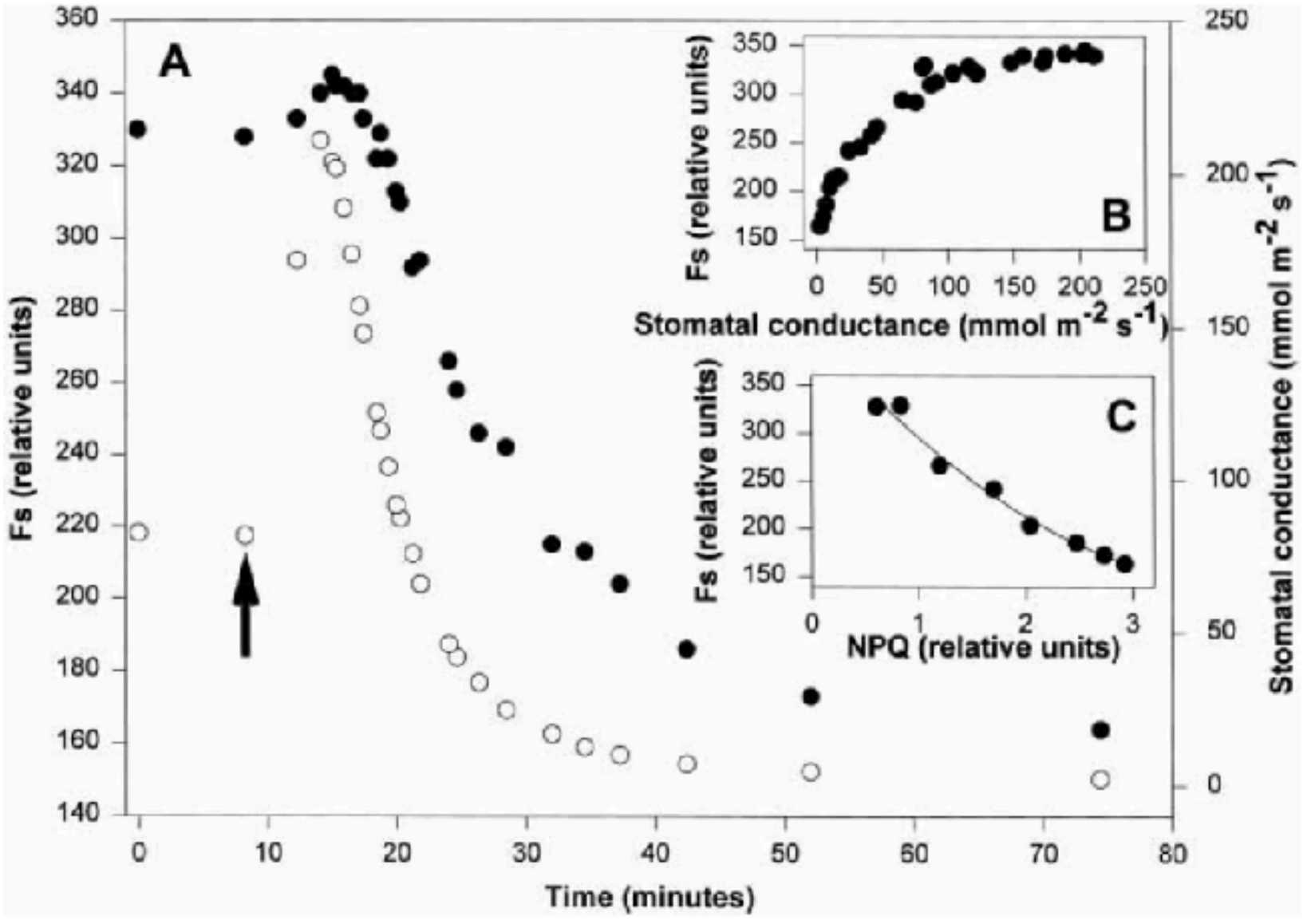
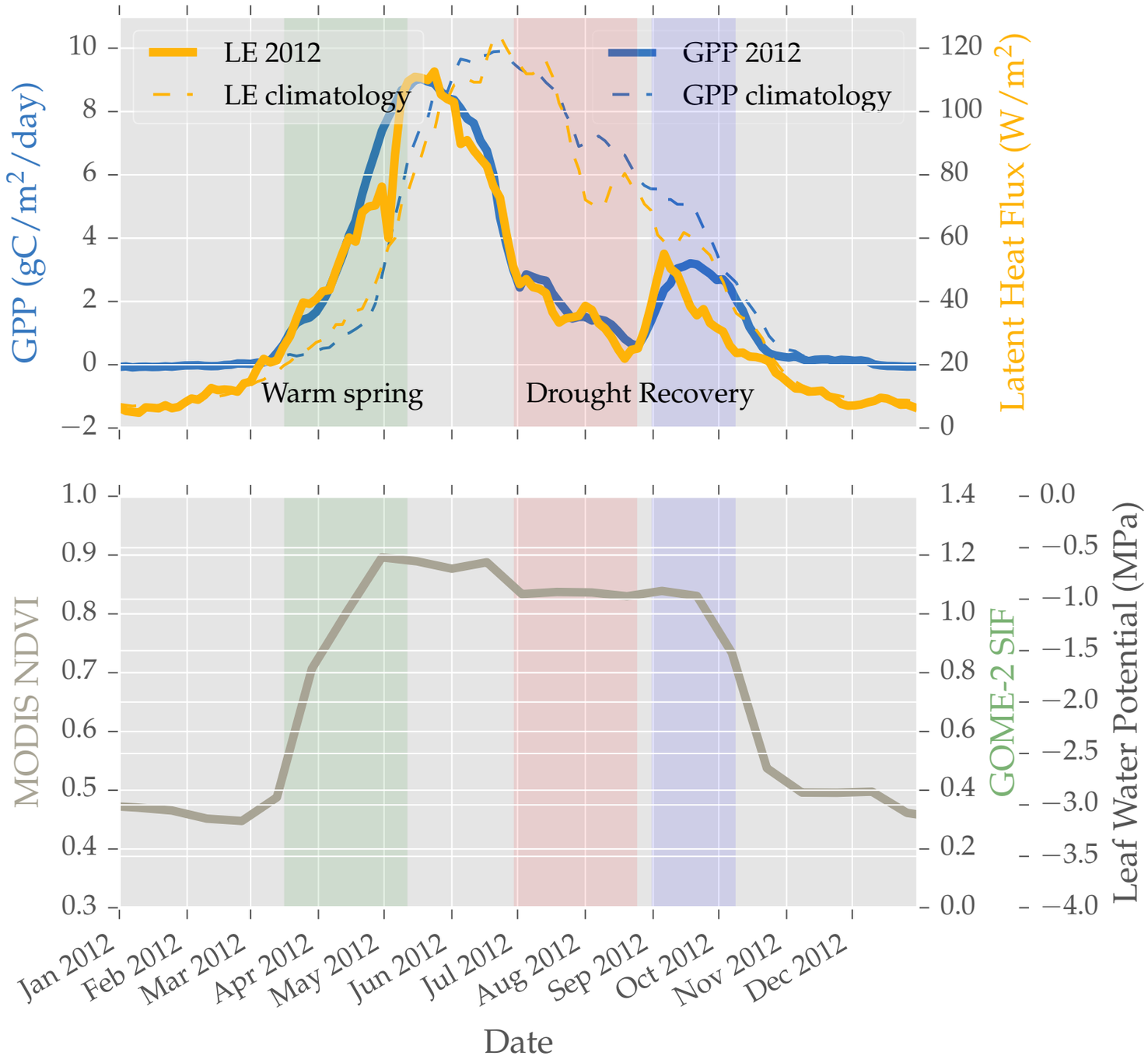


