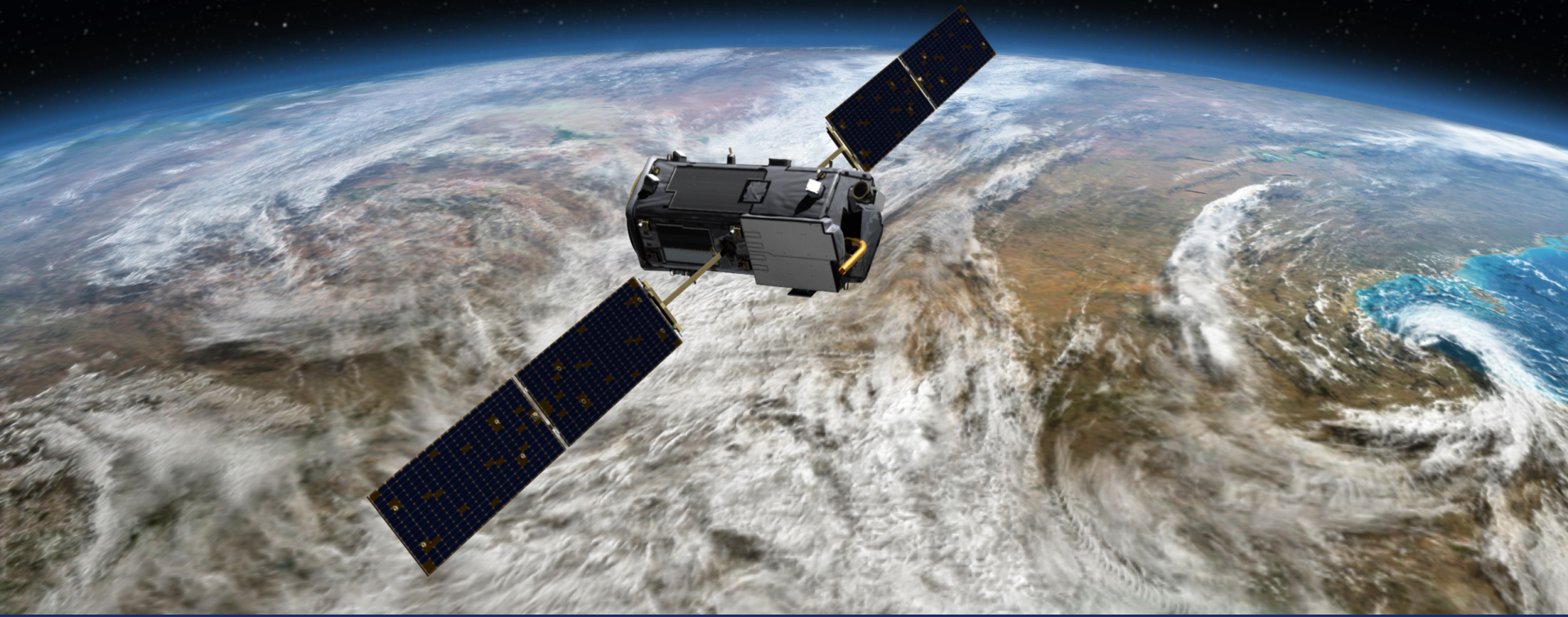
Reconstructed Solar Induced Fluorescence

A machine learning approach to photosynthesis

By Pierre Gentine, Yao Zhang and S. Hamed Alemohammad



Outline

1) *Solar Induced Fluorescence (SIF)*

2) *Difficulties with SIF*

3) *Other vegetation indices (NDVI, EVI, NIRv)*

4) *Defining an "objective" MODIS best product for photosynthesis*

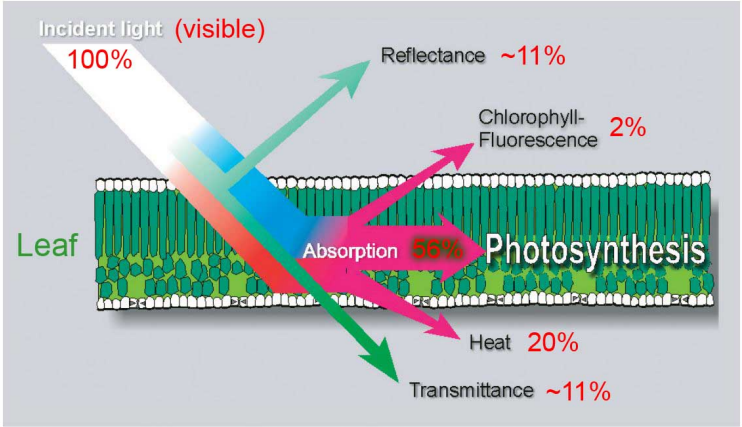
Solar Induced Fluorescence

During photosynthesis a plant absorbs energy through its chlorophyll

- % used for ecosystem gross primary production (GPP)
- % lost as heat
- % re-emitted (SIF: **byproduct**)

Relationship between GPP and SIF is ~ linear

Responds to stressors (water, light, T)



Now **observable from space** (GOSAT, GOME-2, OCO-2, TROPOMI)

Solar Induced Fluorescence (SIF)

Data sampling

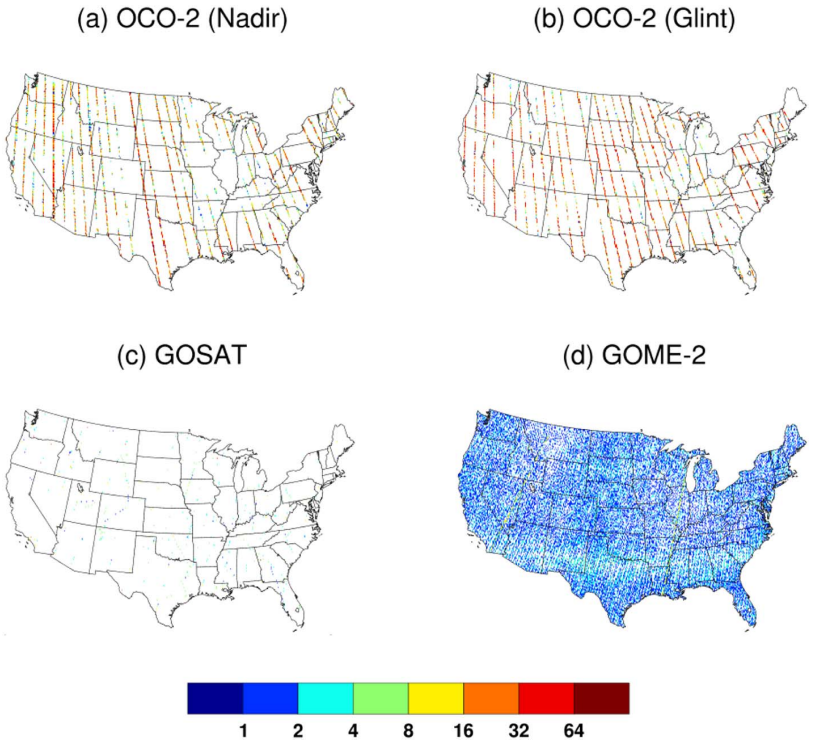
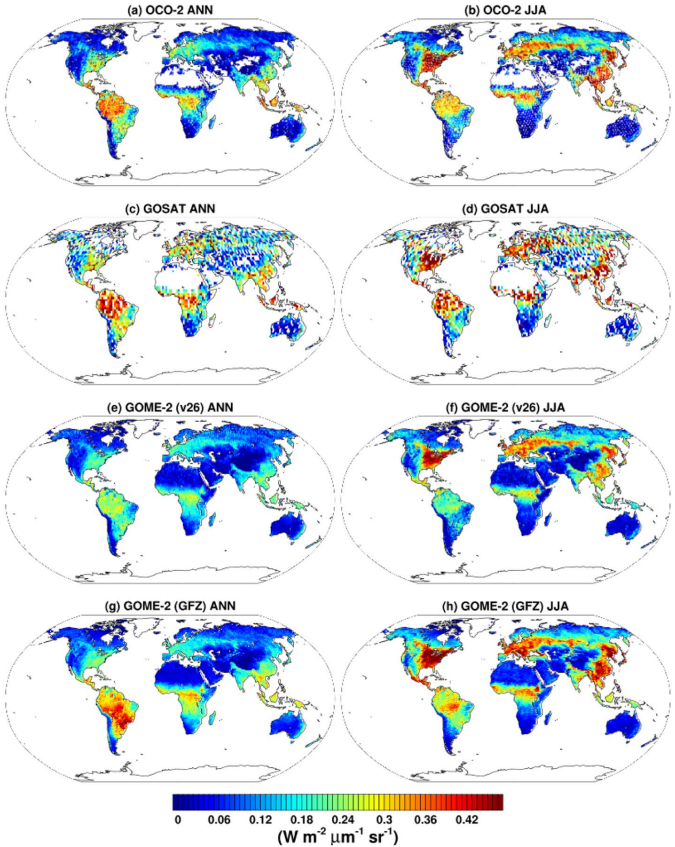


Fig. 1. Illustration of the spatial distribution of the data acquisition, i.e., the number of soundings (represented by colors), of OCO-2, GOSAT-FTS, and GOME-2 onboard MetOp-A, using July 2015 as an example. The level 2 retrieval is aggregated to 0.1° × 0.1°, roughly equivalent to the OCO-2 swath widths (~10 km) in mid-latitude such as US.

