Modeling regional crop GPP by upscaling flux data with satellite sun-induced chlorophyll fluorescence

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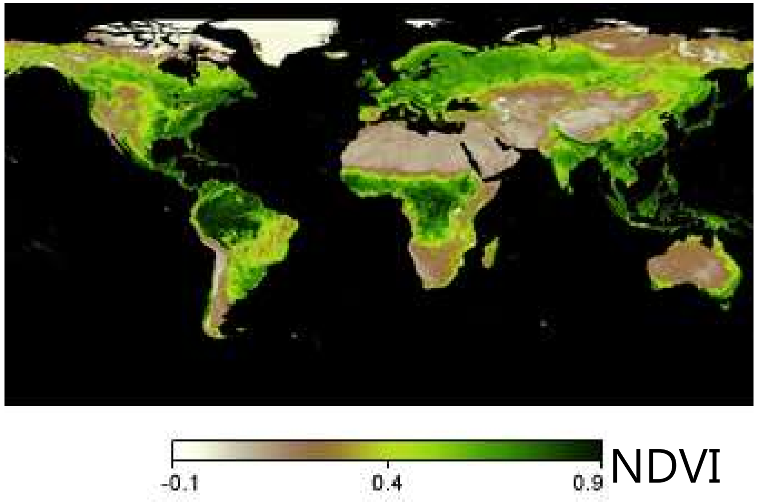
1. Introduction

❖ (traditional) Vegetation remote sensing

- Focused on vegetation indices indicating "greenness"

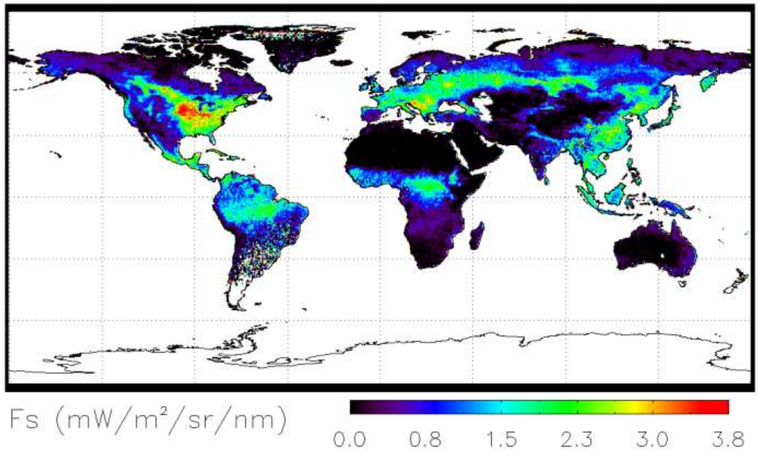
  ~ Biomass x Chlorophyll content

- Reflectance - based vegetation indices are related only to potential photosynthesis



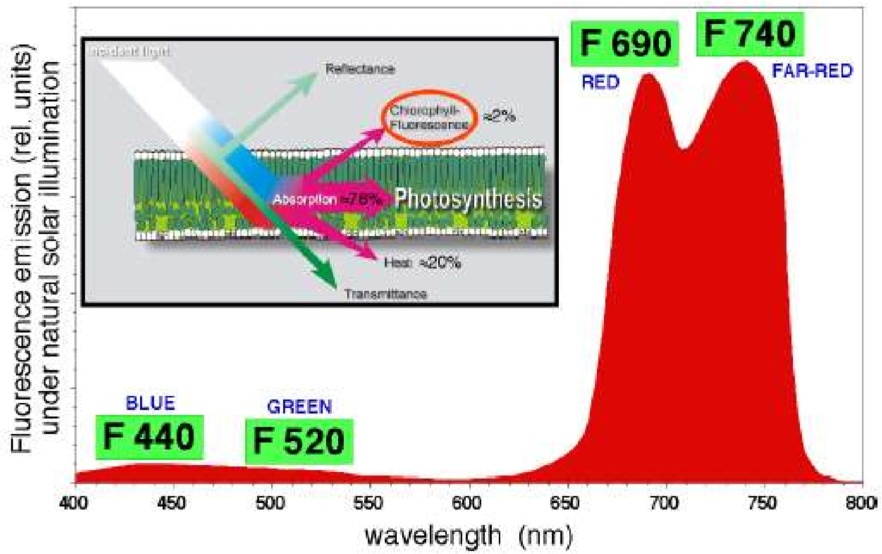
❖ Sun-induced chlorophyll fluorescence

- Fluorescence is an emission signal from the surface
- Fluorescence is a much better predictor of actual photosynthetic activity, not potential ones



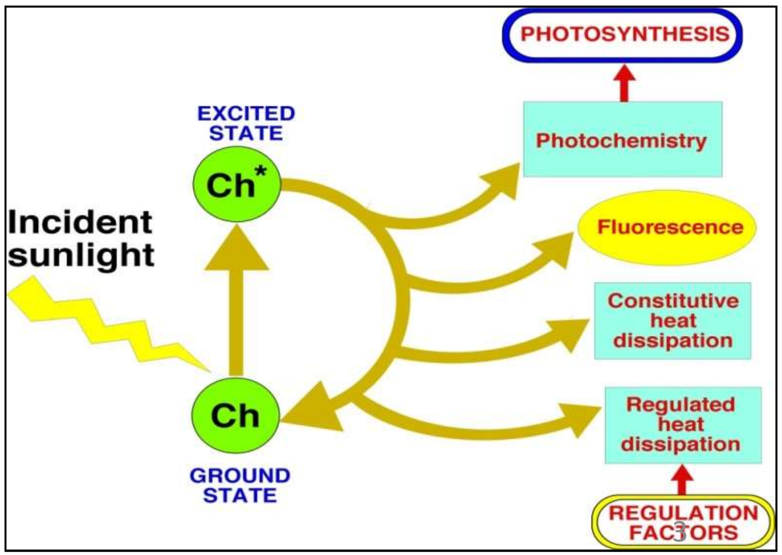
GOME-2 SIF

- **Pathways of solar energy after absorption by chlorophyll:**
  - Part of the energy is used for photochemical processes and photosynthesis resulting in ecosystem gross primary production (GPP).
  - Part of the energy is dissipated as heat.
  - **A remaining fraction is re-emitted as fluorescence.**
- Under natural conditions, fluorescence and photosynthesis are positively correlated → **a measurement of fluorescence can be related to photosynthetic activity.**



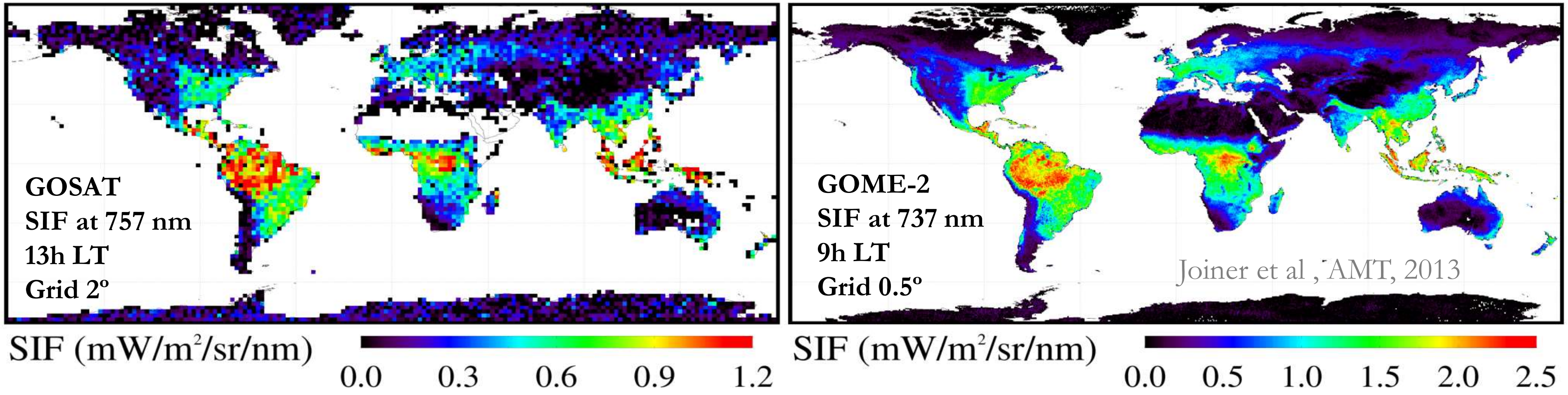
FLEX Assessment Report (2008)

