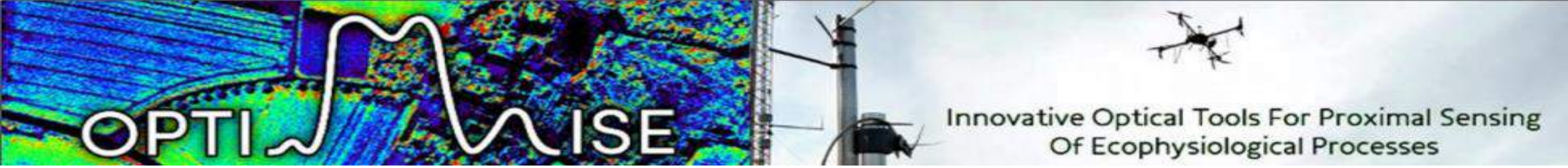

Harnessing remote sensing big data for predicting food production

Dr. Kaiyu Guan (kaiyug@Illinois.edu; kaiyuguan@gmail.com)
Assistant professor, Nature Resources and Environmental Sciences
Blue Waters Professor, National Center for Supercomputing Applications
Affiliated Assistant Professor, Crop Sciences & Civil and Environmental Engineering

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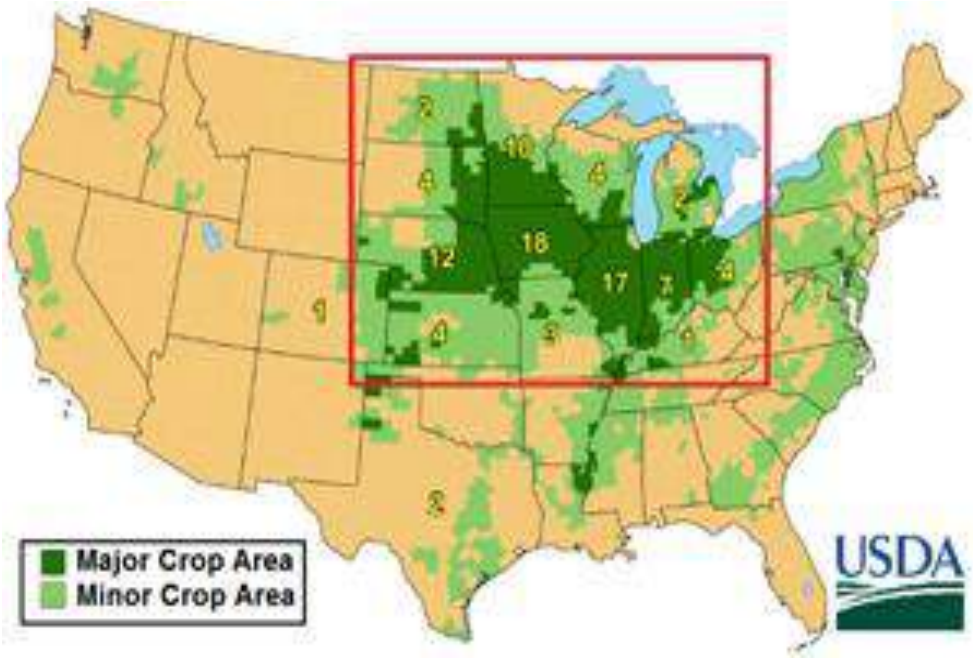
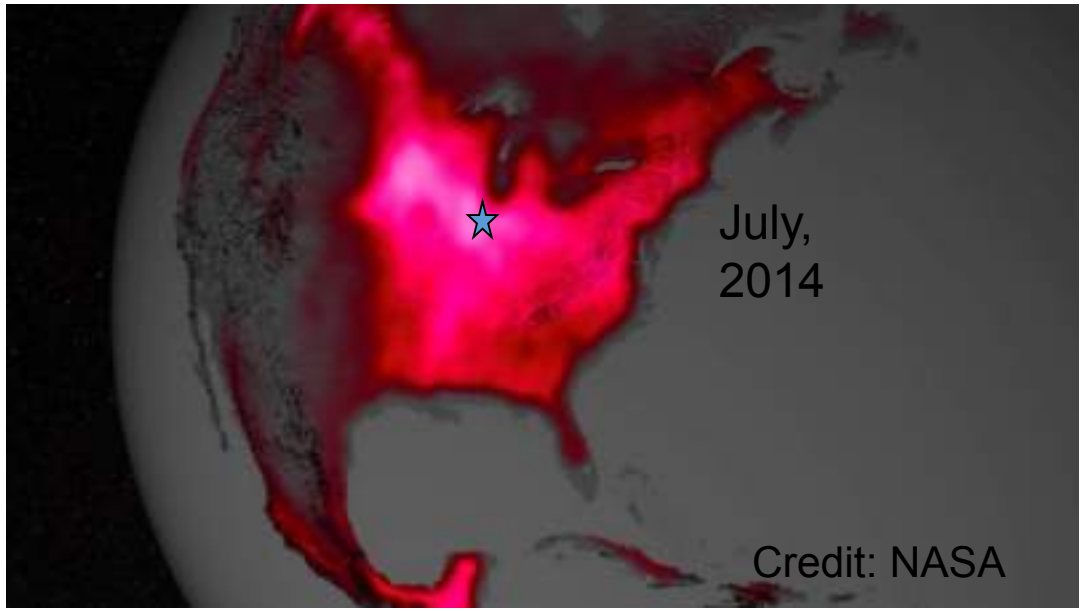
ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Invited Keynote for OPTIMISE 2018
OPTIMISE Final Conference, Feb 21-23 2018, Sofia, Bulgaria

NCSA



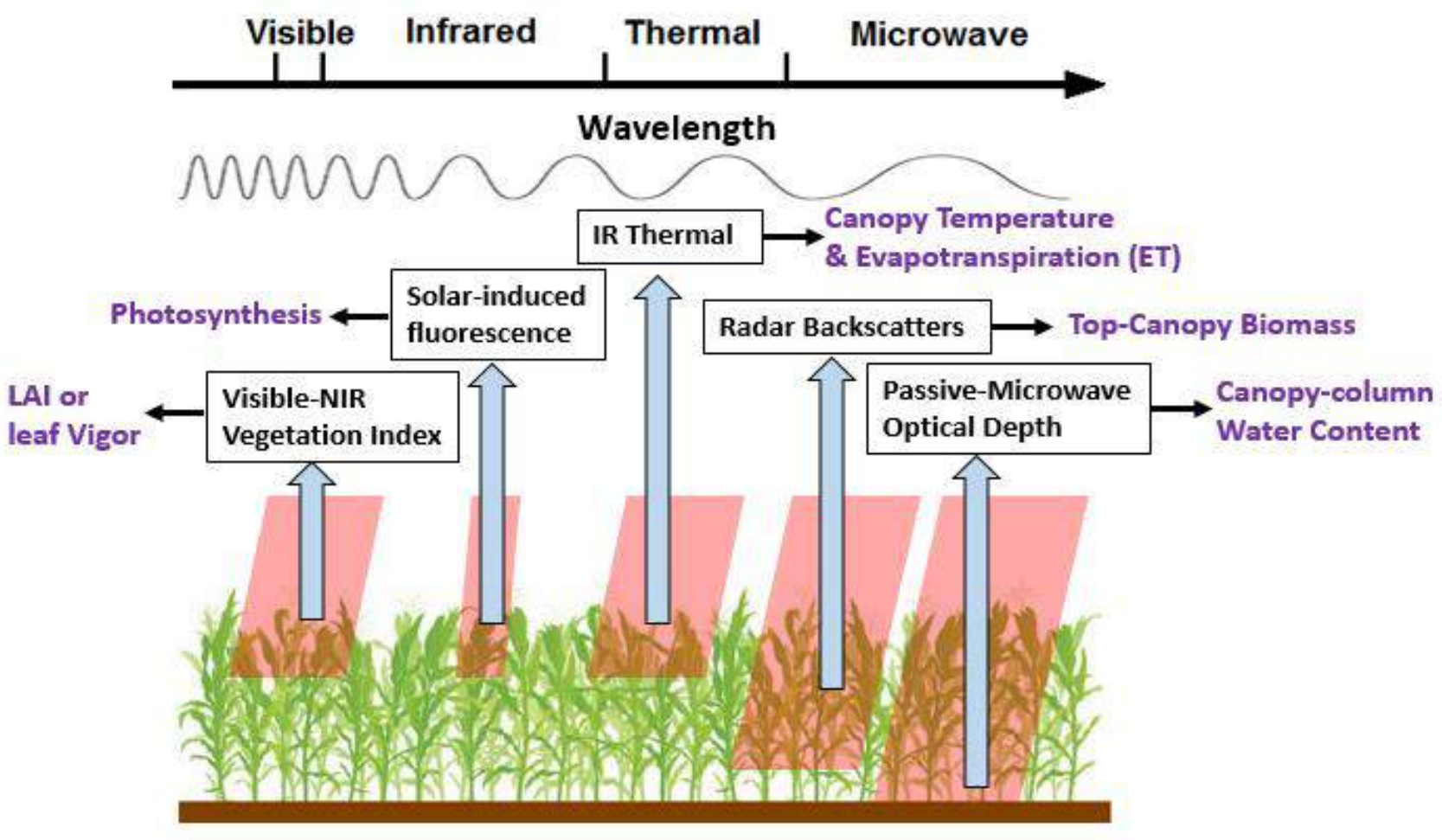
Study domain in red box. The background shows the averaged corn production from 2007-2012, and the numbers indicate the percentage (%) of the state production to the national total corn production.



