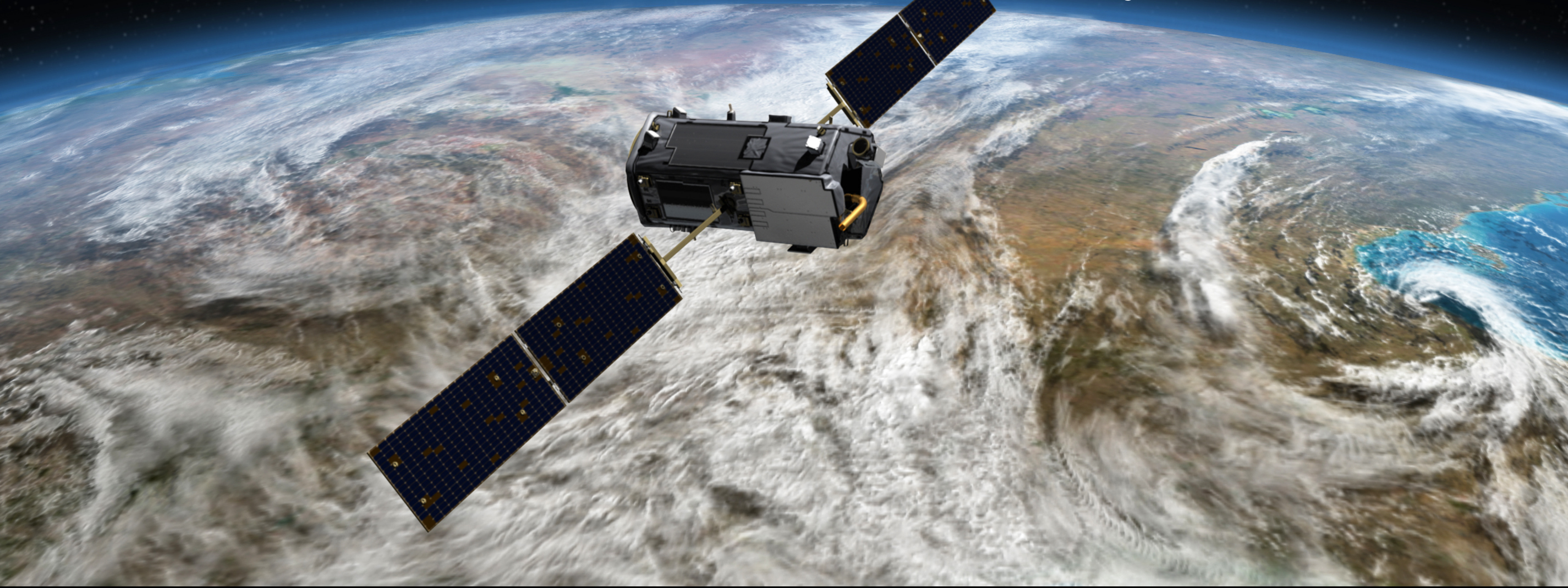
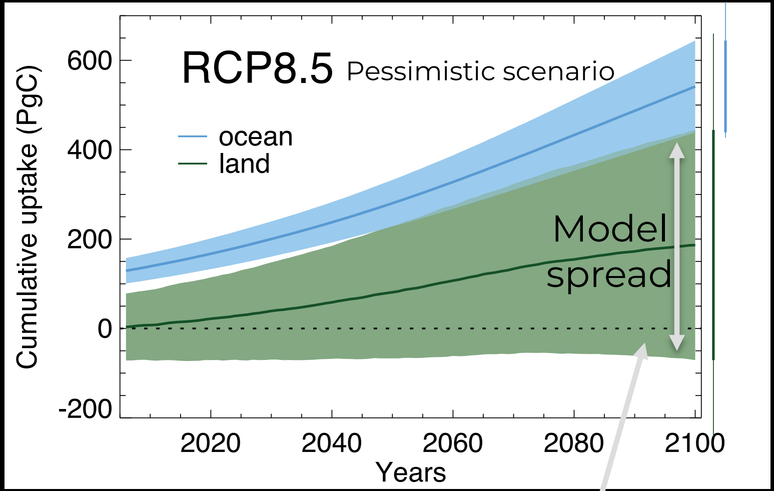
Machine learning to investigate carbon-climate feedbacks

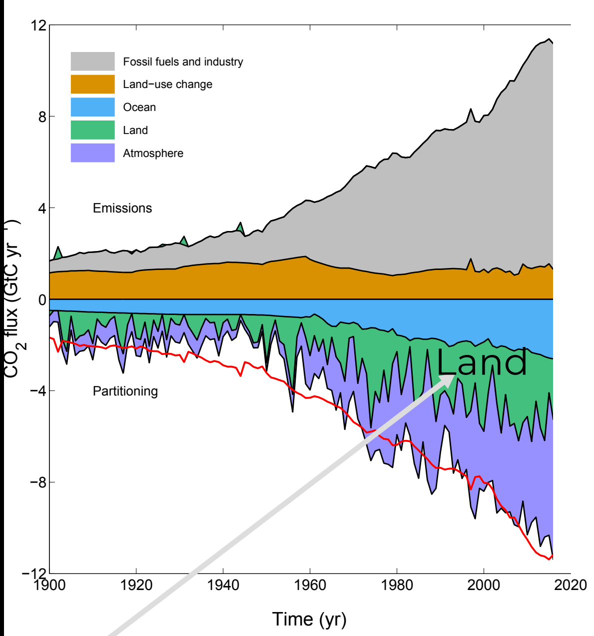
Pierre Gentine – Columbia University



Introduction

Biosphere





Large intermodel spread, large interannual variability
Participate to the definition of $[CO_2]$=f(emission flux)

