Mechanistic modelling of gross primary production and transpiration using sun-induced fluorescence observations in different water and light limitation conditions

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Introduction

Carbon assimilation and transpiration

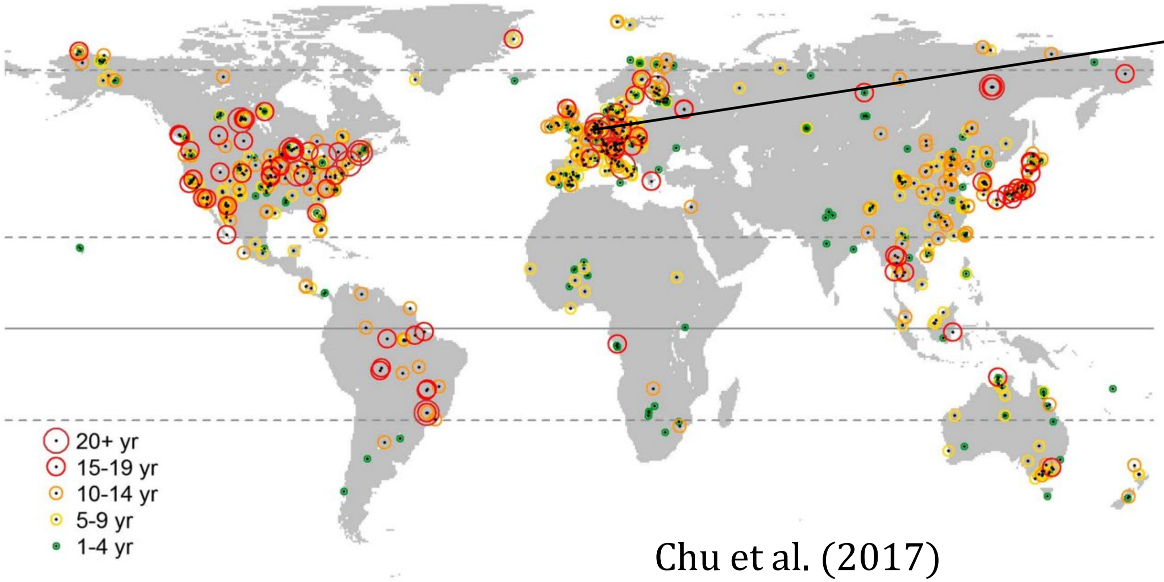
Gross Primary Production (GPP)

- most important flux in the C cycle
- ~1/3 of C emitted by human activities
- Regulation of atmospheric [CO_2]

Transpiration (T)

- 2^{nd} most important flux in the H_2O cycle
- Tightly coupled to GPP
- Drives local/global climate

Eddy-covariance (EC) measurements



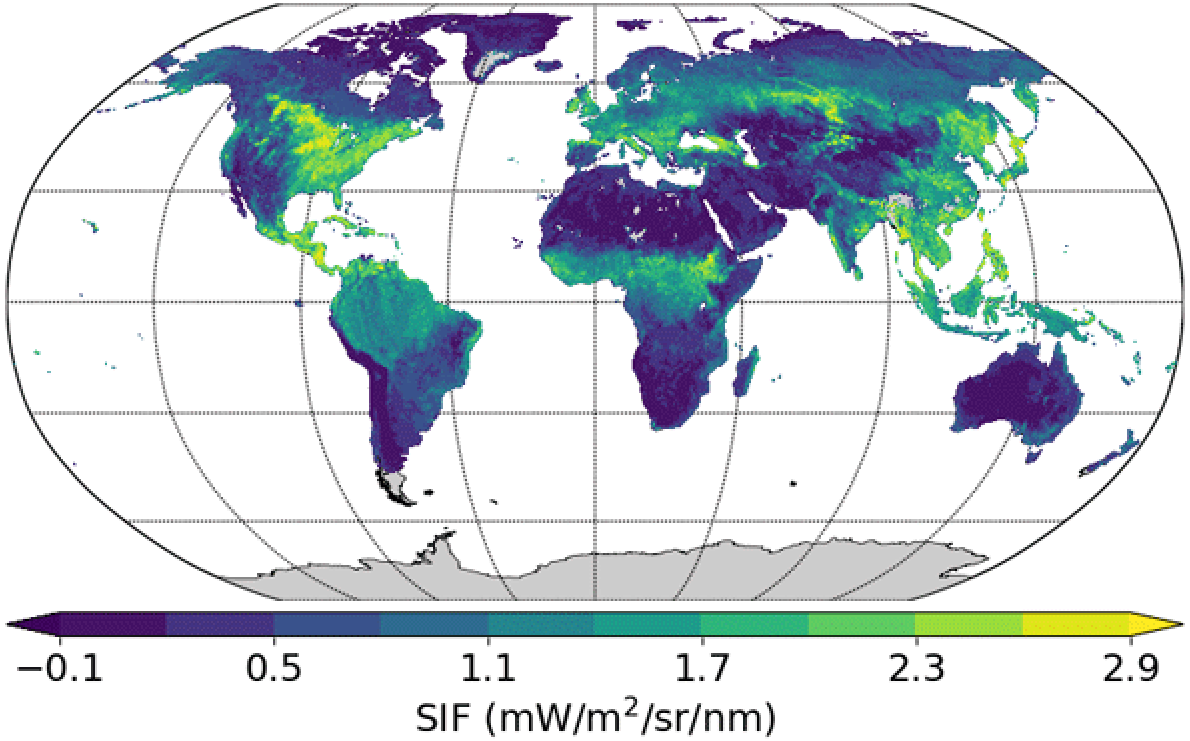
Chu et al. (2017)

Figure 1. Map of active and historical FLUXNET tower sites used in the study. The color and size of the circle indicate the lengths of measurements as of December 2015. The solid and dashed lines denote equator, Tropic of Cancer/Capricorn, and the Arctic Circle, respectively. For data sources and details refer to Table S1.

