Jet Propulsion Laboratory
California Institute of Technology

SIF Based Estimates of Terrestrial Vegetation Photosynthesis

Nicholas Parazoo

Jet Propulsion Laboratory, California Institute of Technology

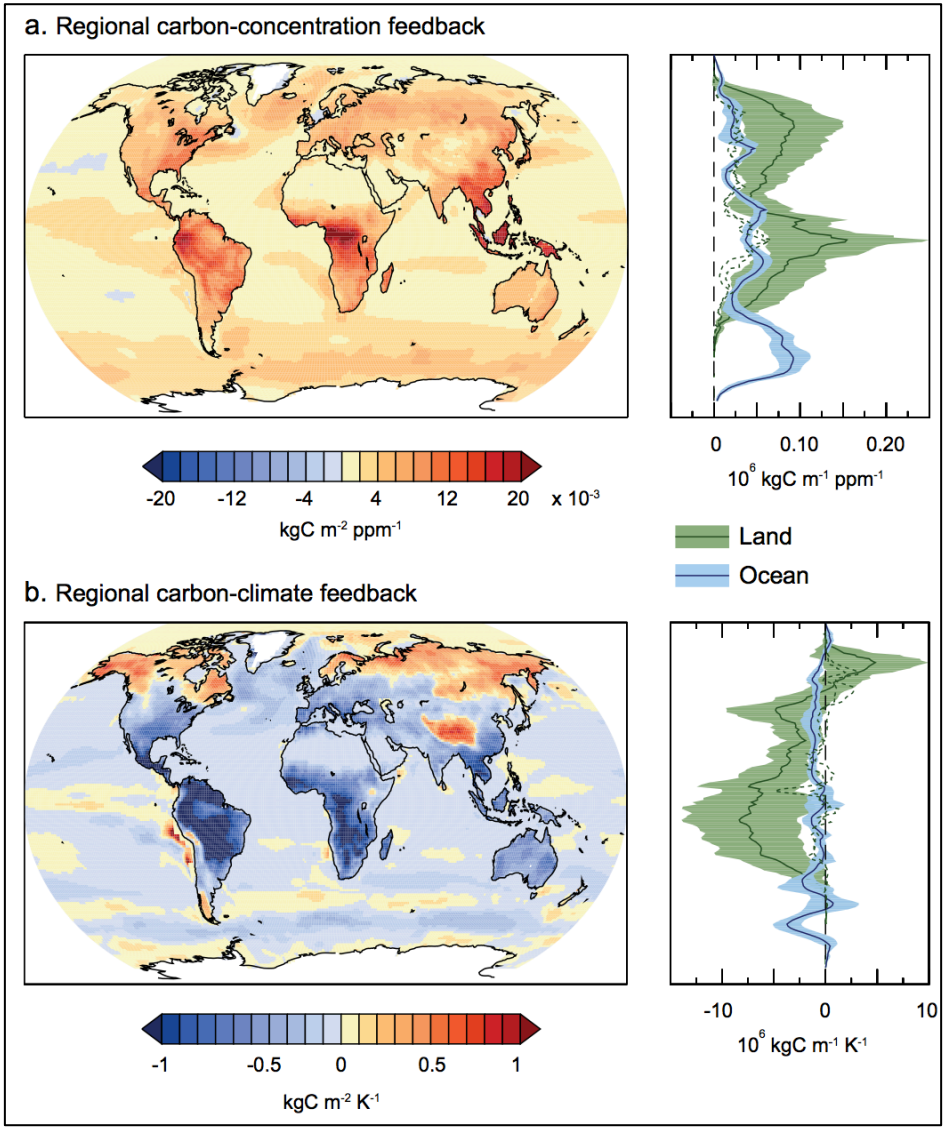
Carbon Cycle and Ecosystems (329G)

Grand Challenge: Consistent explanation of terrestrial ecosystem dynamics from stomata to globe.

Method: Multi-scale synthesis of satellite, airborne, and tower plant **fluorescence**

Workshop Challenge: How to provide complementary information from OCS

Model Predictions of Carbon-Climate Feedback Are Uncertain



CO2 Fertilization

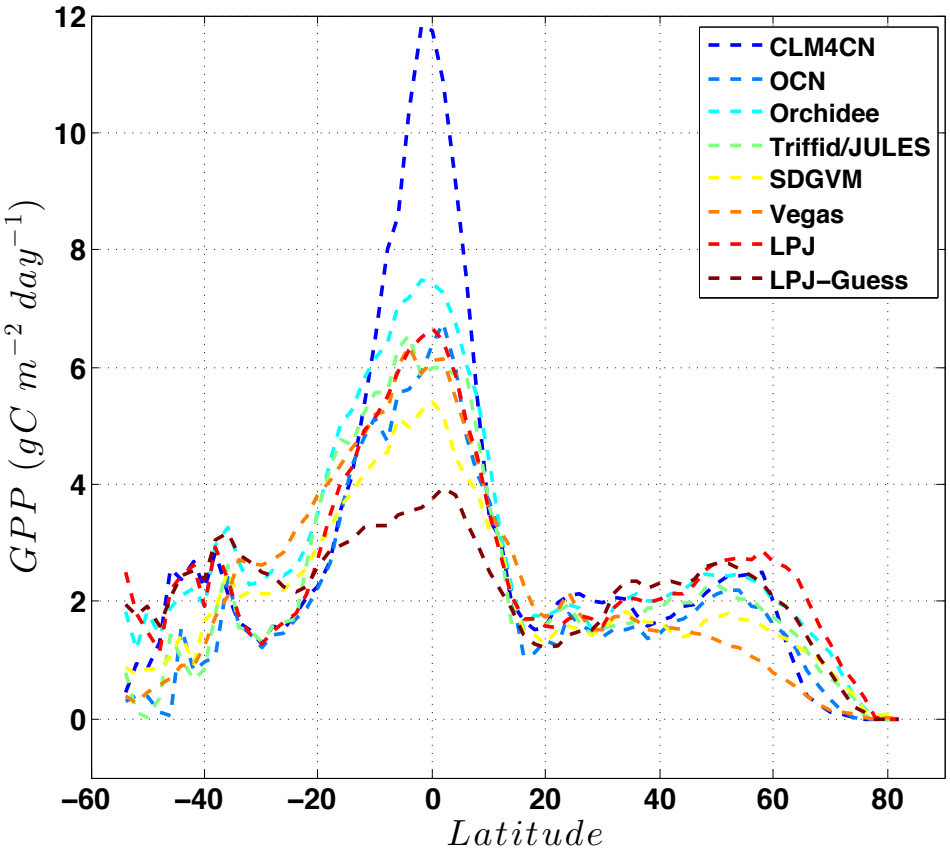
(enhanced uptake scaled to primary production)

Climate

(reduced uptake in response to warming/drying, except in high latitudes)