Introduction

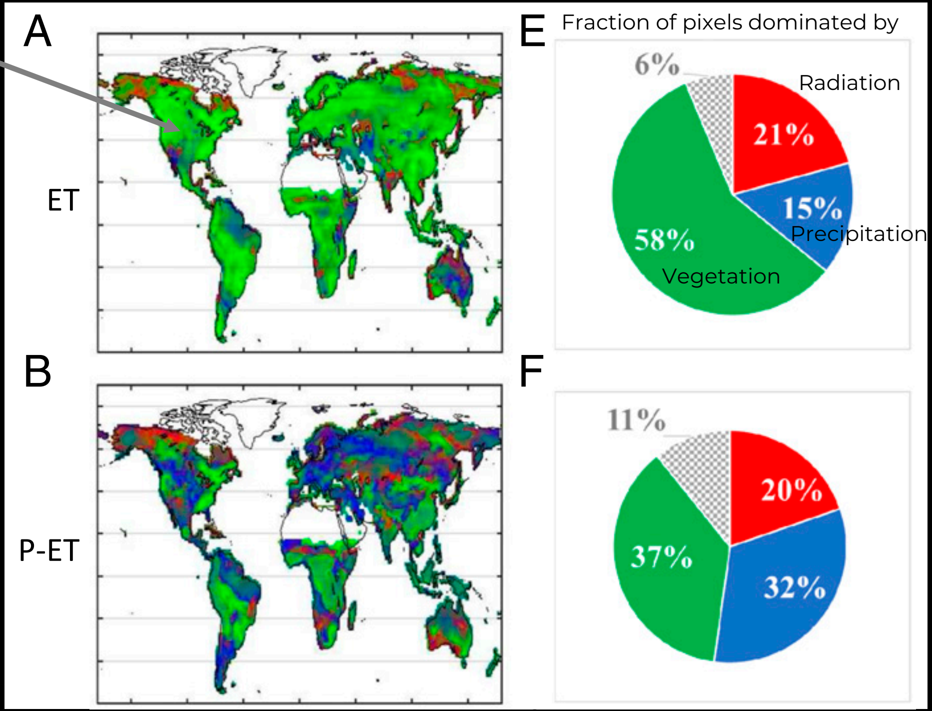
Biosphere

Largely defines continental water cycle response
(as it modulates evapotranspiration ET) (Lemordant et al., 2018)

Green: Veg. dominates changes By 2100

Evapotranspiration

Long-term runoff



Lemordant, L., Gentine, P., et al. (2018)., *PNAS.*
Converse: Green, J.K..., Gentine P., (2019), *Nature*

Addressing those challenges

How can we tackle those issues
to better constrain those predictions?

Approach:
Multiscale modeling/observations
Combined with physical and statistical (when needed) modeling

Why **now**?
Golden age for Earth Observations (e.g. satellites)
+
Dramatic increase in computational power
(many processes can now be resolved)

Biosphere: photosynthesis

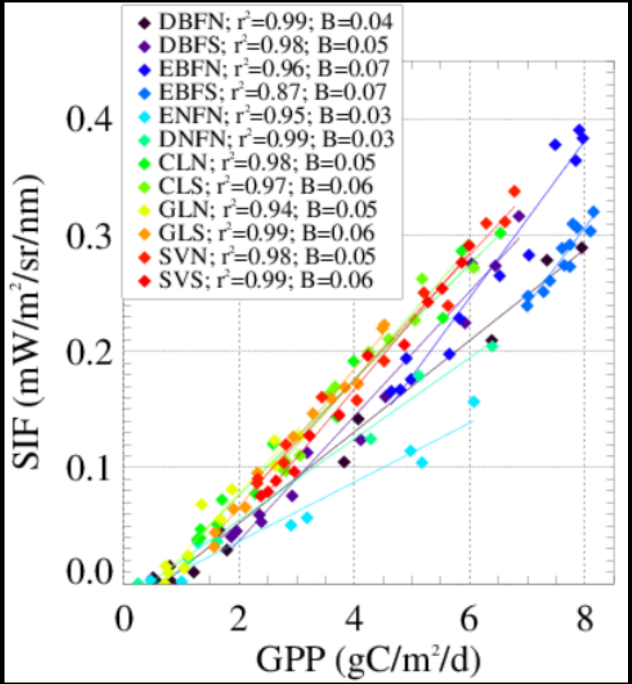
Largest terrestrial CO_2 flux: **photosynthesis (GPP)**
How can we constrain it to inform global env. changes?

We now have a proxy for photosynthesis, called **solar-induced fluorescence (SIF)**

During photosynthesis a plant absorbs energy through its chlorophyll

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

Small flux of a small flux: **a very small and noisy flux**



Photosynthesis

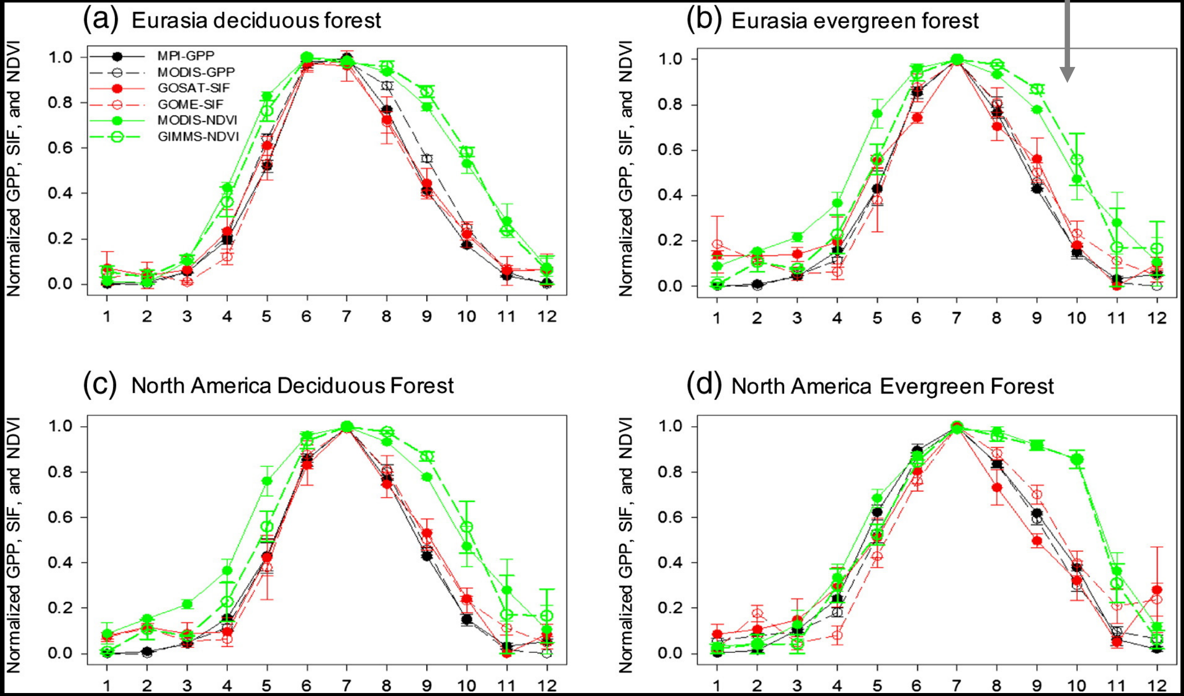
Guanter, L., et al. 2013 *PNAS*
Sun et al., 2018 *Science*
Alemohammad,et al., Gentine P.., 2017, *Biogeosciences*