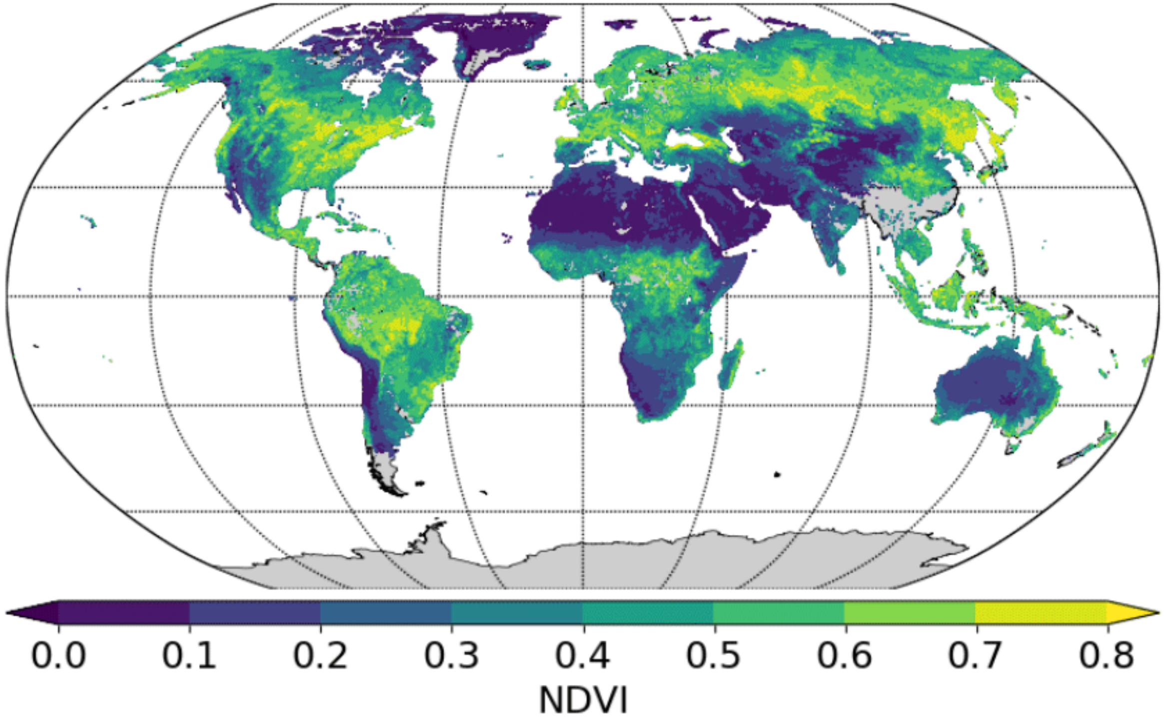
BE-Vie, BE-Dor, BE-Mas, BE-Bra, BE-Loc, BE-Yan

Introduction
Using RS data to fill the gaps

TROPOSIF (0.2°)



TROPOMI NDVI (0.2°)

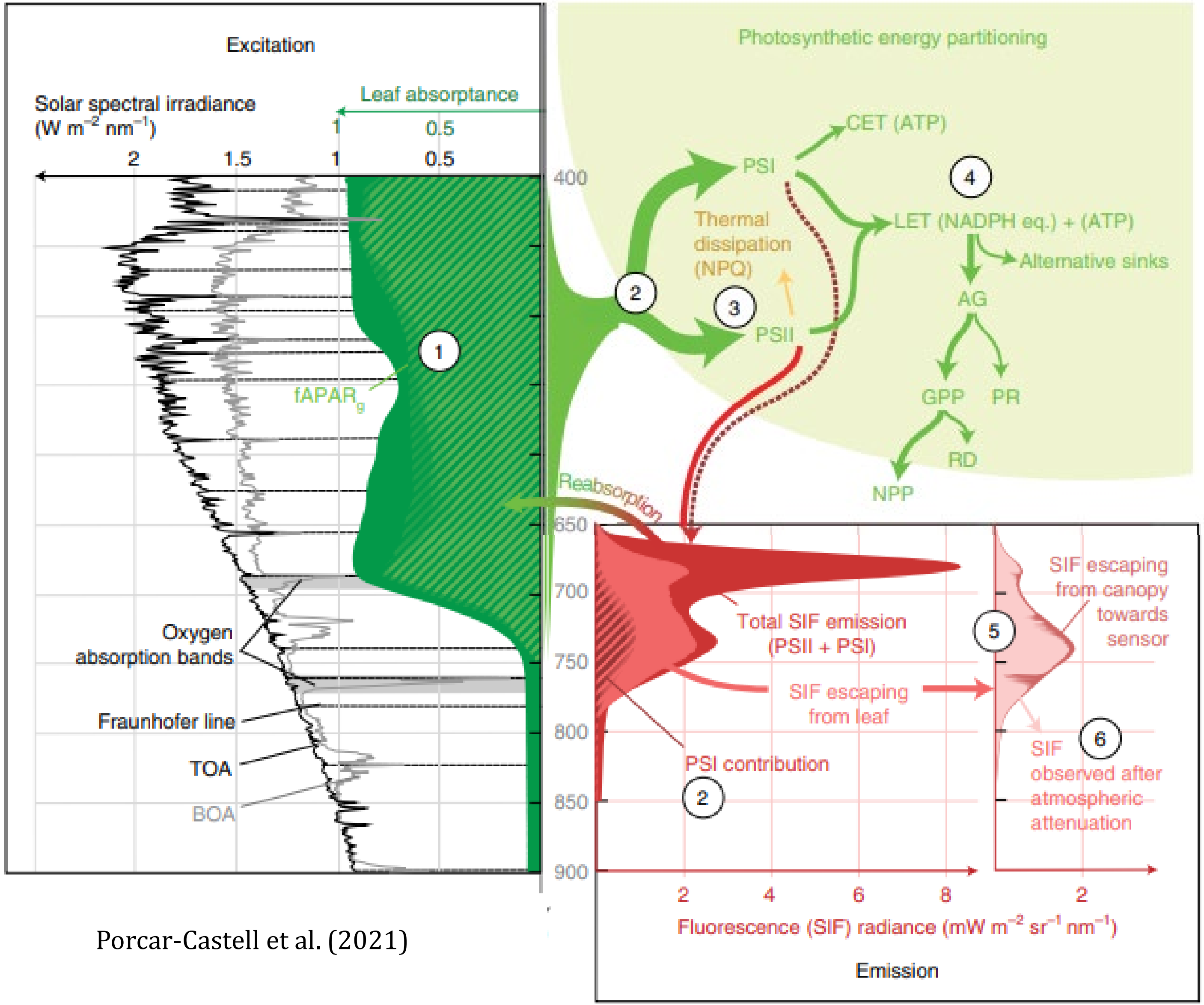


Guanter et al., 2021

Vegetation indexes are undirected related to ecosystem physiology (surface greenness)

SIF provides a window on photosynthesis

Introduction
What is SIF ?