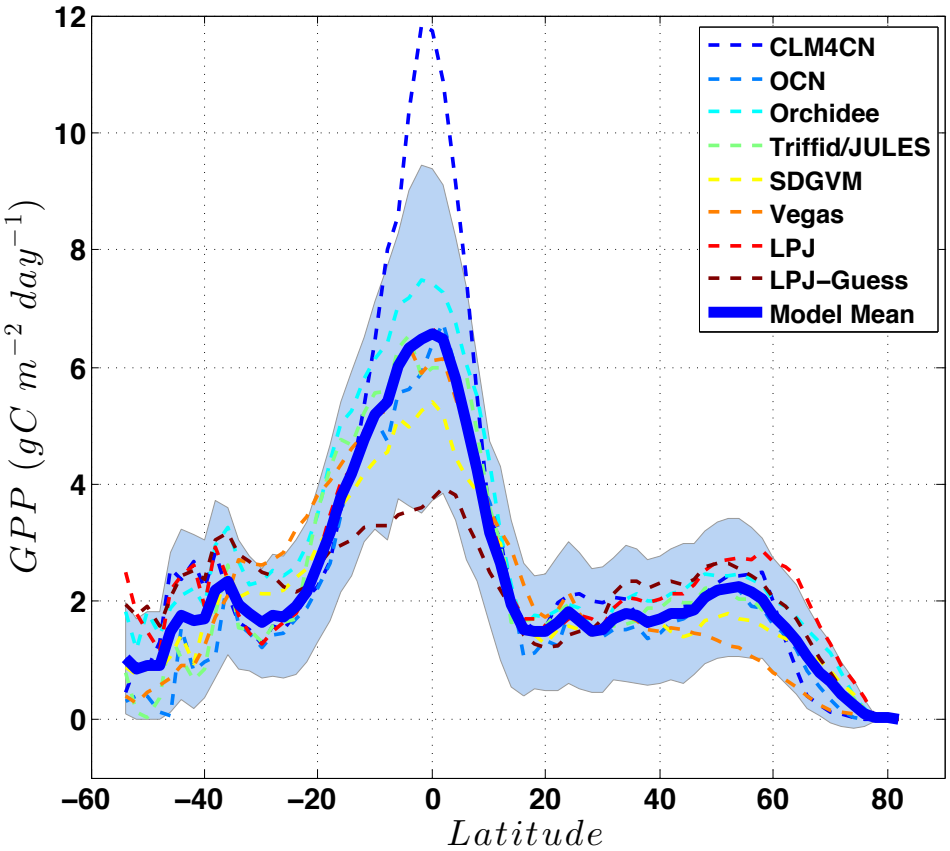
IPCC AR5, Ch 6

Zonal Average Gross Primary Production



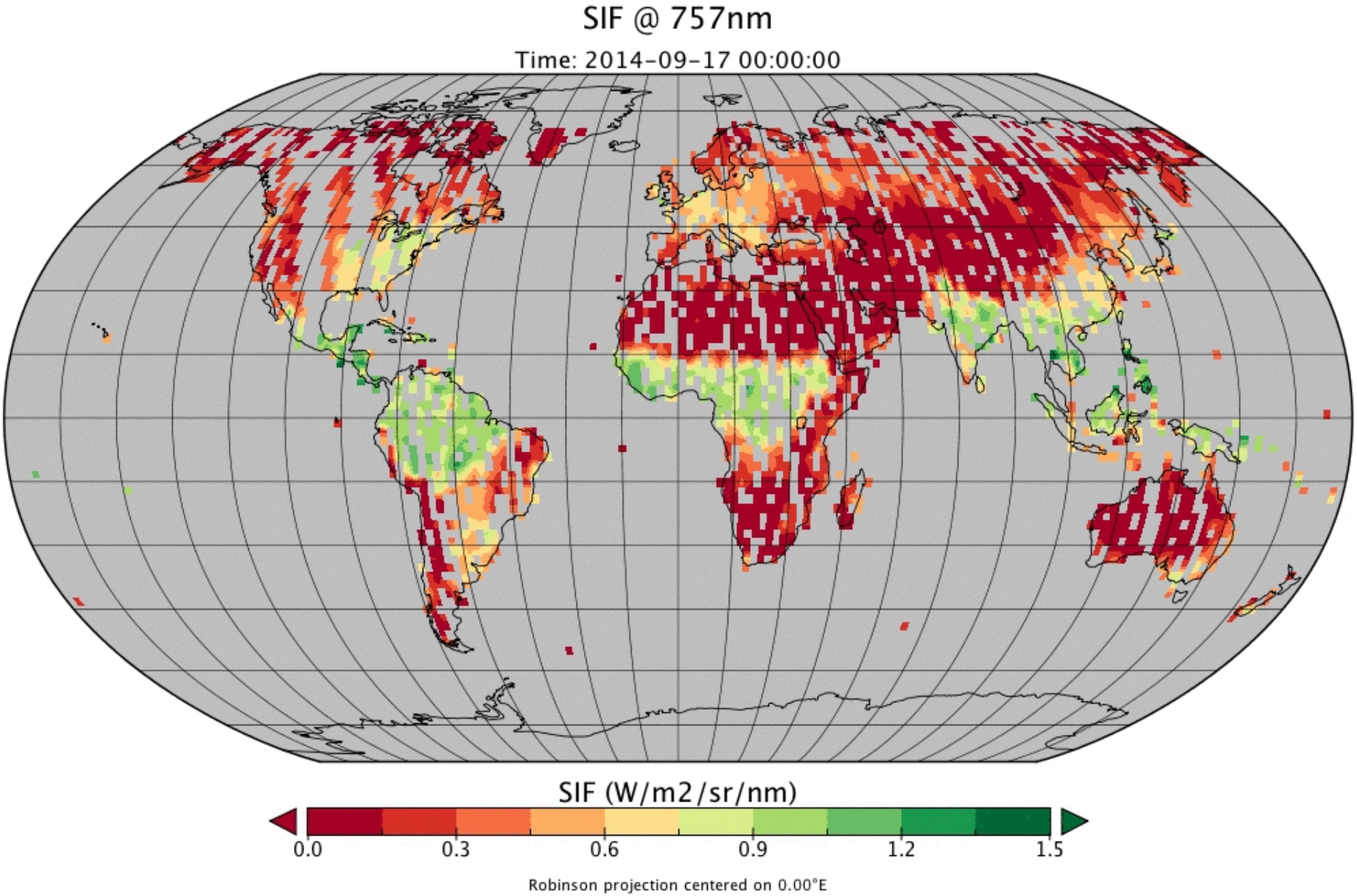
(1) Diverse Process Models Leads to Range in GPP Predictions

Zonal Average Gross Primary Production



(1) Prior uncertainty, based on spread in model predictions, is high

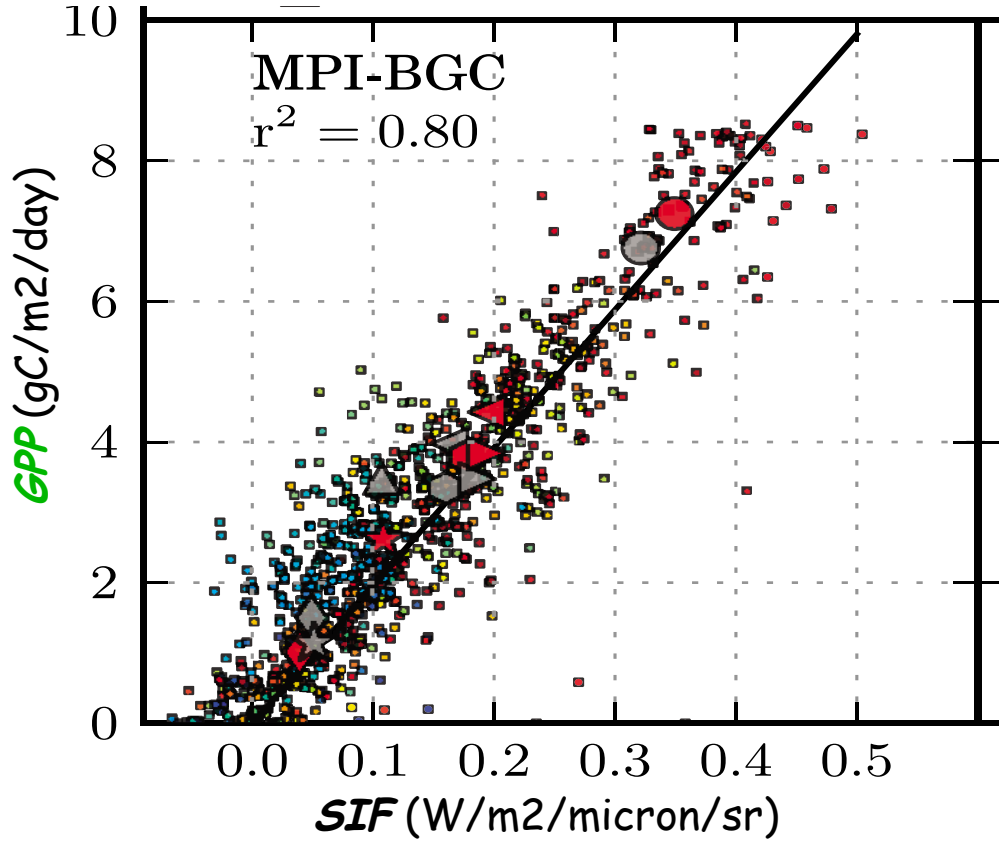
Solar induced fluorescence: SIF



Frankenberg et al., GRL, 2011

Joiner et al., Biogeosciences, 2011;

Guanter et al., Rem. Sens. Env., 2012



Simple light-use efficiency model: $GPP = (f_{PAR} \times PAR) \times \varepsilon$

Heat & Water Stress

SIF

Vegetation index (VI)

Why SIF?