Sun-induced chlorophyll fluorescence (SIF) as a proxy of photosynthesis.

US Corn Belt produces ~45% of global corn production and ~30% of global soybean production.

A New Era of Earth Observation from Satellite: Vegetation Properties



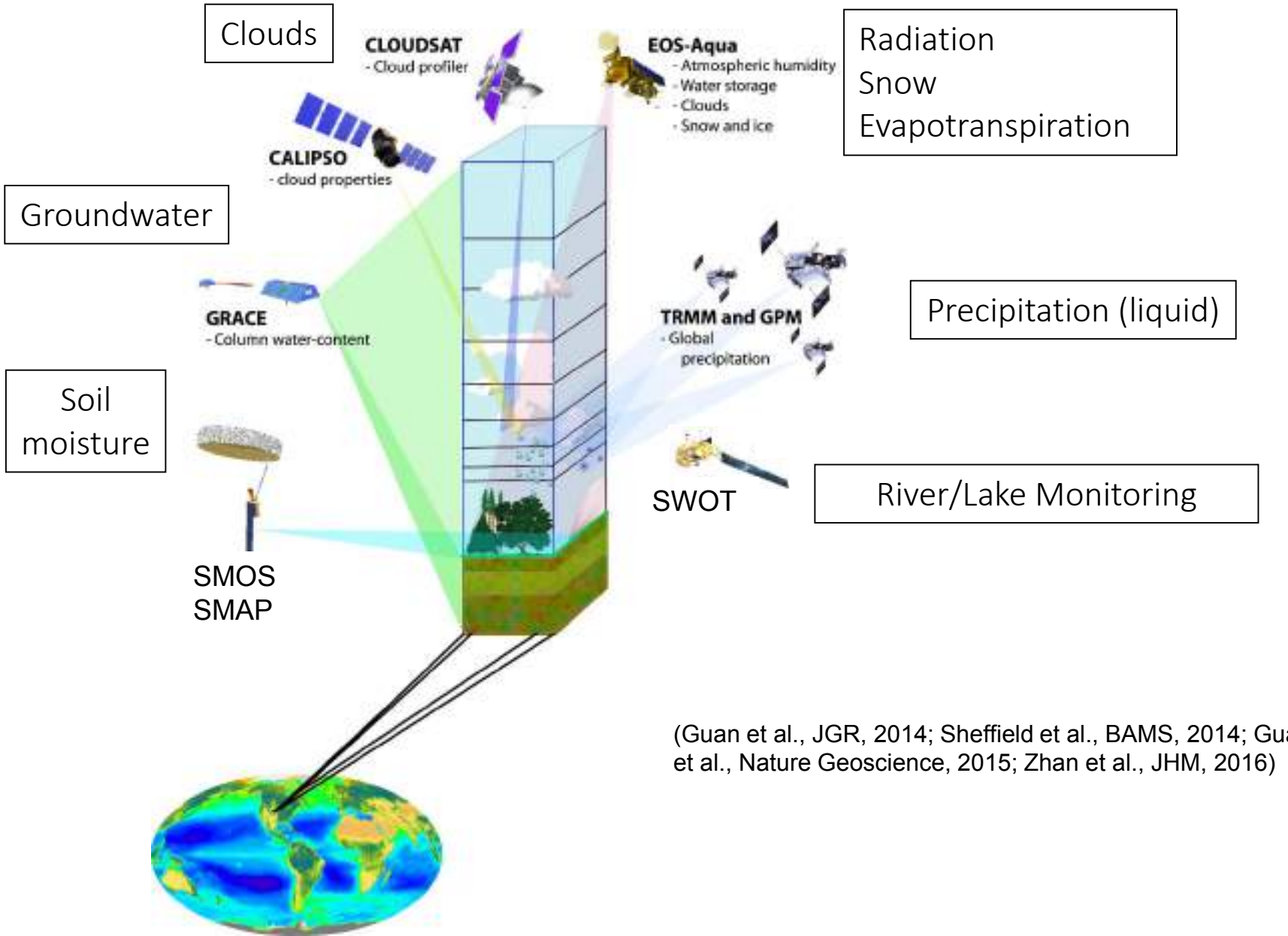
Take home message:

All the satellite data share some common information.

However, when excluding this common information, many data contain their unique information that tremendously improve our understanding of vegetation growth.

(Guan et al., RSE, 2012; Guan et al., Ecosphere, 2013; Guan et al., IEEE, 2014; Guan et al., JGR, 2014; Guan et al., GCB, 2016; He et al., RSE, 2016; Guan et al., RSE, 2017)

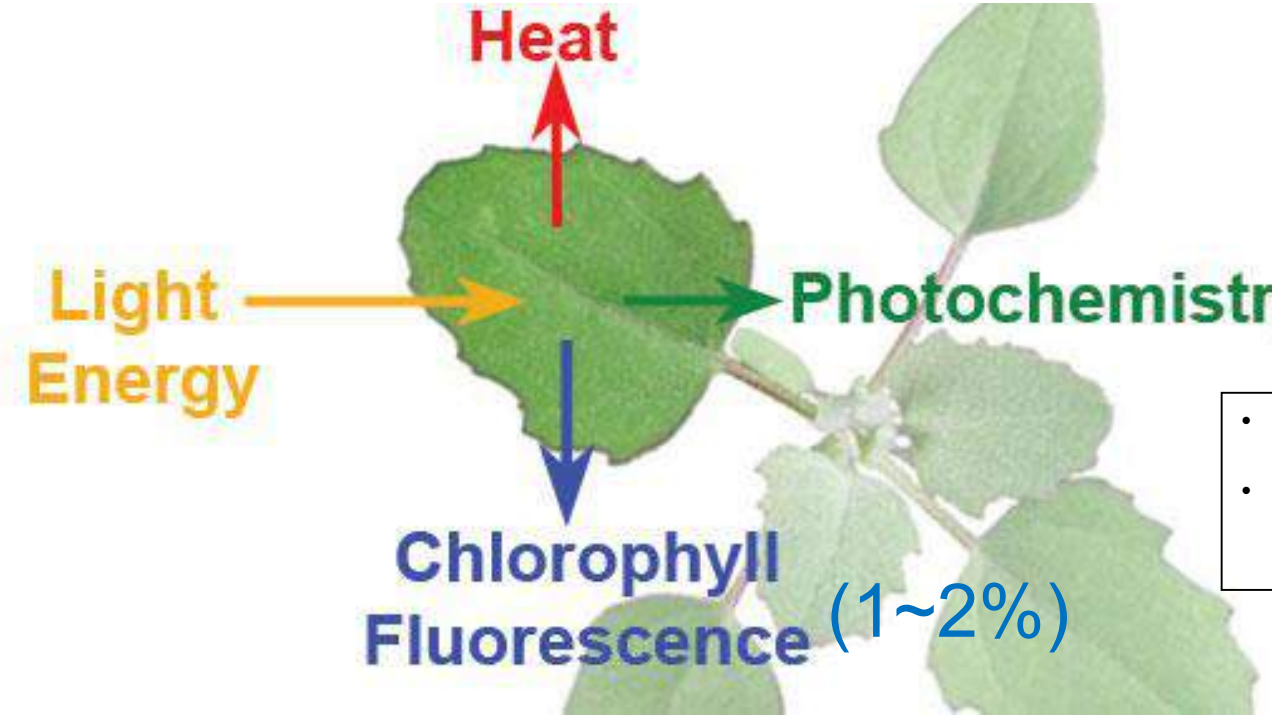
A New Era of Earth Observation from Satellite: Hydrological States



(Guan et al., JGR, 2014; Sheffield et al., BAMS, 2014; Guan et al., Nature Geoscience, 2015; Zhan et al., JHM, 2016)

Innovative use of fluorescence information

What is Solar-induced chlorophyll fluorescence (SIF)?



- Porcar-Castell, A. et al. (2014). *Journal of Experimental Botany*, 1–31.
- Van der Tol, C., Berry, J. A., Campbell, P.K.E. and Rascher, U. (2014).*Journal of Geophysical Research: Biogeosciences*.

SIF is possible to retrieve from space only in a decade, and mature products only became available around 2011.