Fig. 4. Evolution with time of Fs (●) and g (○) after cutting a leaf in air (indicated by an arrow) at constant PPFD (500 µmol $m^{-2}s^{-1}$) and temperature (25°C). Fs values were not normalized as they were measured on the same leaf. The inserts show the relationship between Fs and g and NPQ through the entire time course.

The Ozarks, Missouri (Fluxtower)



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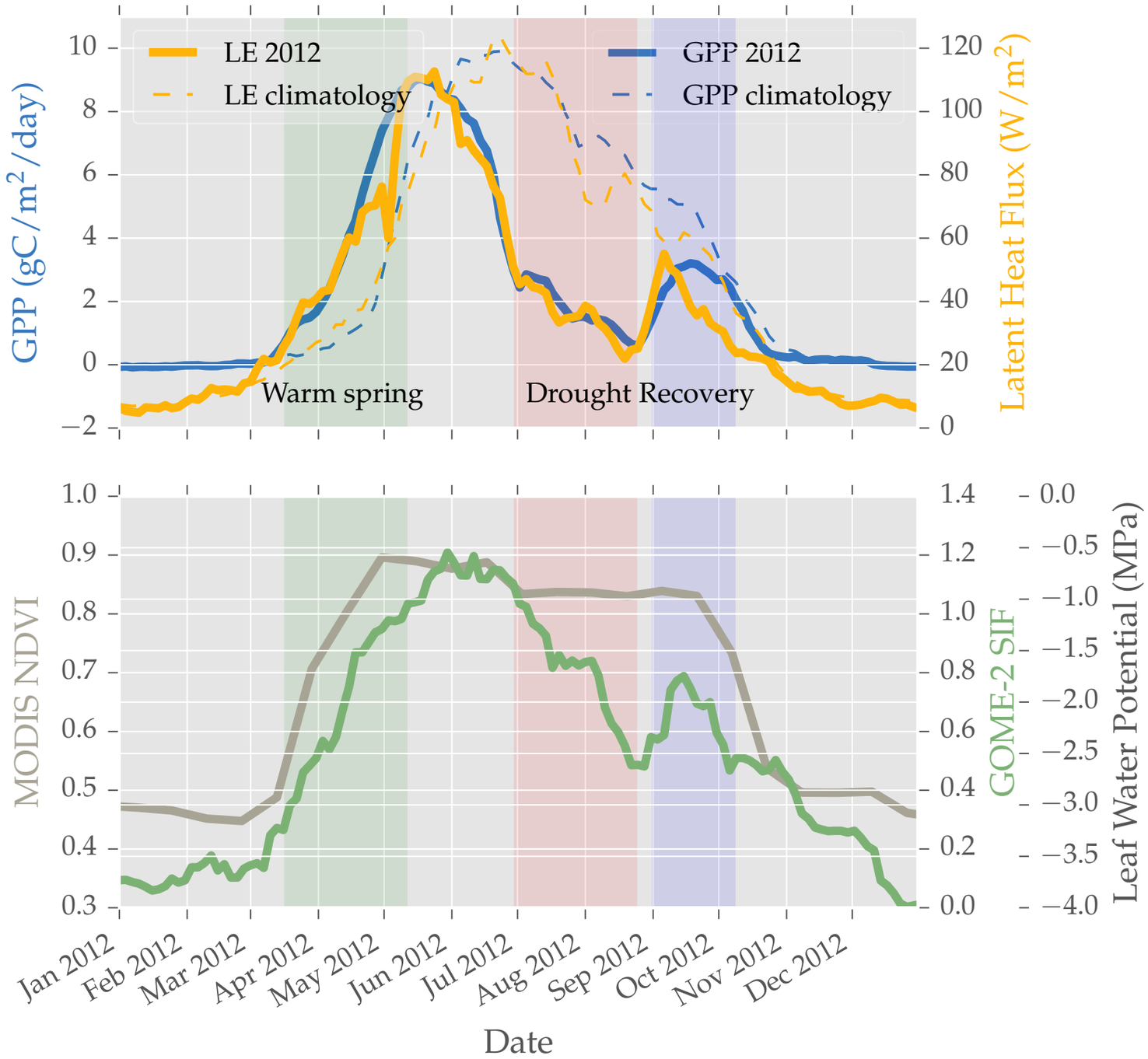