Sun, Y., Frankenberg, C., Jung, M., Joiner, J., Guanter, L., Köhler, P., & Magney, T. (2018). *Remote Sensing of Environment*, *209*, 808–823.

Solar Induced Fluorescence (SIF)

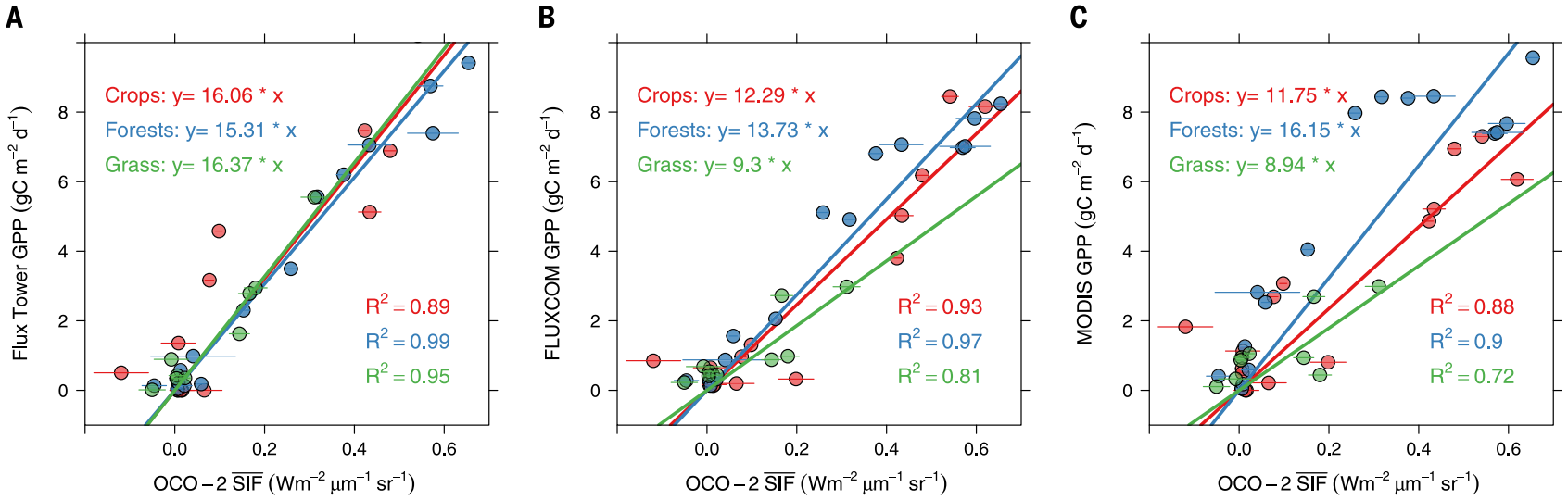
Different retrievals



Sun, Y., Frankenberg, C., Jung, M., Joiner, J., Guanter, L., Köhler, P., & Magney, T. (2018). *Remote Sensing of Environment*, *209*, 808–823.

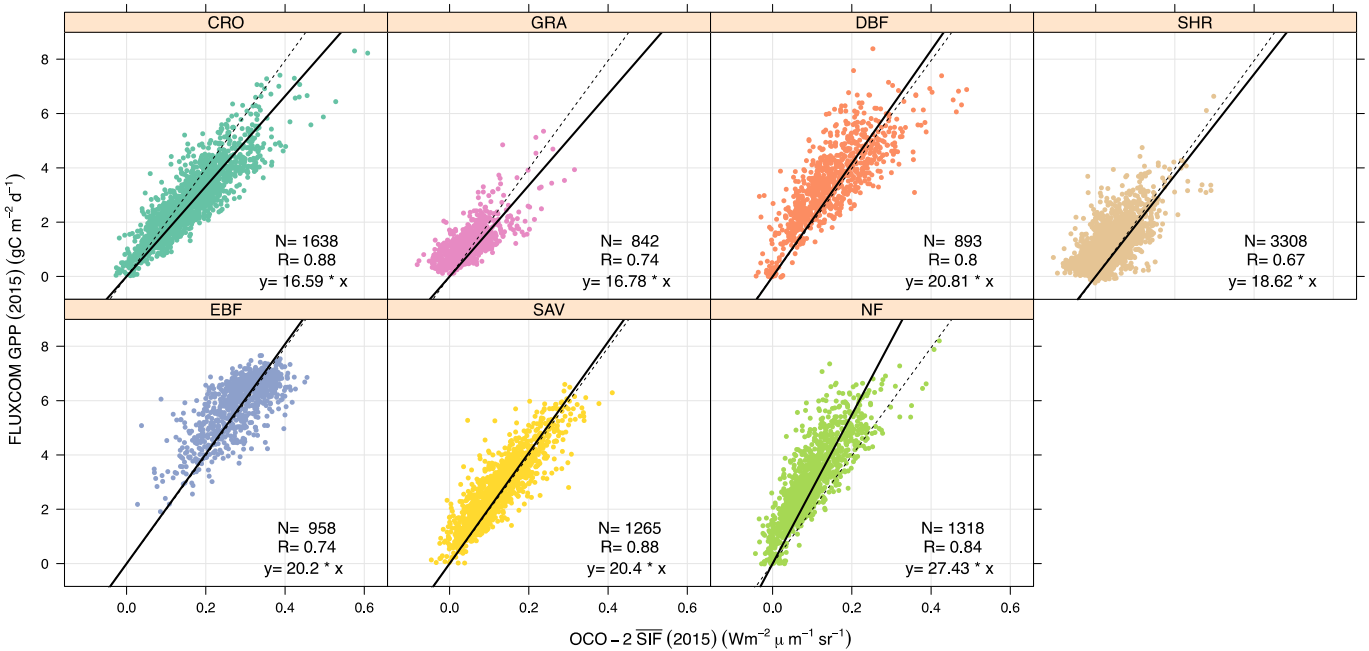
Solar Induced Fluorescence (SIF)

Relationship with ecosystem GPP
~ linear (slope varies though)



Solar Induced Fluorescence (SIF)

Relationship with global GPP retrieval
~ linear (slope varies though)