De-excitation path ways



Global SIF Data Sets

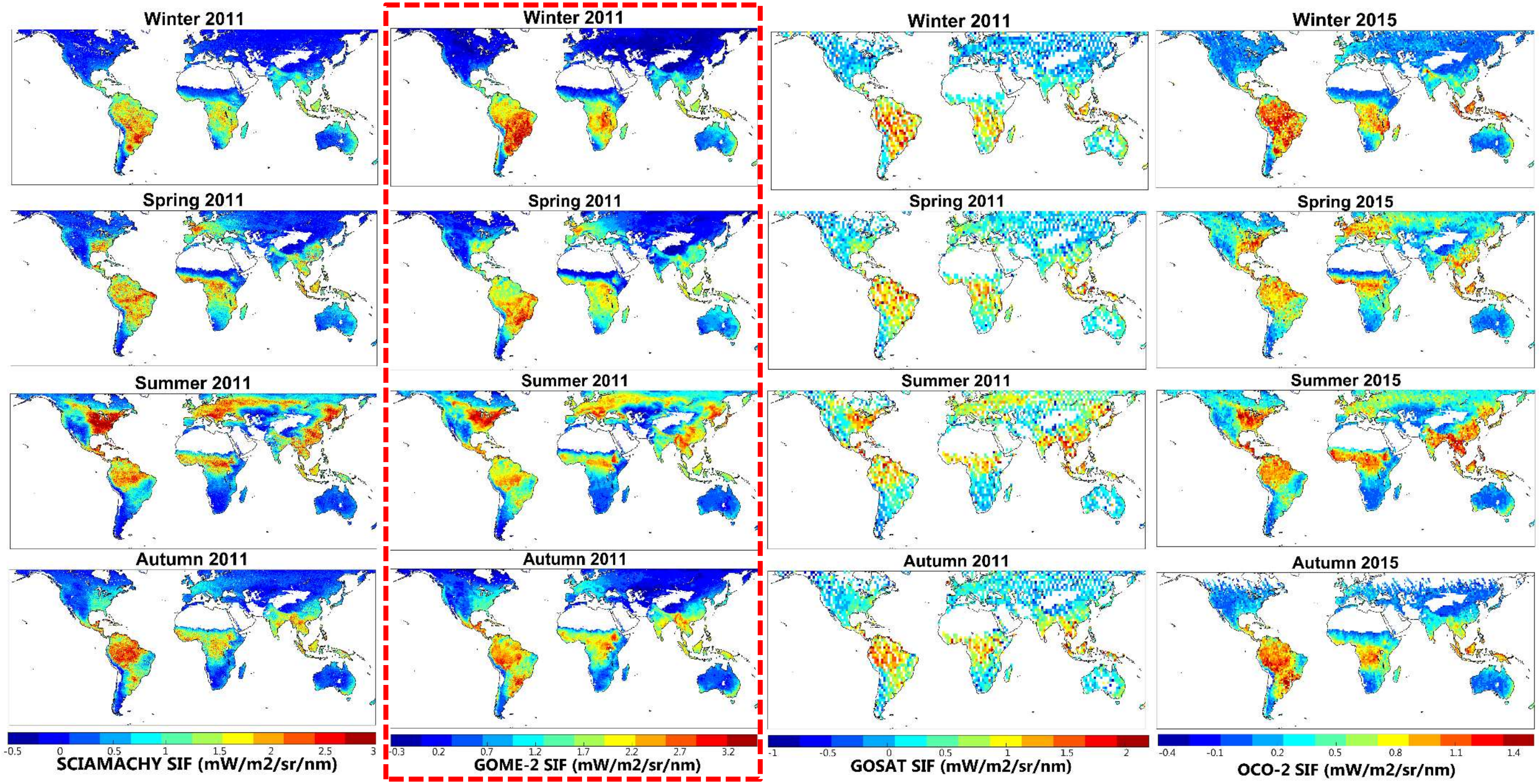
GOSAT, GOME-2, SCIAMACHY, OCO-2 …



	GOSAT	GOME-2	SCIAMACHY	OCO-2	TROPOMI	FLEX
起始时间	2009年6月	2007年1月	2002-2012	2014年7月	2016年	~2022年
过境时段	13:30	9:30	9:30	13:15	13:30	10:00
波段	757-775 nm	650-790 nm	650-790 nm	757-775 nm	675-775 nm	650-780 nm
空间采样方式	间断	连续	连续	间断	连续	连续
像元大小	直径10 km	40×80 km^2	30×240 km^2	1.3×2.25 km^2	7×7 km^2	300×300 m^2
空间分辨率	2×2°	0.5×0.5°	1×1°	1×1°	0.1×0.1°	300×300 m^2
提取时对云的敏感性	低	高	高	非常低	中	低
每天晴空观测像元数	1300	3500	900	～450,000	～400,000	/

Global SIF Data Sets

SCIAMACHY GOME-2 GOSAT OCO-2



Morning Overpass **Noon Overpass**

Modeling ecosystem GPP with SIF

- Empirical statistical approach (see Guanter[#], Zhang[#] et al., PNAS, 2014)

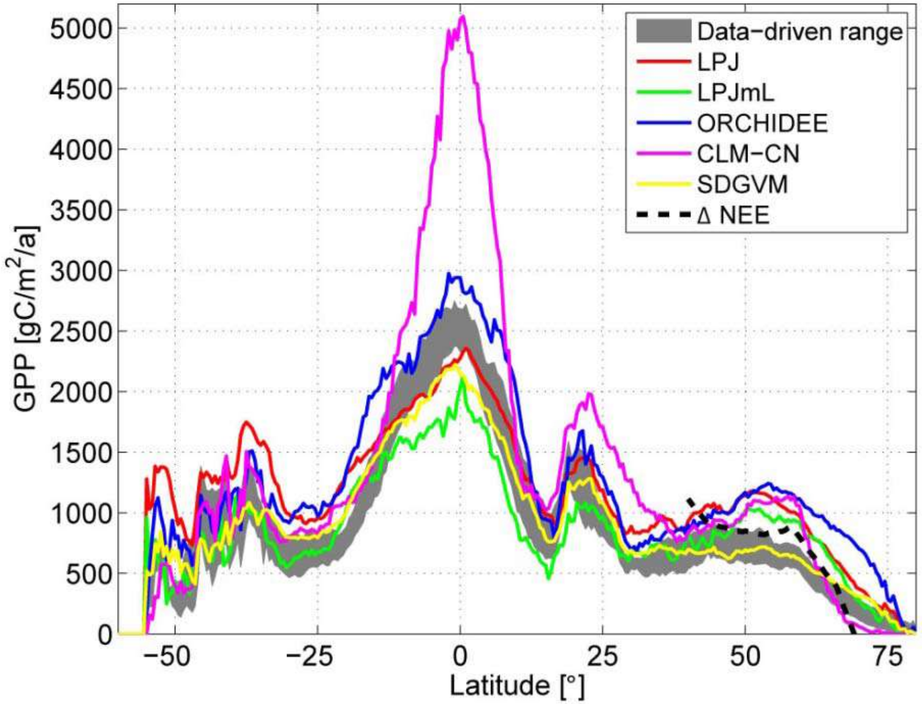
Global and time-resolved monitoring of crop photosynthesis with chlorophyll fluorescence

Luis Guanter[a,1,2], Yongguang Zhang[a,1], Martin Jung[b], Joanna Joiner[c], Maximilian Voigt[a], Joseph A. Berry[d], Christian Frankenberg[e], Alfredo R. Huete[f], Pablo Zarco-Tejada[g], Jung-Eun Lee[h], M. Susan Moran[i], Guillermo Ponce-Campos[i], Christian Beer[j], Gustavo Camps-Valls[k], Nina Buchmann[l], Damiano Gianelle[m], Katja Klumpp[n], Alessandro Cescatti[o], John M. Baker[p], and Timothy J. Griffis[q]

- Hybrid methods based on process-based models

The Problem

High bias in GPP modeling from dynamic vegetation models



Beer, et al., 2010, Science

Causes of GPP bias

- **Model structure error**
  - Canopy radiative transfer
  - Photosynthesis-stomatal conductance
  - Canopy integration
- **Model parameter uncertainty**
  - Maximum rate of Rubisco carboxylation (Vcmax)

Bonan et al., 2011, JGR-Biogeosciences

The Problem

The most influential model in the carbon cycle research

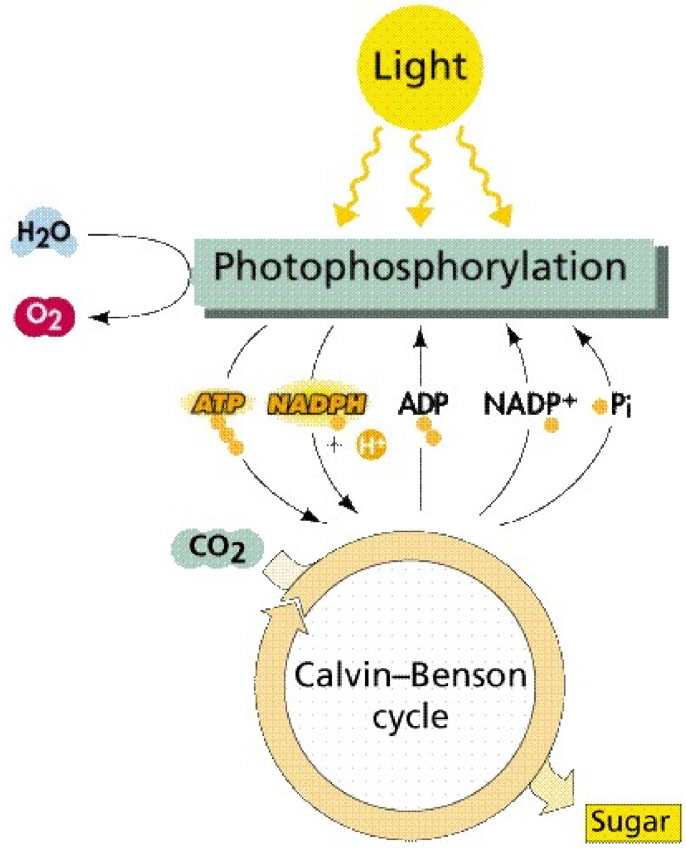
FvCB model

$$W_c = \frac{V_{cmax}(c_i - \Gamma^*)}{c_i + K_c(1 + O_i/K_o)}$$

$$W_j = \frac{J_{max}(c_i - \Gamma^*)}{4(c_i + 2\Gamma^*)}$$

Two key metabolic variables

- Vcmax: Rubisco activity
- Jmax: Electron transport rate

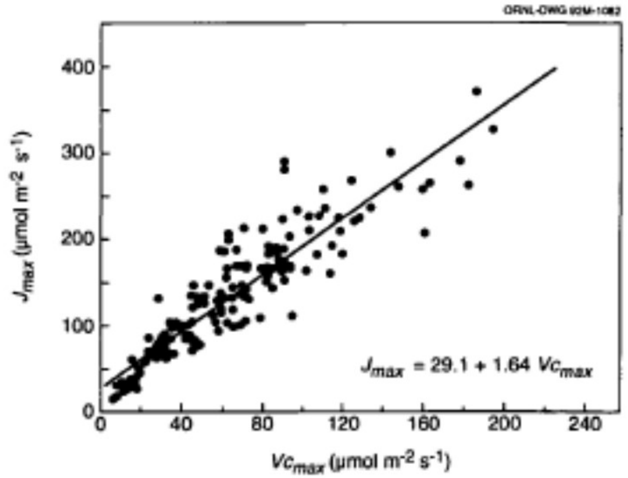


The Problem

FvCB model

Farquhar et al. (1980)

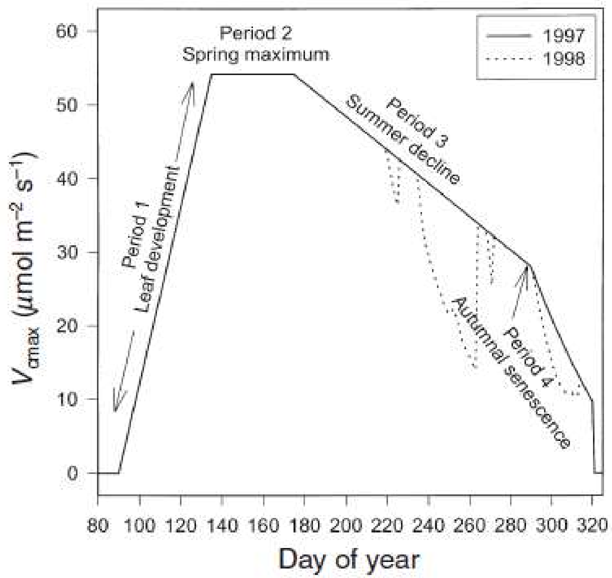
there are two key parameters which, although often correlated in vivo, show important genotypic and phenotypic variation. These are the RuP$_2$ carboxylase capacity of the leaf ($V_{c_{max}} = \rho k_c E_t$) and the electron transport capacity ($J_{max} = \rho j_{max}$). The way in which these two capacities vary, absolutely, and in ratio may well be a key to our understanding of the ecophysiology of plants.