- **Linear correlation to photosynthesis** without ancillary information
- Reflects **dynamic photosynthetic response to heat and water stress**
- Dense, long term global coverage, in **cloudy and remote regions**

Model and SIF-based *GPP* Uncertainties

SIF

1. Measurement Error
2. Coverage
3. Scaling Between SIF and GPP
4. Empirical Model
5. Sampling Bias

Models

1. Processes
2. Inputs
3. Downscaling from monthly to diurnal averages

Combine for Optimal *GPP* Constraint

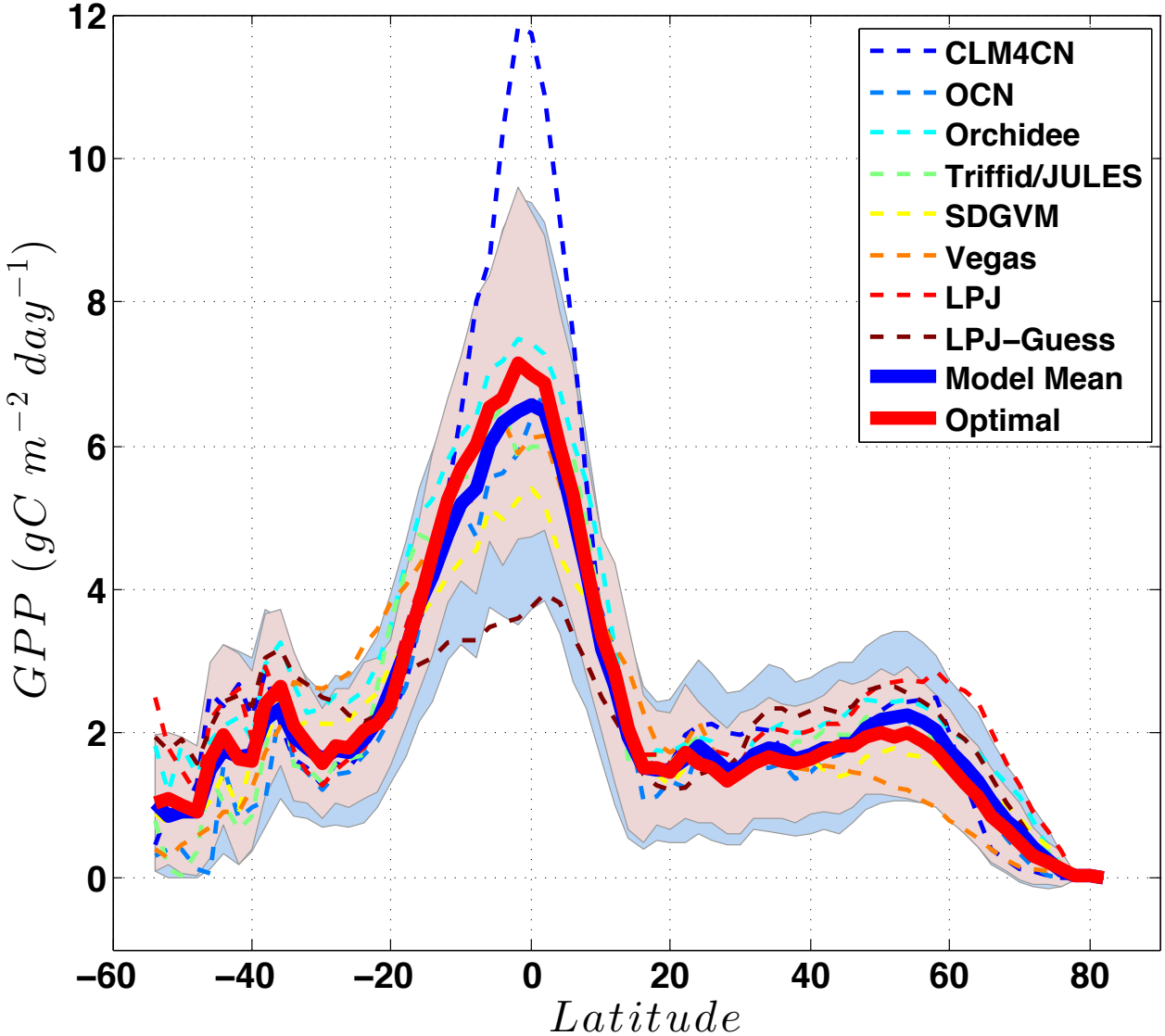
Balance of Estimates from SIF & Models, Weighted by Respective Uncertainties

$$C_{\beta,j} = \frac{1}{2}\left[\boldsymbol{y}_j - \boldsymbol{f}_j(\beta_j)\right]^T \boldsymbol{R}_j^{-1}\left[\boldsymbol{y}_j - \boldsymbol{f}_j(\beta_j)\right] + \frac{1}{2}\left[\beta_j - \beta_b\right]^T P_j^{-1}\left[\beta_j - \beta_b\right]$$

Estimate a Scale Factor For Monthly *GPP*, Called β, At Each Grid Cell For Each Month

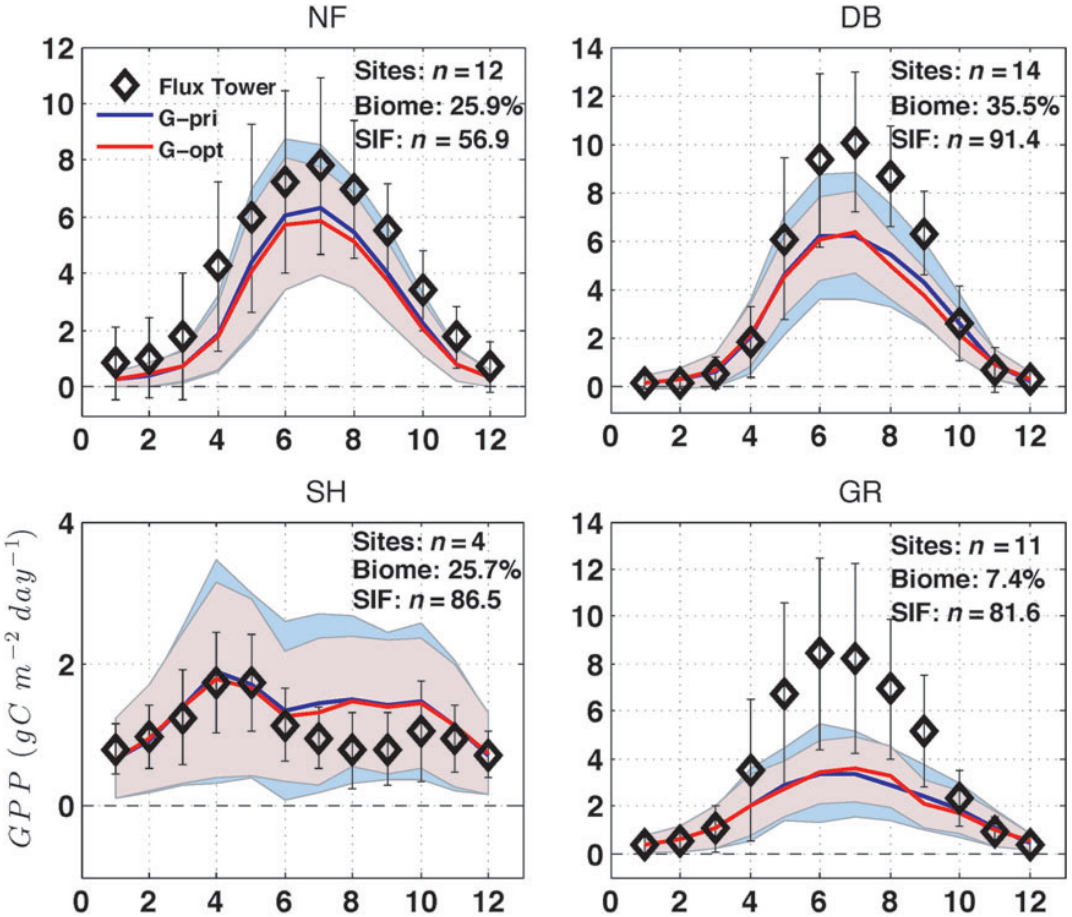
- **y:** vector of monthly GOSAT SIF observations (scaled to GPP using MPI)
- **f**(β): Vector of model estimates sampled at GOSAT overpass, based on diurnal downscaling of monthly GPP from TRENDY ensemble average
- **R**: Observation error (SIF measurement error + scaling error + MPI error)
- β: monthly scale factor
- β_b: prior estimate of monthly scale factor (assumed to be 1)
- P: Error in scale factor (spread of TRENDY models)