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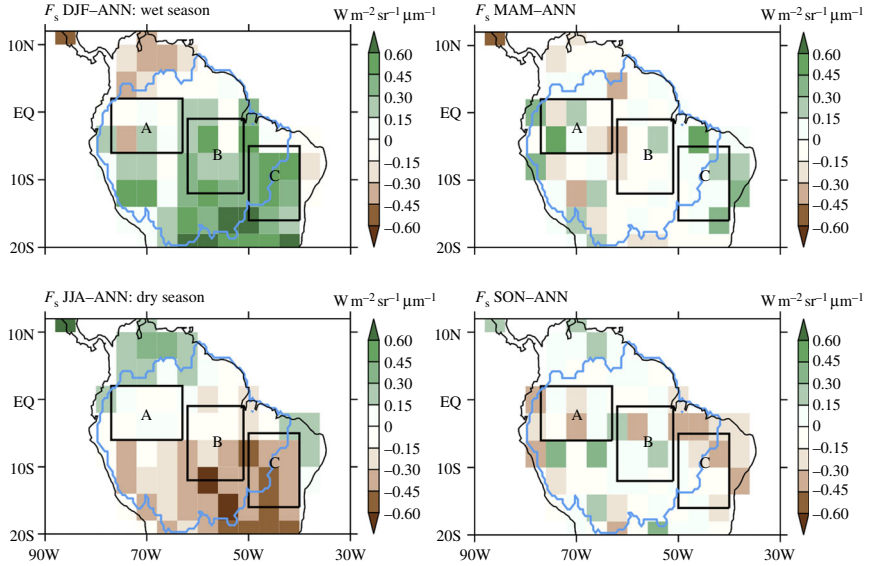
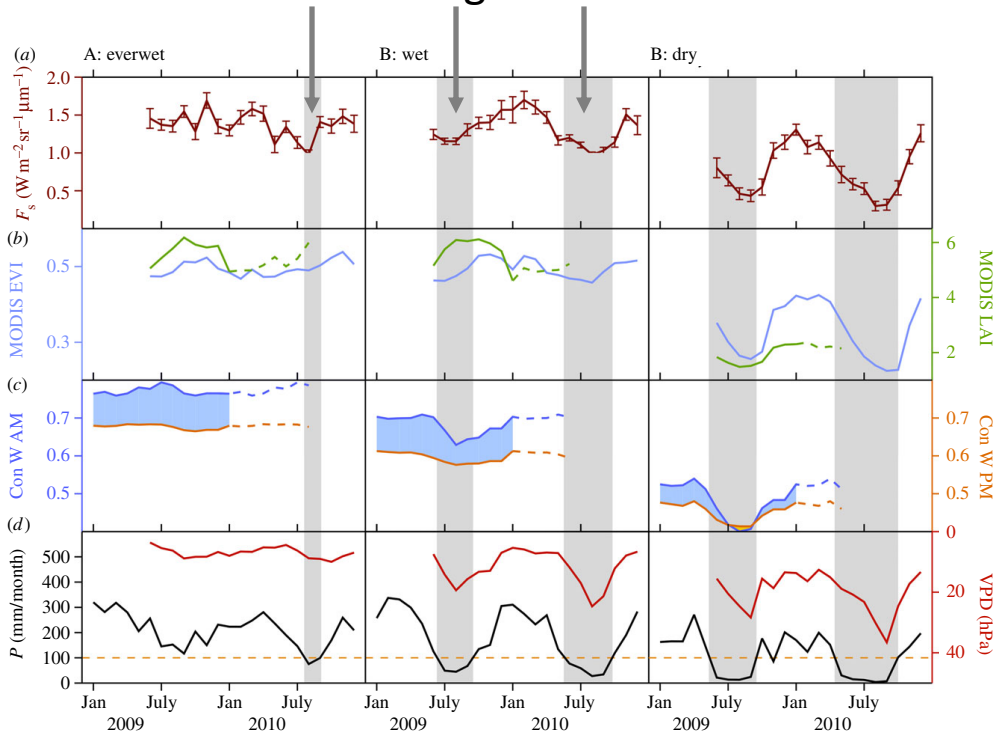
Success with SIF

Tropics: Vegetation drought stress in the Amazon using GOSAT

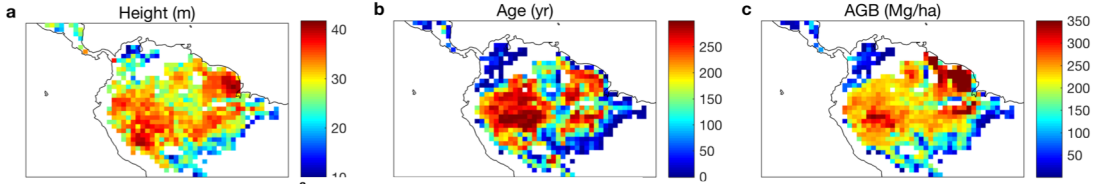


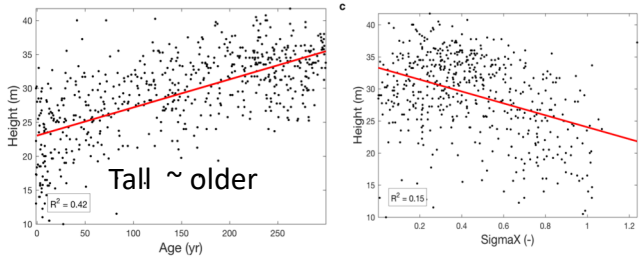


Lee, J.-E., Frankenberg, C., van der Tol, C., Berry, J. A., Guanter, L., Boyce, C. K., et al. (2013). *Proceedings. Biological Sciences*, *280*, 20130171.

Success with SIF

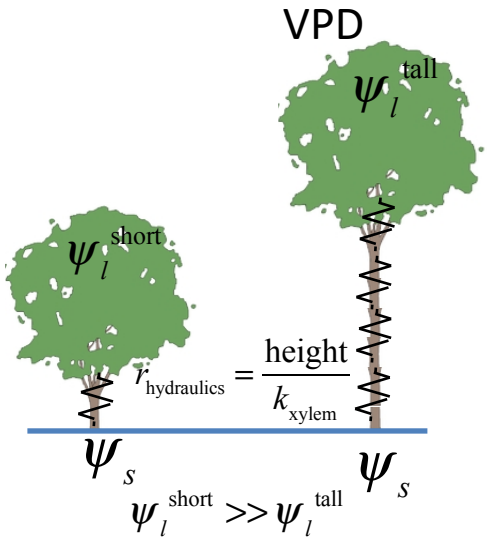
Tropics: Vegetation drought vs aridity stress in the Amazon using GOME-2

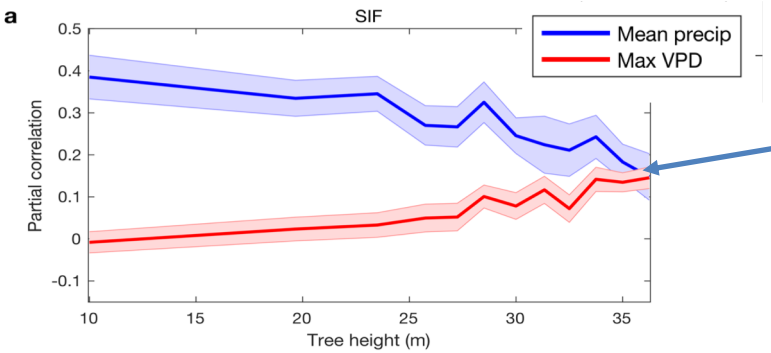




Tall ~ older

Tall ~ more isohydric
(tighter stomata regulation)