Wullschleger, 1993

Determine the key metabolic variables

- •Vcmax: Rubisco activity
- •Jmax: Electron transport rate



Wilson et al., 2001

Contant Vcmax assumed for each PFT in models

Motivation

What: **Constrain GPP modeling with process model**

How: **Optimize photosynthetic capacity parameter (V_{cmax})**

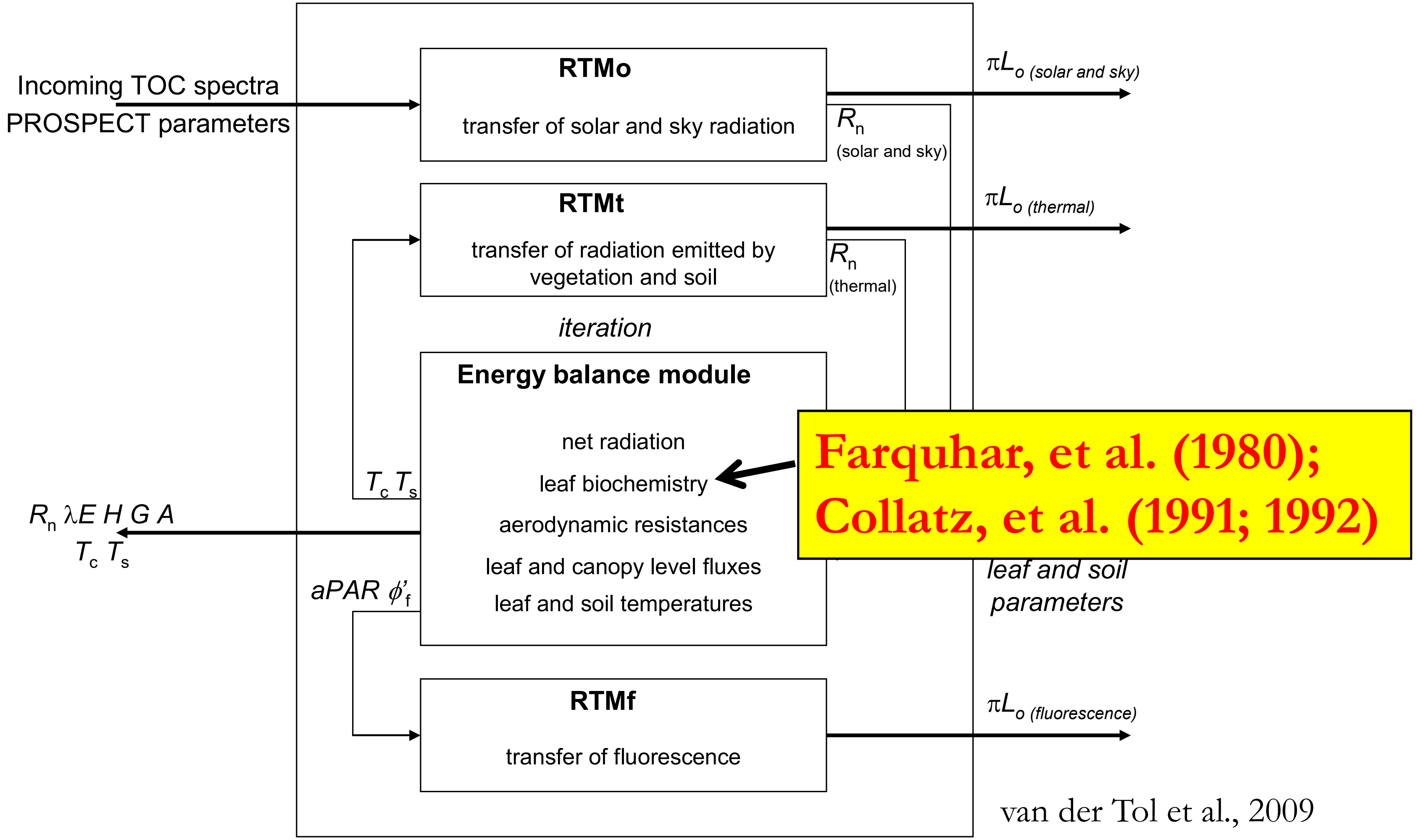
With: **Satellite-based fluorescence data**

And: **A coupled photosynthesis-fluorescence model (SCOPE)**

Model

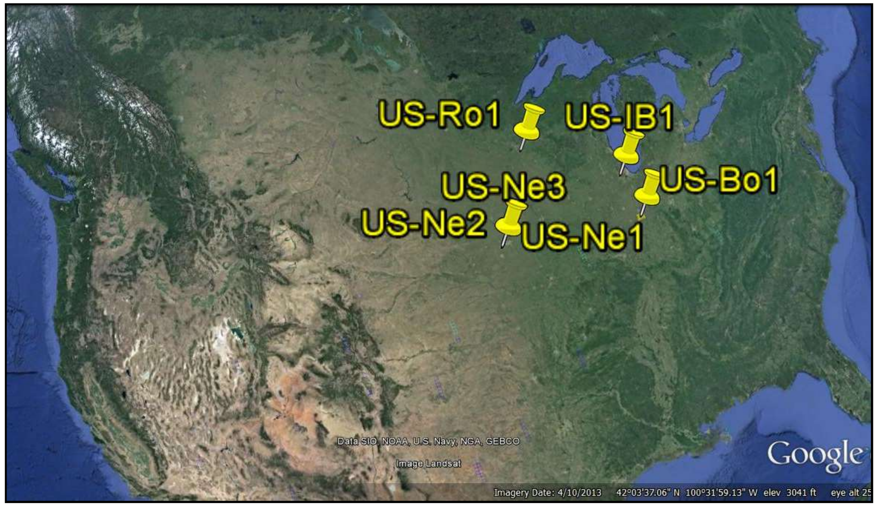
SCOPE

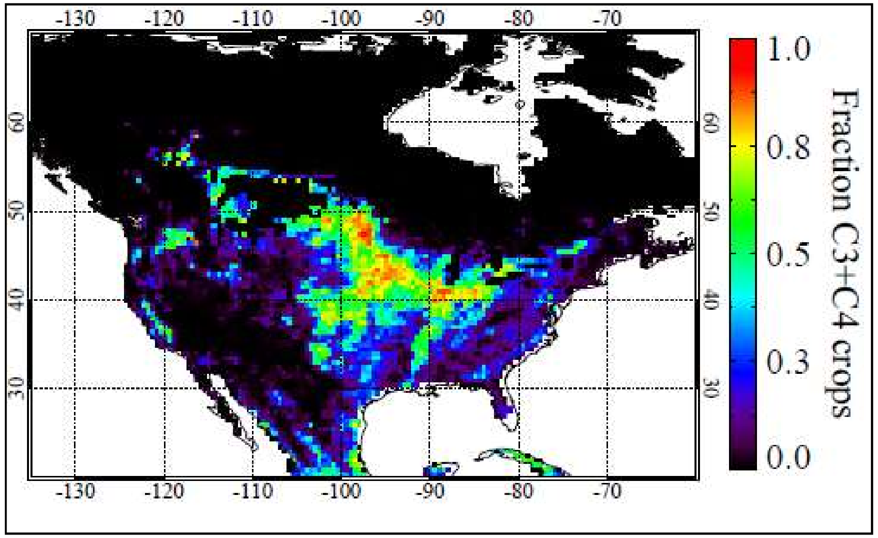
Soil Canopy Observation of Photosynthesis and the Energy balance