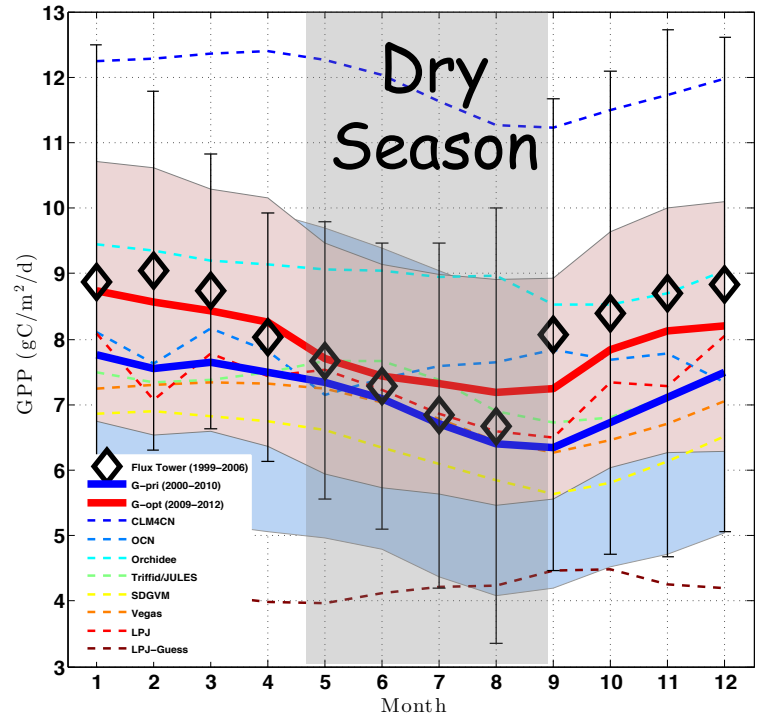
Parazoo et al., 2014, GCB

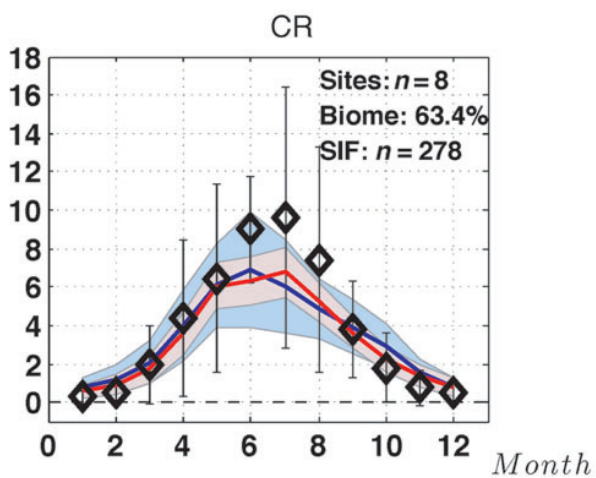


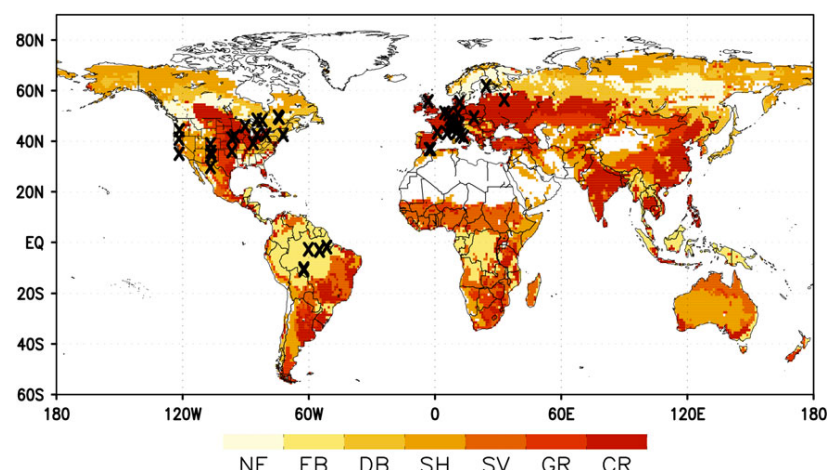
- Posterior uncertainty reduced by ~ 30%
- Opportunity for model benchmarking