Scientific foundations:

$$GPP = PAR \times fPAR \times LUE$$

$$SIF = PAR \cdot fPAR \cdot \Phi_F \cdot \Omega_C$$

$$GPP = SIF \times \frac{LUE}{\Phi_F \times \Omega_C}$$

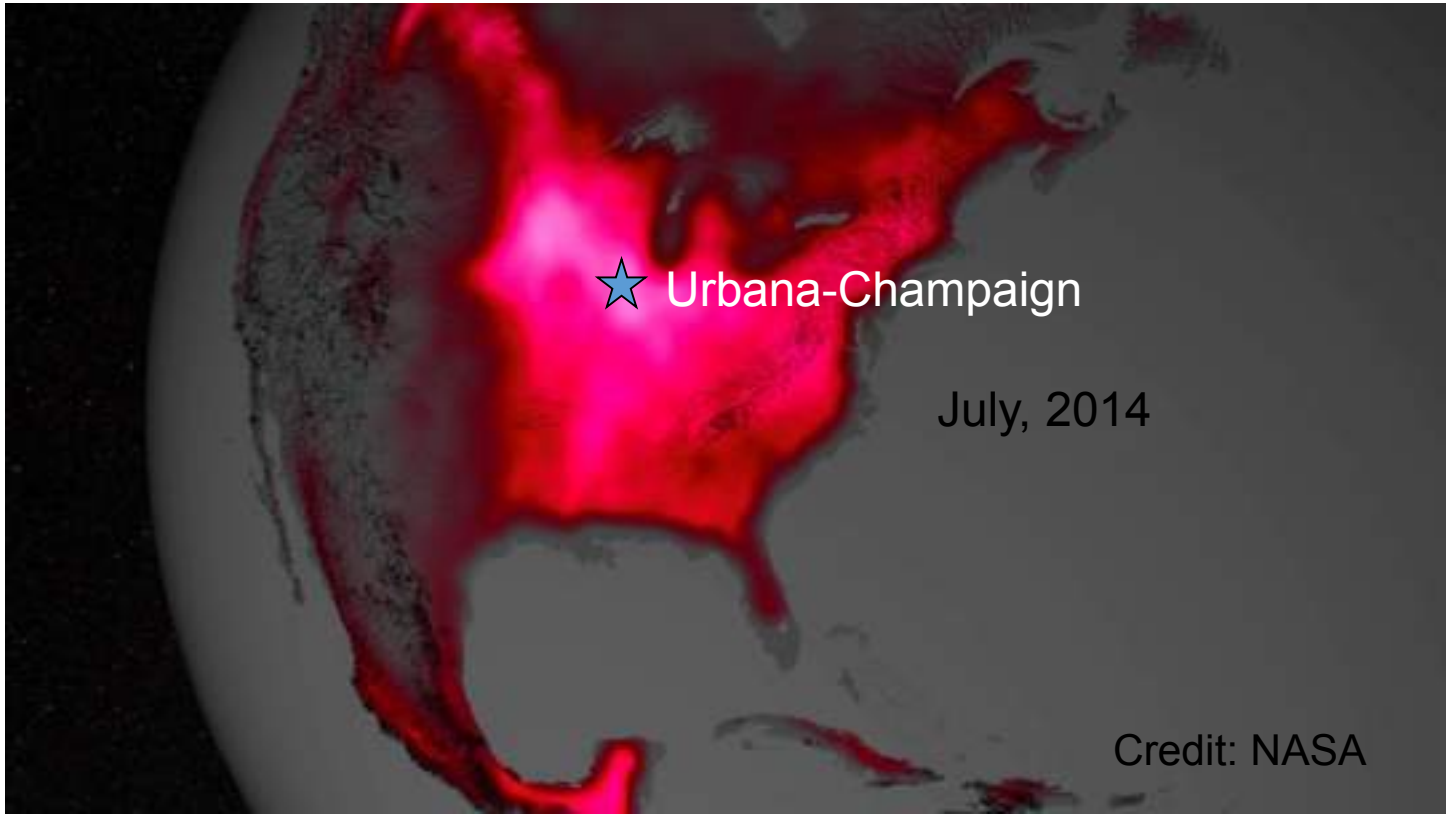
LUE: light use efficiency of photosynthesis.

Φ_F is the yield of fluorescence in the wavelength band of the measurement.

Ω_c is the probability that an emitted photon will escape the canopy to be detected.

- Ref: Frankenberg C and Berry J 2017 *Solar Induced Chlorophyll Fluorescence: Origins, Relation to Photosynthesis and Retrieval* (Elsevier) Online: http://www.sciencedirect.com/science/article/pii/B9780124095489106323

Satellite-sensed photosynthesis



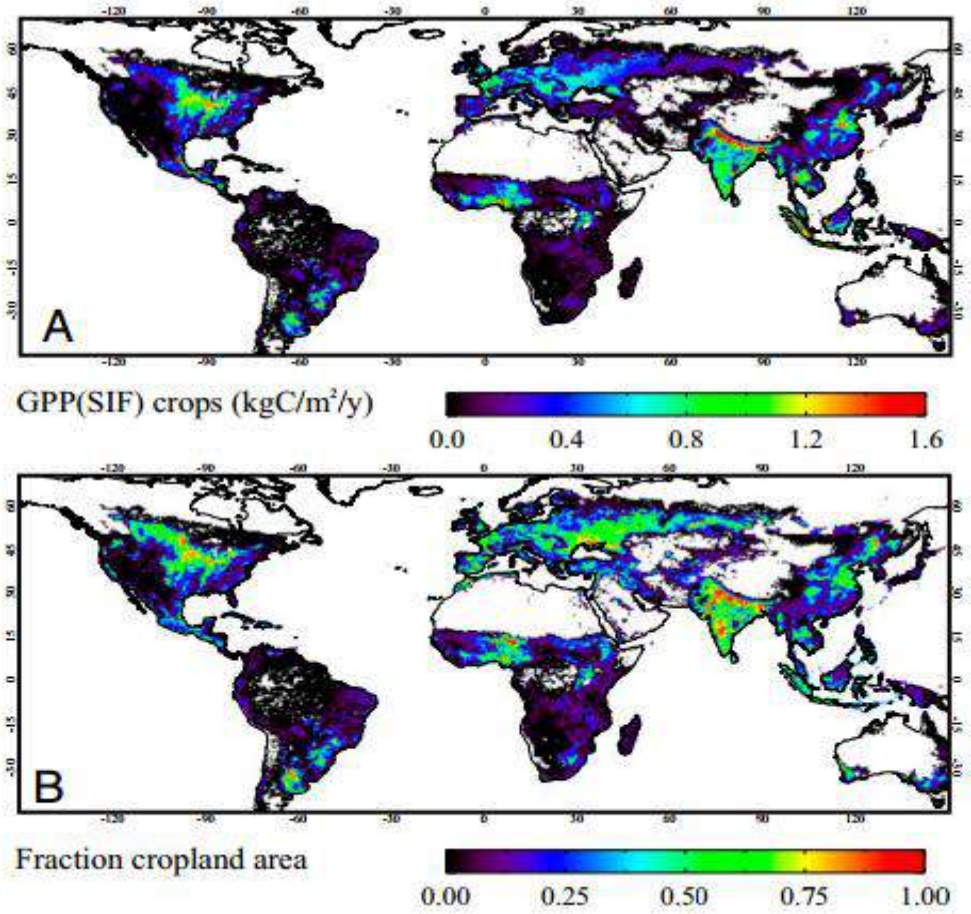
Sun-induced chlorophyll fluorescence (SIF)

Existing satellite-based SIF products (resolutions are all aggregated):