van der Tol et al., 2009

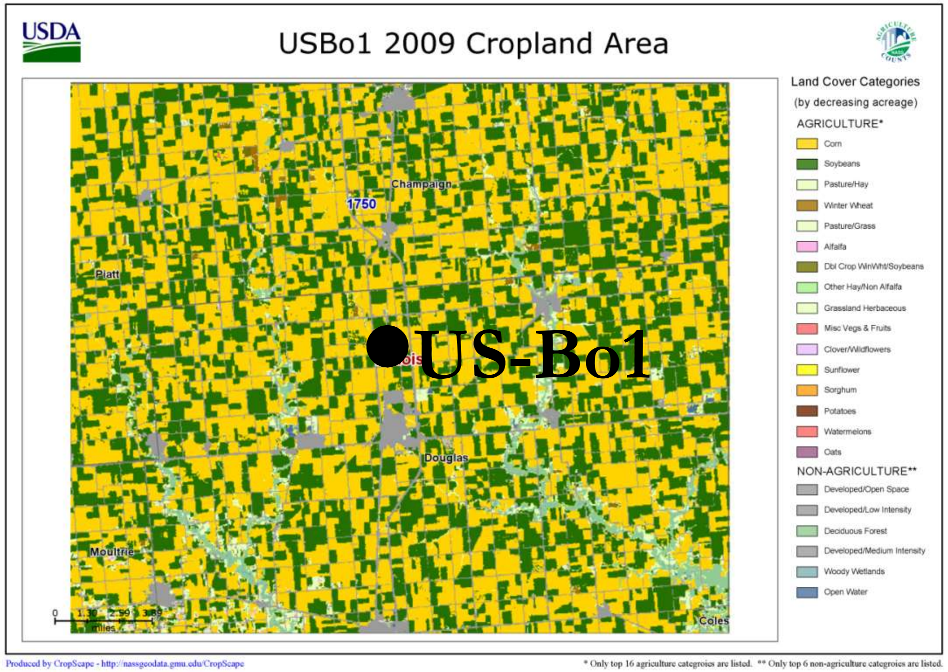
Flux sites





AmeriFlux crop sites

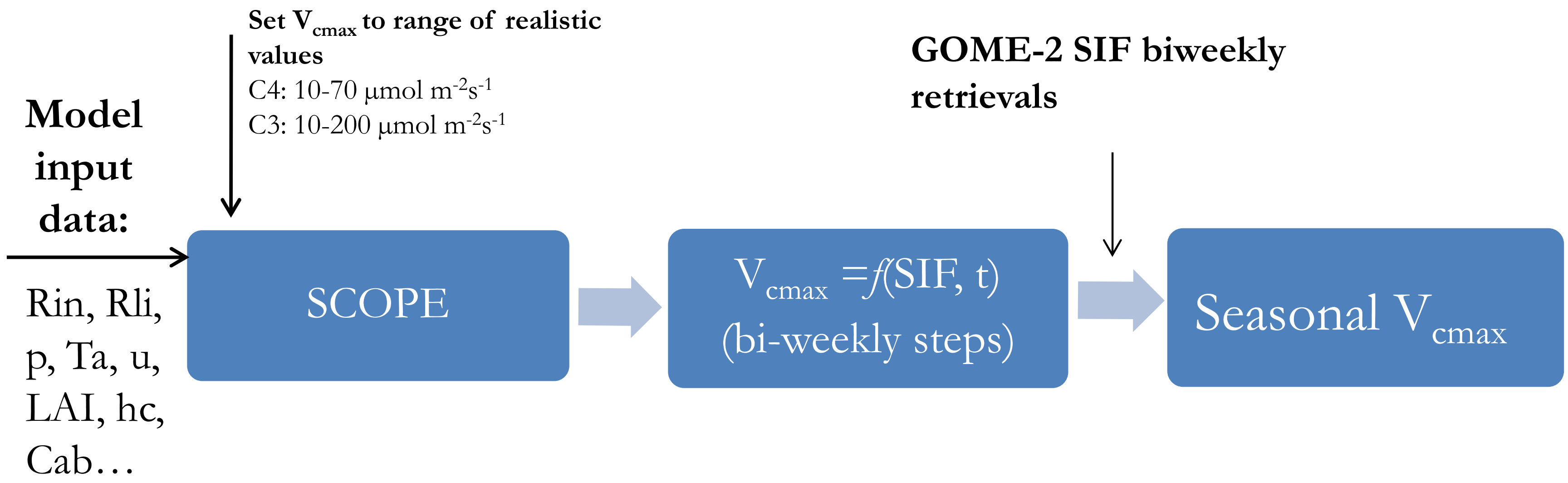
Homogeneous



Corn Soybean

Inversion of V_{cmax}

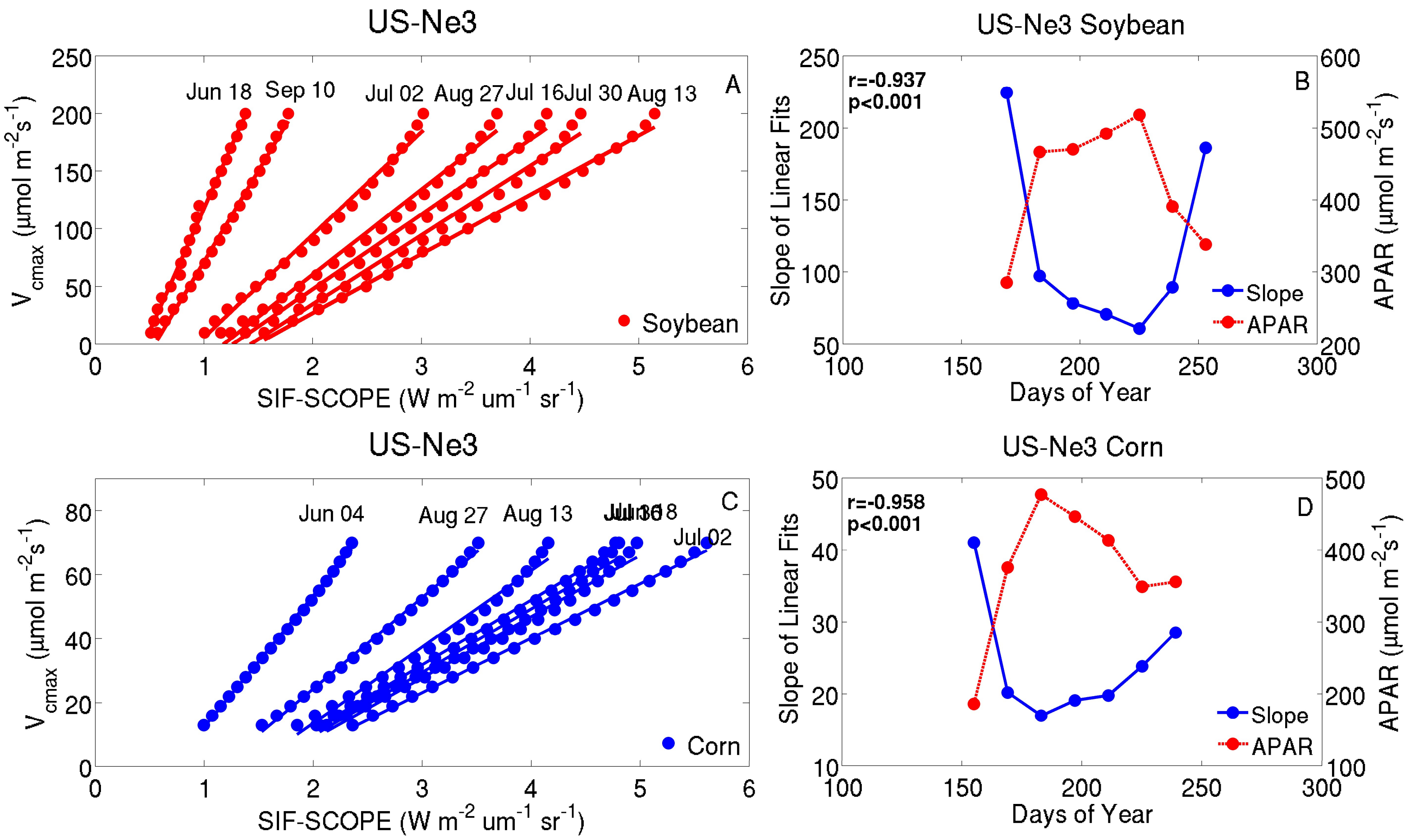
Link fluorescence to V_{cmax}



Inversion of V_{cmax}

Sensitivity of fluorescence to V_{cmax}

LUT -> Vcmax = *f* (SIF, t)

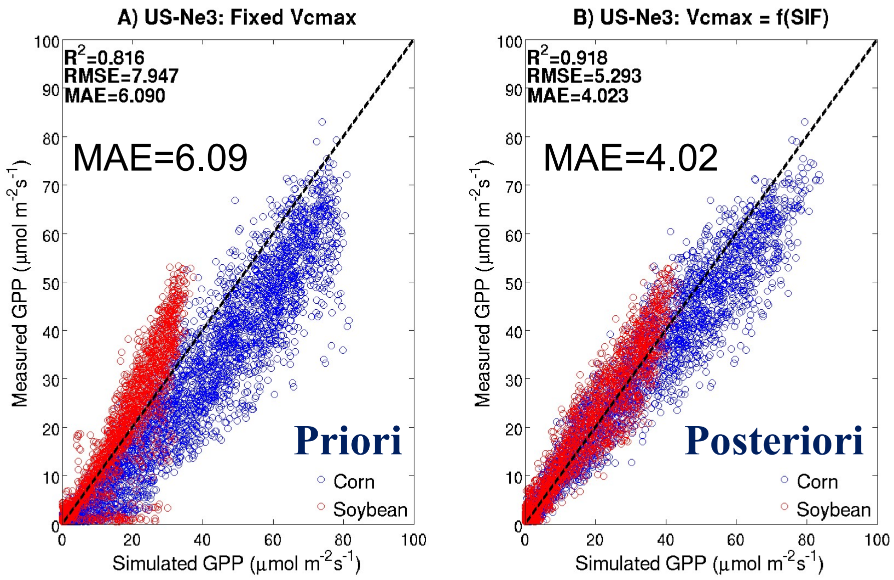


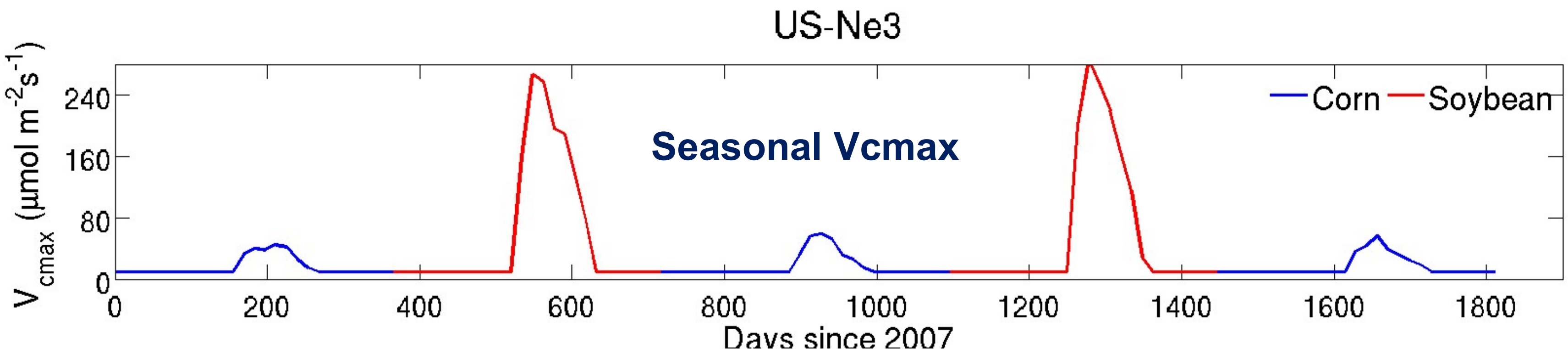
Zhang et al., 2014, GCB

3. Results

Hourly GPP: fixed V_{cmax} vs. $V_{cmax} = f(SIF)$

- Model-based inversion of crop photosynthetic capacity (Vcmax) from GOME-2 SIF data.
- Substantial improvement of GPP modeling with estimated seasonal Vcmax