Biosphere: photosynthesis

Example of success with SIF

Better characterization of phenological cycle

NDVI exaggerates seasonal cycle

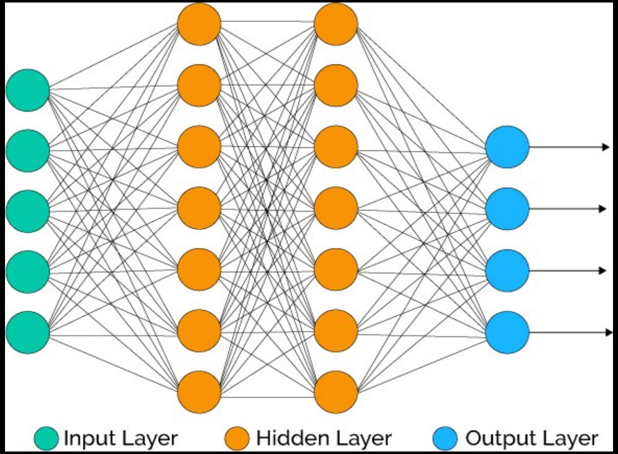


Jeong et al. (2017). *Remote Sensing of Environment*, *190*, 178–187.

Biosphere: photosynthesis

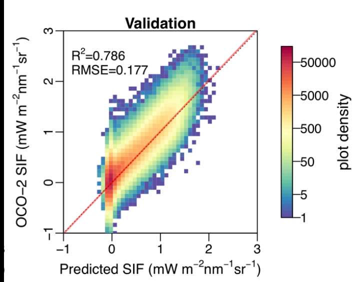
SIF is too noisy, not long enough or not sufficient resolution
Use machine learning:
Reproduce SIF with MODIS (visible and near infrared channels):
higher accuracy and resolution, longer (2002-now)
Called **Contiguous SIF (CSIF)**

MODIS channels



Contiguous
Solar-induced fluorescence
(CSIF)

Cost function:
misfit to SIF observations



Gentine, P., & Alemohammad, S. H. (2018). . *Geophysical Research Letters*.
Zhang, Y., … & Gentine, P. (2018), *Biogeosciences*

Biosphere: photosynthesis

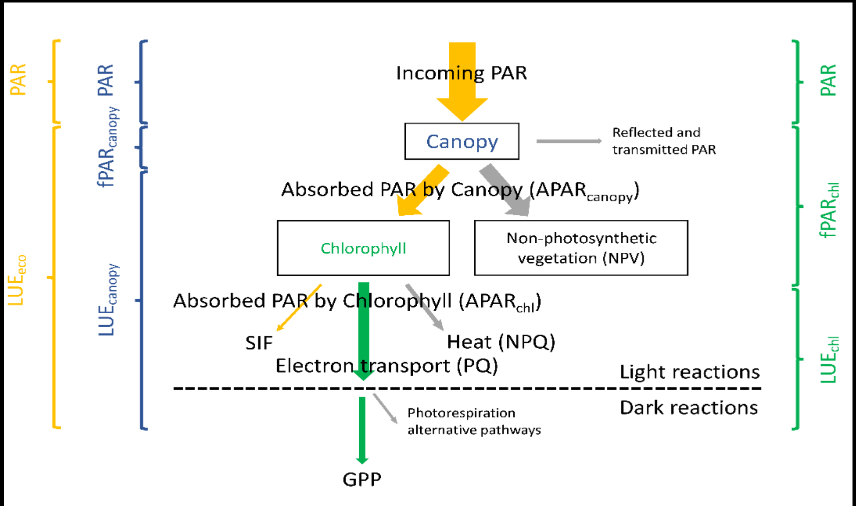
What is the rational behind this?