Porcar-Castell et al. (2021)

Light absorption by leaves

↓

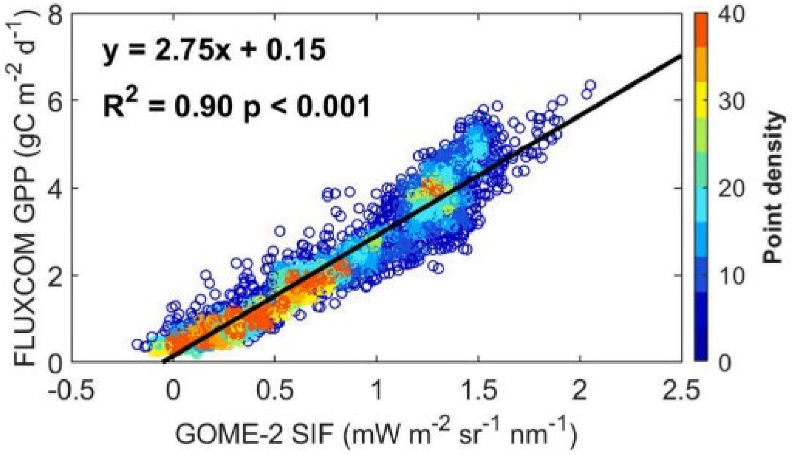
Photosystem excitation by photons

SIF — Photosynthesis — Heat

Only a fraction of the emitted SIF signal is measured by the sensor (atm/canopy scattering and absorption effects)

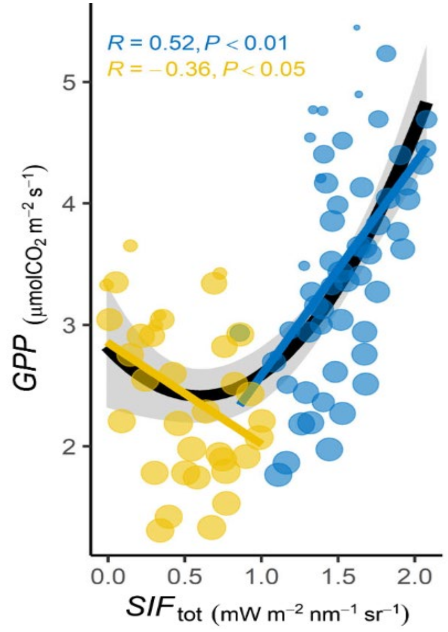
Introduction
SIF-GPP relationship across scales

Regional scale (China) – Satellite data



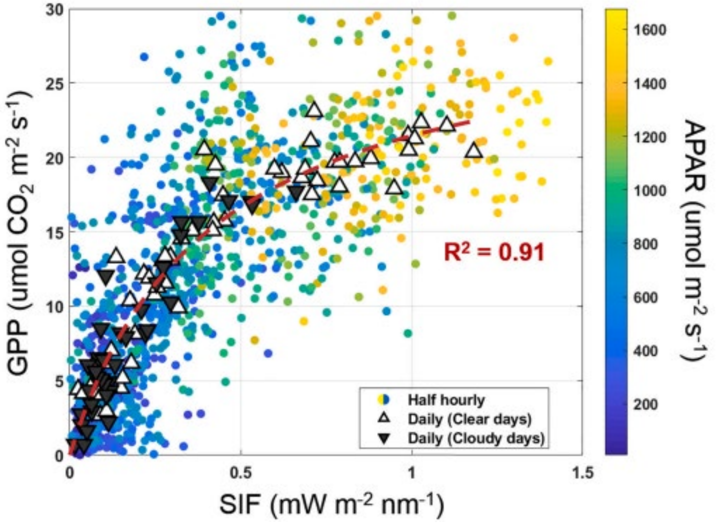
Chen et al., (2020)

Plot scale (Open woodland – heatwave)



Martini et al., (2022)

Plot scale (Evergreen needleef forest – fall transition)



Kim et al., (2021)

- Climate conditions and phenology influence SIF-GPP relationship.
- Empirical approaches are limited
- Process-based model ?

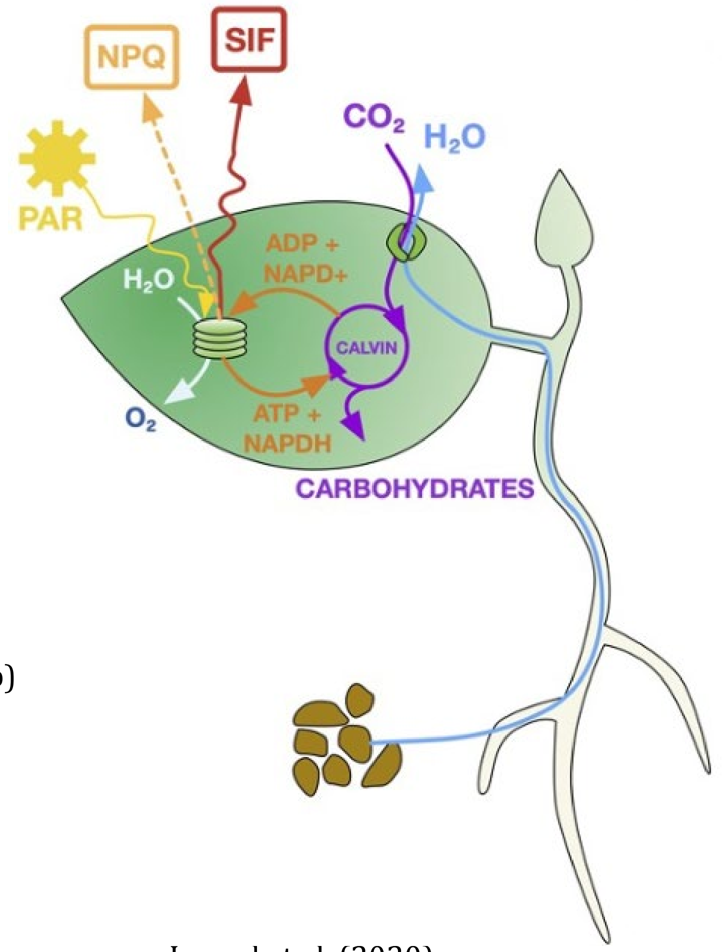
Introduction
Water-Carbon fluxes coupling