Parazoo et al., 2014, GCB







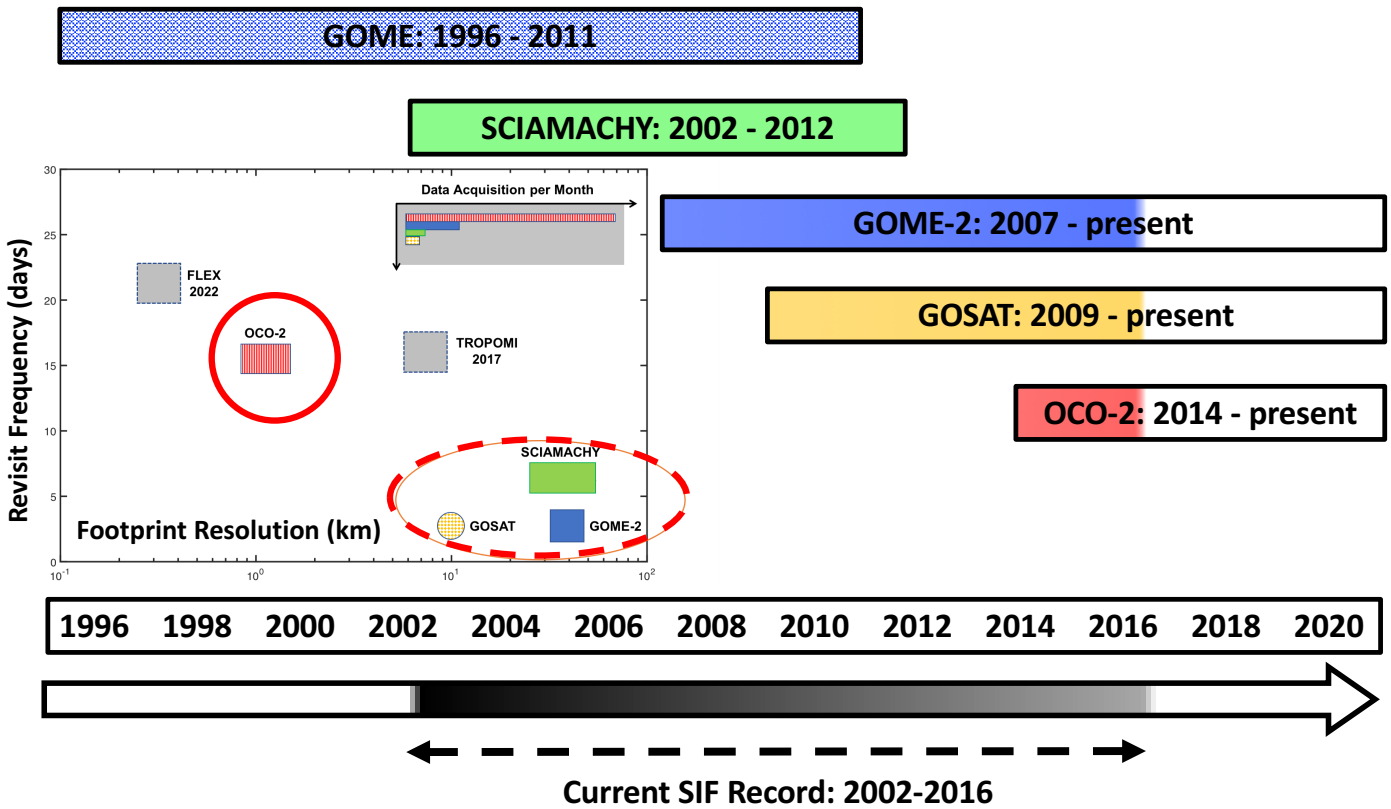


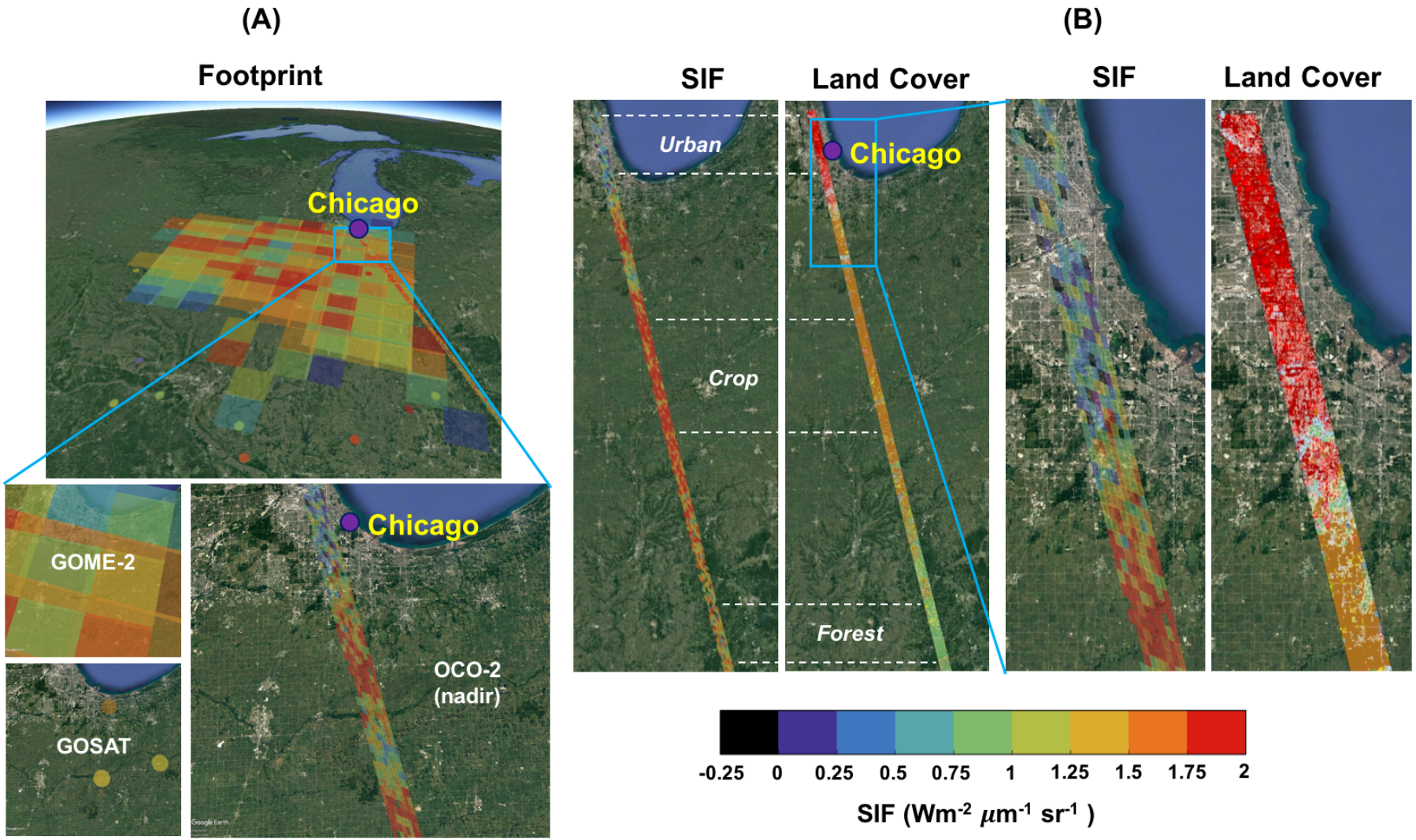
Parazoo et al., 2014, GCB

So this is great – what are the uncertainties?

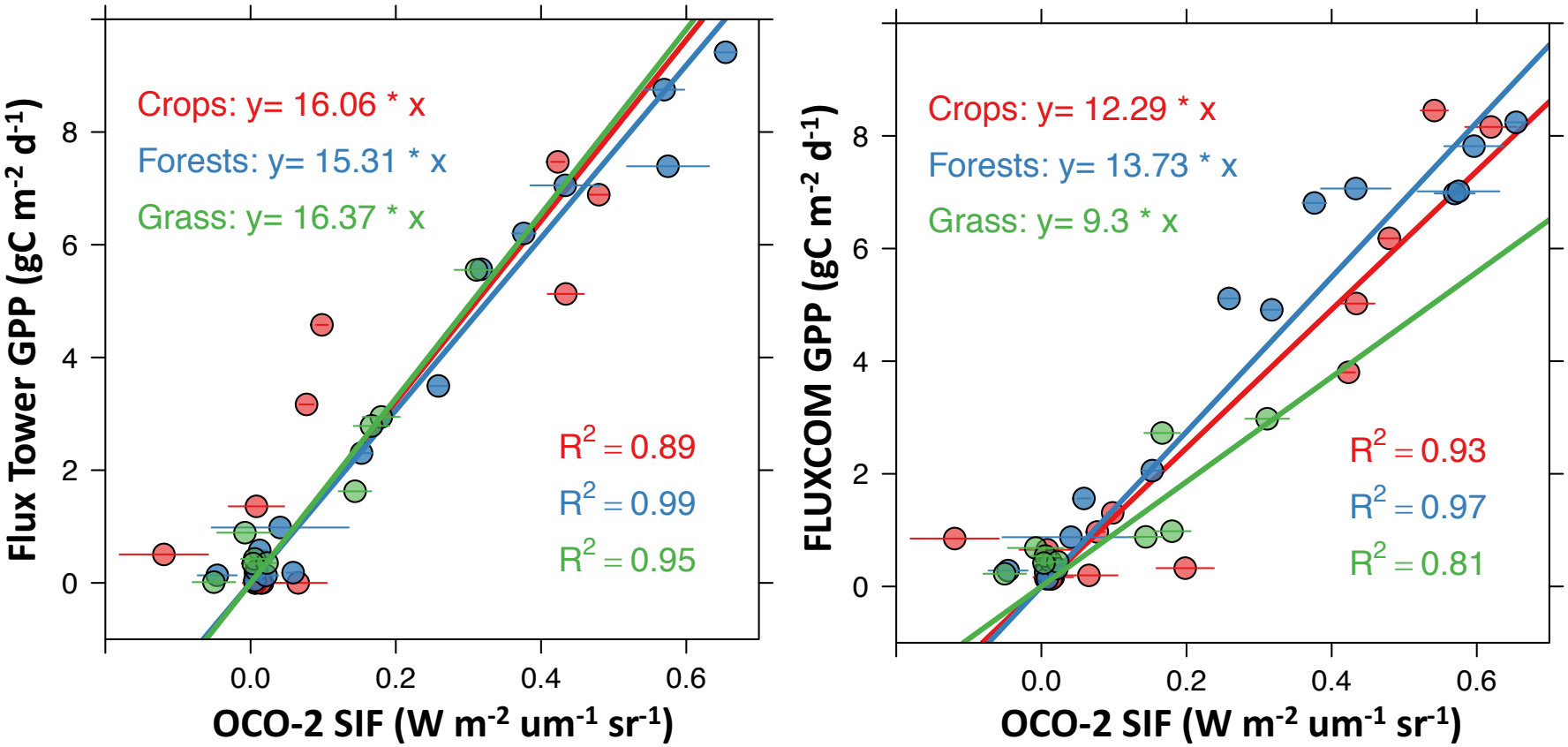
- Multiple satellites
- Multiple retrieval algorithms
- Multiple observing strategies

	GOSAT	GOME-2	SCIAMACHY	OCO-2	TROPOMI
Data since/from	Jun 2009	Jan 2007	2002–2012	Aug 2014	Mid 2016
Overpass time	Midday	Morning	Morning	Midday	Midday
Red/NIR spectral coverage	757–775 nm	650–790 nm	650–790 nm	757–775 nm	675–775 nm
Spectral resolution at 750 nm	∼ 0.025 nm	∼ 0.5 nm	∼ 0.5 nm	∼ 0.05 nm	∼ 0.5 nm
Type of spatial sampling	Sparse	Continuous	Continuous	Sparse	Continuous
Spatial resolution of single measurements	10 km diam.	$40 \times 80\,km^2$	$30 \times 240\,km^2$	$1.3 \times 2.25\,km^2$	$7 \times 7\,km^{2*}$
Typical resolution of global composites	2°	0.5°	1.5°	1°	0.1°*
Approx. number of NIR clear-sky observations over land per day	600	2800	900	∼ 129 900	∼ 544 300*





Sun, Frankenberg et al., Science, Accepted



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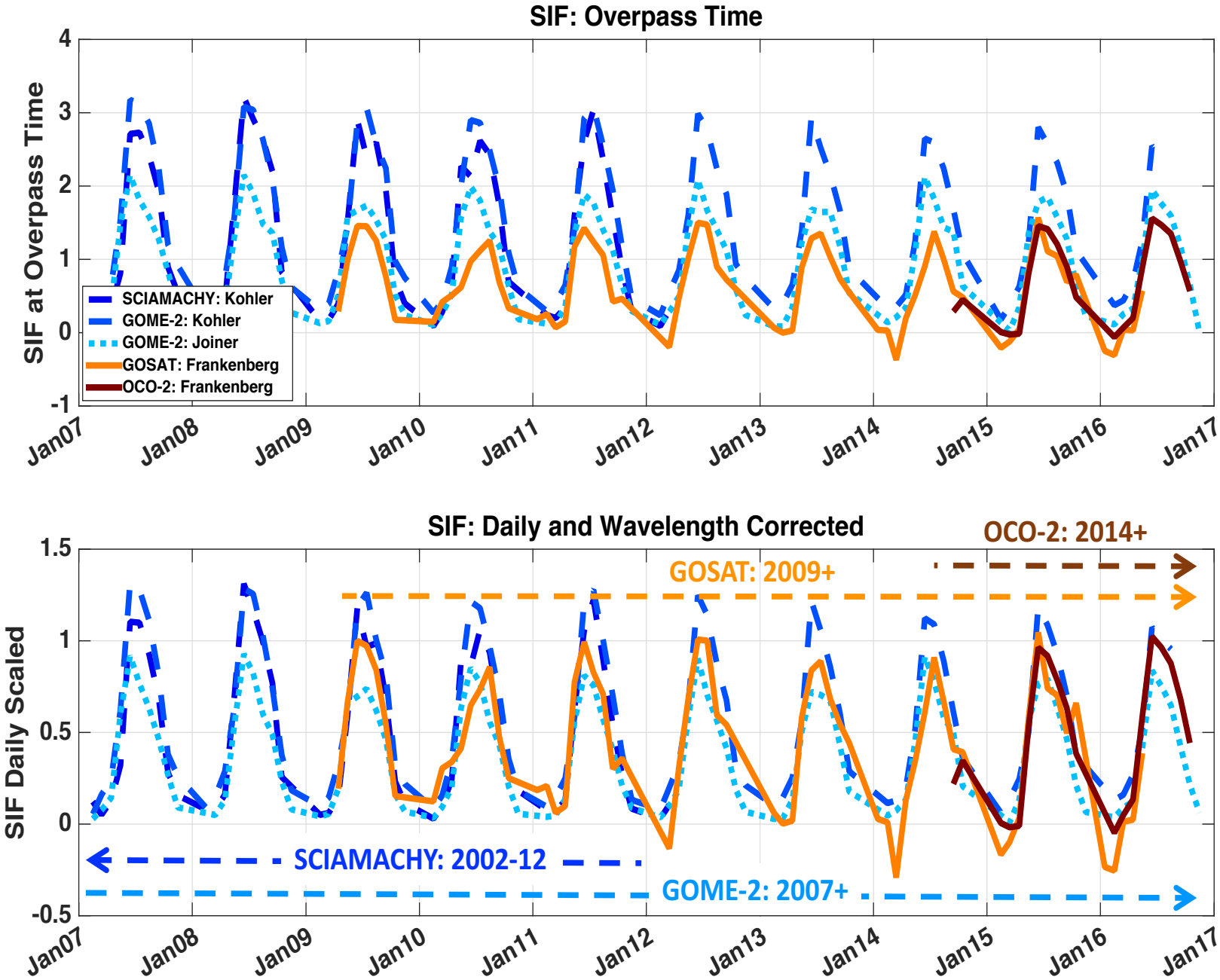