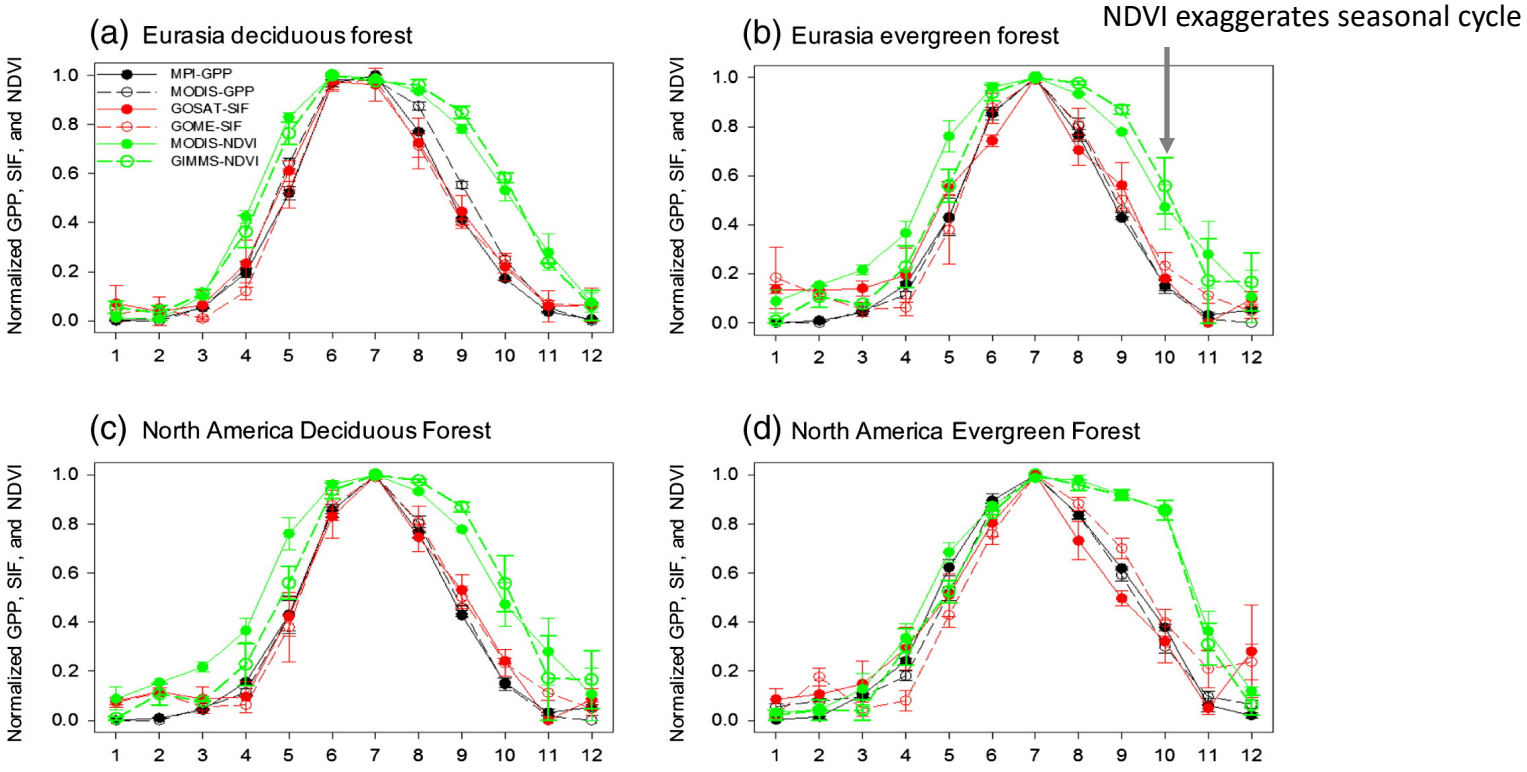


Tall forests less sensitive to rainfall but more to VPD

Giardina, F., Konings, A. G., Kennedy, D., Alemohammad, S. H., Oliveira, R. S., Uriarte, M., & Gentine, P. (2018). Tall Amazonian forests are less sensitive to precipitation variability. *Nature Geoscience*, https://doi.org/10.1038/s41561-018-0133-5

Success with SIF

Cold climates: phenology



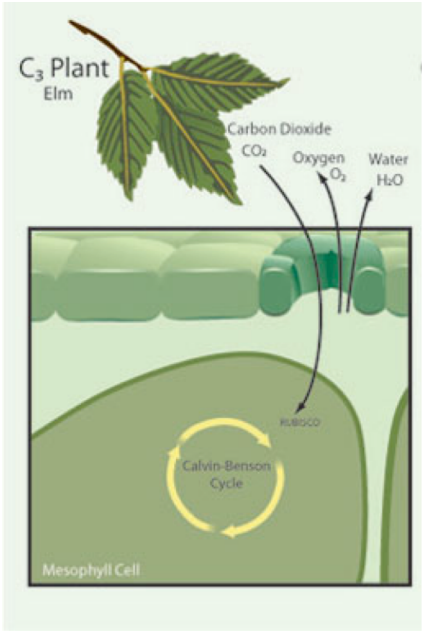
Jeong, S.-J., Schimel, D., Frankenberg, C., Drewry, D. T., Fisher, J. B., Verma, M., et al. (2017). *Remote Sensing of Environment*, *190*, 178–187.

Success with SIF

GPP (**CO_2 uptake**) is directly related to transpiration *T* (**H_2O release**)

$$GPP = wue\, T$$

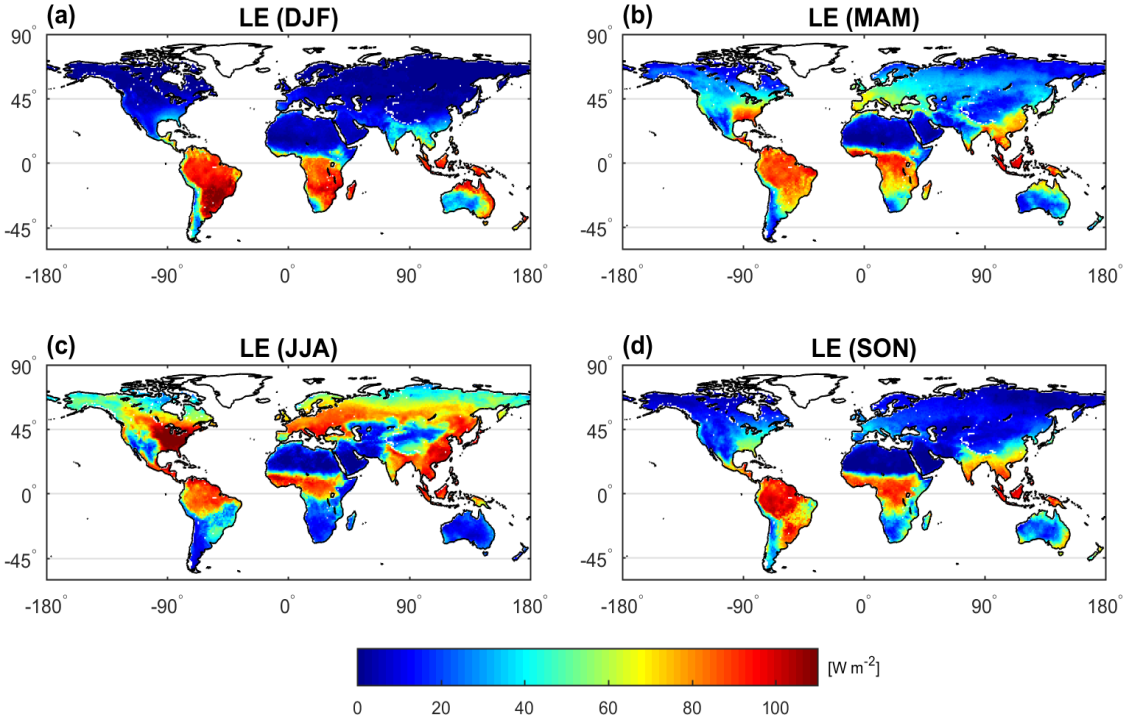
SIF might thus a good **proxy for *T*** (main ET flux)



Success with SIF

Flux retrieval using machine learning and GOME-2 SIF: WECANN

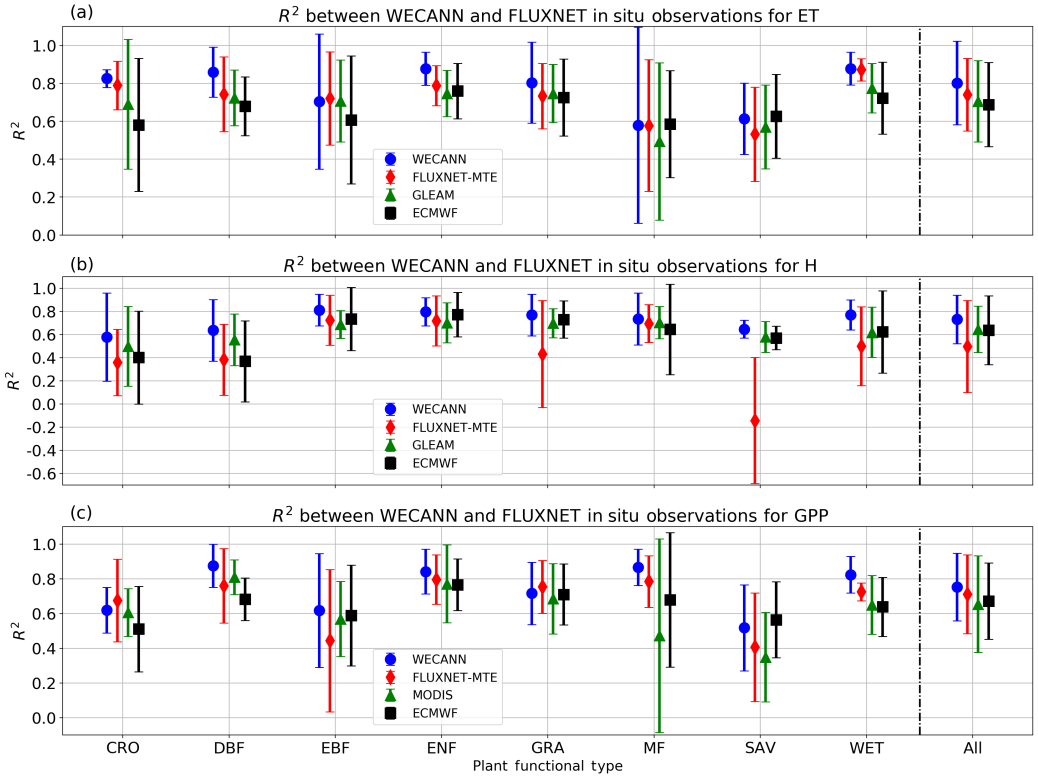
Evapotranspiration



Alemohammad, S. H. *et al.* Water, Energy, and Carbon with Artificial Neural Networks (WECANN). *Biogeosciences* **14,** 4101–4124 (2017) Available at www.gentine.com.