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

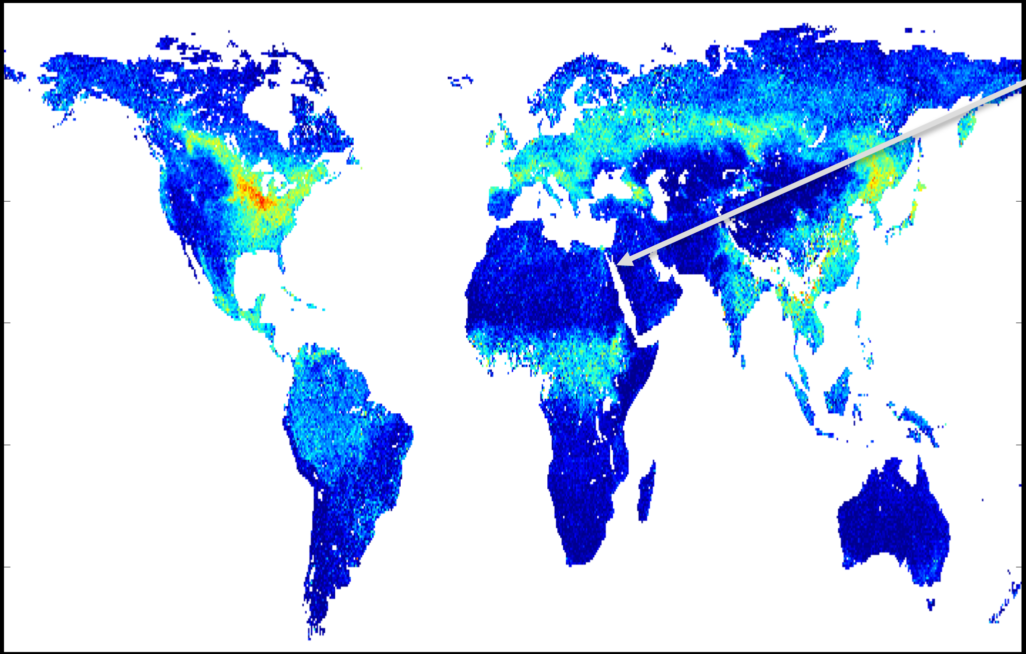
If Yield, LUE_{Chl} are not varying much then

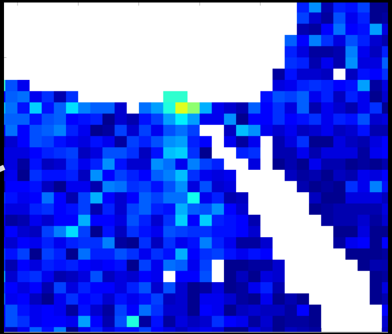
$APAR_{Chl} = fPAR_{Chl}.PAR$ is a good proxy for GPP (and SIF)

Zhang, Y et al. (2018). *Geophysical Research Letters*, *45*(8), 3508–3519.
https://doi.org/10.1029/2017GL076354

Nile example

Original SIF (GOME-2) - 0.5 degree

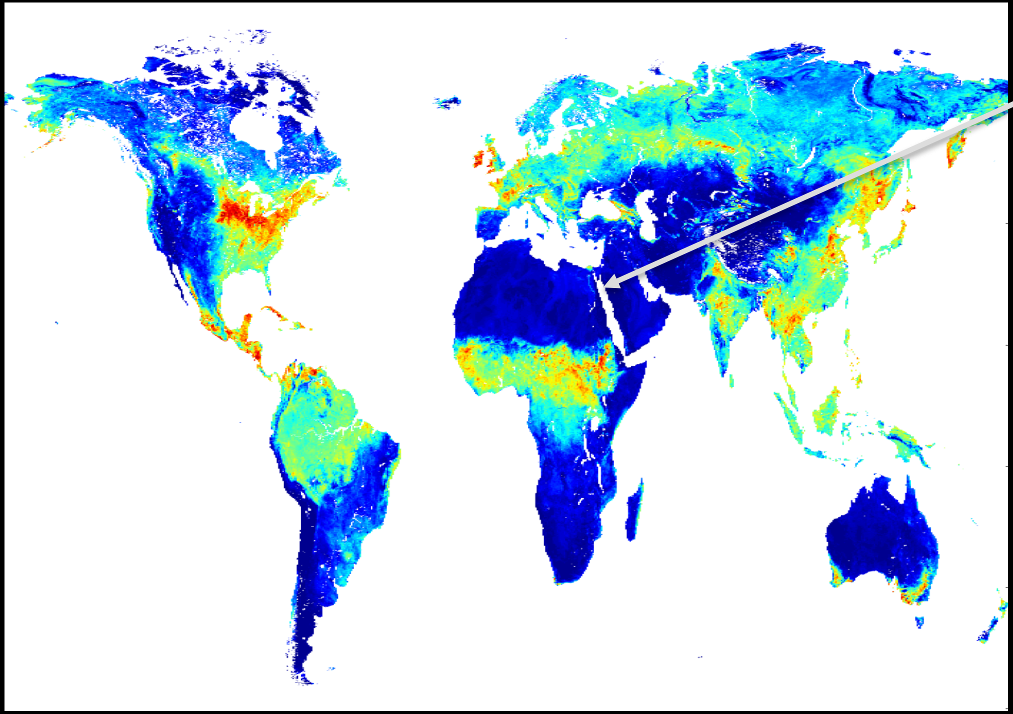


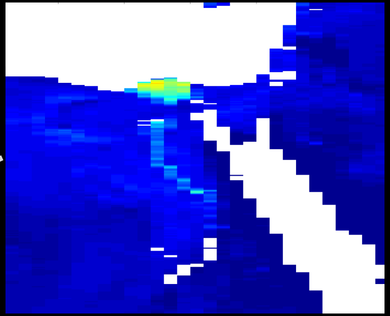


Gentine, P., & Alemohammad, S. H. (2018). . *Geophysical Research Letters*.
Zhang, Y., ... & Gentine, P. (2018), *Biogeosciences*