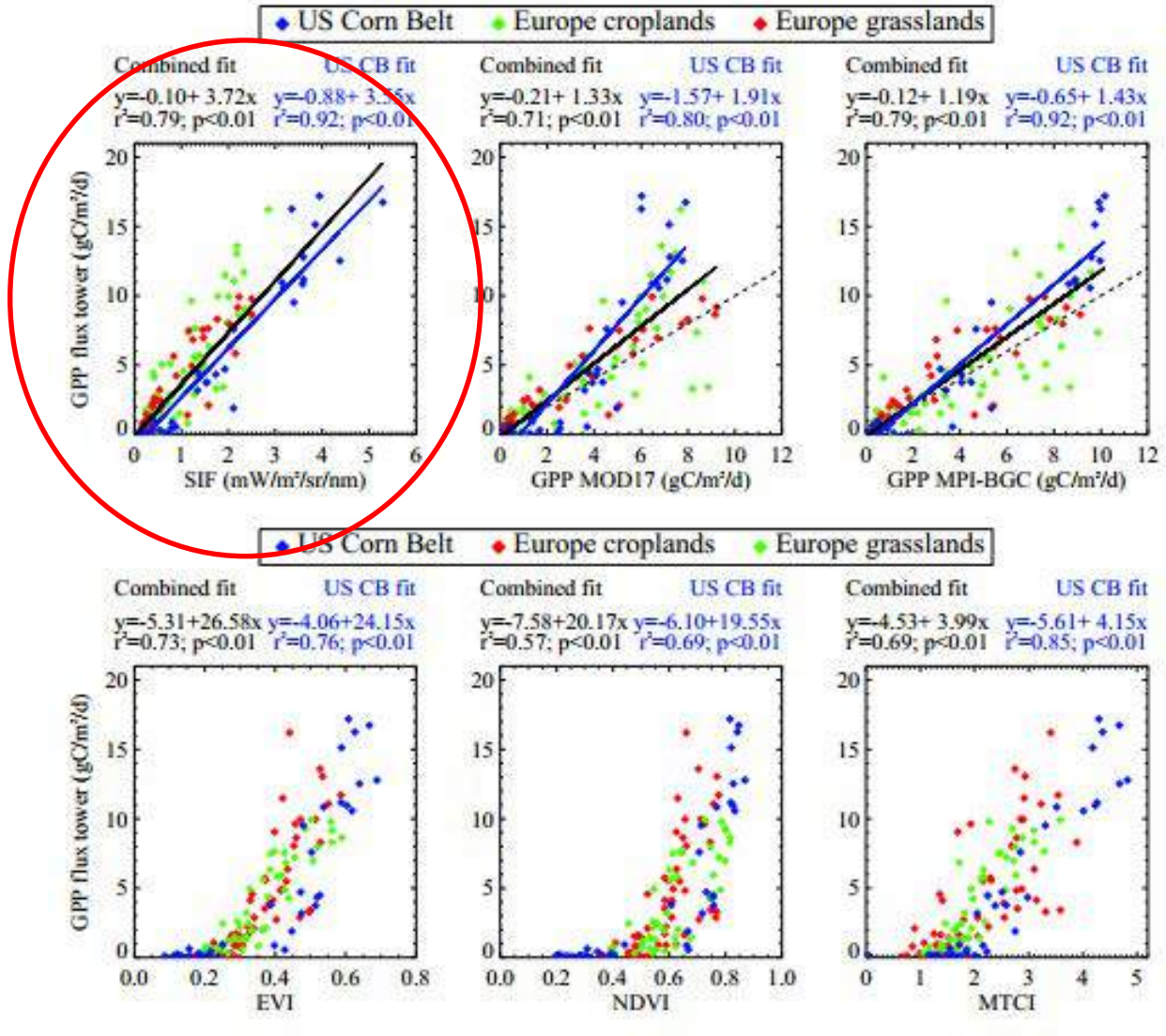
GOSAT (2 degree, monthly), GOME-2 (0.5 degree, biweekly), SCHYMACHY (1 degree, monthly), OCO-2 (~1-2 degree, monthly)

(sadly OCO3 is ceased for funding …)

(Frankenberg, Butz, et al., 2011; Guanter et al., 2014; Joiner et al., 2011, 2013)

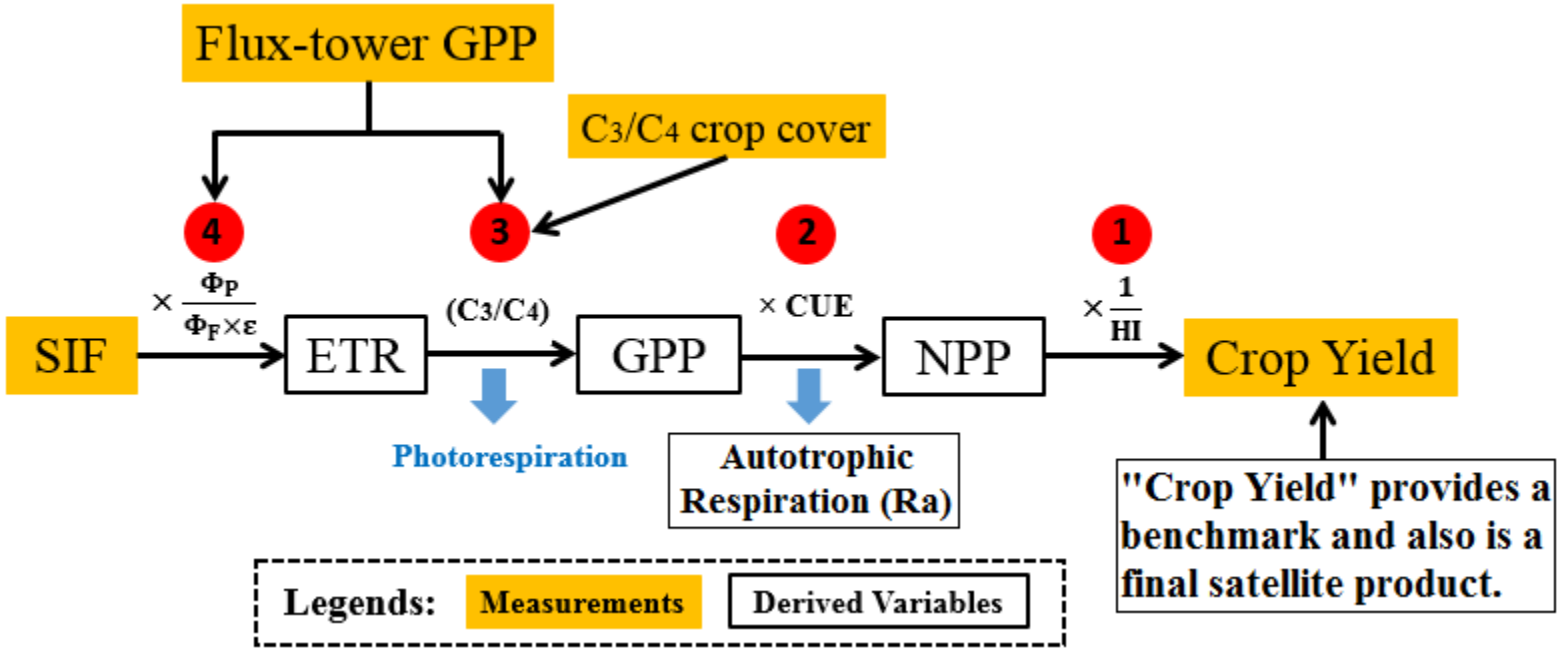


Global fluorescence hotspots (from GOME-2 satellite) are all in agriculture area (adapted from Guanter et al., 2014).

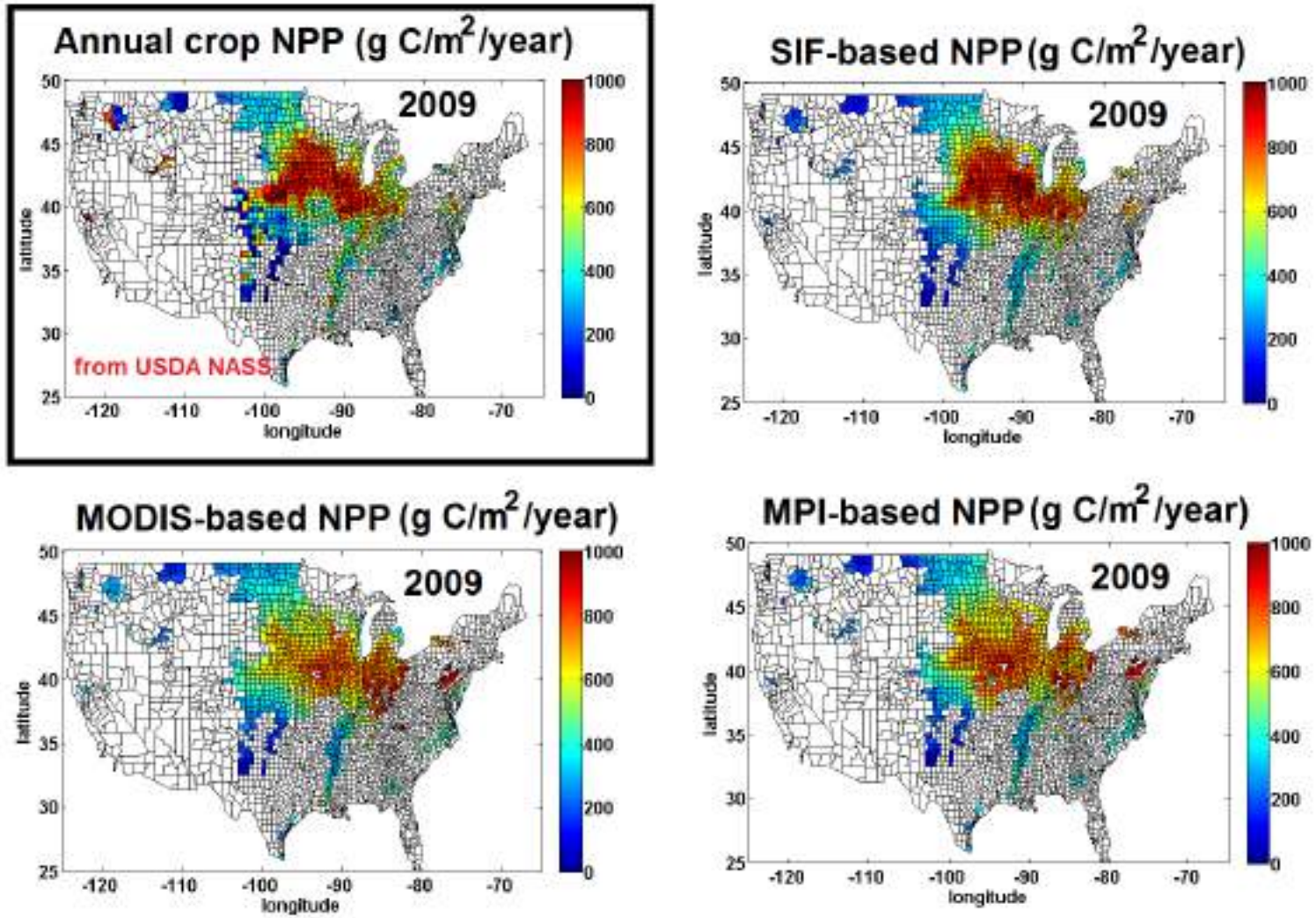


- Guanter L, Zhang Y et al. (2014) Global and time-resolved monitoring of crop photosynthesis with chlorophyll fluorescence *Proc. Natl. Acad. Sci.* **111** E1327–33