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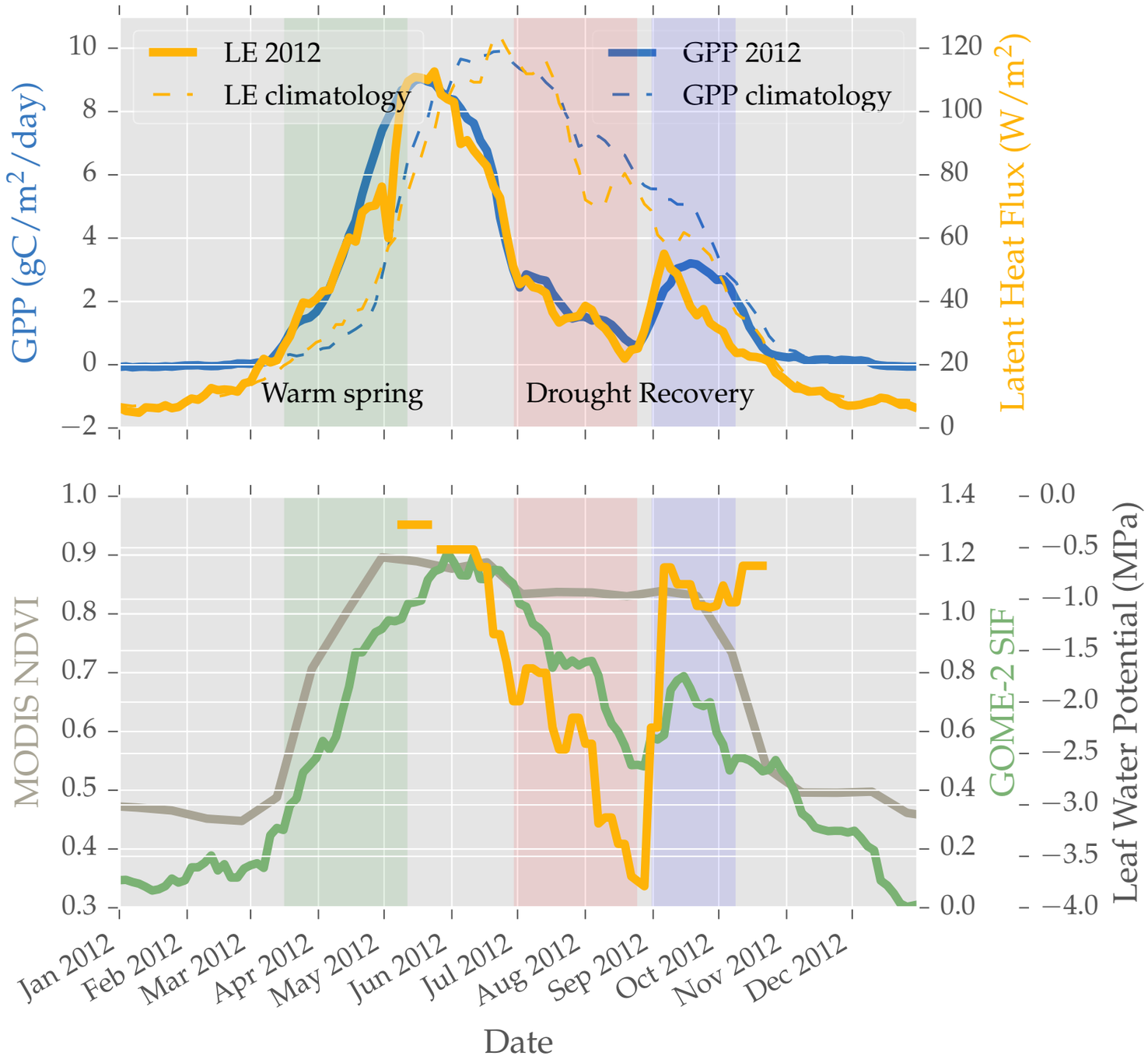