SIF: Overpass Time
SIF at Overpass Time
4
3
2
1
0
-1
SCIAMACHY: Kohler
GOME-2: Kohler
GOME-2: Joiner
GOSAT: Frankenberg
OCO-2: Frankenberg
Jan07
Jan08
Jan09
Jan10
Jan11
Jan12
Jan13
Jan14
Jan15
Jan16
Jan17
SIF: Daily and Wavelength Corrected
SIF Daily Scaled
1.5
1
0.5
0
-0.5
OCO-2: 2014+
GOSAT: 2009+
SCIAMACHY: 2002-12
GOME-2: 2007+
Jan07
Jan08
Jan09
Jan10
Jan11
Jan12
Jan13
Jan14
Jan15
Jan16
Jan17

SIF Grand Challenge:

How does SIF-GPP linear relationship vary from stomata to globe?

Challenge 1:

How does linearity vary with canopy structure and plant functional type?

Challenge 2:

How valid is the assumption from snapshot to integral

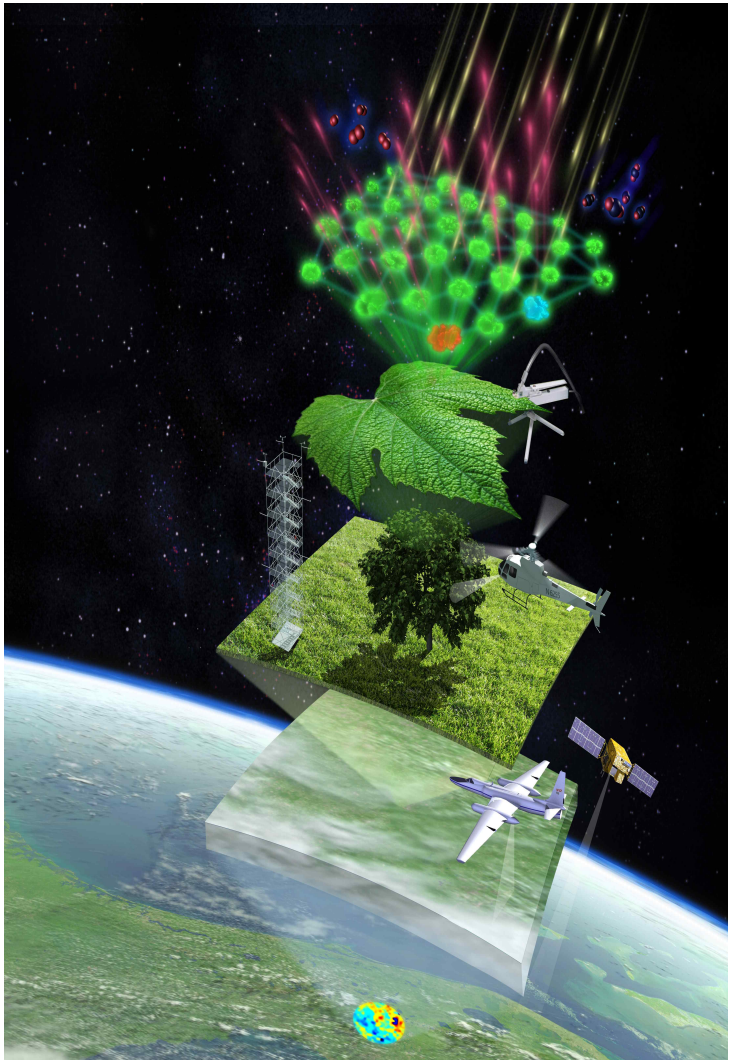
- Tower to pixel
- Overpass to day

Challenge 3:

What are the influences of environmental conditions and structure?

Challenge 4:

Can we achieve consistent SIF retrievals across satellites



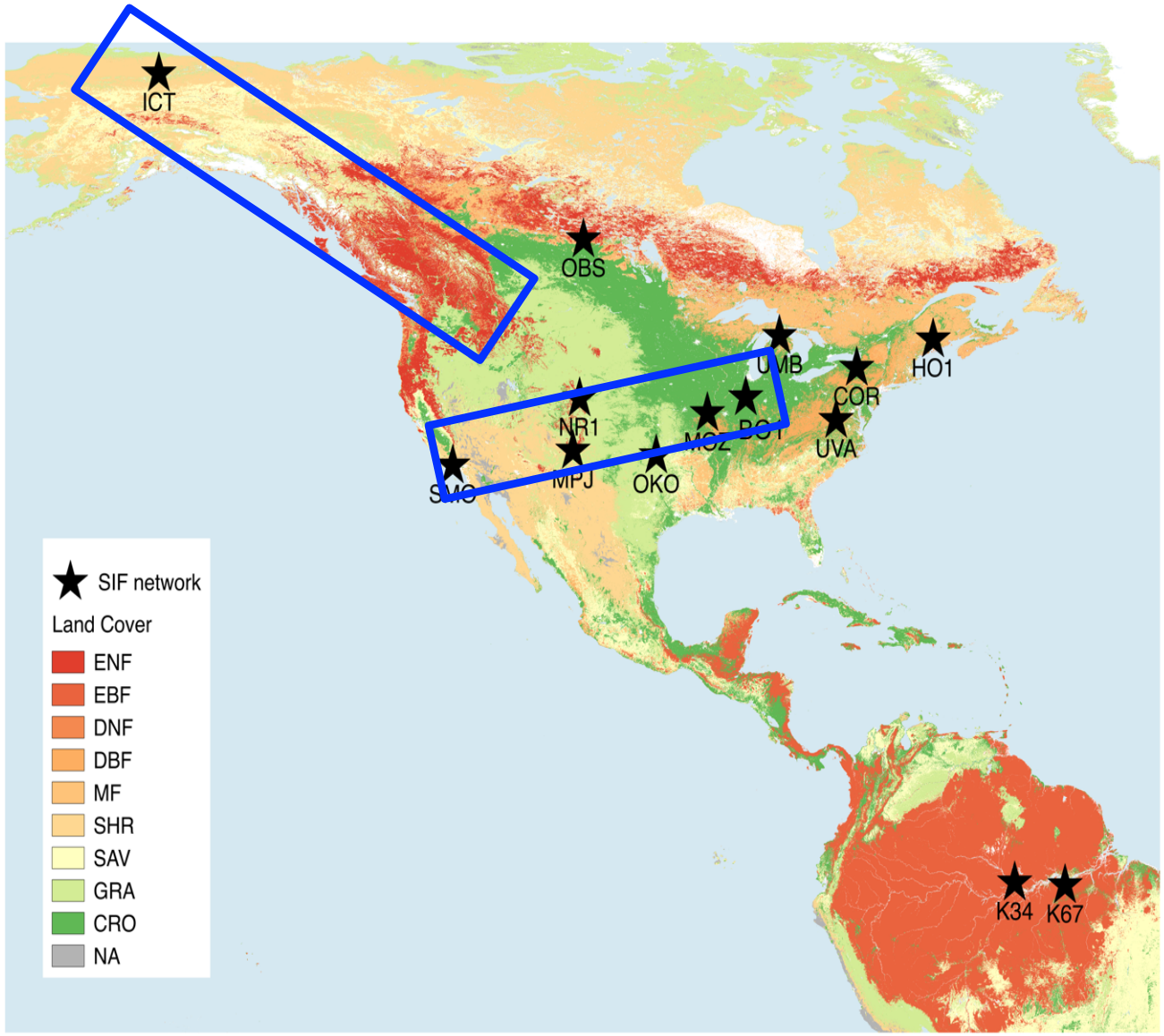
How to deal with this?