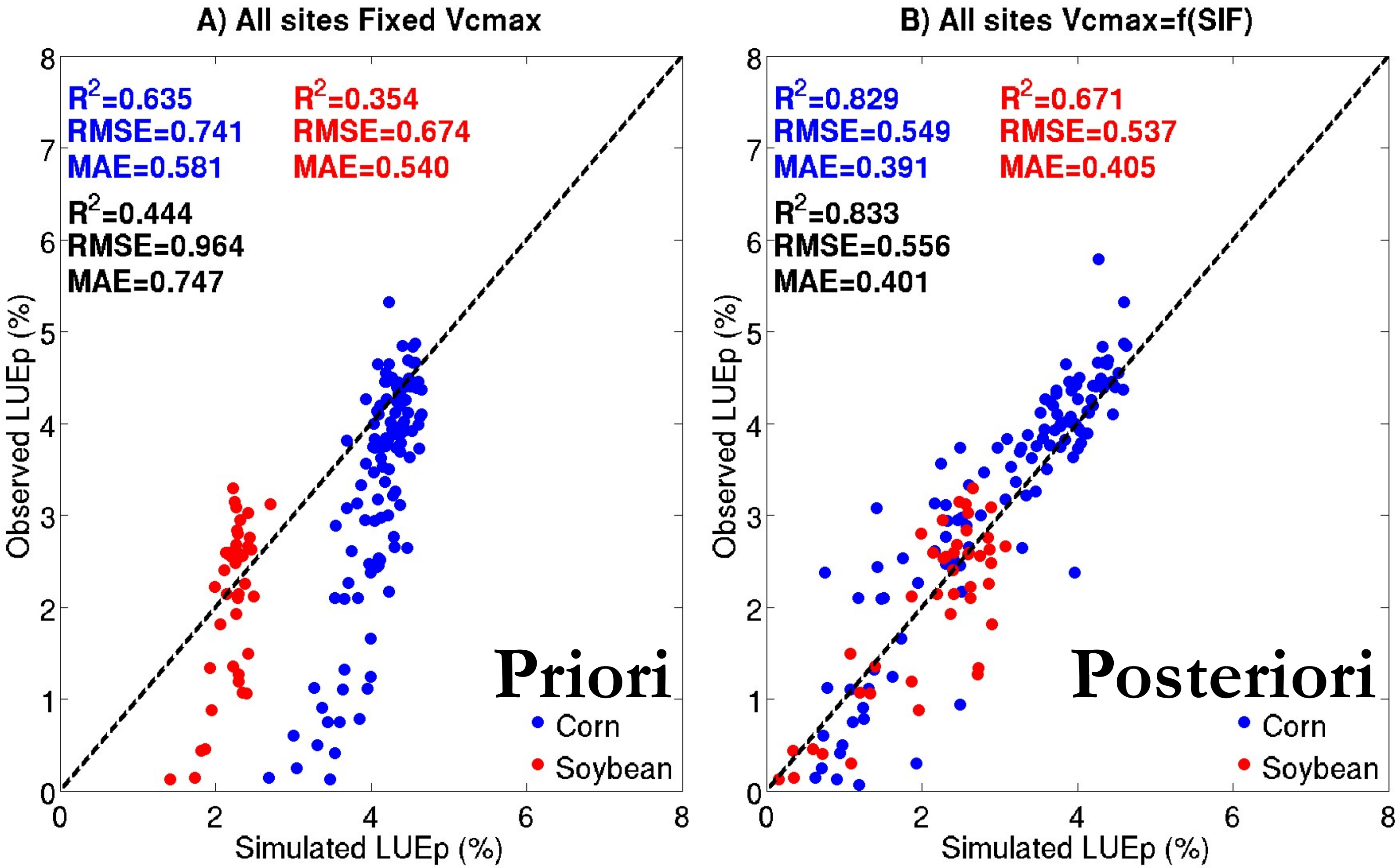


Zhang et al., 2014, GCB

3. Results

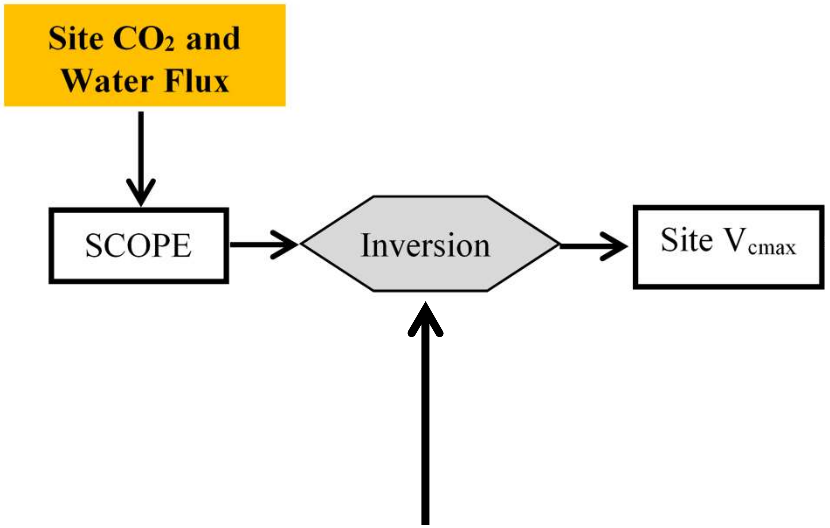
Light Use Efficiency for photosynthesis (LUEp):

fixed V_{cmax} vs. $V_{cmax} = f(SIF)$



Zhang et al., 2014, GCB

How SIF relates to independently estimation of V_{cmax} at seasonal scale?

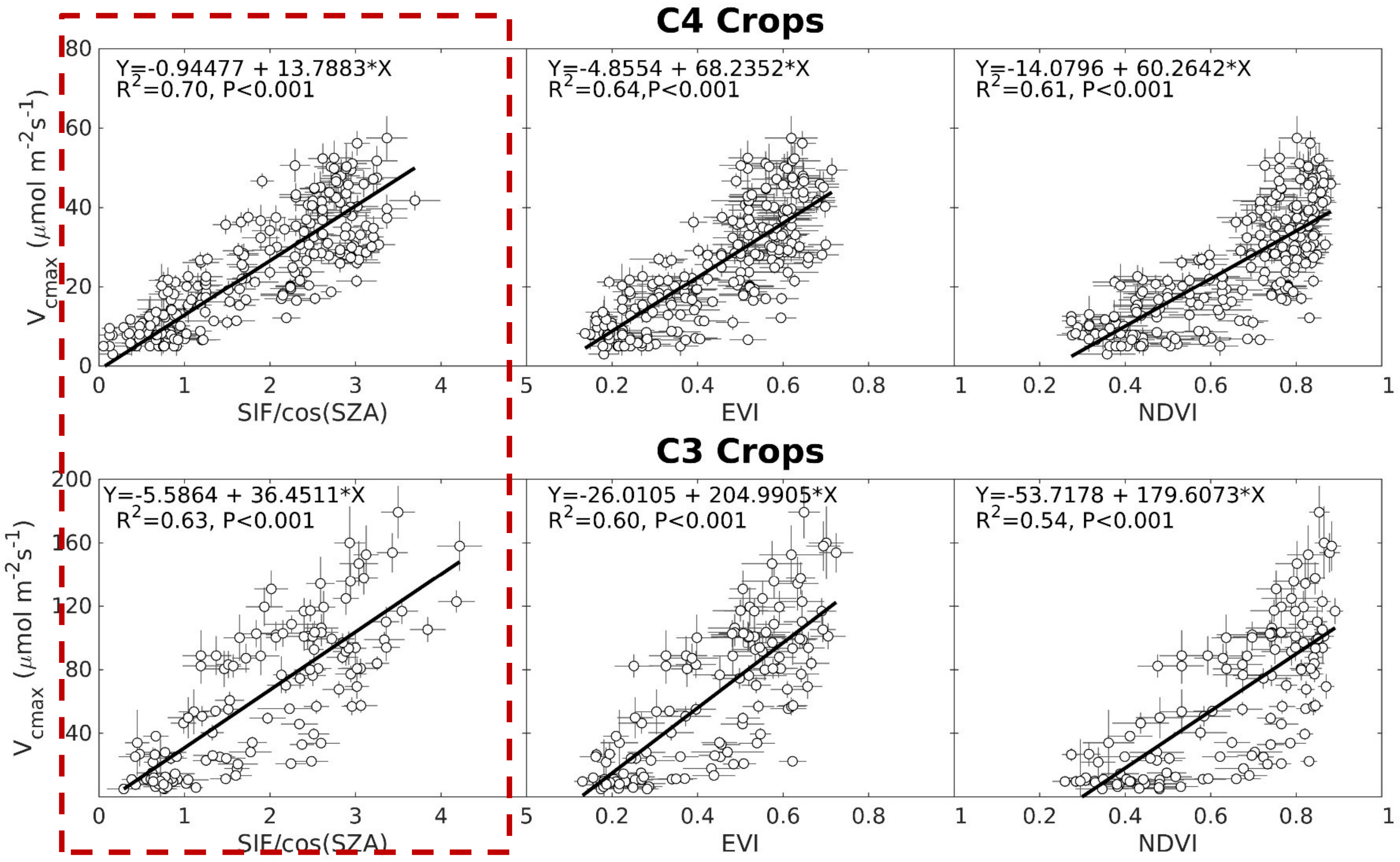


$$min(F(V_{cmax})) = \sum_{t=1}^{n}\left(\frac{GPP_t - GPP_m}{\overline{GPP_m}} + \frac{LE_t - LE_m}{\overline{LE_m}}\right)$$

Zhang et al., RSE (under review)

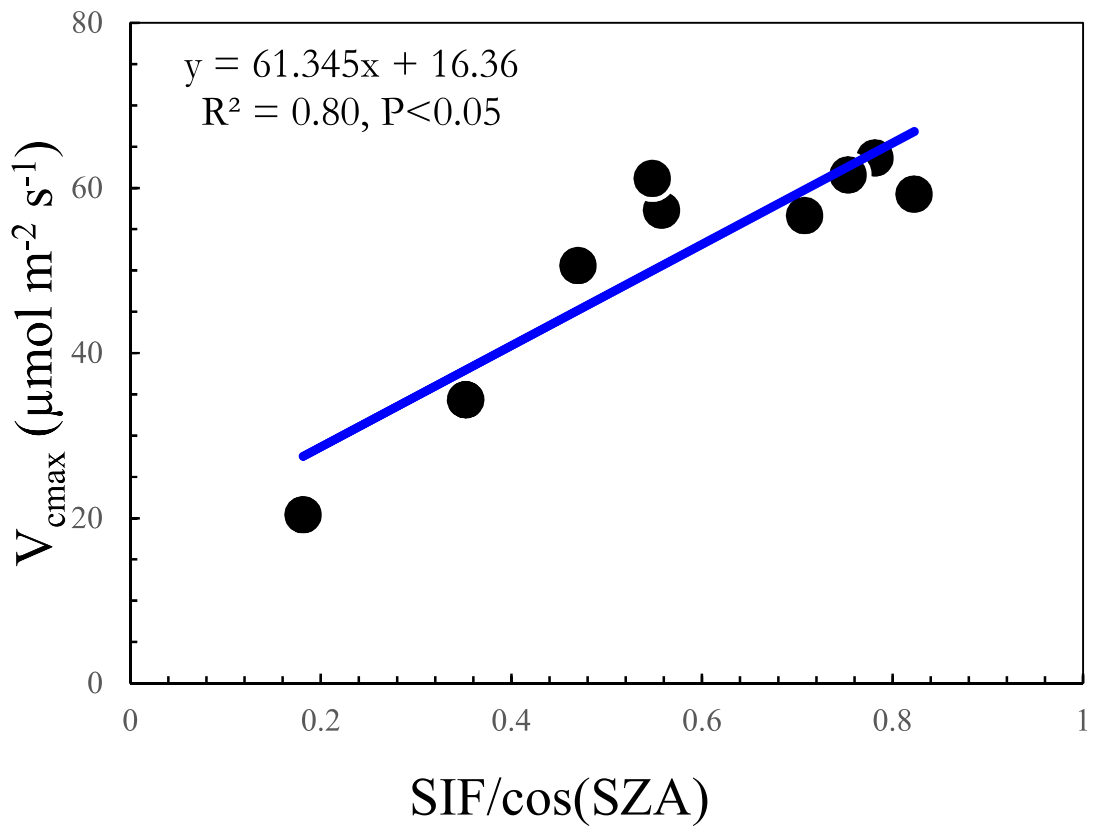
4. Continuing work

Sensitivity of canopy SIF to V_{cmax}



Zhang et al., RSE (under review)