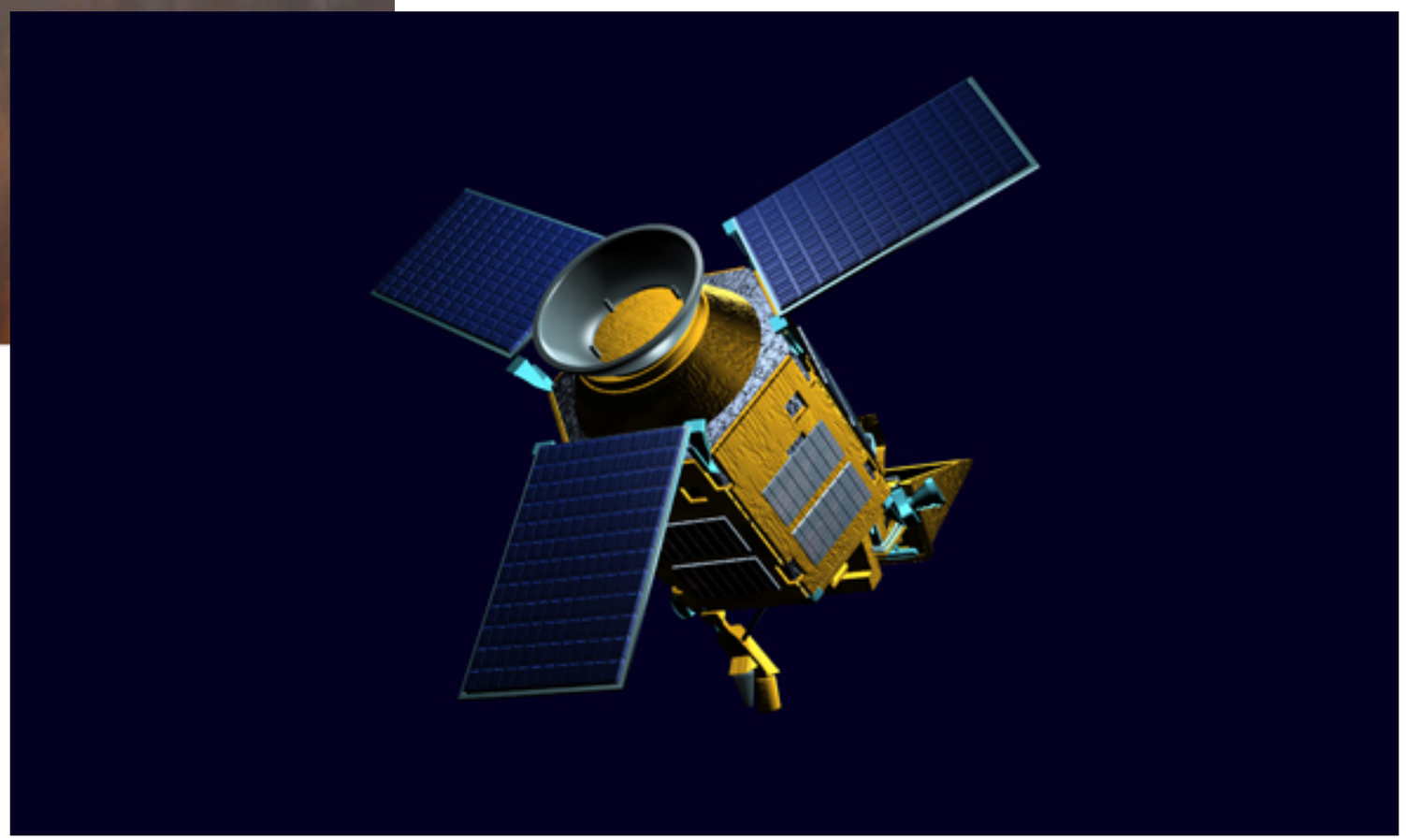
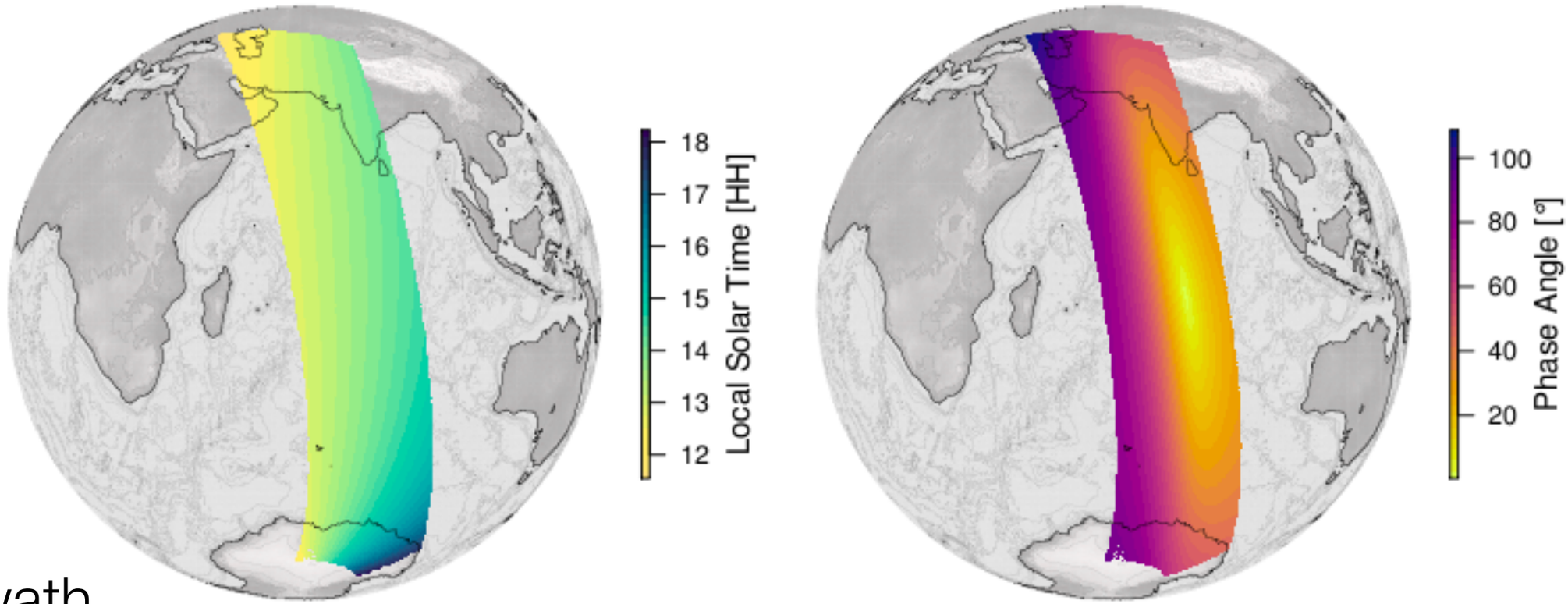