Nile example

Contiguous SIF Modis - 0.5 degree

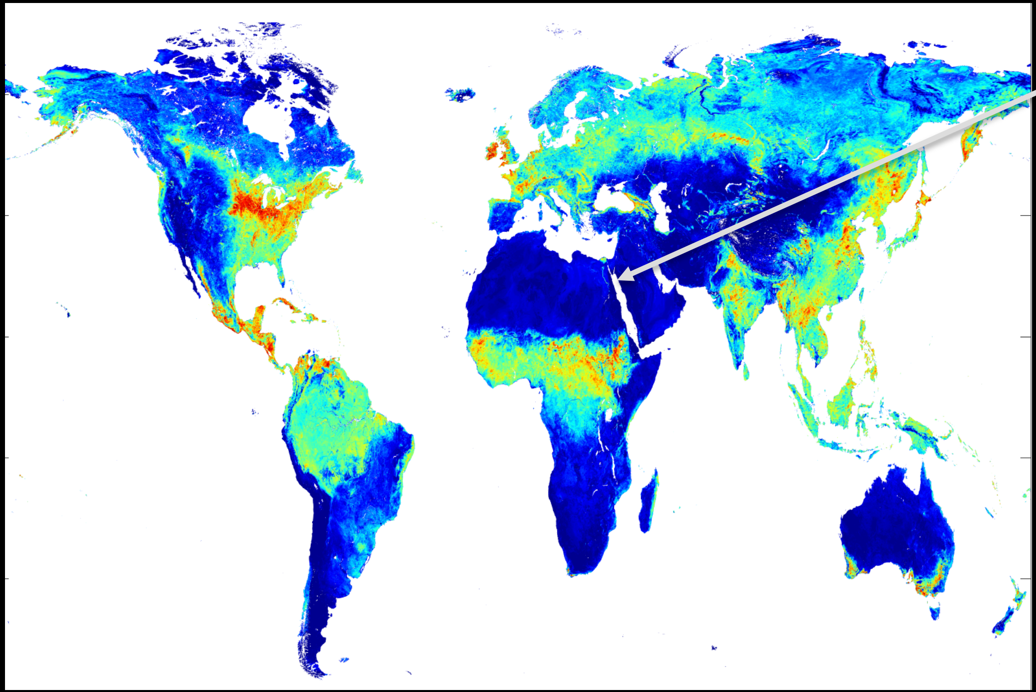


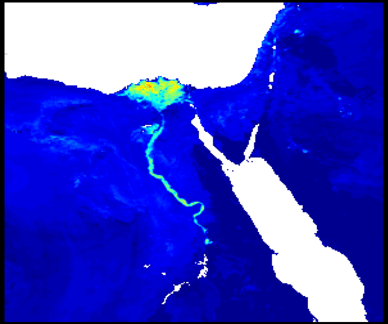


Gentine, P., & Alemohammad, S. H. (2018). . *Geophysical Research Letters.*
Zhang, Y., ... & Gentine, P. (2018), *Biogeosciences*

Nile example

Contiguous SIF Modis - 0.05 degree



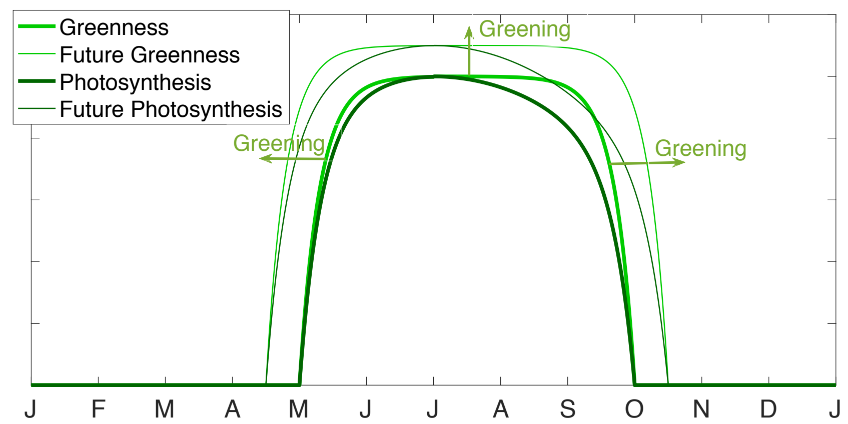


Gentine, P., & Alemohammad, S. H. (2018). *Geophysical Research Letters*.
Zhang, Y., ... & Gentine, P. (2018), *Biogeosciences*

Application 1. Northern latitude temperature sensitivity

Use Contiguous SIF to understand sensitivity to warming

T ↑ ➡ greener vegetation



Zhang, Y., Commane R., Gentine P. Light limits end of season northern ecosystem carbon uptake, submitted

Application 1. Northern latitude temperature sensitivity

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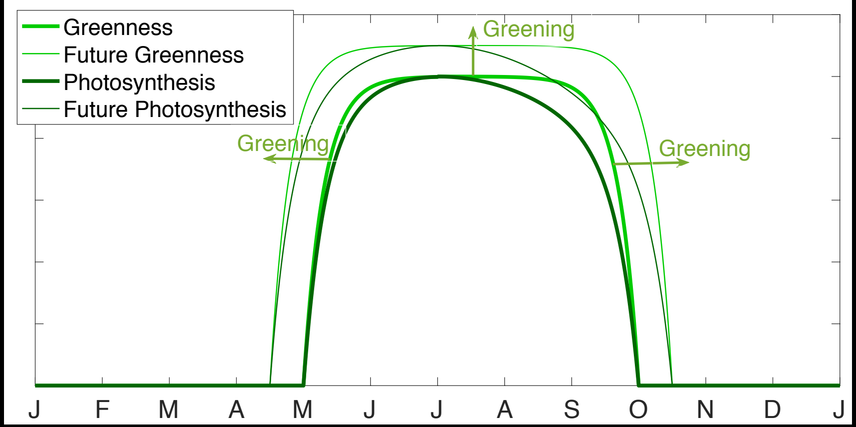


?

