Mechanistic Modelling of Gross Primary Production (GPP) and Transpiration (T) of a Winter-wheat Crop from Sun-Induced Fluorescence (SIF) under varying light and water-limiting conditions

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BACKGROUND AND RESEARCH QUESTION

GPP and T are two pivotal fluxes in the C and H_2O cycles

- GPP and T are measured by eddy covariance (EC) flux towers (**GPP_{EC}** - **T_{EC}**).
- EC flux towers network only sparsely covers global terrestrial ecosystems.
- Use of remote sensing (RS) to increase the spatial coverage of GPP_{EC} and T_{EC}.
- SIF provides a proxy of photosynthetic processes at various scales (field sensors, drones, airplanes, satellites).

How to estimate GPP from SIF ?

- The **linear** relationship between SIF and GPP[1,2] **changes** during climate extremes[3] or strong physiological control[4].
- Empirical models and machine learning approaches **do not fully exploit** the **physiological message** carried by the SIF signal.

New approach with the MLR – USO model

- Gu et al.[5] : Actual electron transport rate from SIF + Farquhar[6] model = MLR model for **GPP_{SIF}**.
- Coupling of the MLR model with a stomatal conductance model (USO[7]) and the PM[8] equation = modeling of **T_{SIF}**.
- **Straightforward approach** (few equations) which exploits the information on physiological processes provided by SIF.

Can the MLR – USO model reproduce GPP and T dynamics at the ecosystem scale under varying light and water conditions ?

METHODOLOGY

1 The MLR model

$$GPP_{SIF} = SIF \cdot f_{esc^{-1}} \cdot f_{\lambda} \cdot f_{PSII} \cdot \frac{\phi_{PSII,max} \cdot (1 + k_{DF}) \cdot q_L}{(1 - \phi_{PSII,max})} \cdot \frac{(C_i - \Gamma^*)}{(4C_i + 8\Gamma^*)}$$

FloX box (JB Hyperspectral)
Automatic 30' measurements

LICOR LI-6400XT
Manual campaigns

2 The USO model

$$G_{sw,SIF} = 1.6\left(1 + \frac{G_1}{\sqrt{VPD}}\right)\frac{GPP_{SIF}}{C_a}$$

Modeling of canopy conductance ($G_{sw,SIF}$). Calibration on EC data (G_1).

3 The PM equation

$$T_{SIF} = \frac{\Delta \cdot (R_n - G) + \rho_a \cdot c_p \cdot VPD_{can} \cdot G_{ah}}{\Delta + \gamma \cdot \left(1 + \frac{G_{aw}}{G_{sw,SIF}}\right)}$$

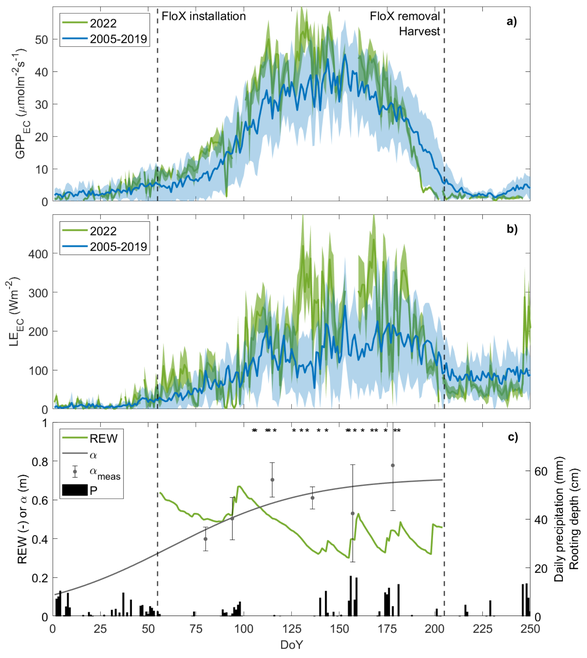
Calculation of T_{SIF} from $G_{sw,SIF}$ and meteorological variables.