- Multi-scale observations
  - **Satellites**: Global coverage
  - **Airborne**: High spatial resolution, target hotspots
  - **Tower**: Canopy level, diurnal resolution, continuous
  - **Leaf**: PAM fluorescence, develop process understanding
- Refine mechanistic SIF-GPP relationship
  - Environmental vs structural influences

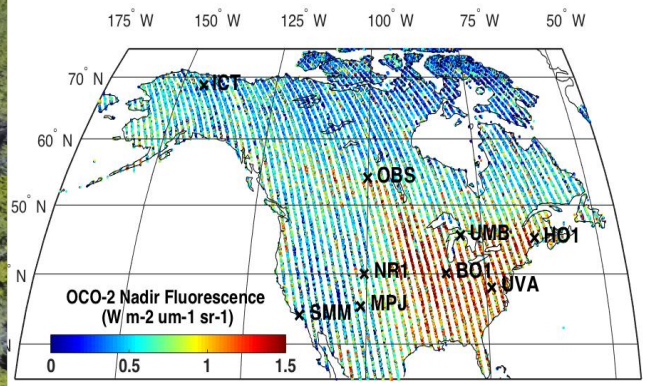
$$GPP = APAR \times \phi_P = APAR \times f(VPD, T, SM)$$
$$SIF = APAR \times \phi_{SIF} \times c \times f_{esc}$$
$$GPP = SIF \times (\phi_P / \phi_{SIF}) \times (c \times f_{esc})^{-1}$$

- Directional Effect (BRDF)
  - Observed vs emitted SIF
  - Changes in plant structure or observing angle

Tower Network + Aircraft Campaigns



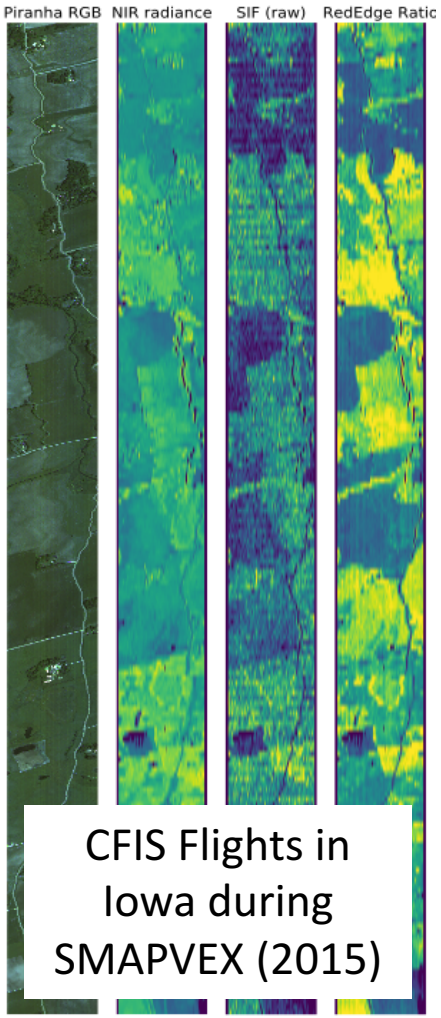
SIF Tower Network



Twitter.com/Photo_spec

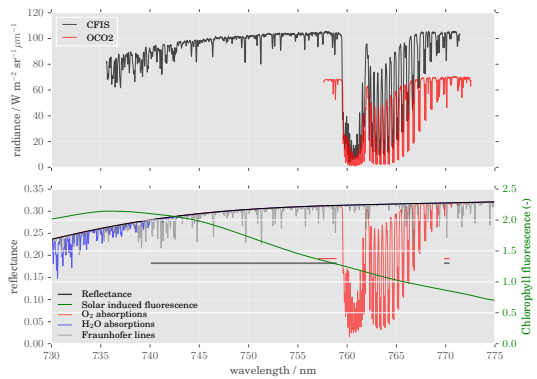
Chlorophyll Imaging Fluorescence Spectrometer (CFIS)

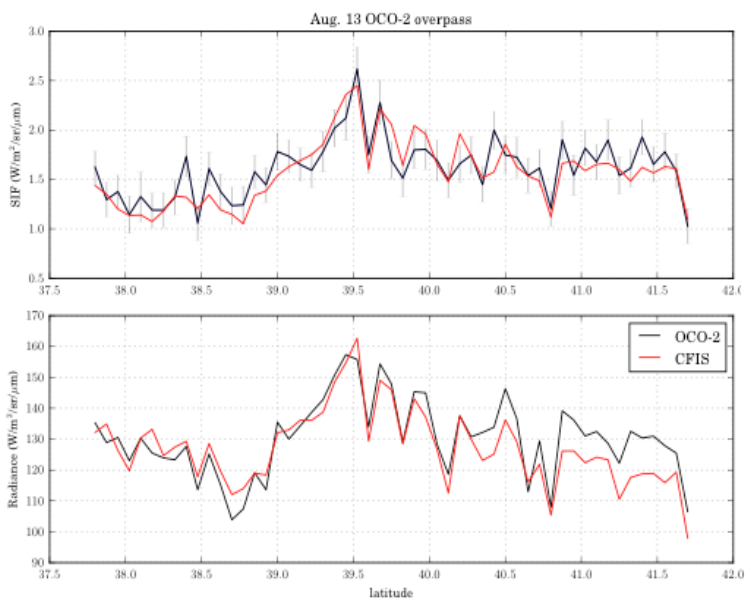
Small footprint + vegetation gradients



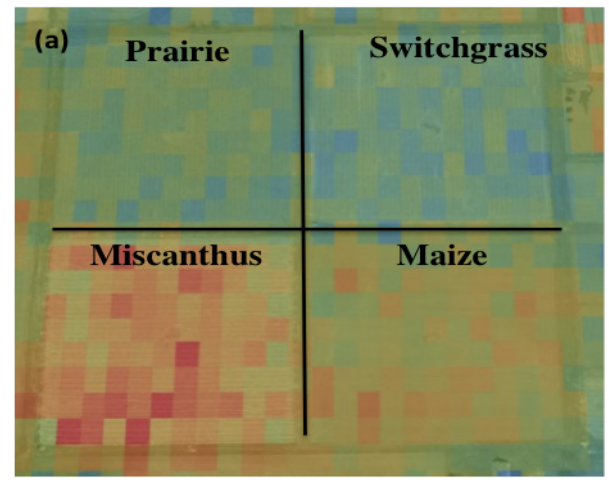
CFIS Flights in Iowa during SMAPVEX (2015)