Success with SIF

Flux retrieval using machine learning and GOME-2 SIF: WECANN



ET

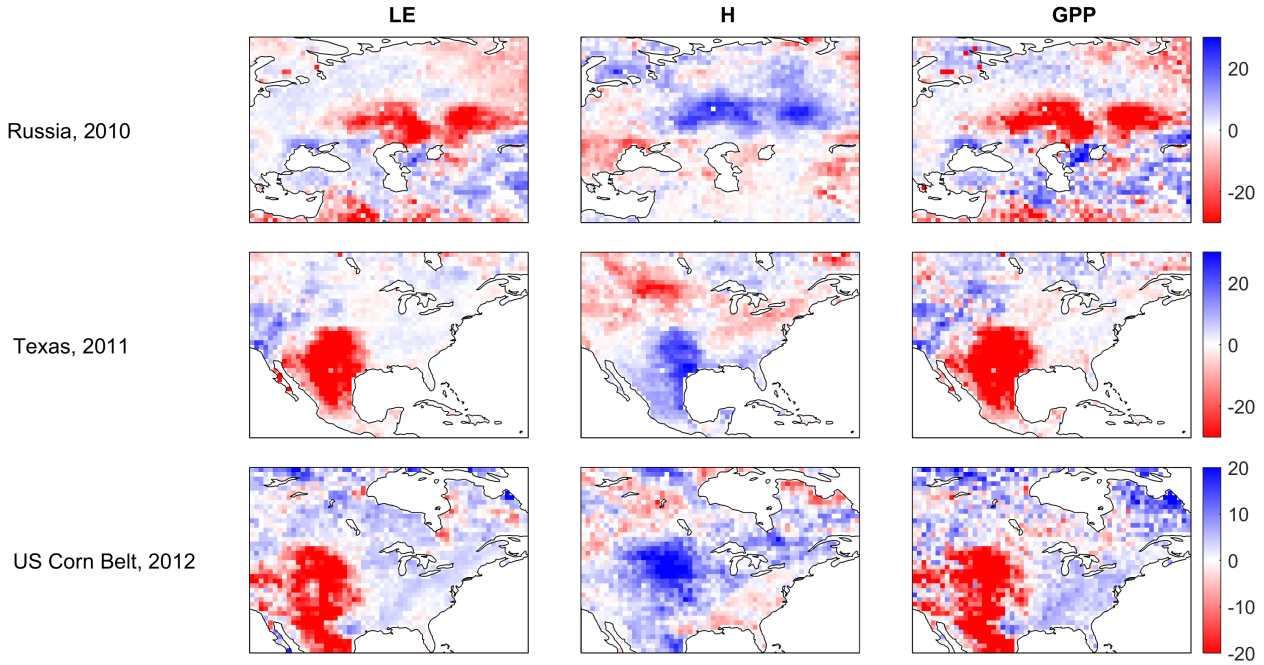
H: sensible heat flux

GPP

Alemohammad, S. H. *et al.* Water, Energy, and Carbon with Artificial Neural Networks (WECANN). *Biogeosciences* **14,** 4101–4124 (2017) Available at www.gentine.com.

Success with SIF

Flux retrieval using machine learning and GOME-2 SIF: WECANN
Nice interannual variability (unlike FLUXCOM or FLUXNET-MTE)



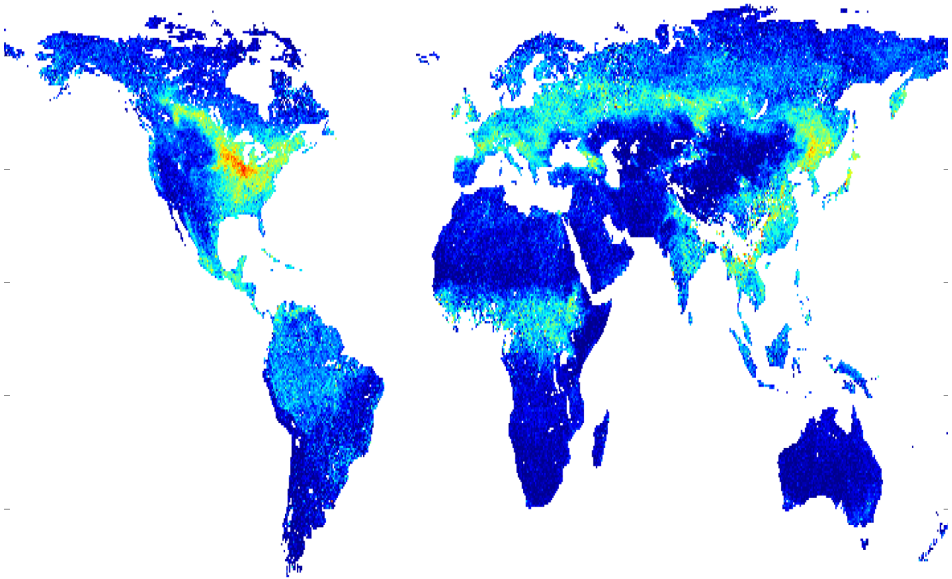
Alemohammad, S. H. *et al.* Water, Energy, and Carbon with Artificial Neural Networks (WECANN). *Biogeosciences* **14,** 4101–4124 (2017)
Available at www.gentine.com.

So we are all good, right?

Nope

SIF has disadvantageous: main ones

- **Very very noisy**
- **Coarse scale**



GOME-2 JJA

What are our options?

Use vegetation indices instead

- **NDVI**:

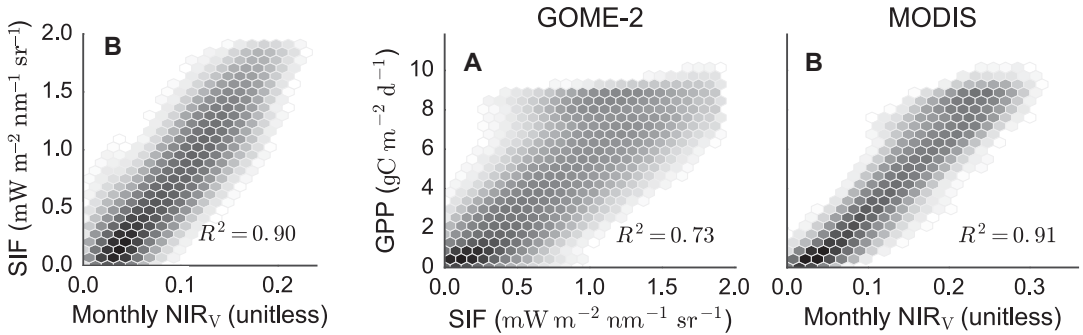
Issue: saturates very quickly, very sensitive to snow, basically color only

- **EVI**:

improved NDVI but share same issues

-**NIR_V**=$NIR_{reflectance}$.NDVI

looks promising



But:

- Still based on NDVI (share some issues – snow)

- No radiation information: Only reflectance, not a flux (only correlated with it)

Badgley, G., Field, C. B., & Berry, J. A. (2017). Canopy near-infrared reflectance and terrestrial photosynthesis. *Science Adv*, https://doi.org/10.1126/sciadv.1602244

What are our options?