Another example from Harvard Forest

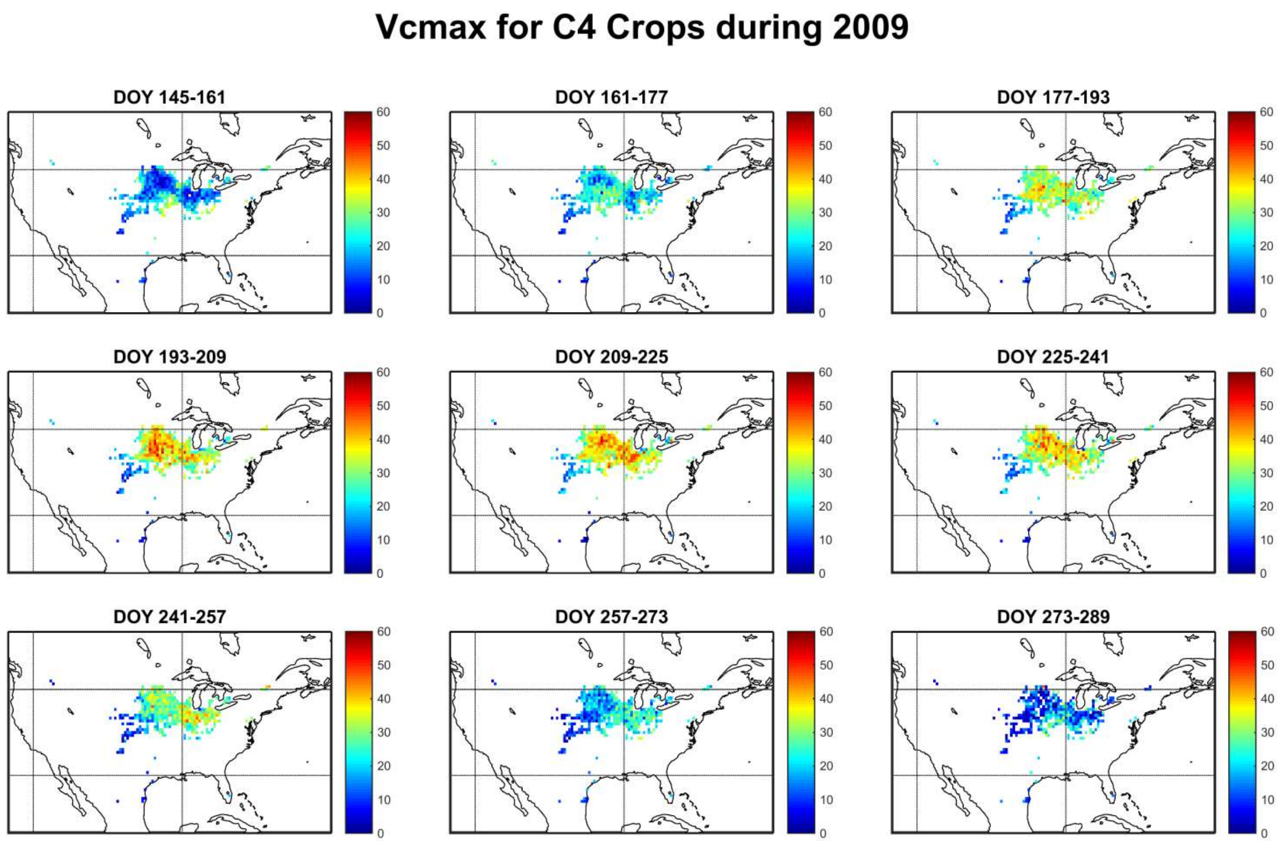


Field measurements of SIF during the growing season of 2013 (Yang et al., 2015)

Zhang et al., RSE (under review)

Upscaling to a bigger scale

Regional V_{cmax} for C4 crop during the growing season

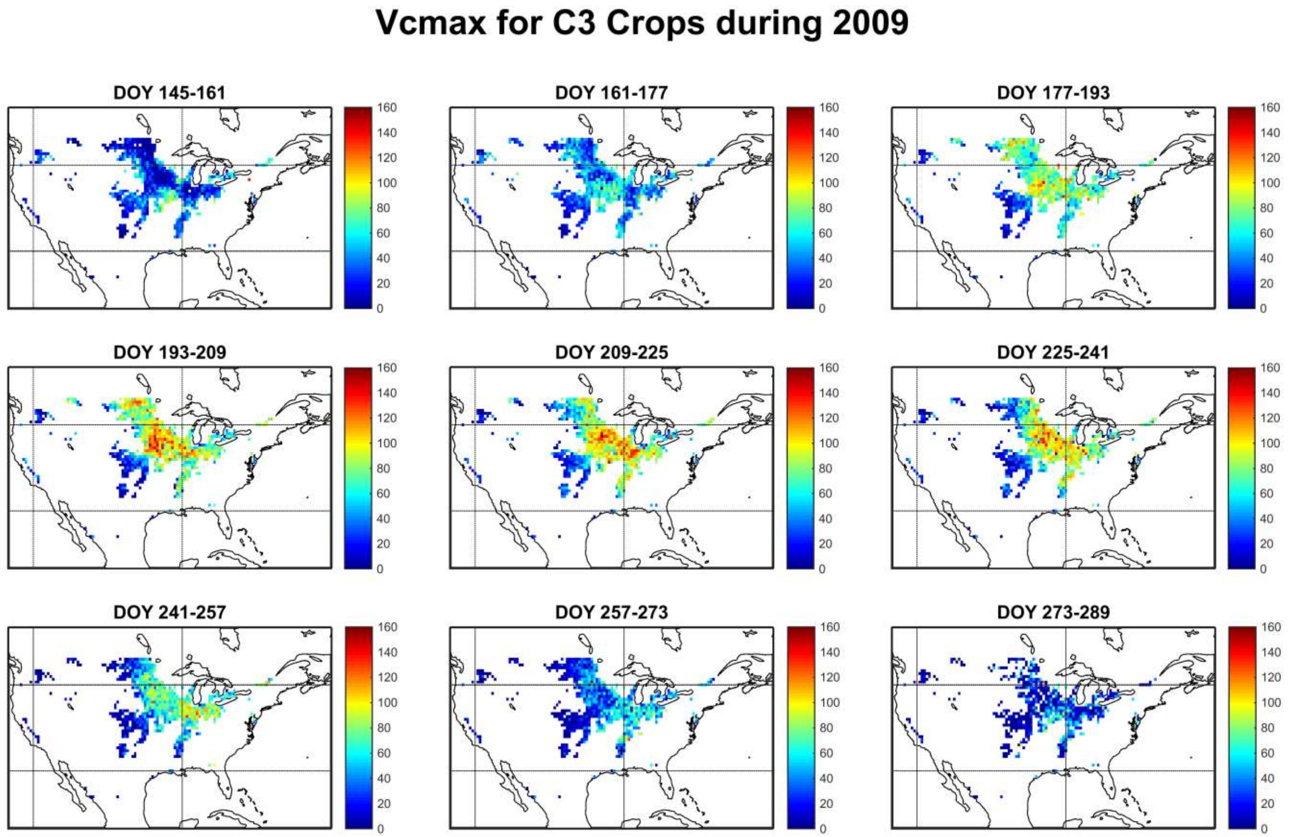


Seasonally and spatially varied for C4 crop

Zhang et al., RSE (under review)

Upscaling to a bigger scale

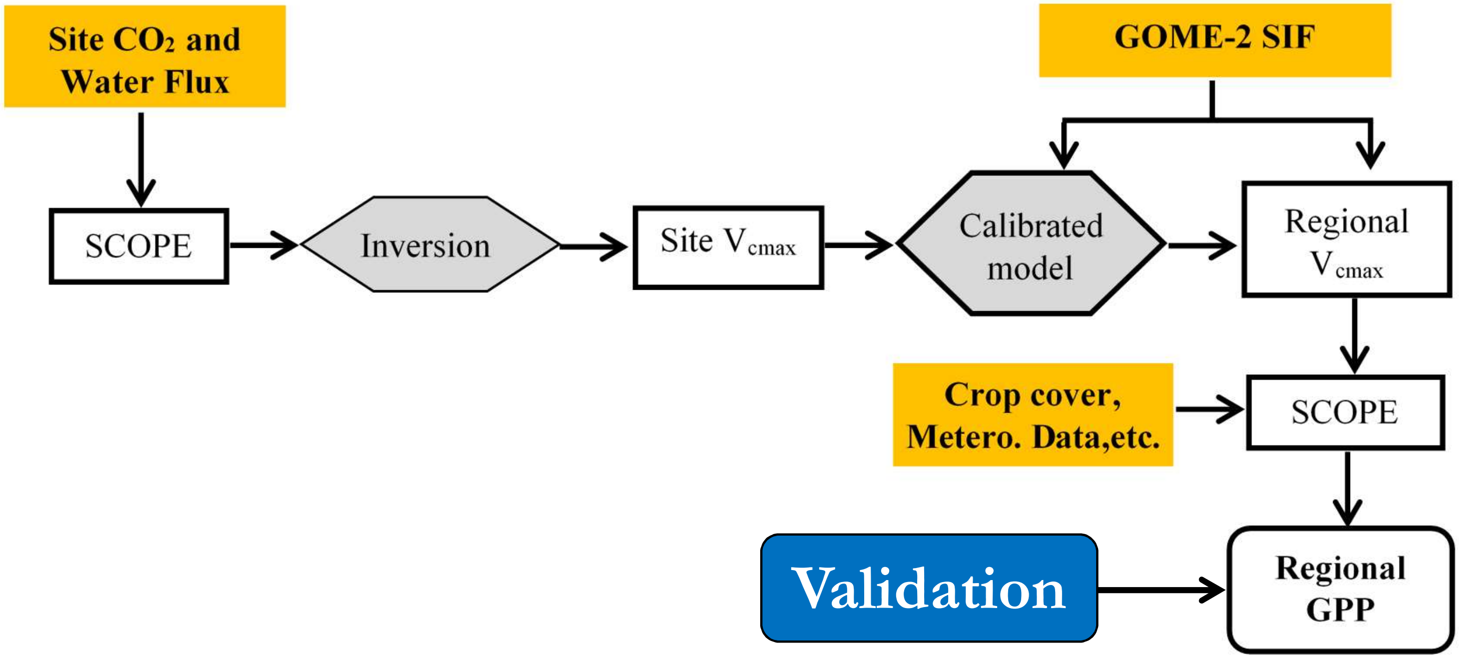
Regional V_{cmax} for C3 crop during the growing season



Seasonally and spatially varied for C3 crop

Zhang et al., RSE (under review)