- Stomata opening controls carbon and water exchanges
- Photosynthesis and transpiration are closely related through stomatal conductance
- 3 modeling components
    - Stomatal conductance (USO) (Medlyn et al., 2011)
    - Photosynthesis (FvCB) (Farquhar et al., 1980)
    - SIF

Stomatal conductance (USO) + Photosynthesis (FvCB) → MLR (Gu et al., 2019)

Stomatal conductance (USO) + Photosynthesis (FvCB) + SIF → MLR-USO (Beauclaire et al., in prep)

- MLR-USO : using SIF observations, photosynthesis processes and stomatal optimality to estimate GPP and T

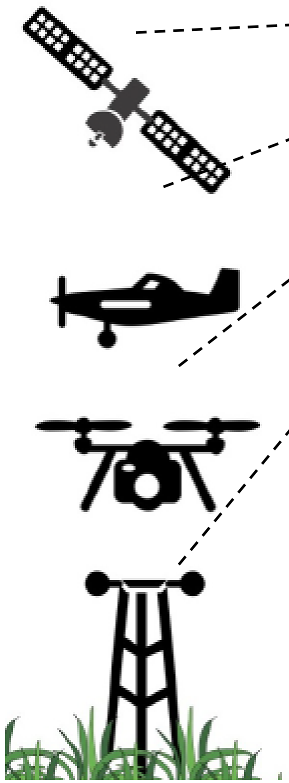


Jonard et al. (2020)

Method
MLR-USO model

$\mathbf{SIF_{TOC,760}}$ —MLR model→ $\mathbf{GPP_{SIF}}$ —USO model (G_1)→ $\mathbf{T_{SIF}}$

$$GPP_{SIF} = q_L \cdot \frac{\phi_{PSII,max} \cdot (1 + k_{DF}) \cdot SIF_{TOC,760} \cdot \sum f_i}{(1 - \phi_{PSII,max})} \cdot \frac{(C_i - \Gamma^*)}{(4C_i + 8\Gamma^*)}$$



Jonard et al. (2020)

e.g., LICOR 6400XT

e.g., BE-Lon

SIF measurements

Measurements of MLR parameters

USO calibration on EC data

Validation on EC data

Method
MLR-USO model

$$GPP_{SIF} = q_L \cdot \frac{\phi_{PSII,max} \cdot (1 + k_{DF}) \cdot SIF_{TOC,760} \cdot \sum f_i}{(1 - \phi_{PSII,max})} \cdot \frac{(C_i - \Gamma^*)}{(4C_i + 8\Gamma^*)}$$

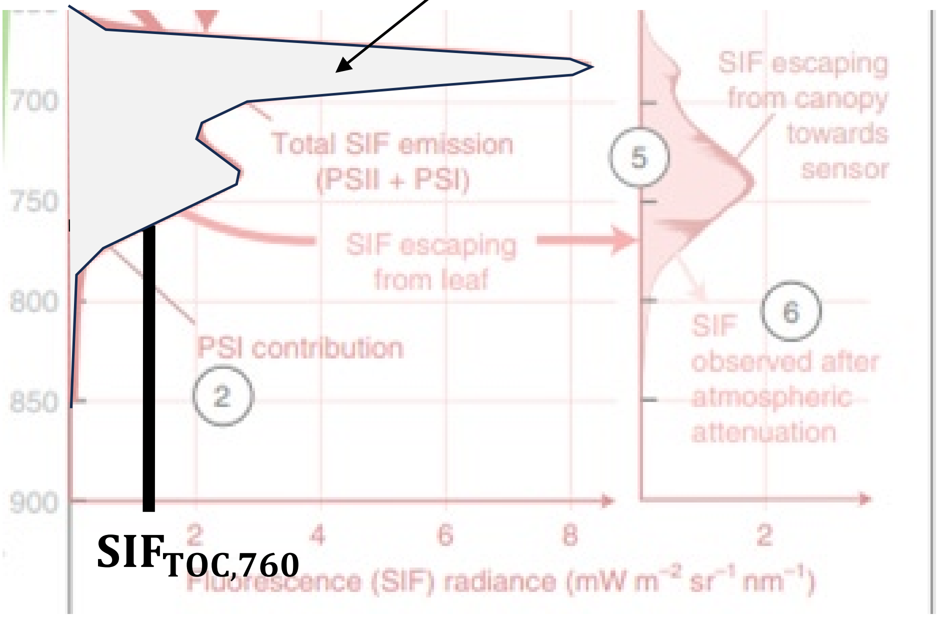
$SIF_{TOC,760}$ → $\sum f_i$ → SIF_{TOT}

f_λ SCOPE

f_{PSII}

$f_{esc} \sim \frac{NIRv}{fAPAR}$

SIF_{TOT}



$SIF_{TOC,760}$

LICOR 6400XT

FloX

Method

Objectives

- How do MLR-USO model predictions correlate with EC data at the plot scale ?
- Is the MLR-USO model robustness impacted by climate conditions (temp, irradiance, edaphic/atm dryness) ?