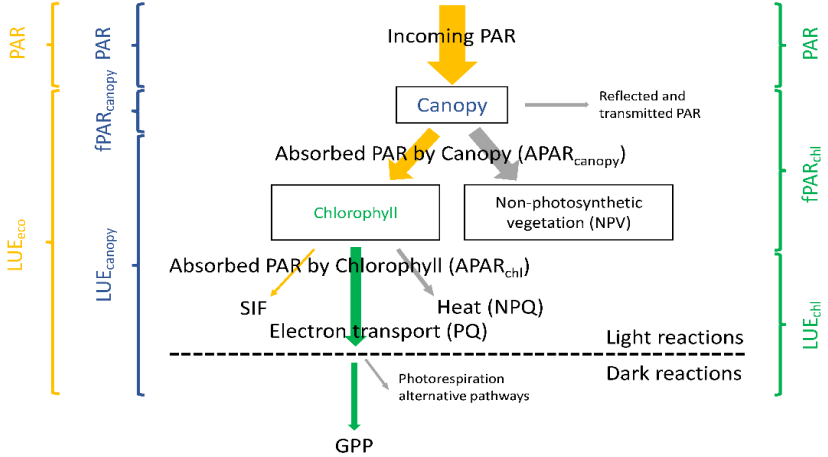
We want an objective assessment of GPP

Let us go back to the basics (light use efficiency a la Monteith)

$GPP = LUE_{Chl}.fPAR_{Chl}.PAR$

Similarly

$SIF = Yield.fPAR_{Chl}.PAR$



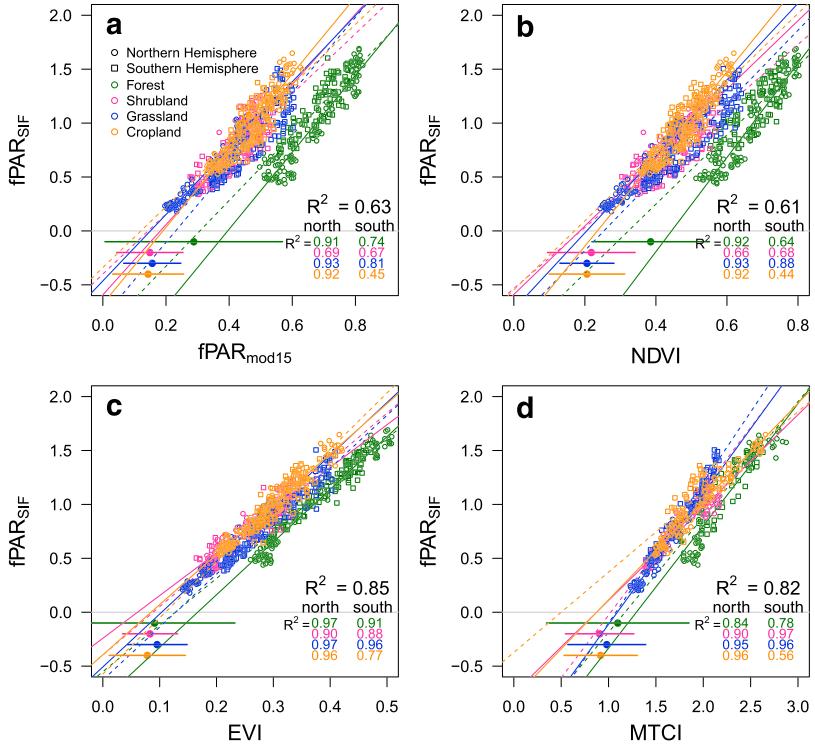
So $SIF = Yield/ LUE_{Chl} . GPP$

If Yield, LUE_{Chl} are not varying much then **$fPAR_{Chl}$.PAR is a good proxy for GPP** (and SIF)

Zhang, Y., Xiao, X., Wolf, S., Wu, J., Wu, X., Gioli, B., et al. (2018). *Geophysical Research Letters*, *45*(8), 3508–3519. https://doi.org/10.1029/2017GL076354

What are our options?

Is $fPAR_{Chl}$ a good proxy for SIF/PAR?
Mostly yes



MERIS terrestrial chlorophyll index (MTCI)

Zhang, Y., Xiao, X., Wolf, S., Wu, J., Wu, X., Gioli, B., et al. (2018). *Geophysical Research Letters*, *45*(8), 3508–3519. https://doi.org/10.1029/2017GL076354

How can we define an objective product?

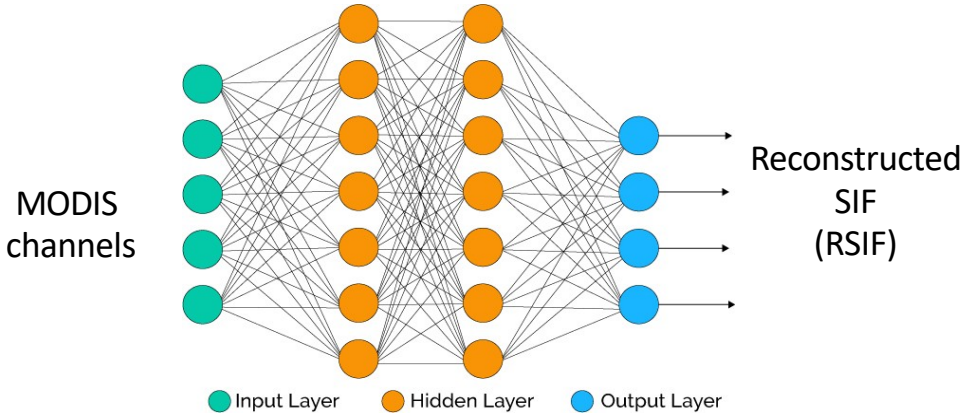
Objective:

Try to reproduce SIF/PAR ~ $fPAR_{Chl}$ with MODIS

Called **Reconstructed SIF (RSIF)**

Based on GOME-2 v26 Joiner SIF

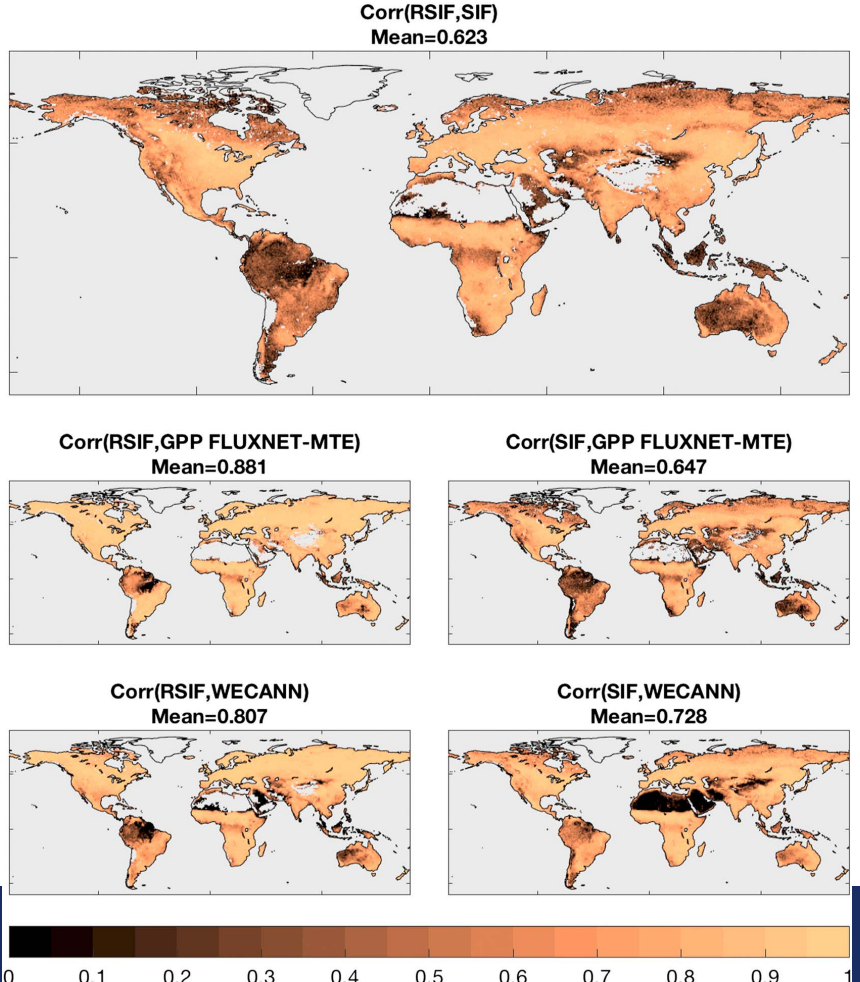
PAR: BESS product (Ryu et al. 2017)



Daily $APAR_{Chl}$ = PAR_{daily} . RSIF / $PAR_{9:30AM}$

Gentine, P., & Alemohammad, S. H. (2018). RSIF (Reconstructed Solar Induced Fluorescence). *Geophysical Research Letters (in press), available at www.gentine.com*