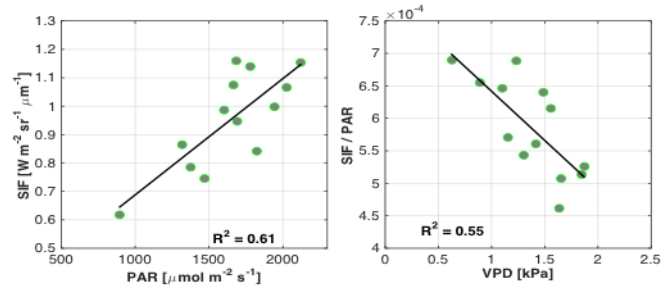
Validation of OCO-2 SIF





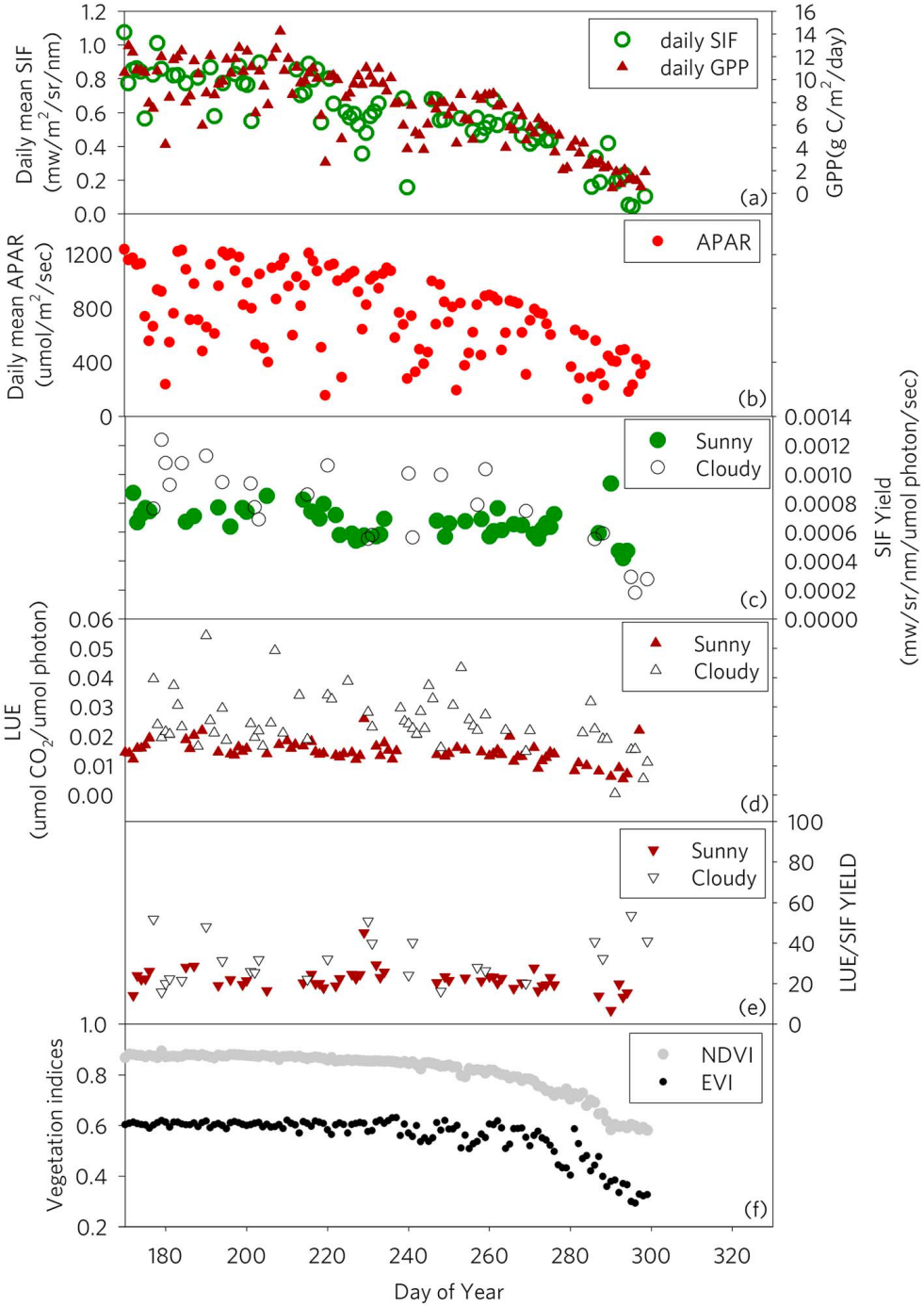
Diurnal scaling and stress impacts

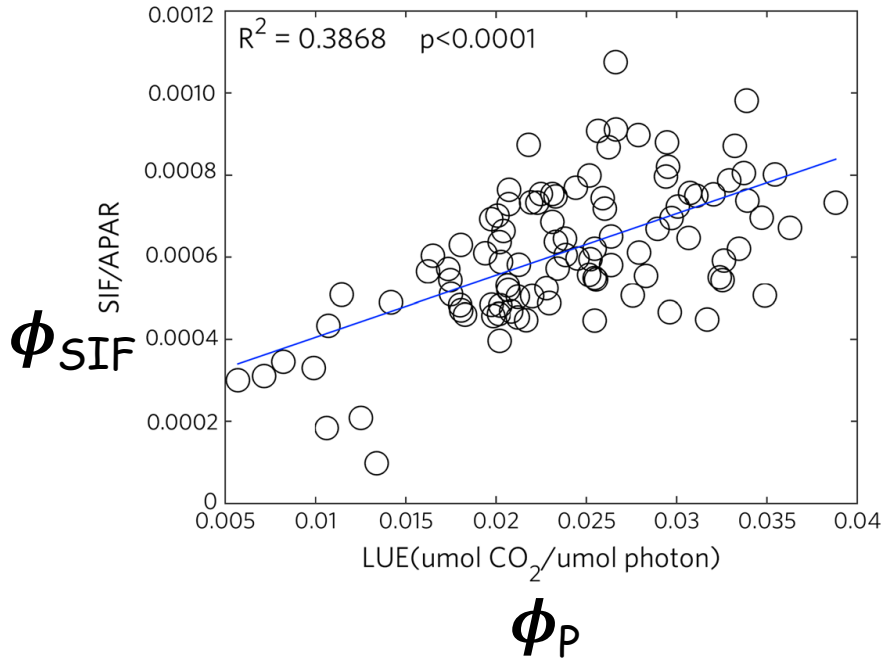




Sun & Frankenberg et al., Science, Accepted

Harvard Forest





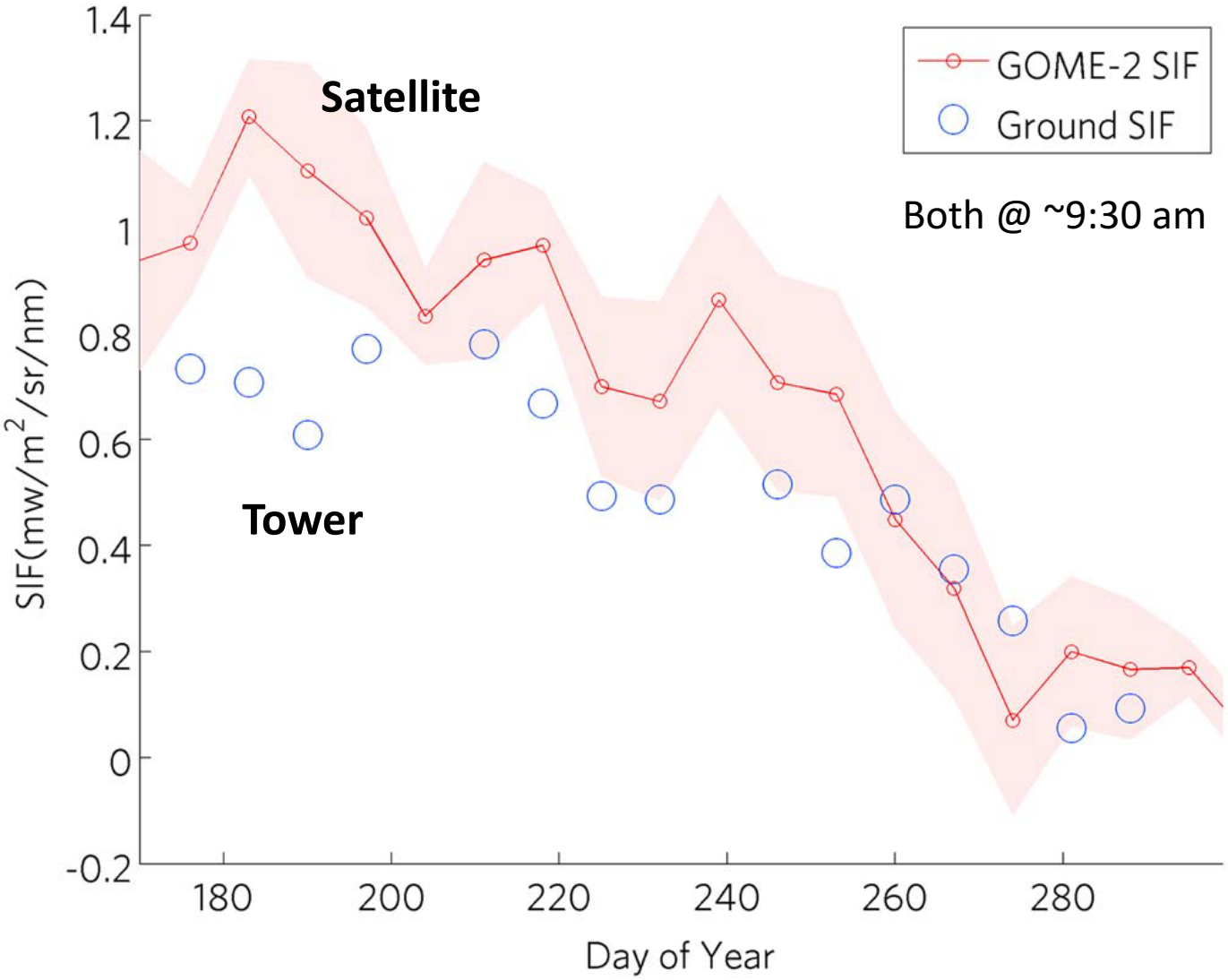
ϕ_{SIF}

ϕ_P

$$GPP = SIF \times (\phi_P / \phi_{SIF})$$

Yang et al., 2015, GRL

Harvard Forest



Yang et al., 2015, GRL

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