Site description

- Winter wheat (BE-Lon ICOS station – 2022)
- FloX box measurements for SIF and f_{esc}
- Other MLR parameters measured with a LI6400XT
- Validation of GPP_{SIF} and T_{SIF} on GPP_{EC} and T_{EC}

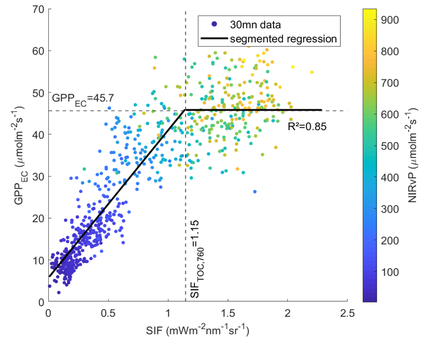
RESULTS

GPP_{EC}, latent heat (LE_{EC}), drought index (REW) and crop rooting depth (α)



- The soil water status was monitored by calculating the relative extractable water in the root zone (REW).
- Rooting depth reached 60-80 cm.
- Several drying up episodes occured (decrease in REW – lack of precipitation)

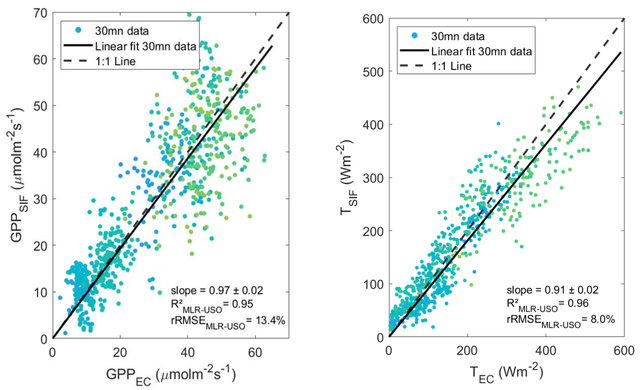
$SIF\text{-}GPP_{EC}$ relationship



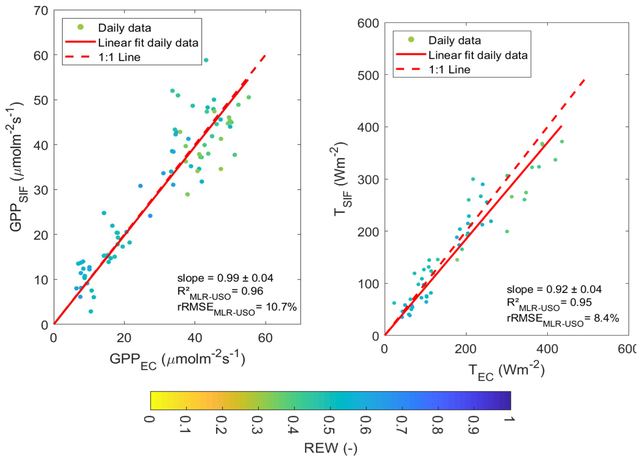
- Saturation of GPP_{EC} from a SIF threshold corresponding to a NIRvP (NIRv*PPFD) ≈ 500 µmolm^{-2}s^{-1}.
- Control of physiological processes and irradiance on the SIF-GPP relationship.

Validation of MLR-USO model estimates

Half-hourly timescale



Daily timescale



- $R^2 \geq 0.95$, rRMSE<13.4% for both timescales.
- Slope ≈ 1 (GPP)
- Slope <1 (T)
- No effect of the decrease in REW on model robustness for GPP (residuals analysis).

For T:
➔ Slight underestimation of T_{SIF} compared to T_{EC}.
➔ Effect of edaphic drought on G_1 should be considered[9,10].

MLR model parameters

- Temporal variability of MLR model parameters explained by irradiance (q_L, f_{PSII}) and leaf temperature (C_i).
- Extrapolation with PPFD and canopy temperature.

TAKE-HOME MESSAGE

The MLR-USO approach:

- gives **very good estimates** of **GPP** and **T** from SIF (high accuracy when compared to EC data)
- **improves the estimation** of GPP based on RS during drought
- **capture the effects of drought** on ecosystem physiology by using the SIF signal
- model parameters can be determined from irradiance and surface temperature (also from RS)

Under review in Remote Sensing of Environment (RSE) – special issue "VSI:Remote Sensing of SIF"

PERSPECTIVES

- Testing the MLR-USO model on **forest ecosystems** with SIF measurements at the ecosystem scale
- Application of the model using **RS SIF (e.g., FLEX, TROPOMI)**
- Estimation of GPP and T at **regional scales**

ANY QUESTIONS ?

Scan me !

REFERENCES

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