TROPOMI, the new kid on the block…

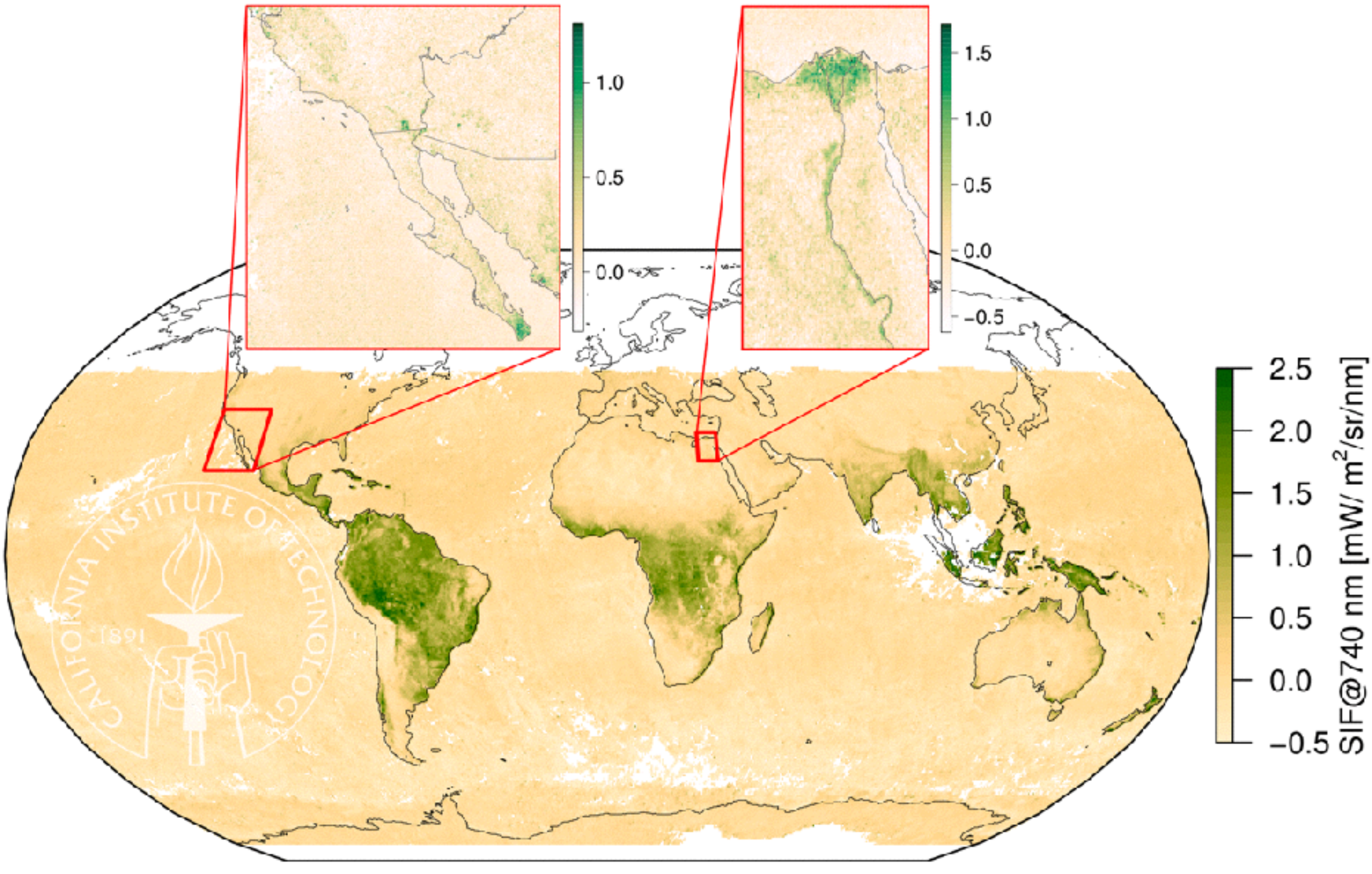


launched on 13 October 2017

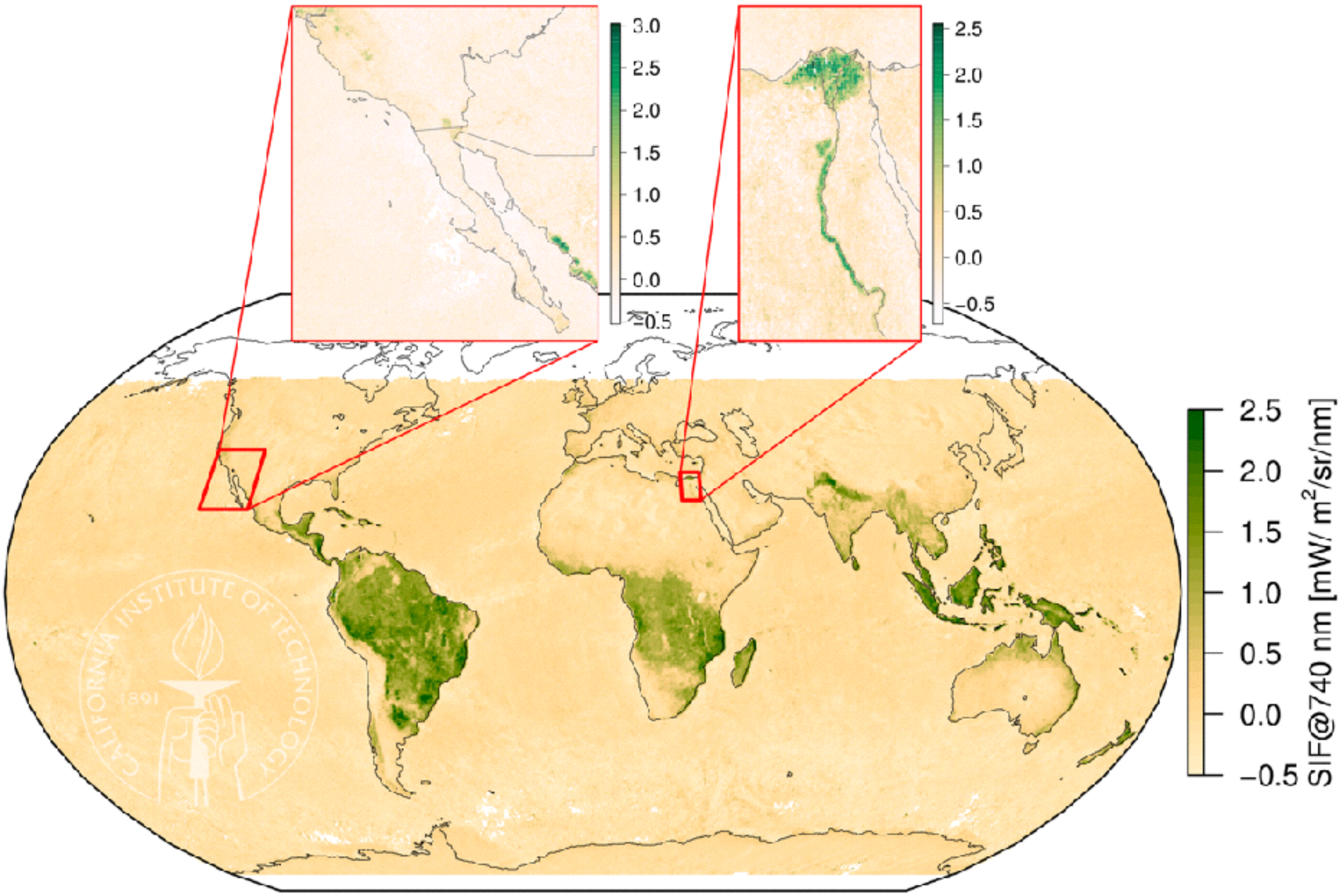