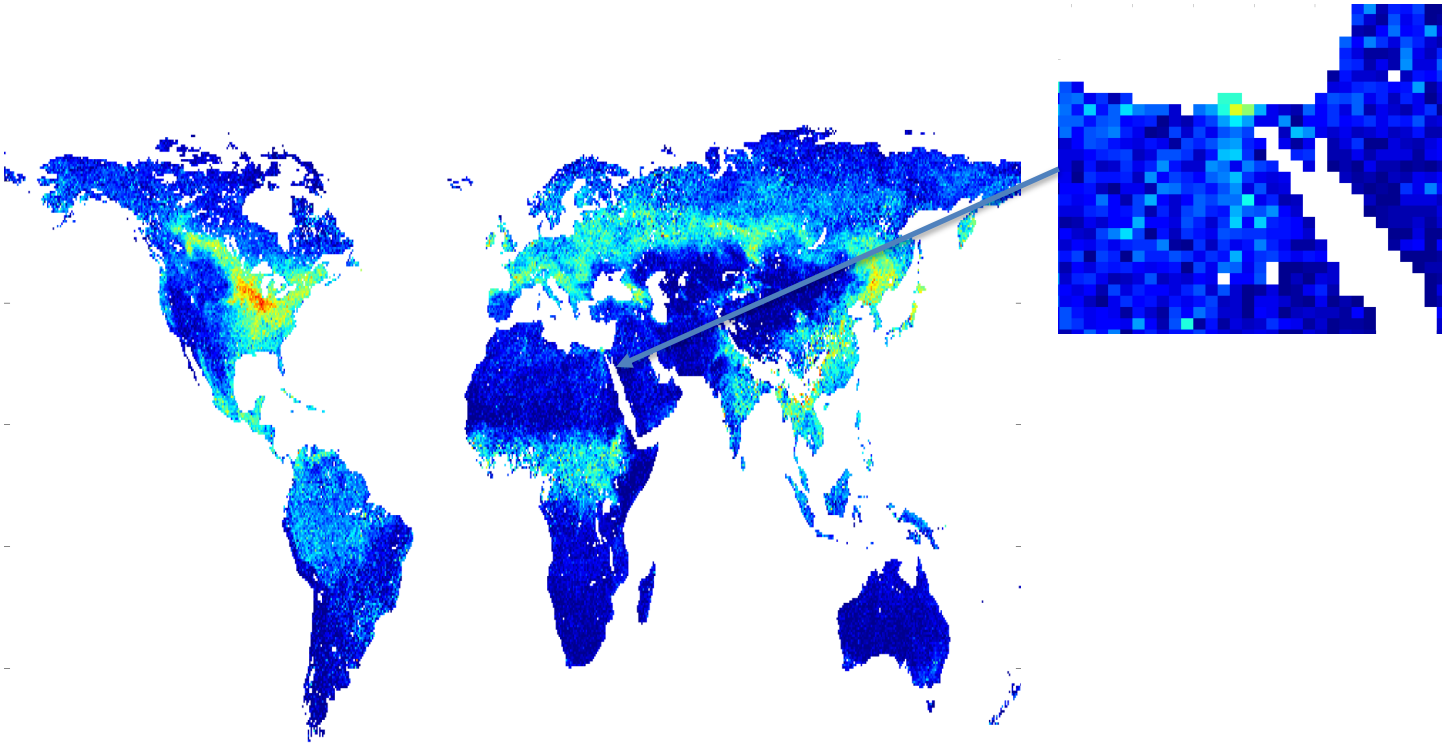
How can we define an objective product?