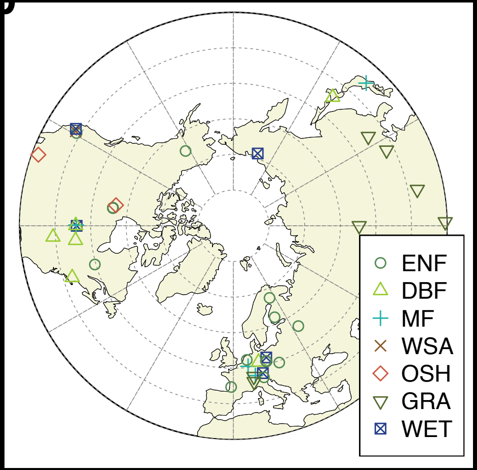
Increased sink
(photosynthesis>respiration)

Increased source
(photosynthesis<respiration)

Zhang, Y., Commane R., Gentine P. Light limits end of season northern ecosystem carbon uptake, submitted

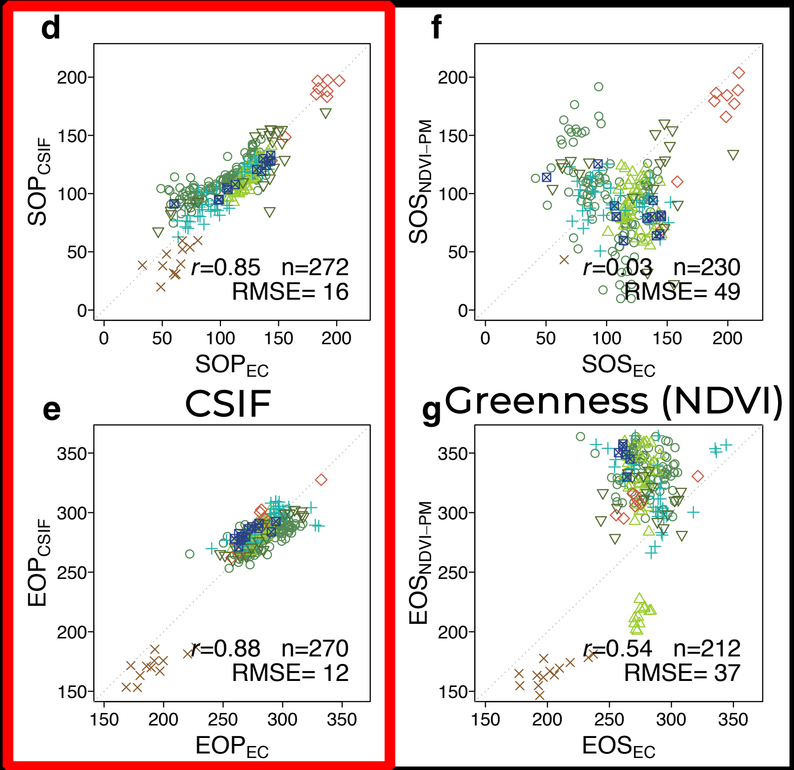
Application 1. Northern latitude temperature sensitivity

Contiguous SIF: comparison with eddy covariances



Start day of photosynthesis

End day of photosynthesis



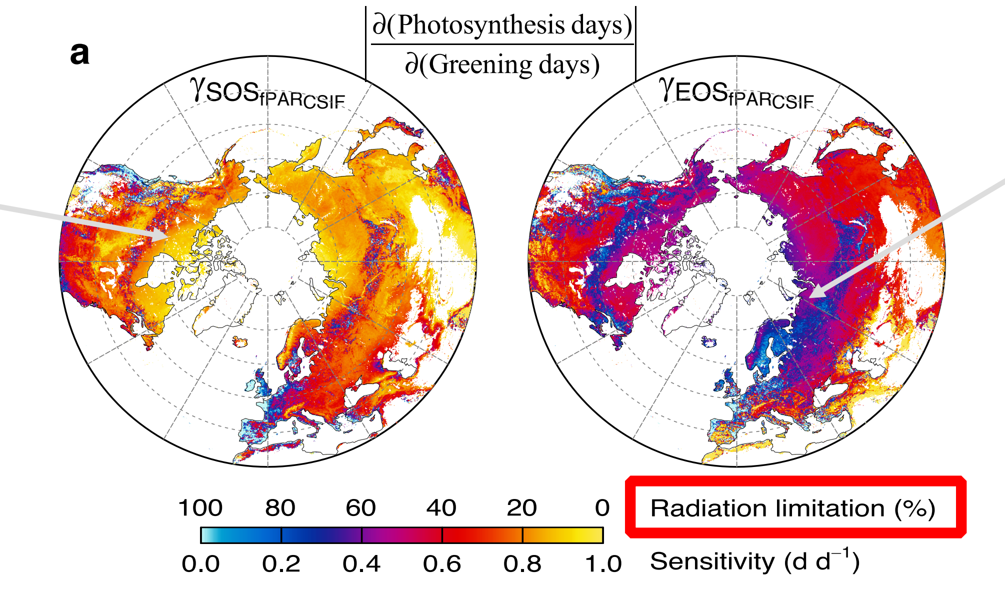
Eddy-covariance *in situ* observations

Zhang, Y., Commane R., Gentine P. Light limits end of season northern ecosystem carbon uptake, submitted

Application 1. Northern latitude temperature sensitivity

Contiguous SIF: Start and End of season light limitation
Day of photosynthesis gain per increased day of greening

SOS:
no light
limitation
(benefits of
being
greener)



EOS:
lots of light
limitation
(no benefits
of being
greener)

Greening: beneficial for beginning of season
not much benefits for end of season (light limitations)