BE-Lon

FloX

Experimental setup

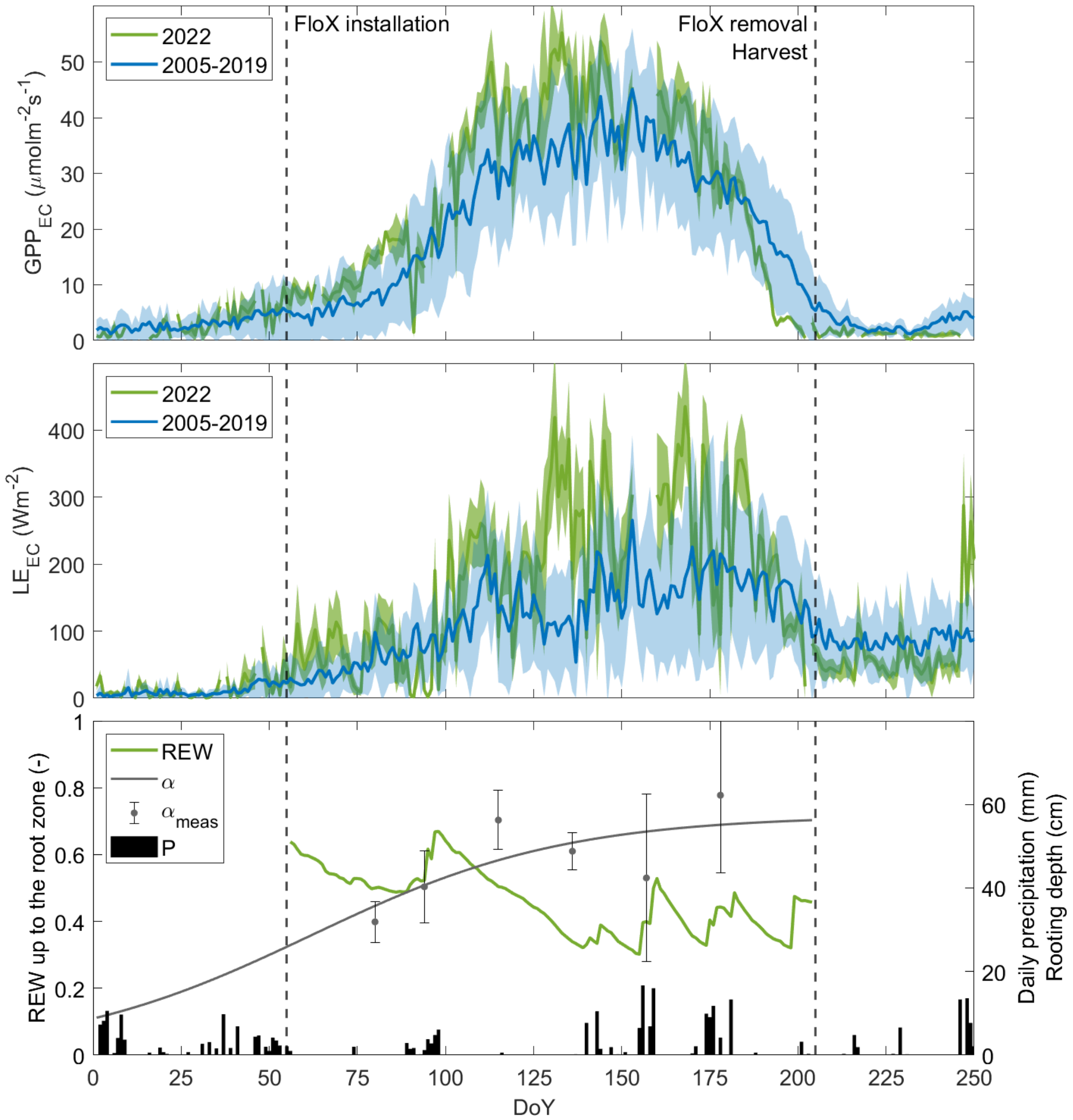
Scale : plot
EC site for validation : BE-Lon (ICOS station class 2)
PFT : C3 crop (winter wheat)
Date : February to July 2022
SIF : FloX (JB hyperspectral)
MLR parameters : LI6400 XT
Soil water status : relative extractable water (REW) from SWC and root biomass measurements
Meteo data: meteo station (EC)

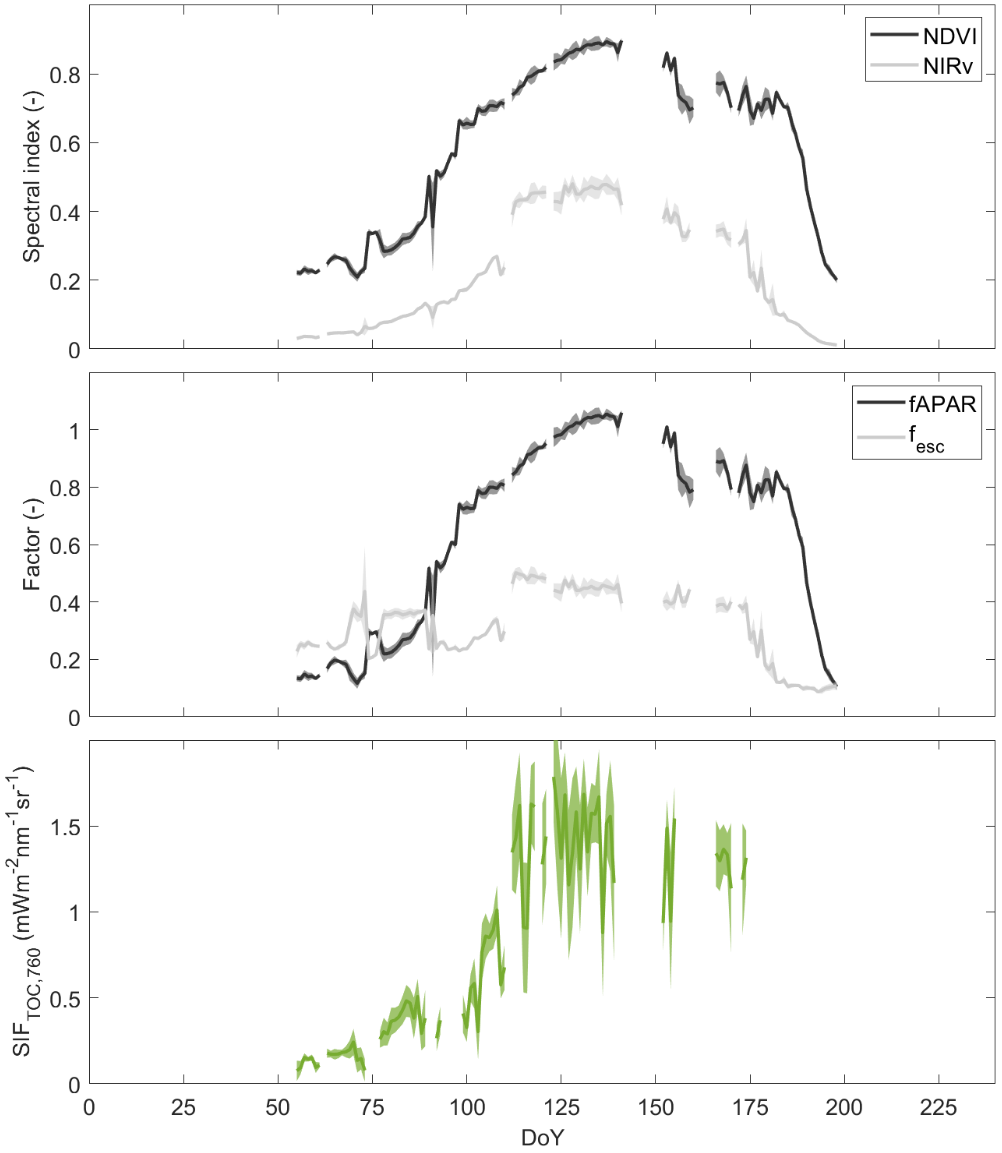
EC data selection

Source : ICOS carbon portal (OneFlux)
GPP : nighttime partitioning method
No gapfilling