Better against FLUXNET-MTE

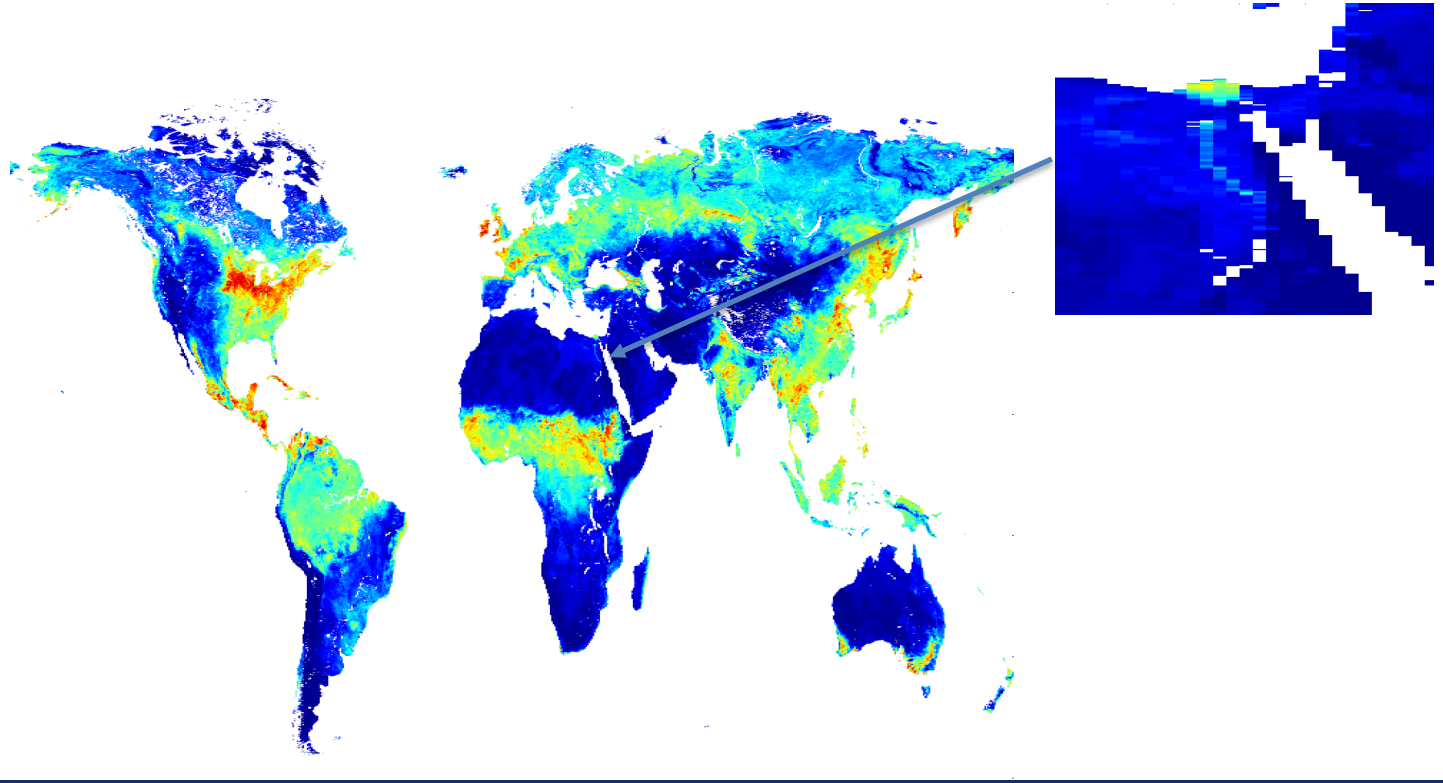
Better with WECANN which uses SIF ☺

Example: Nile



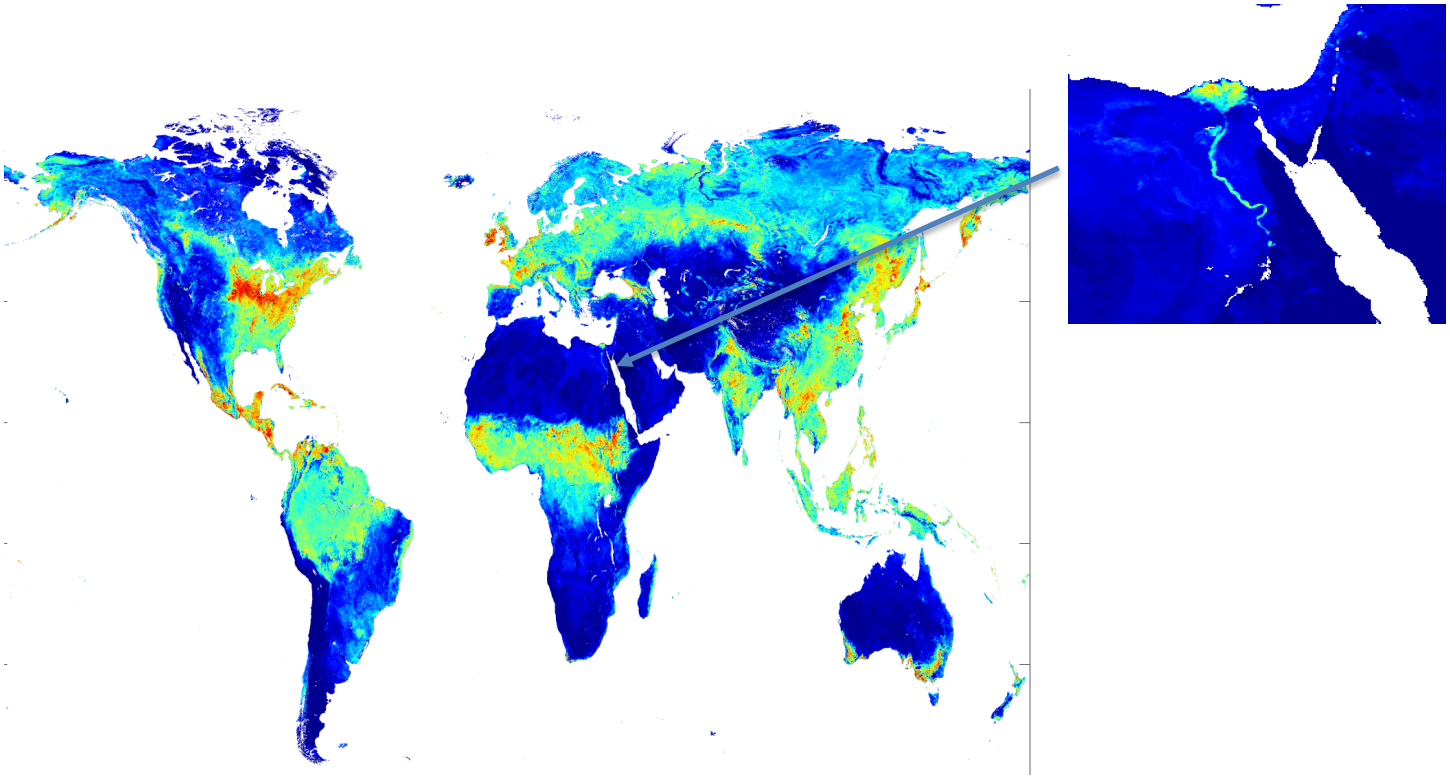
Example: Nile

RSIF reduces noise

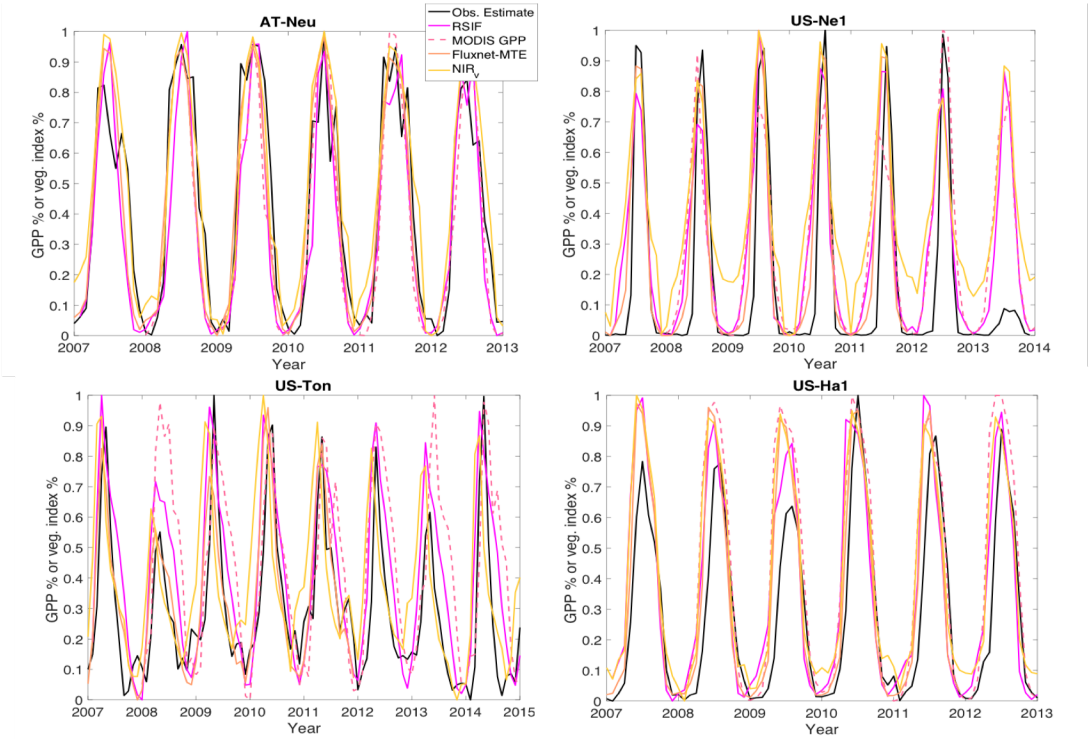


Example: Nile

Can go to higher resolution (**500m**) ☺



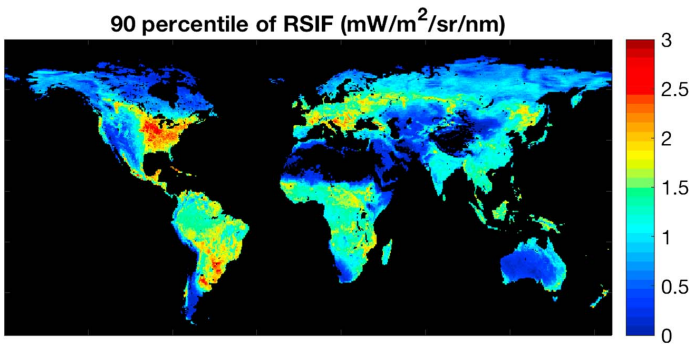
RSIF site comparisons

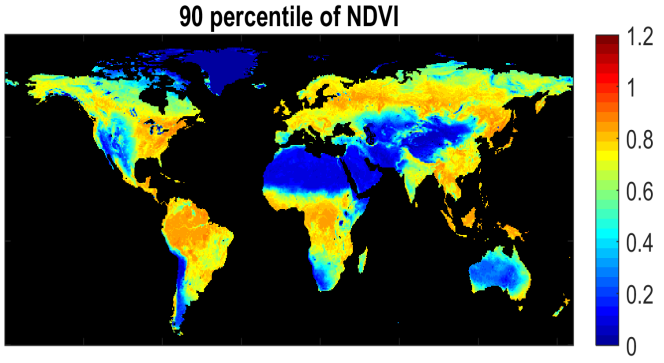


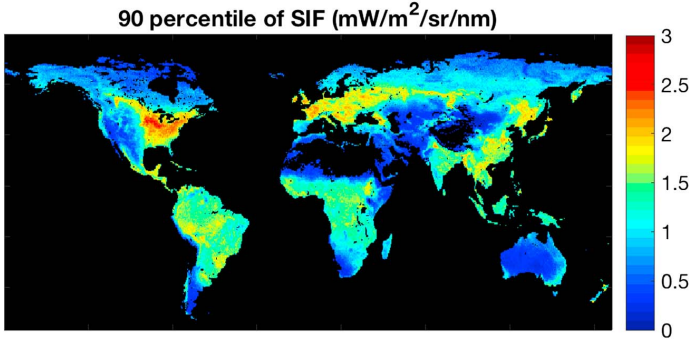
Not impacted by snow,

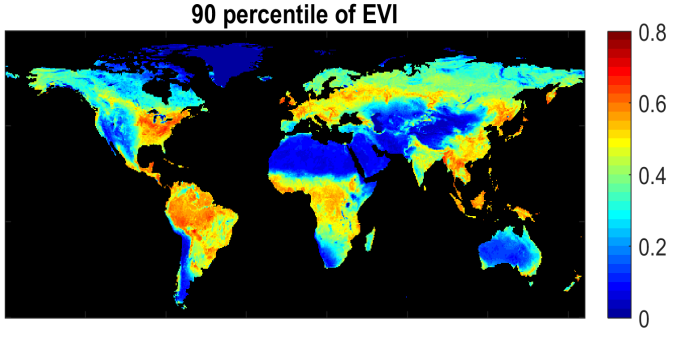
Can track seasonal dryness in California (no need for LUE_{Chl} change)

Comparison with vegetation indices









Can pick up **peak in GPP in Ag region like SIF but unlike NDVI/EVI**

Next steps

Still several (important) steps for GPP:

- What we see includes: Radiation attenuation/escape factor (PFT and atmosphere dependent)
- Initial GOME-2 estimate has issues/biases: use another better (higher Signal/noise) estimate e.g. OCO-2, TROPOMI
- More bands? Hyperspectral
- Are LUE_{Chl} important? Can we observe them?

Zhang, Gentine et al. submitted


Thank you for your attention
Questions?