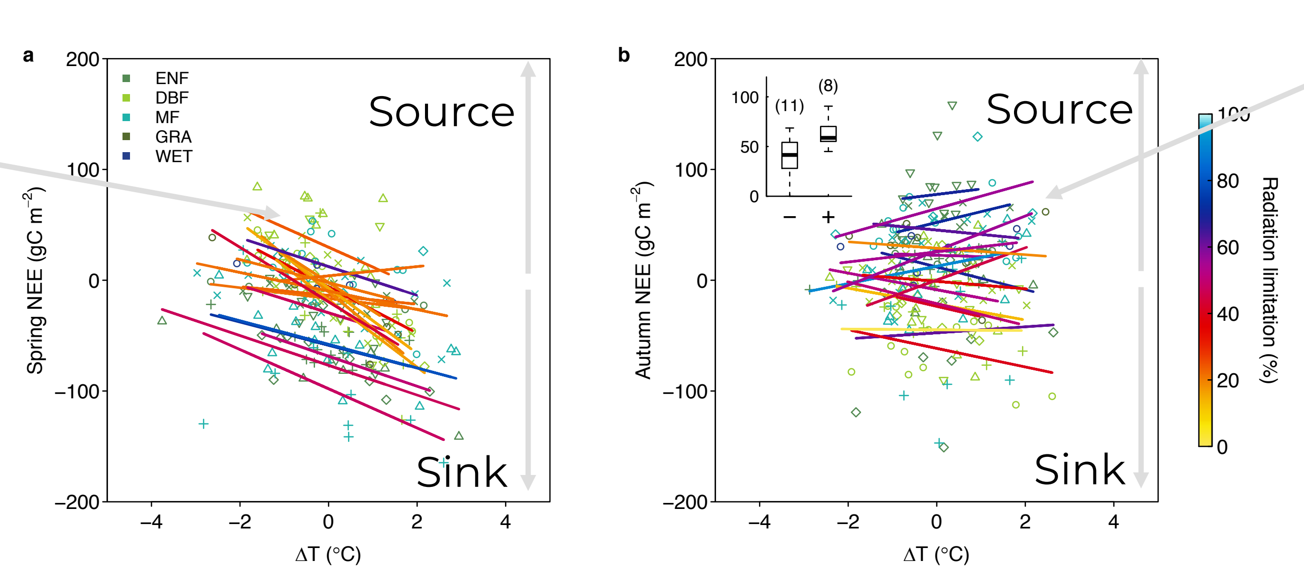
Zhang, Y., Commane R., Gentine P. Light limits end of season northern ecosystem carbon uptake, submitted

Application 1. Northern latitude temperature sensitivity

Validation: *In situ* eddy-covariance Net Ecosystem Exchange (NEE)

NEE = -(Photosynthesis - Respiration) < 0 ➡ Sink

SOS
no light limitation
(benefits of being greener)



EOS
lots of light limitation
(no benefits of being greener, **increased CO_2 source** with increased T)

Temperature beneficial for beginning of season

not much benefits for end of season (light) but large spatial variations

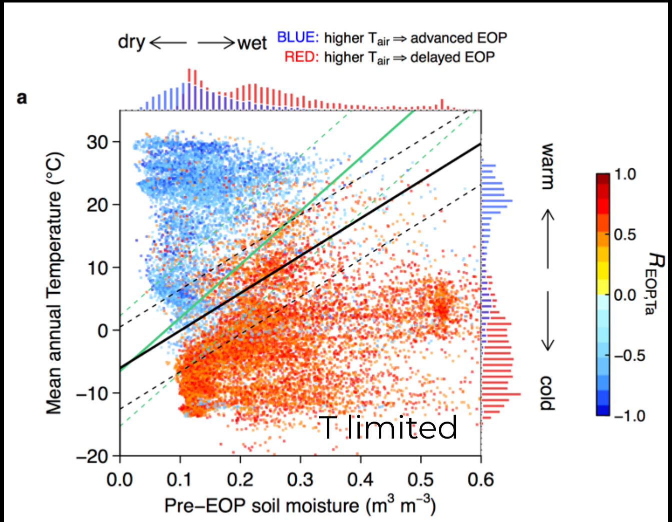
Models do not capture this

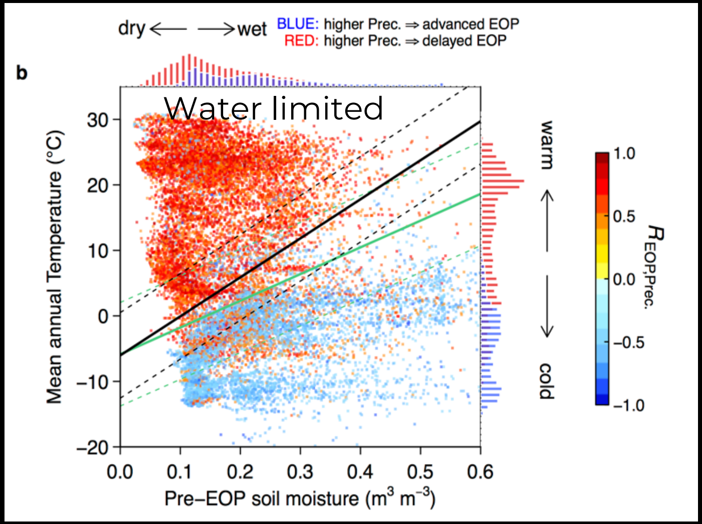
Zhang, Y., Commane R., Gentine P. Light limits end of season northern ecosystem carbon uptake, submitted

Application 2. End of season water stress

End of photosynthesis (EOP) date:
dependence on pre-season T (Reanalysis) and Soil moisture (SMAP)

Correlation (EOP, T) **Correlation (EOP, P)**





Regions not T limited are water limited
Clear separation between them using Support Vector Machine classification
Confirmed by eddy covariances (not shown)

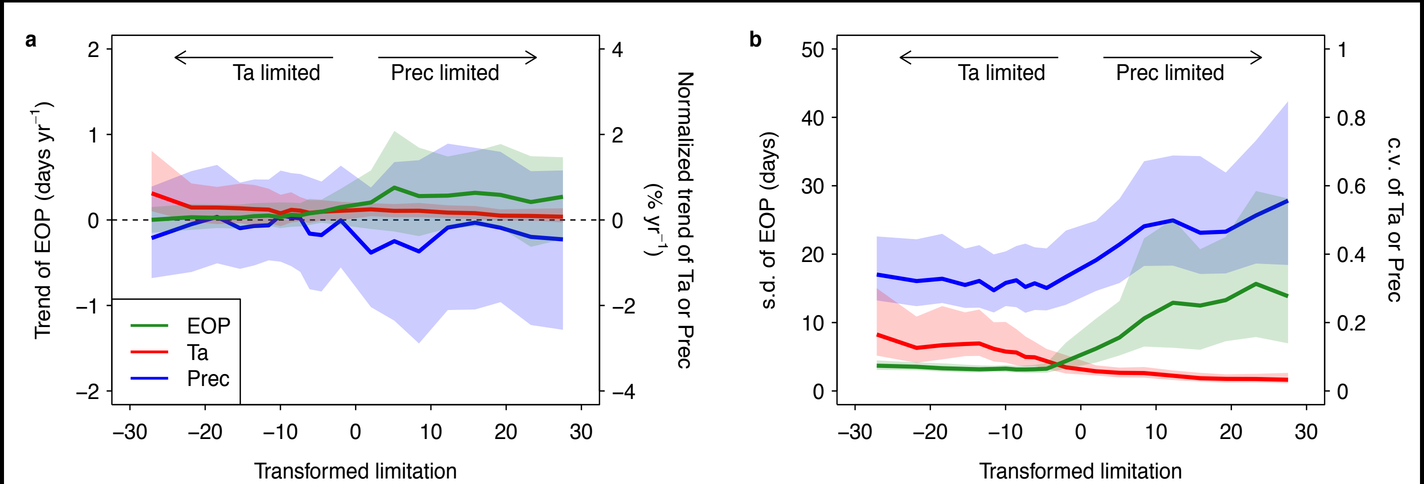
Zhang, Y., Gentine P. , Parazoo N. Zhou S., Piao S., Compound temperature and moisture constraints on end-of-season plant photosynthesis , submitted