2300km Swath
daily global coverage



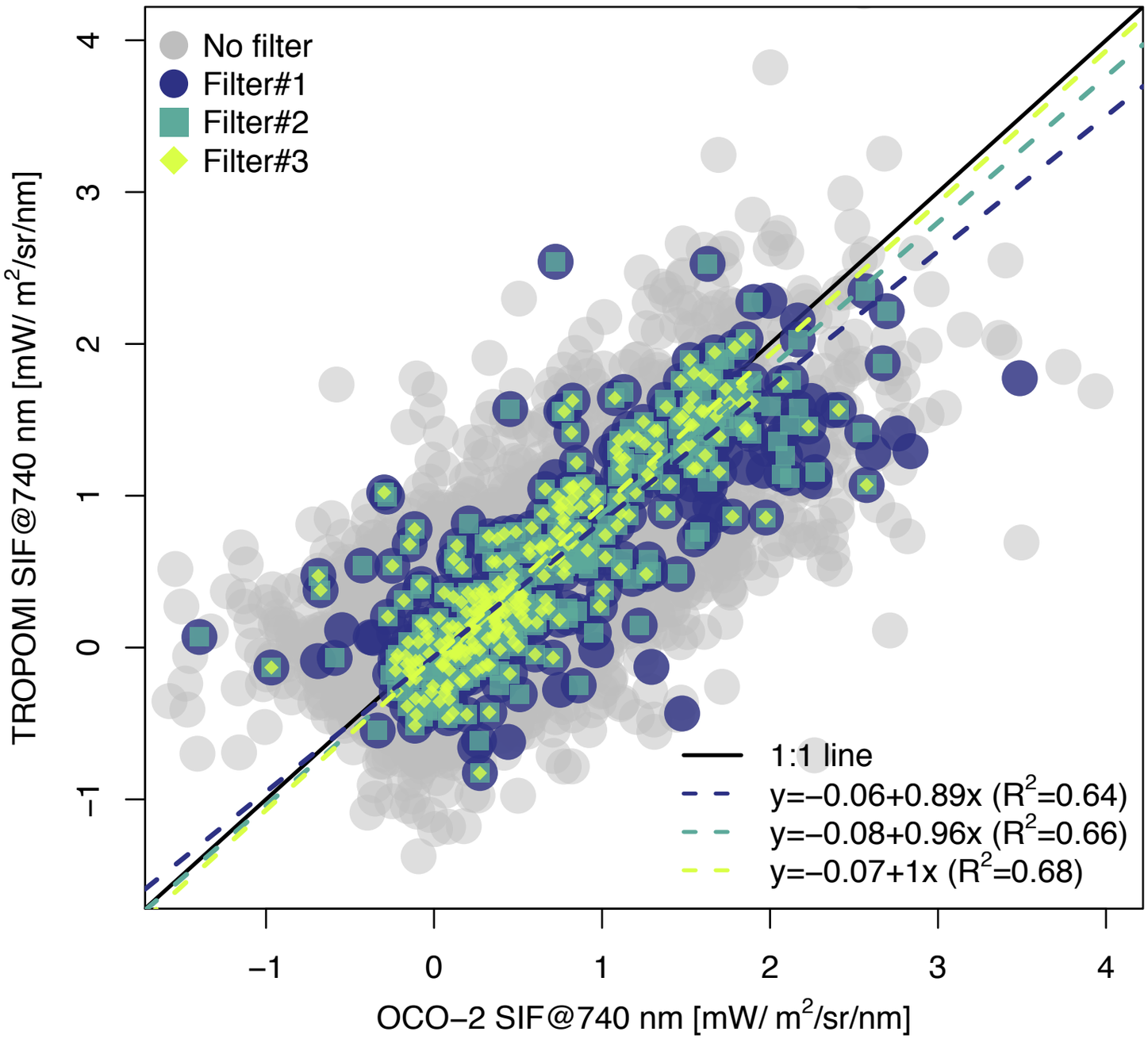
First global map (4 days in November)



First global map (few days in February)