A new framework of using SIF for crop monitoring



(Guan et al., "Improving the monitoring of crop productivity using spaceborne solar-induced fluorescence", Global Change Biology, 2016)



(Guan et al., "Improving the monitoring of crop productivity using spaceborne solar-induced fluorescence", Global Change Biology, 2016)

Long-term measurements of solar-induced fluorescence (SIF)

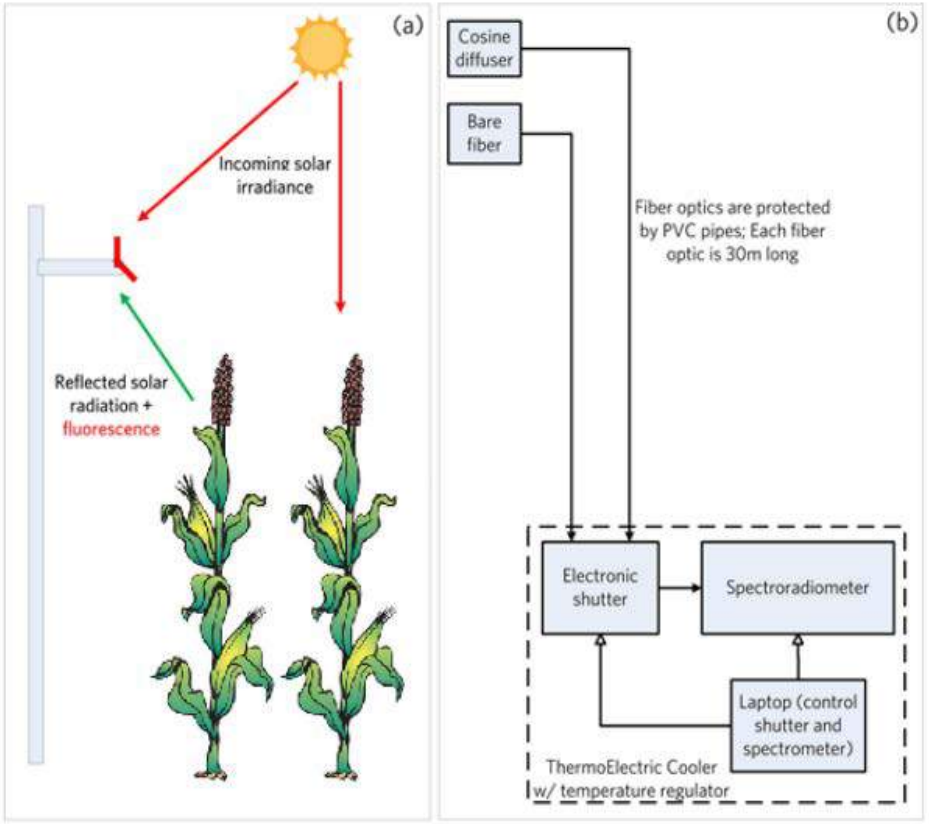
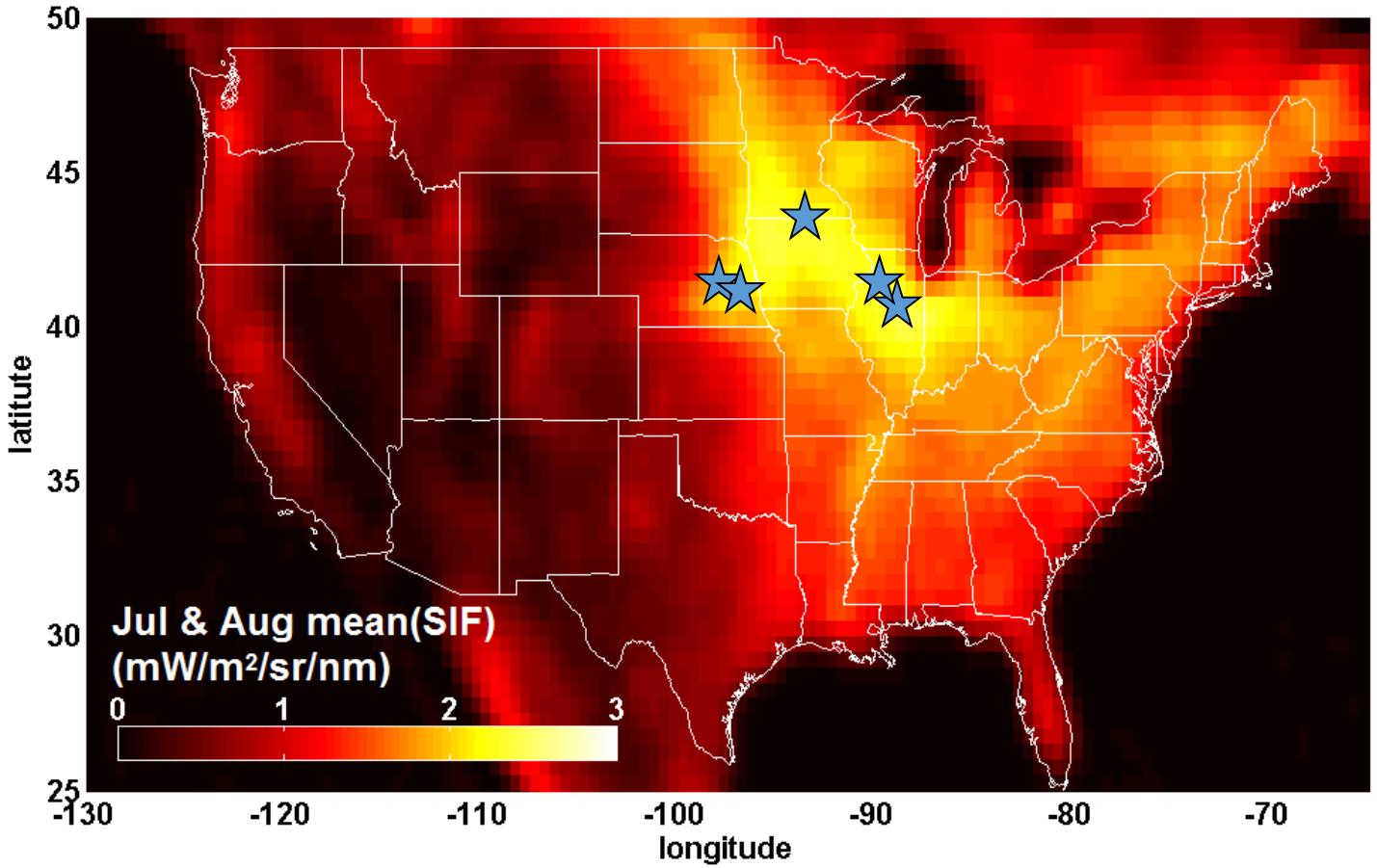