Results

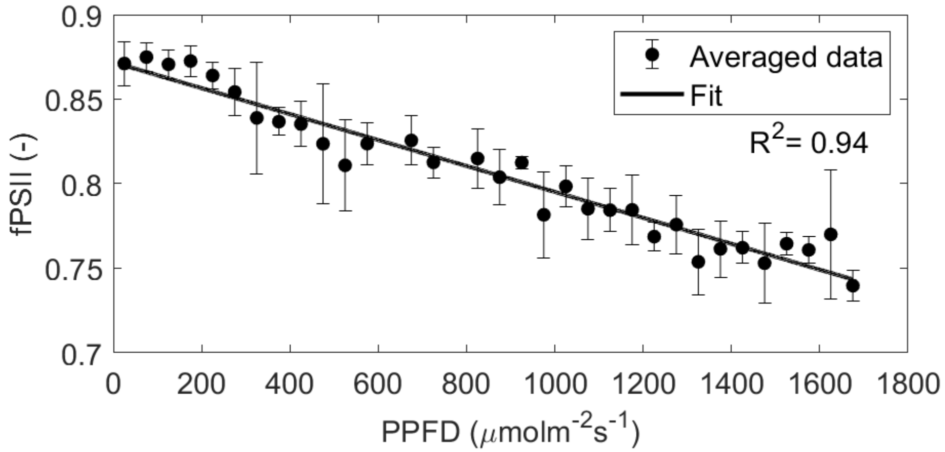
EC fluxes and spectral measurements

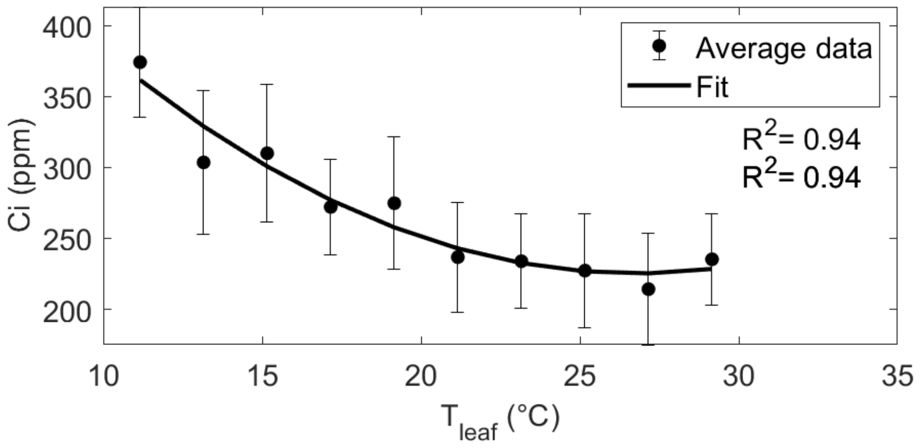


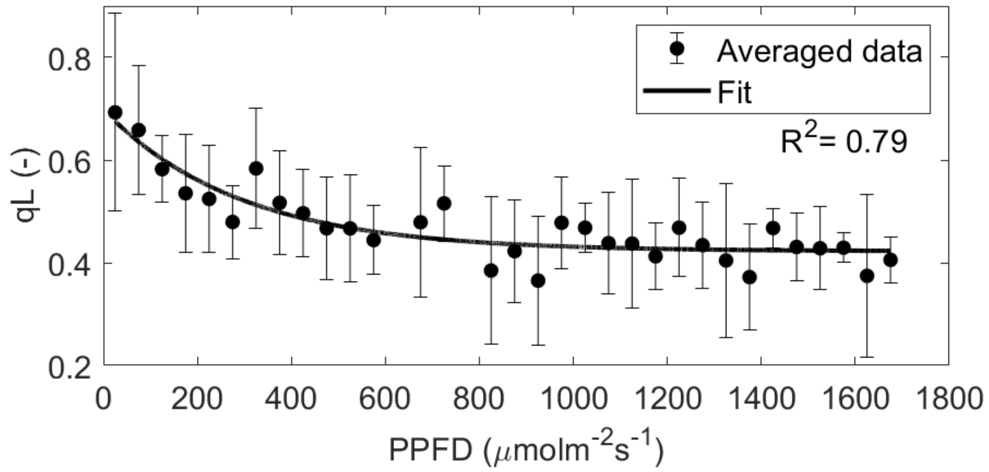


Results
Model parameters

$$GPP_{SIF} = q_L \cdot \frac{\phi_{PSII,max} \cdot (1 + k_{DF}) \cdot SIF_{TOC,760} \cdot \sum f_i}{(1 - \phi_{PSII,max})} \cdot \frac{(C_i - \Gamma^*)}{(4C_i + 8\Gamma^*)}$$