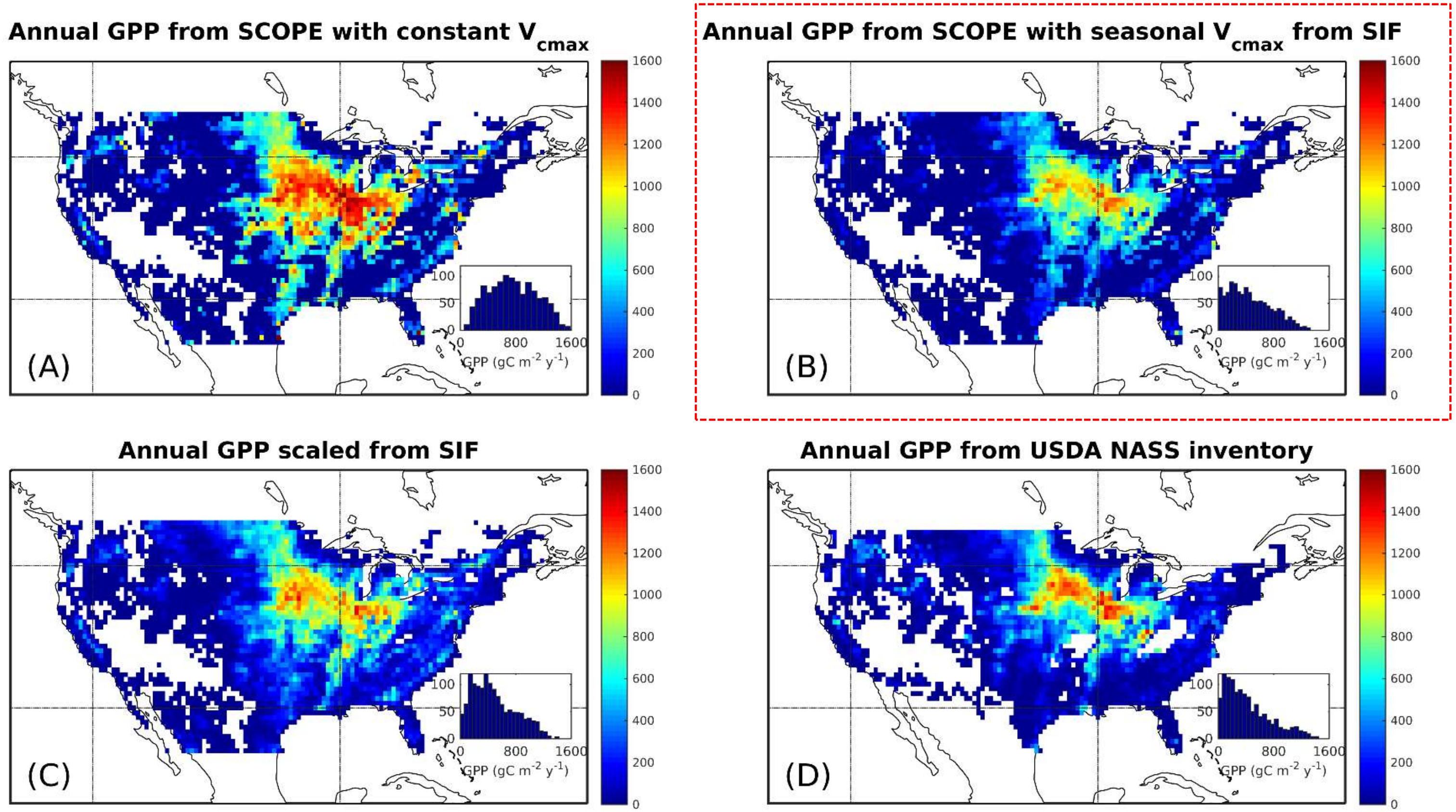
Modeling regional GPP with V_{cmax} from SIF



Zhang et al., RSE (under review)

Validation

"Validation": comparison with GPP scaled from SIF and NPP data from agricultural inventories by USDA



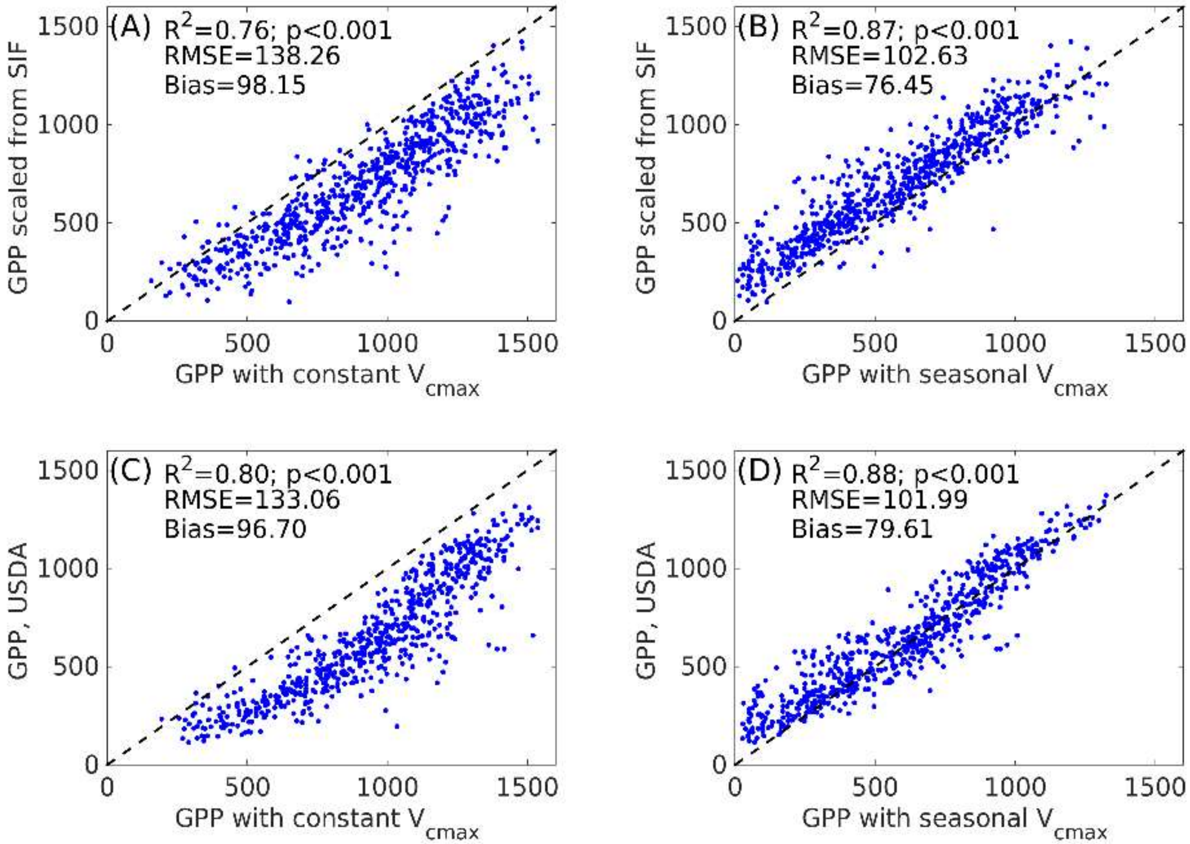
Zhang et al. (under review)

Validation

"Validation": comparison with GPP scaled from SIF and NPP data from agricultural inventories by USDA

Modeling regional GPP with constant Vcmax

Modeling regional GPP with Vcmax from SIF

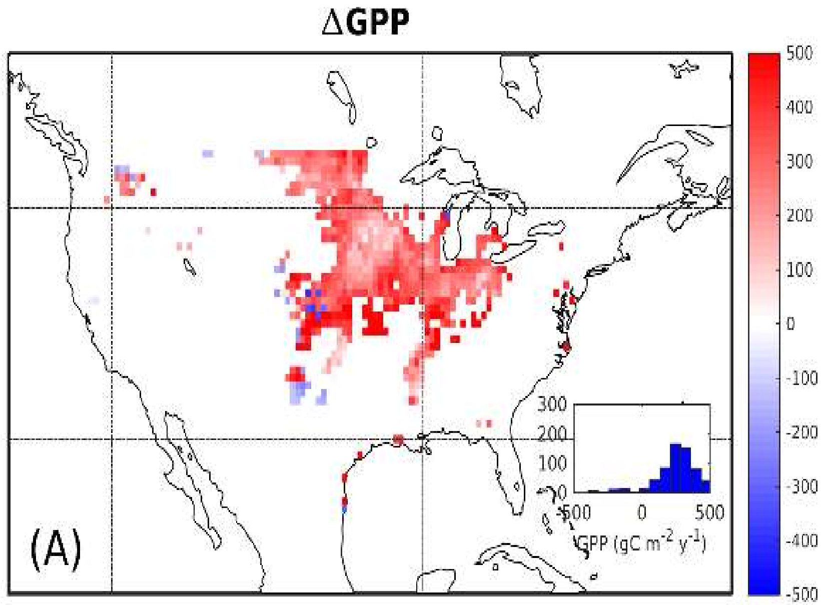


Zhang et al., RSE (under review)

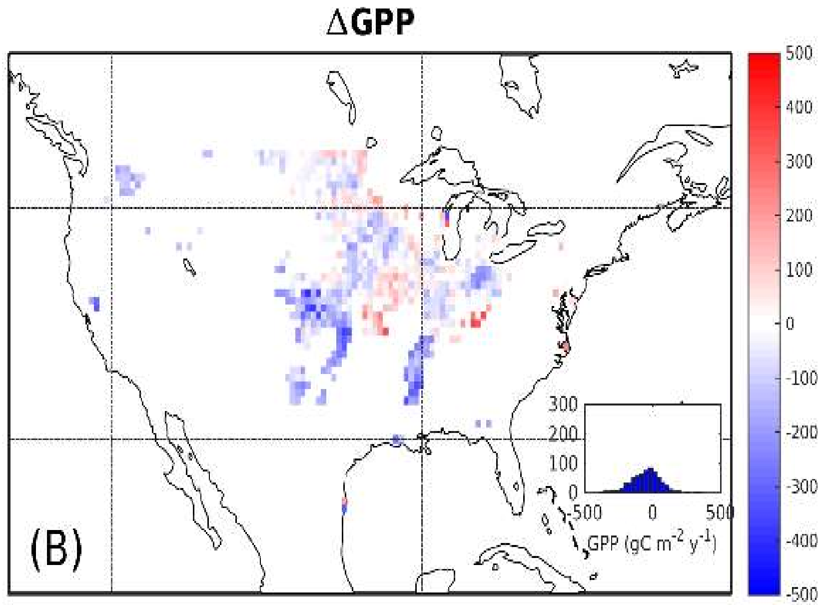
Validation

"Validation": comparison with GPP derived from agricultural inventories by USDA

$$\Delta GPP = GPP_{sim} - GPP_{inv}$$



Modeling regional GPP
with constant Vcmax



Modeling regional GPP
with Vcmax from SIF

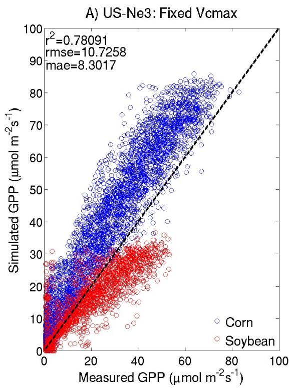
Zhang et al., RSE (under review)

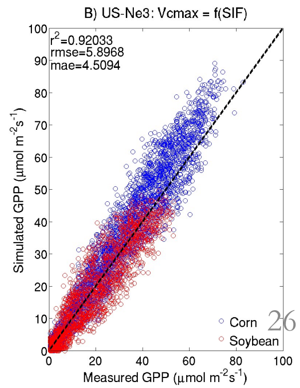
5. Summary

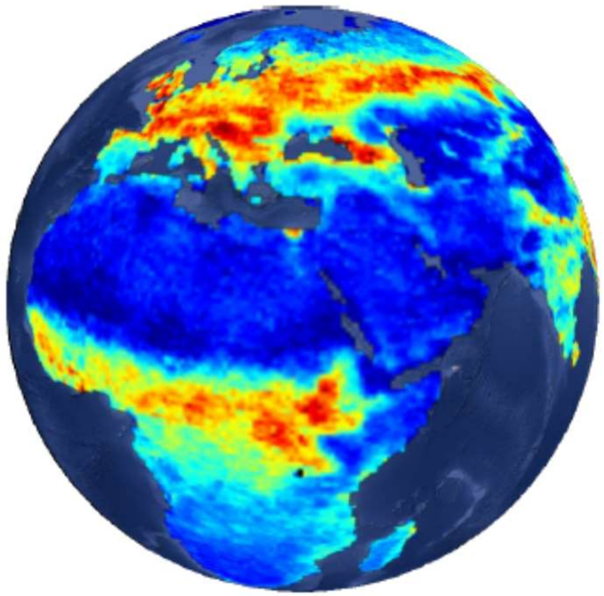
1. Satellite fluorescence retrievals could be **a proxy of seasonally-varying maximum rate of carboxylation (V_{cmax})**

2. A potential to **parameterize V_{cmax}** seasonally from satellite fluorescence data for terrestrial biosphere models

3. **Discussion**: What is the difference between Vcmax derived from DVMs and leaf measurements?