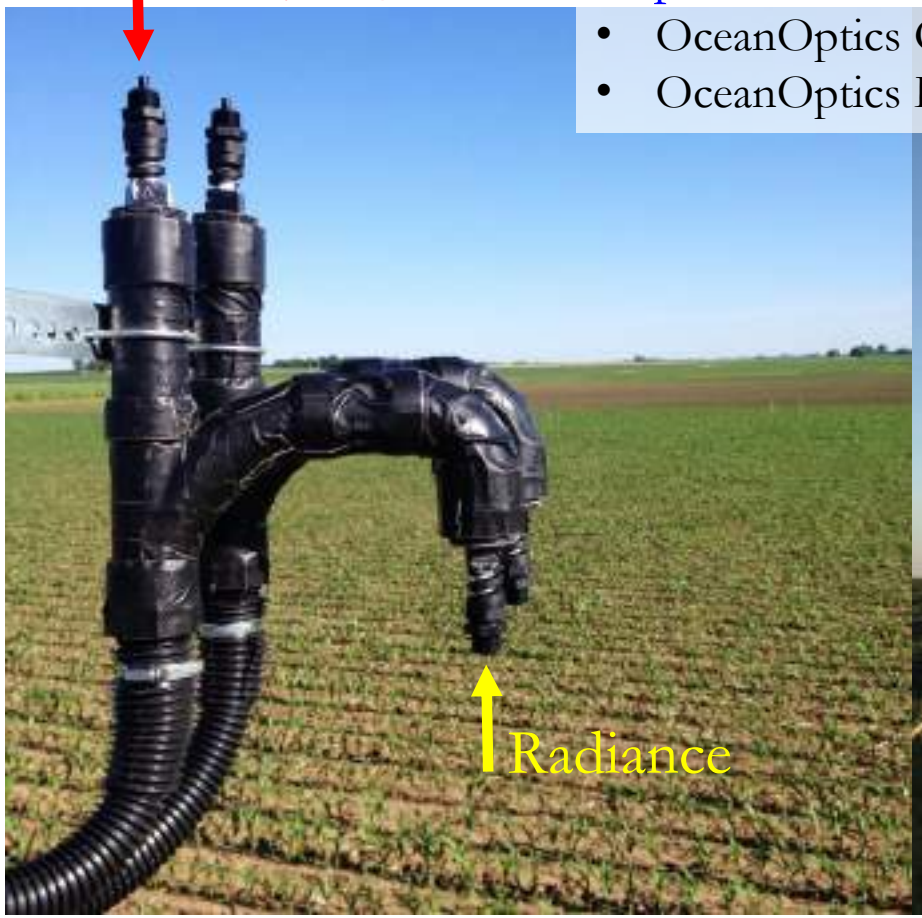
Fig 5. The design of FluoSpec2 designed by Dr. Xi



(Guan et al., NASA New Investigator, 2016)
(Frankenberg, Guan et al., NASA Carbon Sciences, 2016)

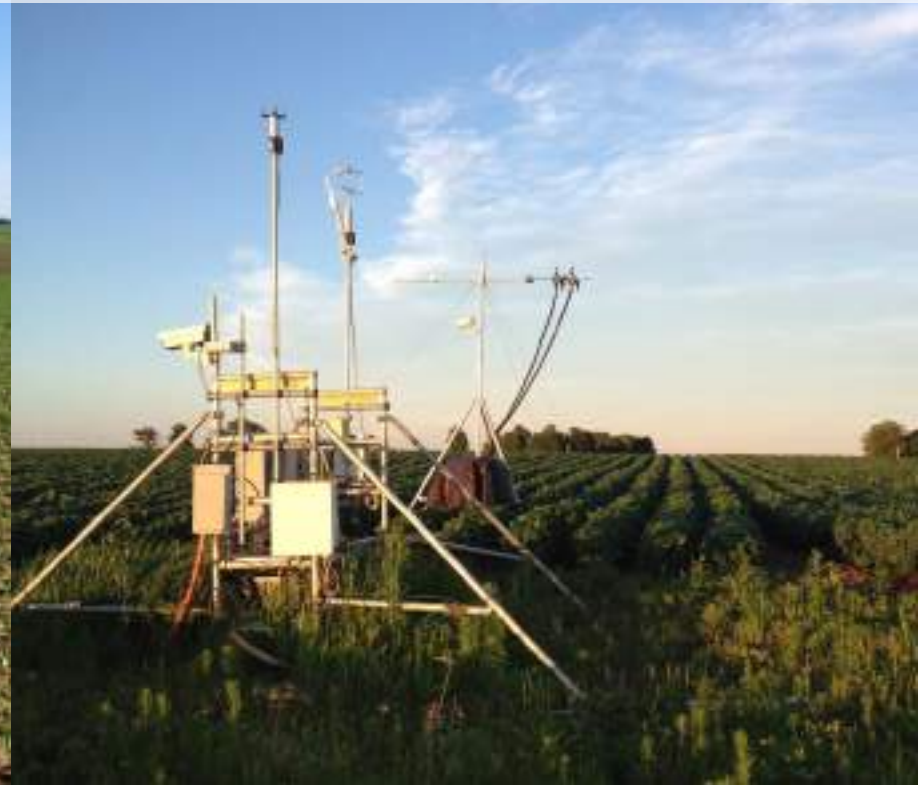
Instrumentation
(Fluospec – Yang et al. 2015)

	Fiber height (h)	Footprint (diameter d = (h-hc)*tan(12.5)*2)
Soybean	3.6 m	1.1 m (if h-hc = 2.5 m)
Maize	4.8 m	0.9 m (if h-hc = 2.0 m)



2 spectrometers per site:

- OceanOptics QEPRO: 730-780 nm (0.04-0.07 nm)
- OceanOptics HR2000+: 400-900 nm (0.42-0.47 nm)



Our SIF systems at University of Illinois (postdoc: Guofang Miao)

The long-term seasonal SIF measures on crops (the first one for the US cropland)

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Biogeosciences

RESEARCH ARTICLE

10.1002/2017JG004180

Key Points:

- Sun-induced fluorescence was continuously measured at the canopy level across multiple growth stages in a soybean field
- The positive relationship between SIF and GPP was dominated by a strong relationship between SIF and APAR
- SIF yield was positively correlated with APAR and negatively correlated with LUE under stable sunny conditions

Supporting Information:

- Supporting Information S1
- Movie S1

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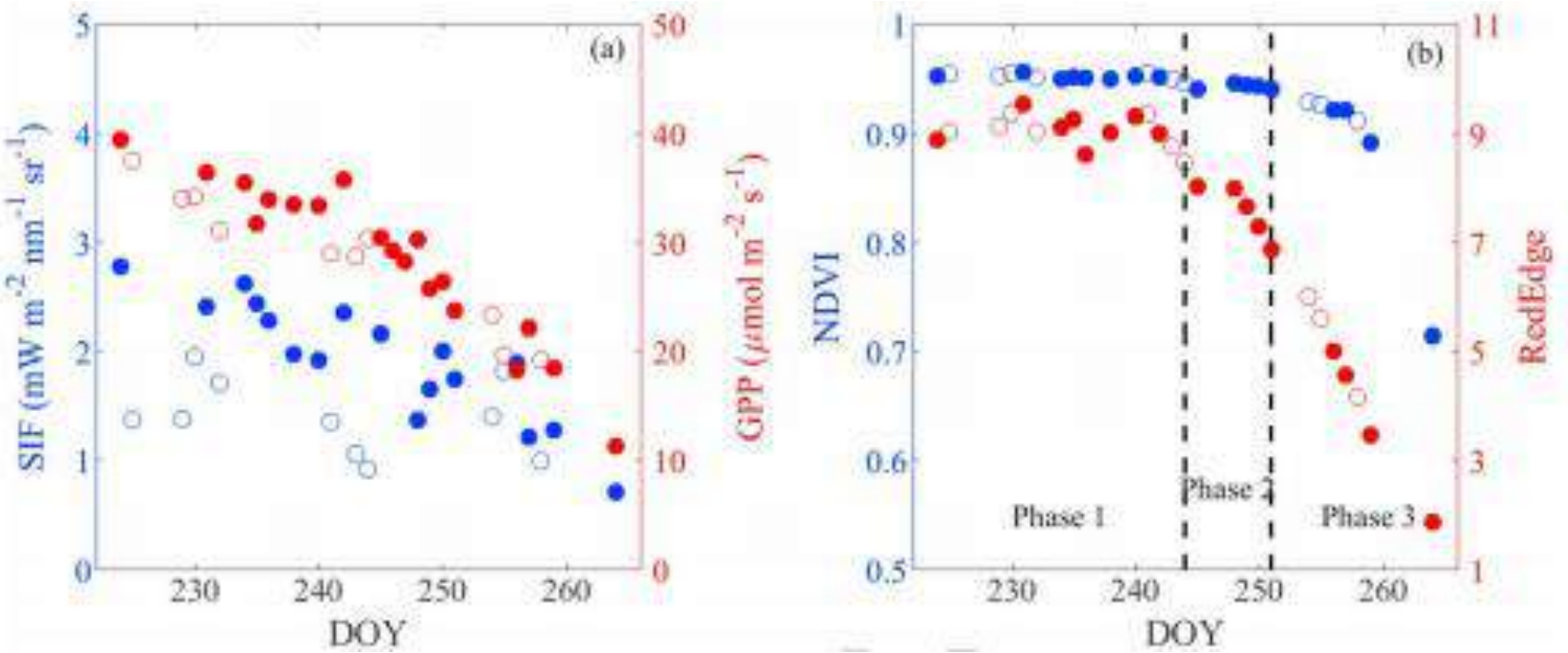
gmiao@illinois.edu;
kaiyug@illinois.edu

Sun-Induced Chlorophyll Fluorescence, Photosynthesis, and Light Use Efficiency of a Soybean Field from Seasonally Continuous Measurements