Application 2. End of season water stress

Interannual Variability (IAV) still dominates the signal

Trend in CSIF

IAV in CSIF



Limitation

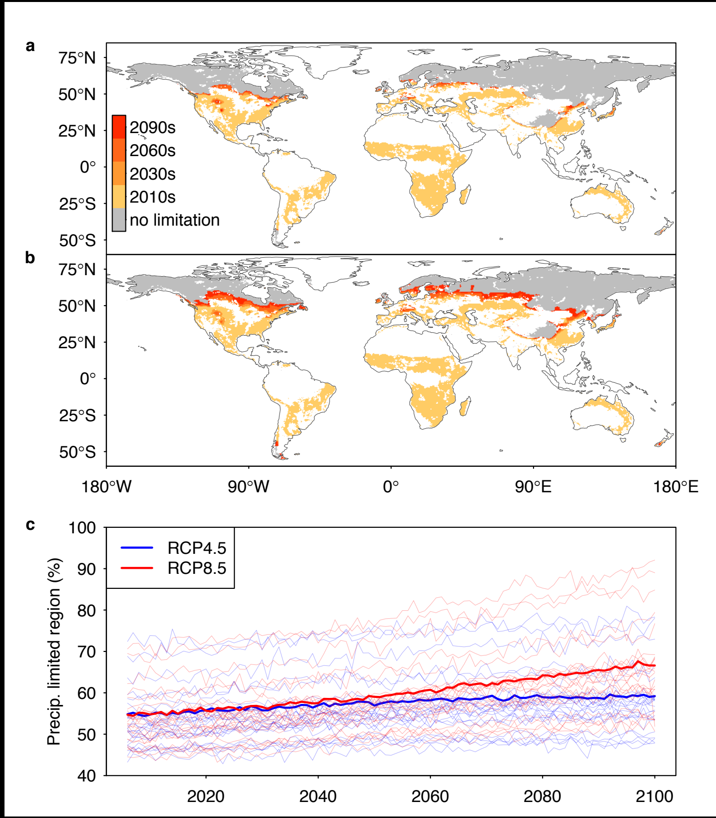
Trend is still too weak compared to trend in MODIS record
Turn to Earth System Models that relatively correctly capture this threshold

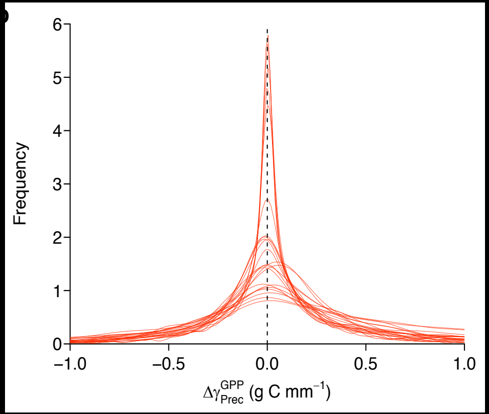
Zhang, Y., Gentine P. , Parazoo N. Zhou S., Piao S., Compound temperature and moisture constraints on end-of-season plant photosynthesis , submitted

Application 2. End of season water stress

Future prediction of regions with EOP limited by precipitation

Change dominated by warming (demand) not by precipitation (supply, too variable)





Little change n P sensitivity

Zhang, Y., Gentine P. , Parazoo N. Zhou S., Piao S., Compound temperature and moisture constraints on end-of-season plant photosynthesis , submitted

Conclusions

Machine learning applied to remote sensing
as a ”filter” for noisy but good data

Two examples of end of season impact on carbon uptake:

1. Light limitation

Machine-learning retrievals of photosynthesis provide **new observational constraints** on GPP response across climates/ecosystems

- **Cold regions: Light is the main regulator of end-of-season photosynthesis and carbon uptake temperature sensitivity**

2. Dryness change

Clear threshold dependent on both T and P

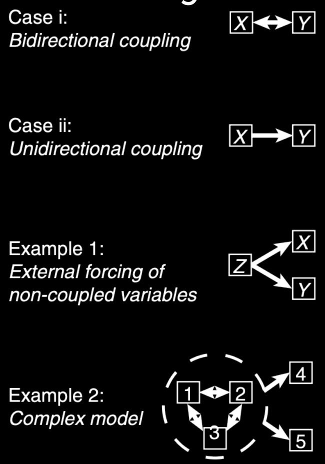
Supply vs. demand

Demand T change is expected to have more future impact than P

Next steps

Not just correlations, we want to **assess causation**, **predict** (e.g. climate change) and **interpret**

1) **Causation**: need to decompose cause and consequence, i.e. directionality and strength



2) **Prediction**: implies good out-of-sample generalization (beside basic overfitting avoidance)
3) **Interpretability** (black boxes)

THANK YOU

Questions?