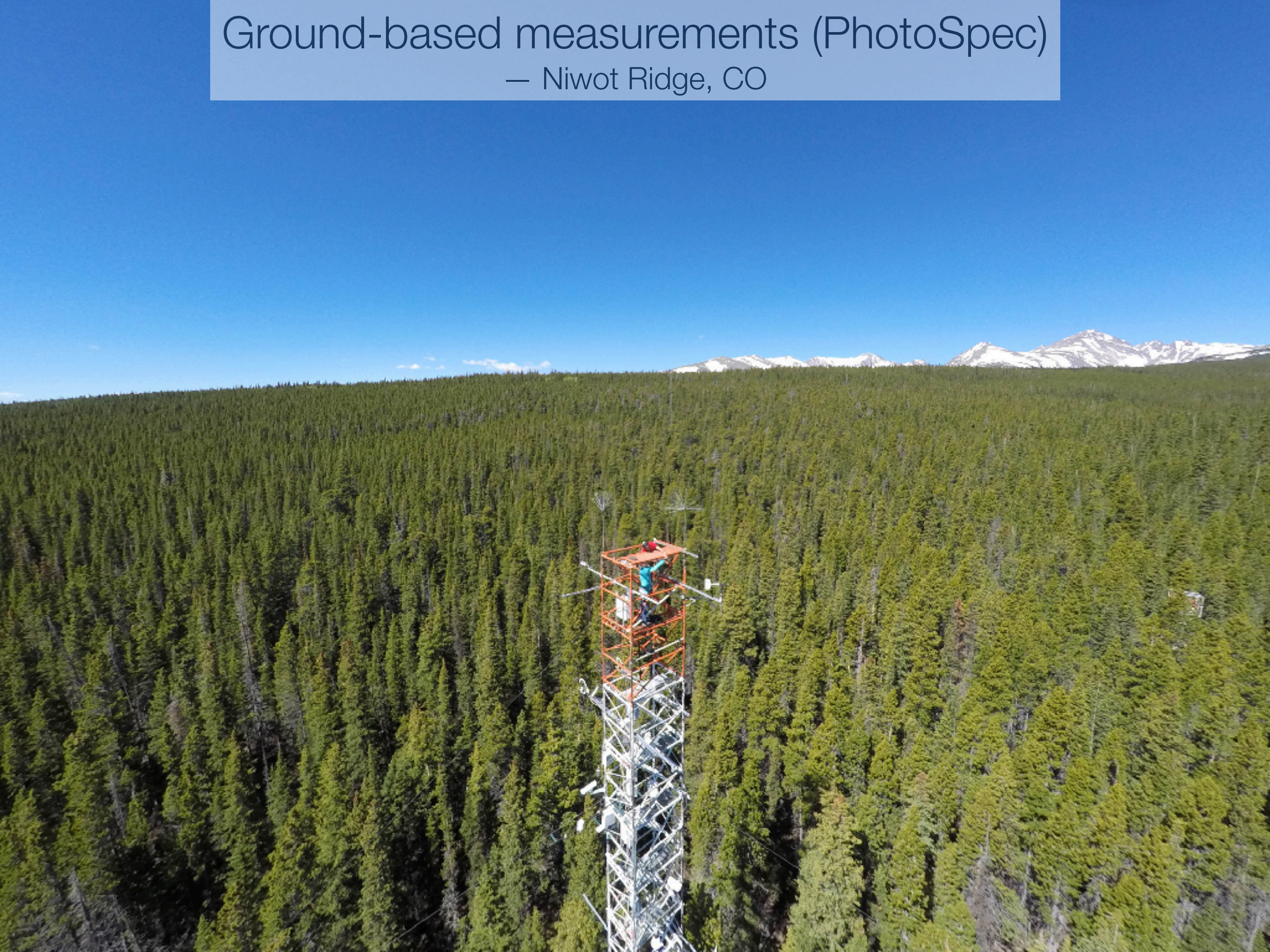


Validation against OCO-2



Ground-based measurements (PhotoSpec)

— Niwot Ridge, CO



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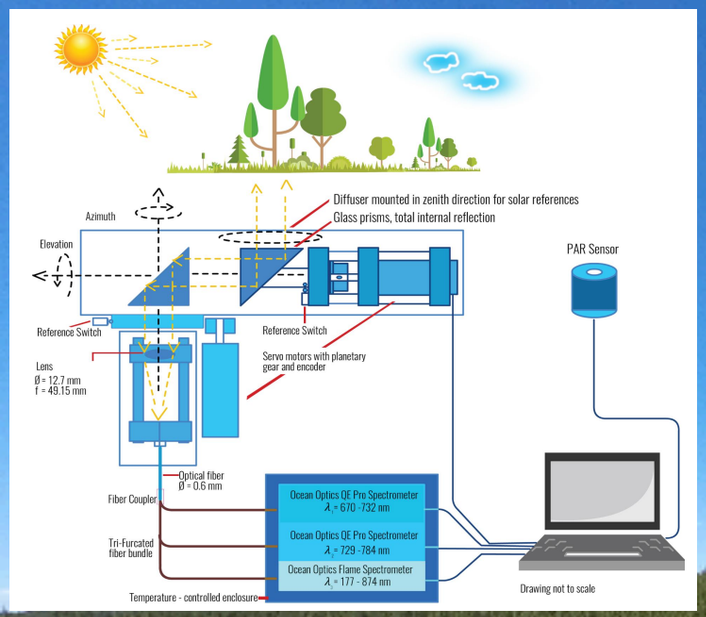


Thoughts

- SIF is powerful but even leaf-level formulation is still empirical (but we have more data now)

- Should be easy to implement in ESM

- [GPP,ET,SIF,reflectance] = F(V_{cmax}, LAI, PAR, C_{ab}, CO_2, T, VPD)

  Y = F(x)

  —> To test F, we really need constraints on x and Y (too many knobs to just do parameter tuning, which might get Y kind of right but for the wrong reasons)

- Water stress: Still mostly implemented as downscaling V_{cmax}, need for more mechanistic canopy approaches.

- Make more use of ET!