Guofang Miao[1], Kaiyu Guan[1,2], Xi Yang[3], Carl J. Bernacchi[4,5,6], Joseph A. Berry[7], Evan H. DeLucia[4,6,8], Jin Wu[9], Caitlin E. Moore[4,6], Katherine Meacham[4,6], Yaping Cai[10], Bin Peng[2], Hyungsuk Kimm[1], and Michael D. Masters[4,6,8]

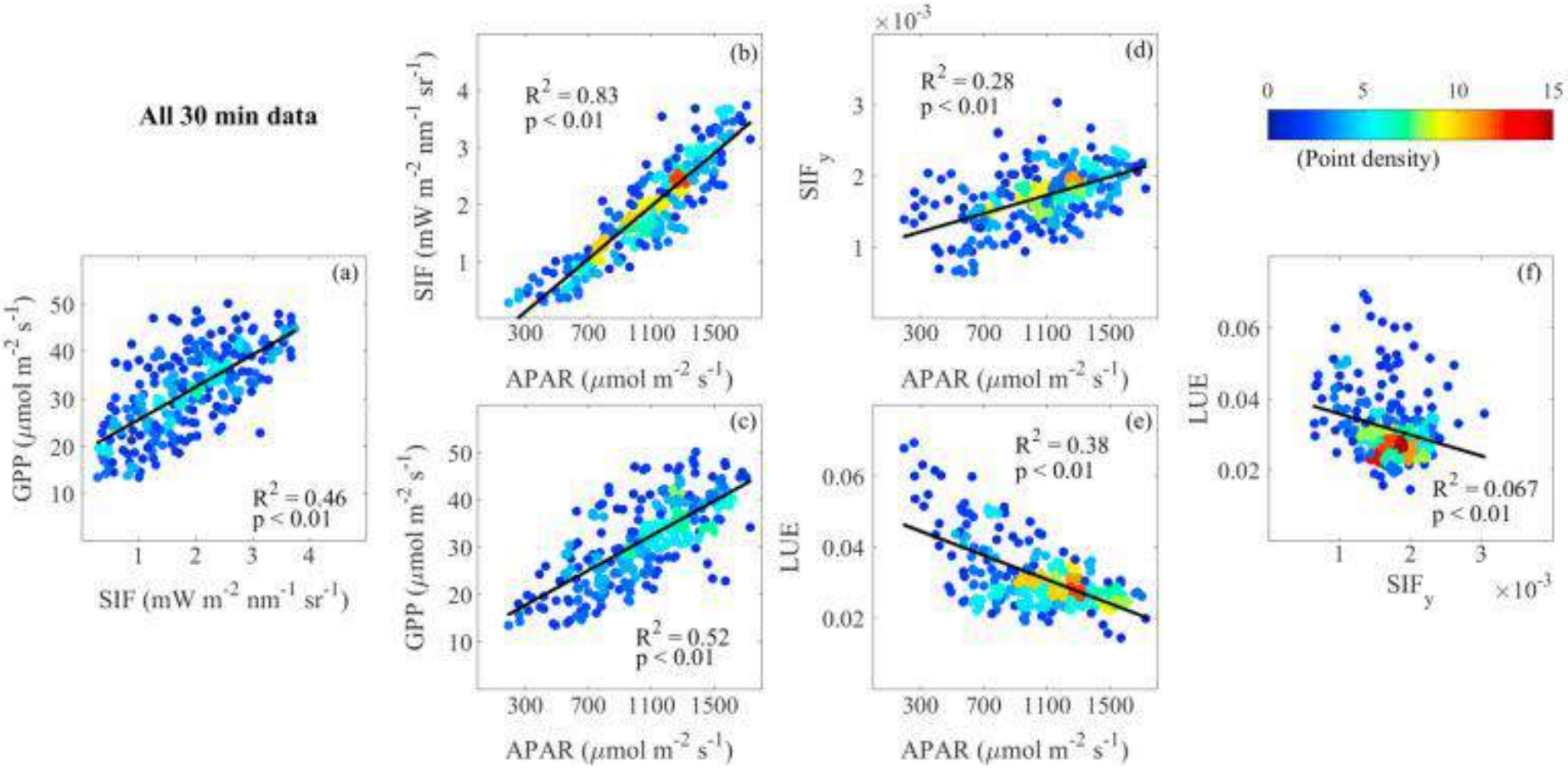
[1]Department of Natural Resources and Environmental Sciences, University of Illinois at Urbana-Champaign, Urbana, IL, USA, [2]National Center of Supercomputing Applications, University of Illinois at Urbana-Champaign, Urbana, IL, USA, [3]Department of Environmental Sciences, University of Virginia, Charlottesville, VA, USA, [4]Department of Plant Biology, University of Illinois at Urbana-Champaign, Urbana, IL, USA, [5]USDA ARS Global Change and Photosynthesis Research Unit, Urbana, IL, USA, [6]Carl R. Woese Institute for Genomic Biology, University of Illinois at Urbana-Champaign, Urbana, IL, USA, [7]Department of Global Ecology, Carnegie Institution for Science, Stanford, CA, USA, [8]Institute for Sustainability, Energy, and Environment, University of Illinois at Urbana-Champaign, Urbana, IL, USA, [9]Environmental and Climate Sciences Department, Brookhaven National Laboratory, Upton, NY, USA, [10]Department of Geography and Geographic Information Science, University of Illinois at Urbana-Champaign, Urbana, IL, USA

Abstract Recent development of sun-induced chlorophyll fluorescence (SIF) technology is stimulating studies to remotely approximate canopy photosynthesis (measured as gross primary production, GPP).



Daily mean time series at the soybean field from 11 August to 20 September (day of year 224 to 264): (a) Sun induced chlorophyll fluorescence (blue) and gross primary productivity (red); (b) Normalized Difference Vegetation Index (blue) and Rededge Index (red). The solid circles represent for sunny days and open circles for cloudy days.

- ***Miao, G.****, **Guan, K.***, Yang, Xi, et al. (2018). "Sun-induced Chlorophyll Fluorescence, Photosynthesis, and Light Use Efficiency of a Soybean Field from seasonally continous measurements", ***Journal of Geophysical Research-Biogeosciences***.



Relationship of 30 min (a) GPP-SIF, (b) SIF-APAR, (c) SIFyield-APAR, (d) GPP-APAR, (e) LUE-APAR and (f) LUE- SIFyield across study period at the soybean site. Color represents point density.

- ***Miao, G.****, **Guan, K.*****, Yang, Xi, et al. (2018). "Sun-induced Chlorophyll Fluorescence, Photosynthesis, and Light Use Efficiency of a Soybean Field from seasonally continous measurements", ***Journal of Geophysical Research-Biogeosciences***.

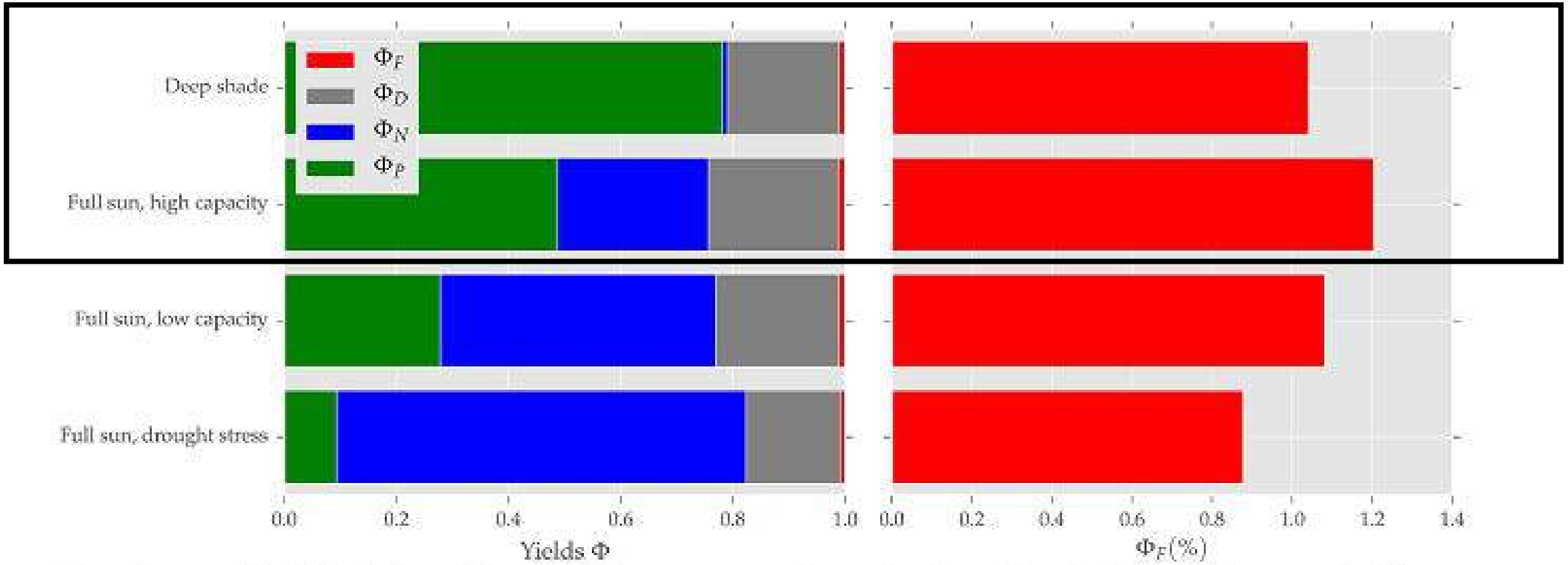


Fig. 2 Quantum yields (Φ) for the four pathways used by leaves to process photons depend on whether the leaf is shaded or exposed to full sun, whether the leaf has a high or low photosynthetic capacity, and whether drought stress is present. In the histogram, *green* denotes photosynthesis (PSII yield); *blue*, nonphotochemical quenching; *gray*, nonradiative decay; and *red*, fluorescence. The results shown here were obtained with a laboratory instrument called a PAM fluorometer. As the *right panel* shows, the fluorescence quantum yield changes less than the PSII yield but also noticeably with varying conditions, especially once nonphotochemical quenching becomes dominant.