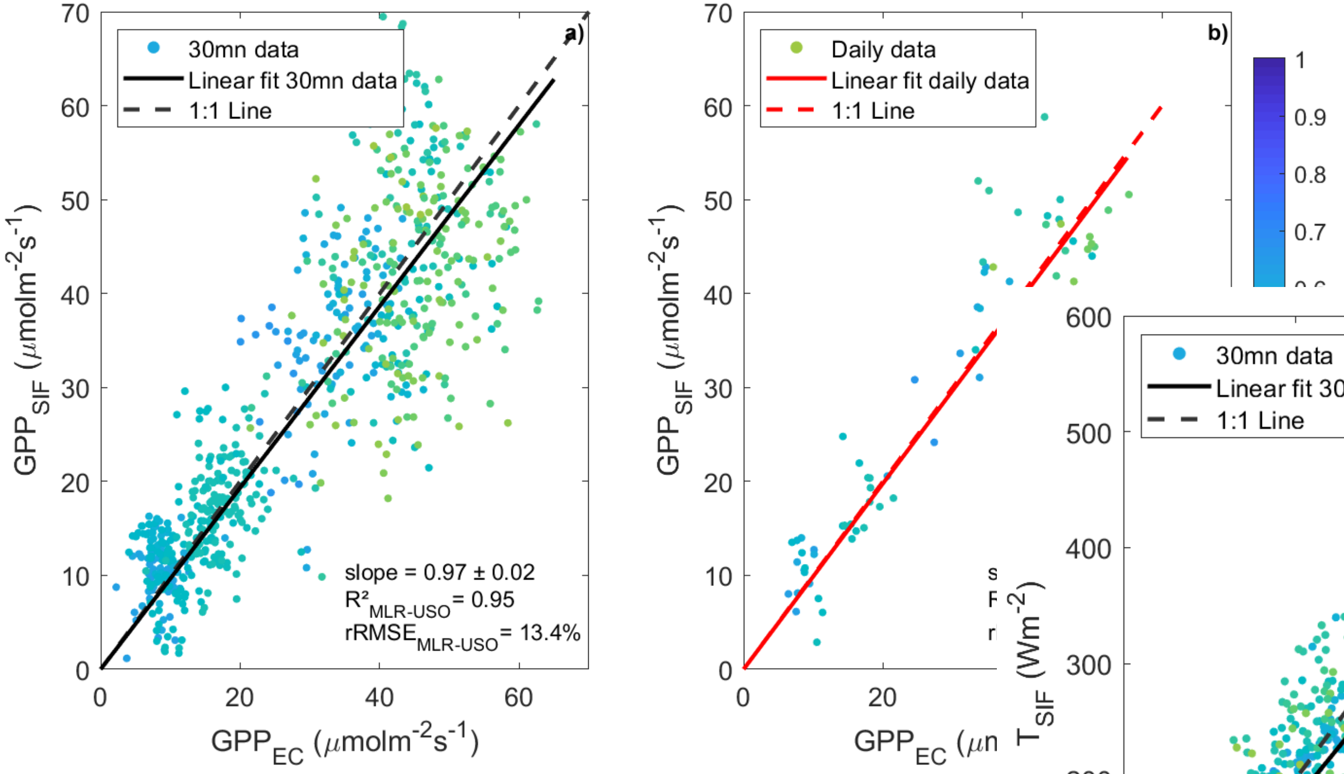




$$q_L = f(PPFD)$$
$$C_i = f(T_{can})$$
$$f_{PSII} = f(PPFD)$$

$$\phi_{PSII,max} = 0.76$$
$$G_1 = 4.38\ kPa^{0.5}$$

Results
Validation with EC data

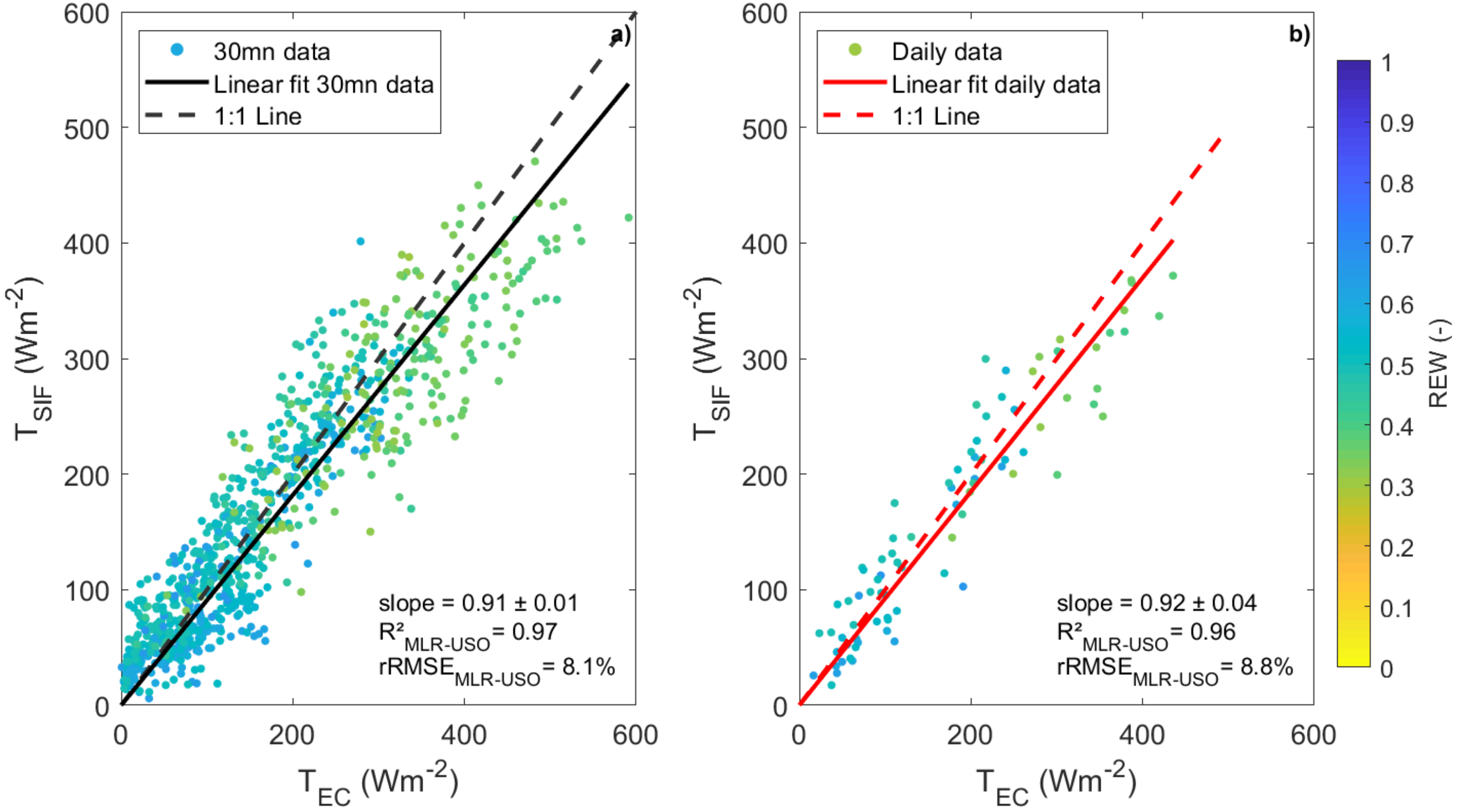


T

Slopes < 1

(-->calibration of USO model using constant G_1)