P-3

Detector Array

Spectrometer

Slit

Telescope

C-23

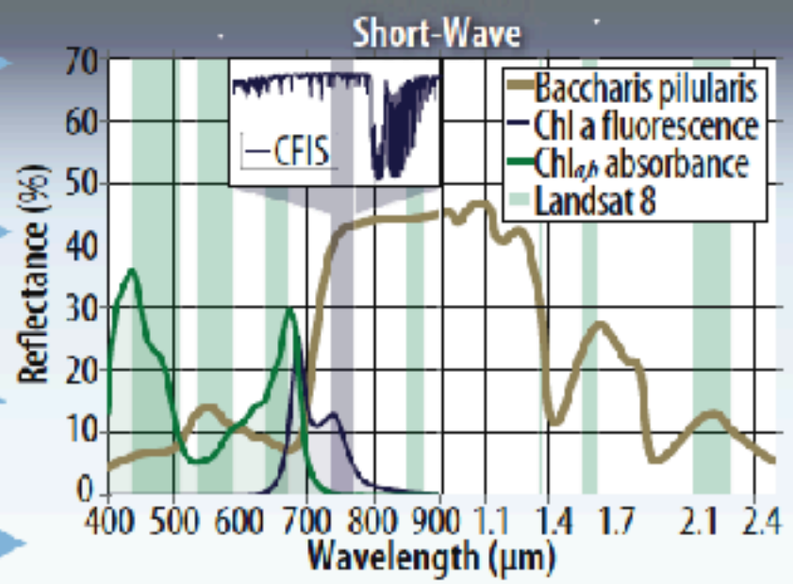
CFIS
- SIF

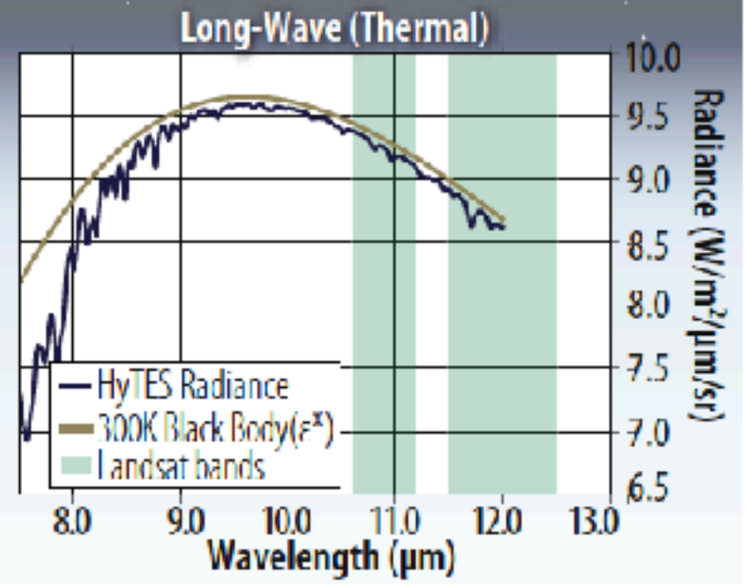
AVIRIS-NG
- Vegetation traits

HyTES
- LST and ET

CARAFE

CO_2, OCS, and H_2O fluxes





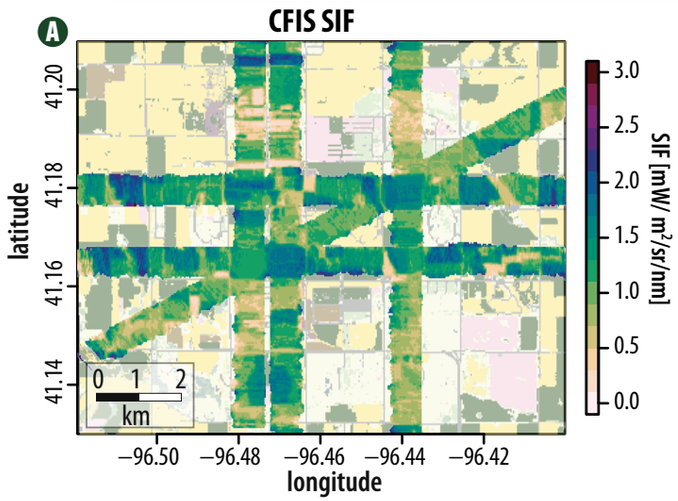
Flux Tower

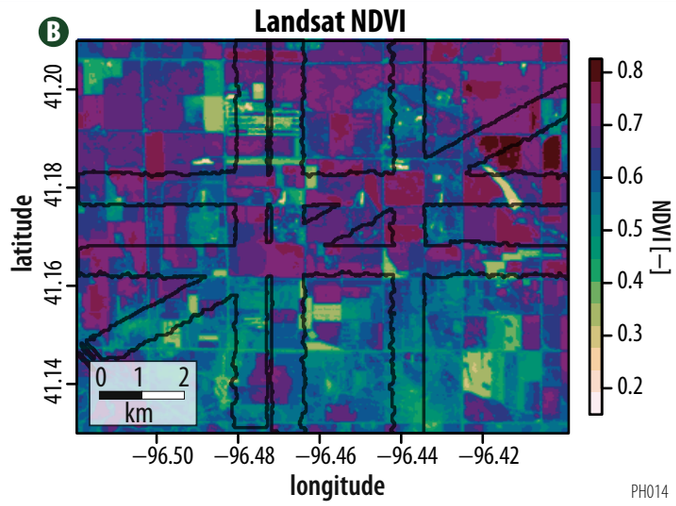
Earth System Model

Soil Moisture

Drainage

*Not to scale





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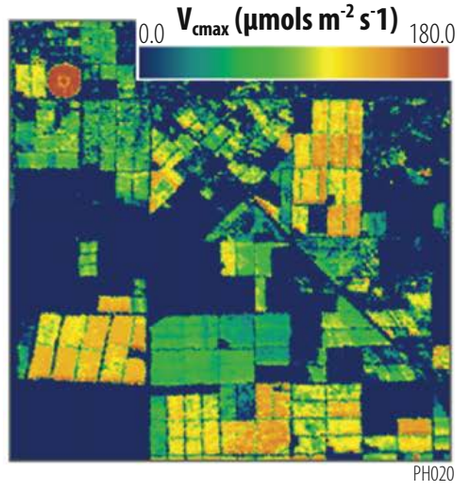

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