- **Ref: Frankenberg C and Berry J 2017 *Solar Induced Chlorophyll Fluorescence: Origins, Relation to Photosynthesis and Retrieval* (Elsevier) Online: http://www.sciencedirect.com/science/article/pii/B9780124095489106323**

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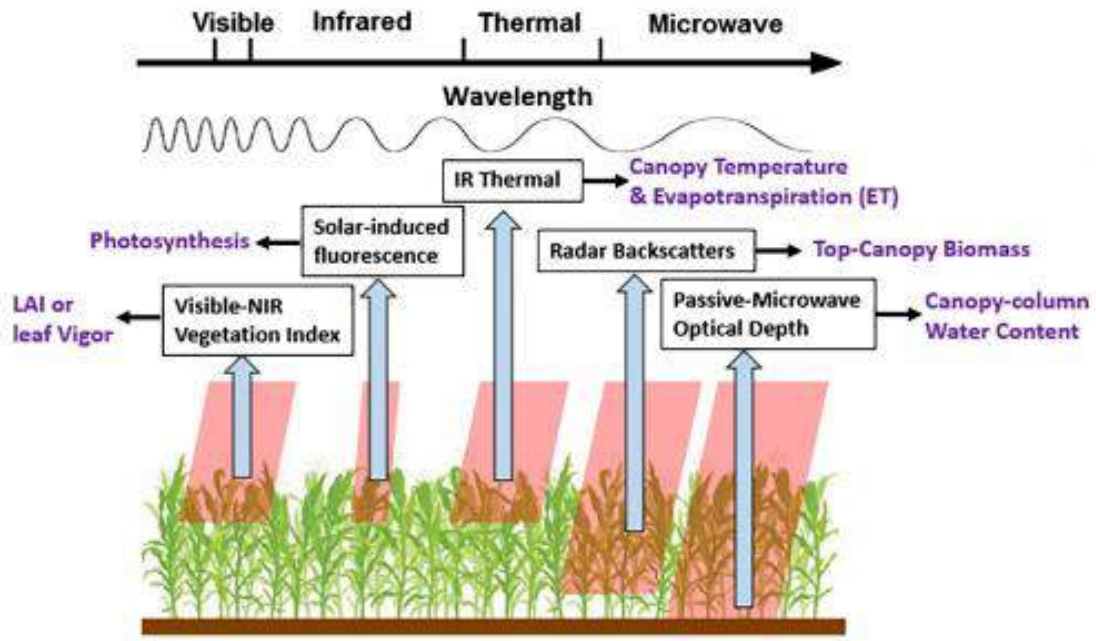
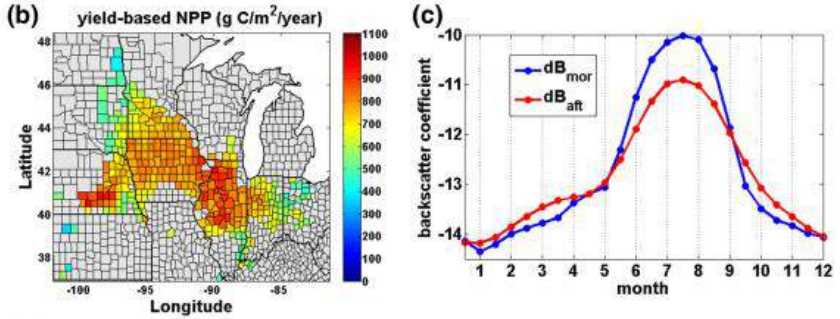
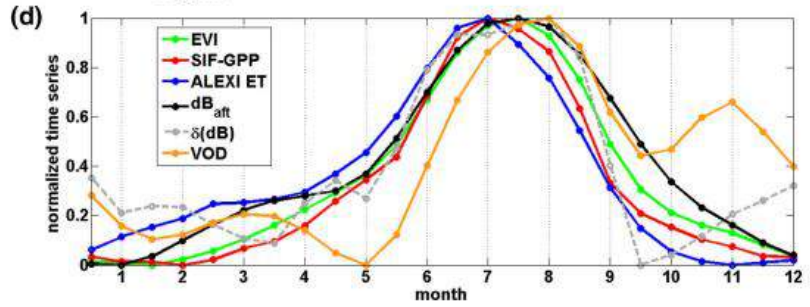
journal homepage: www.elsevier.com/locate/rse

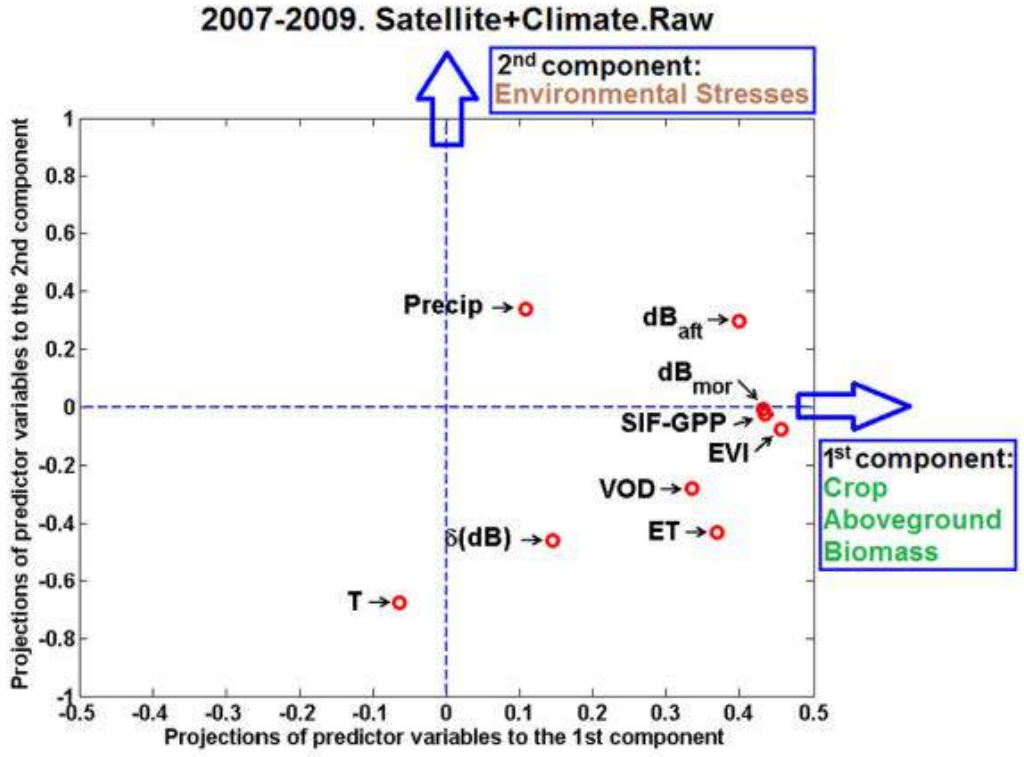
The shared and unique values of optical, fluorescence, thermal and microwave satellite data for estimating large-scale crop yields

Kaiyu Guan [a,*], Jin Wu [b], John S. Kimball [c,d], Martha C. Anderson [e], Steve Frolking [f], Bo Li [g], Christopher R. Hain [h], David B. Lobell [i]









Challenges and Opportunities of satellite SIF

- **Existing satellite-based SIF data:**

GOSAT, GOME-2, SCHYMACHY, OCO-2 (sadly OCO3 is ceased for funding …)

They are coarse resolutions and low frequency -> SIF's advantage has not been fully tapped at all!!

- **Incoming and future satellite SIF data:**

TROPOMI (Sentinel-5P) – launched on Oct 2017, 3*7km2 footprint, daily coverage (∼200x increase in observations compared with any previous global SIF data set).

FLEX mission (Rascher et al., 2008): expected launch in 2022.

A series of geostationary satellites: SIF measurements in hourly intervals or better over some regions in Europe (Sentinel-4) and the Americas (TEMPO and GeoCARB).