High R^2, low rRMSE

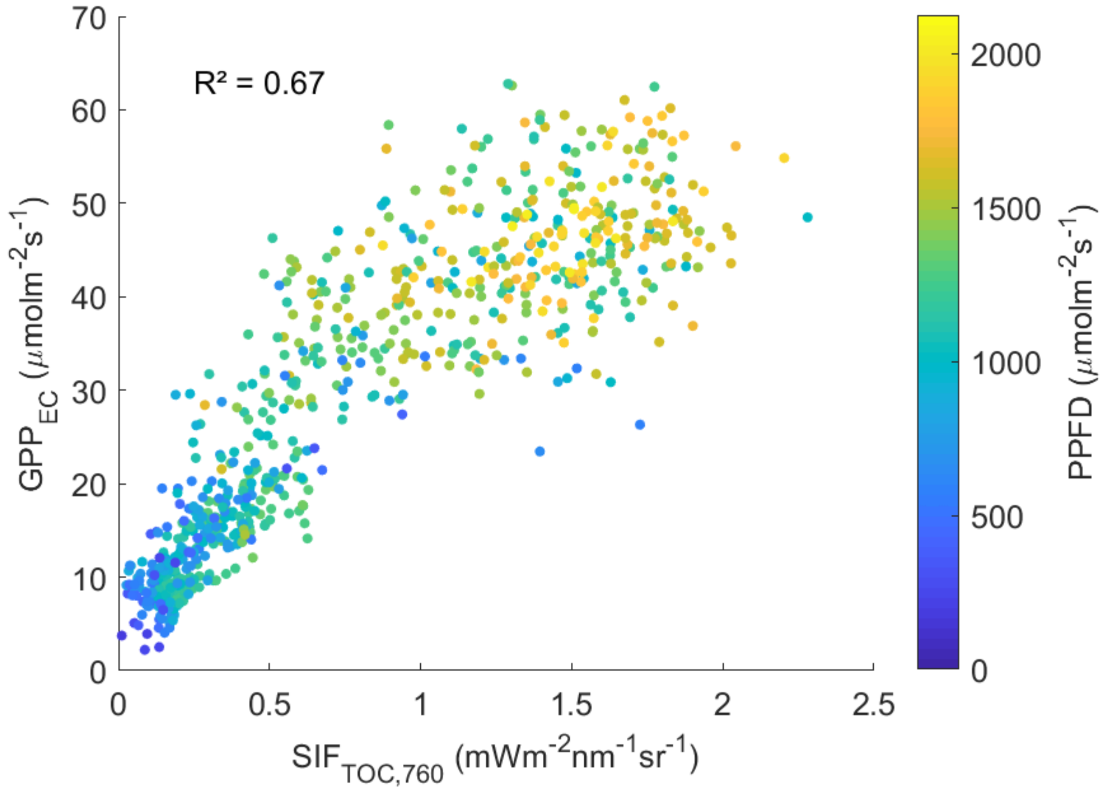


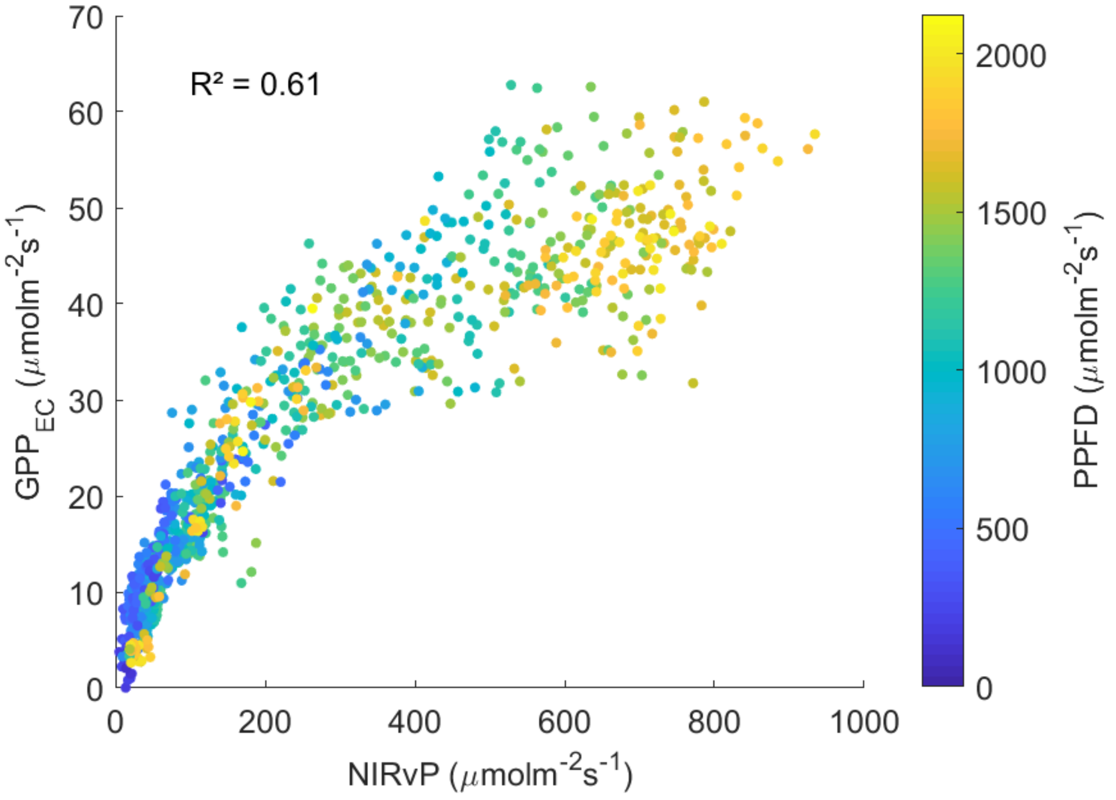
GPP

Slopes ~ 1

High R^2, low rRMSE

Results
Advantage of using MLR-USO model over empirical approaches





$$\text{NIRvP} = \text{NIRv} \cdot \text{PPFD}$$

NIRvP: PAR and chlorophyll content. No physiology.
Increase in R^2 when using SIF with MLR-USO model

Conclusion

- MLR-USO model predicted carbon and water fluxes from SIF at a high accuracy (R^2>0.9, rRMSE<15%)
  - Parcel scale (winter wheat)
  - Broad range of irradiance, vapor pressure deficit, REW, temperature…

Future perspectives

- Applicability of the MLR-USO model :
  - at larger space scales (RS data – FLEX)
  - for other ecosystems (forests)

- Estimation of GPP and T at regional scales by coupling climate models, satellite data and the MLR-USO model

Thank you for listening!

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