You are welcome to join SIF Session at AGU 2017:

Session Title: Chlorophyll fluorescence as a proxy of photosynthesis: from field to satellite measurements, modeling and applications (Kaiyu Guan, Yongguang Zhang, Joanna Joiner, and Xi Yang)

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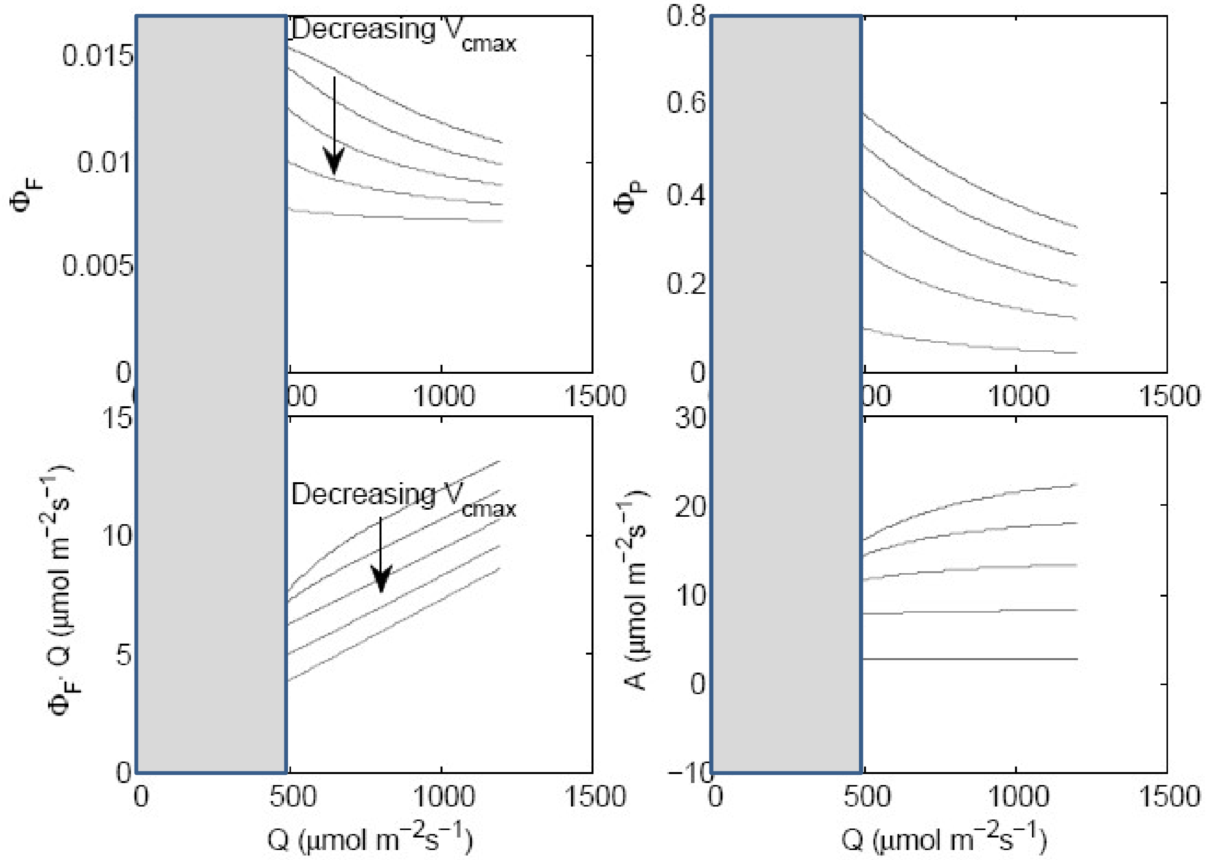
Thank you for your attention！

2. Methods

Links between Fluorescence and Vcmax

Fs yield and photochemical yield related to Vcmax

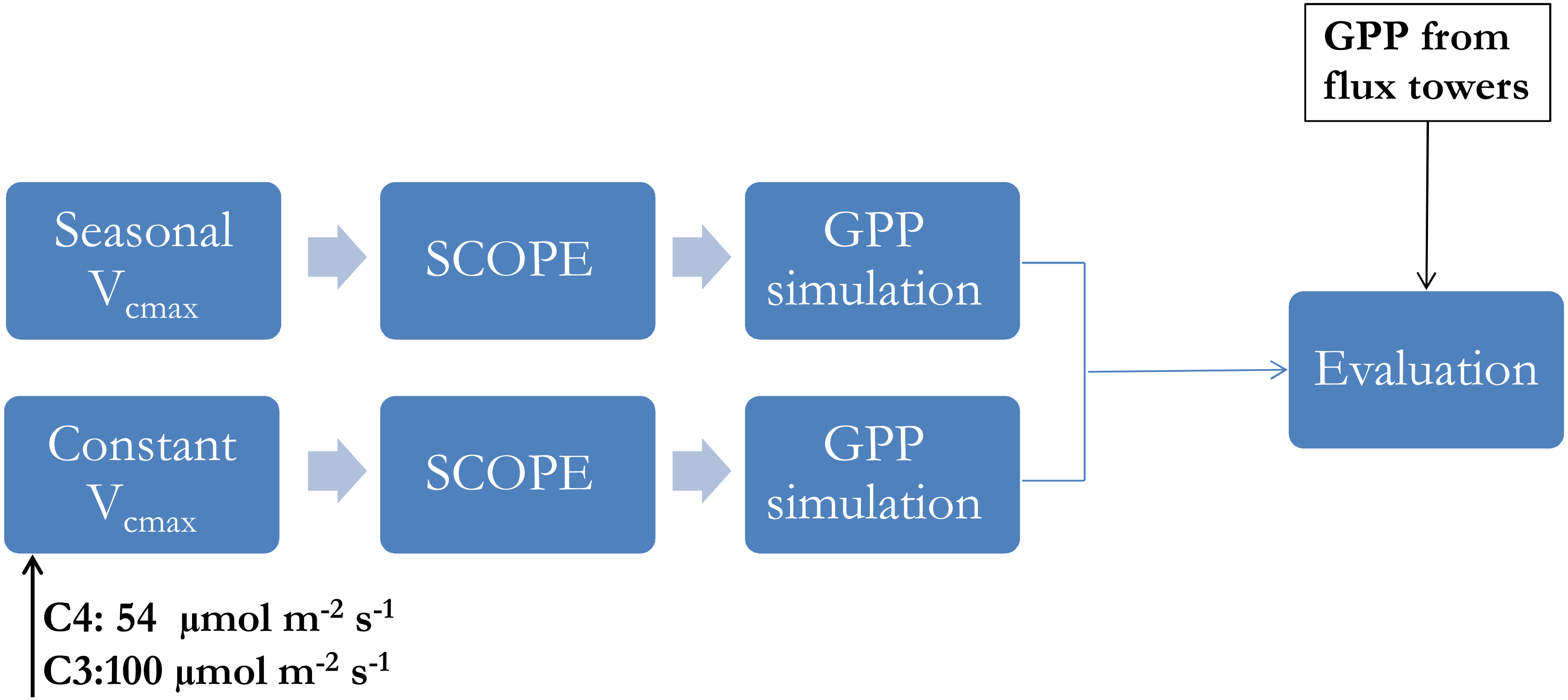


van der Tol, et al., 2014

Modelled Fs yield ΦF , photochemical yield ΦP , photosynthesis A, and ΦF multiplied by irradiance, as functions of irradiance, for the following values of Vcmax: 10, 30, 50, 70 and 90

Evaluation

Incorporation of optimized V_{cmax} into SCOPE and comparison with fixed V_{cmax} in terms of GPP and other parameters

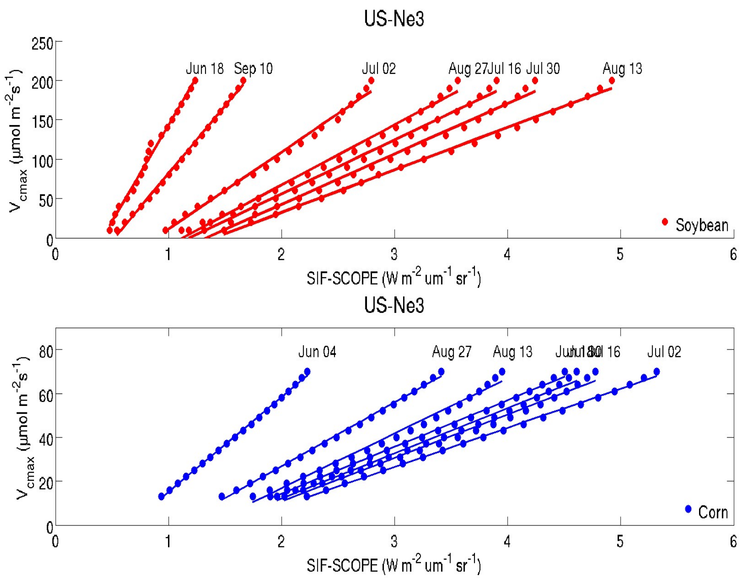


3. Results

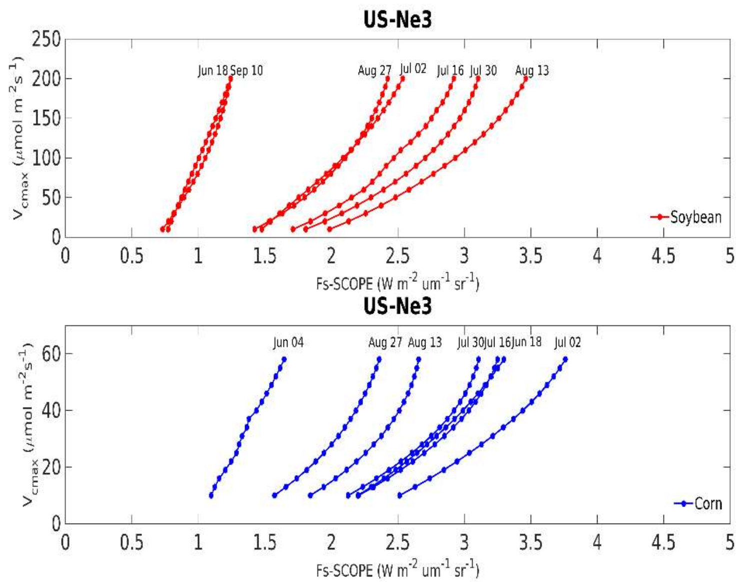
Sensitivity of fluorescence to V_{cmax}

LUT -> Vcmax = *f* (SIF, t)

SCOPE old version



SCOPE new version



2/3 sensitivity of new version compared to old one

Zhang et al., 2014, GCB