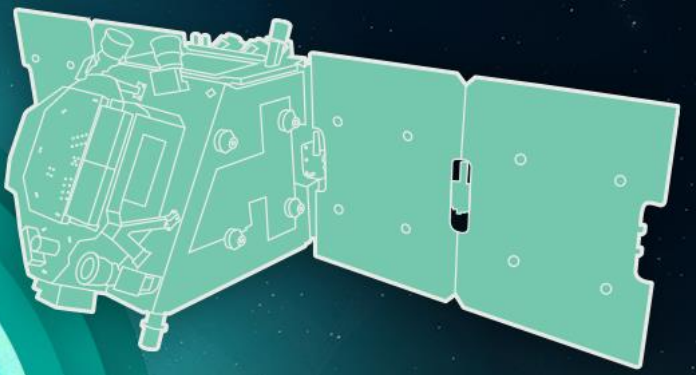
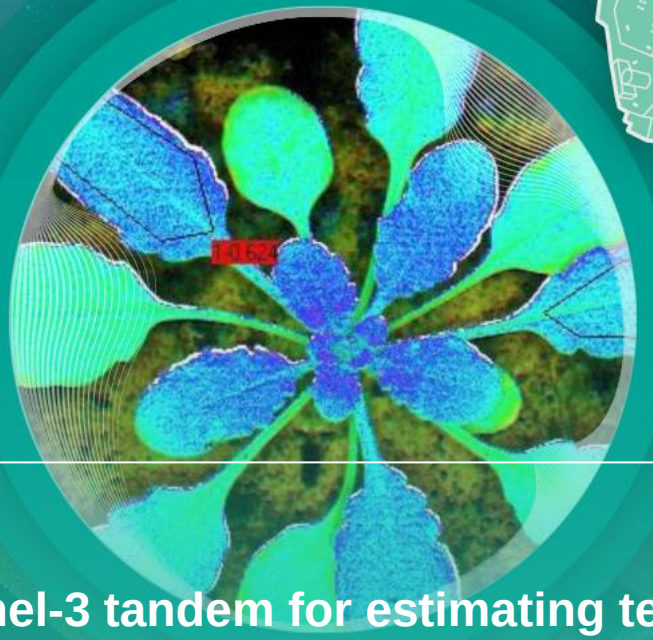
FLEX Fluorescence Workshop 2023

19 – 21 September 2023
ESA – ESRIN | Frascati (Rome), Italy





Assessing the potential of FLEX-Sentinel-3 tandem for estimating terrestrial carbon fluxes: a hybrid synergistic approach supported by TROPOMI fluorescence retrievals

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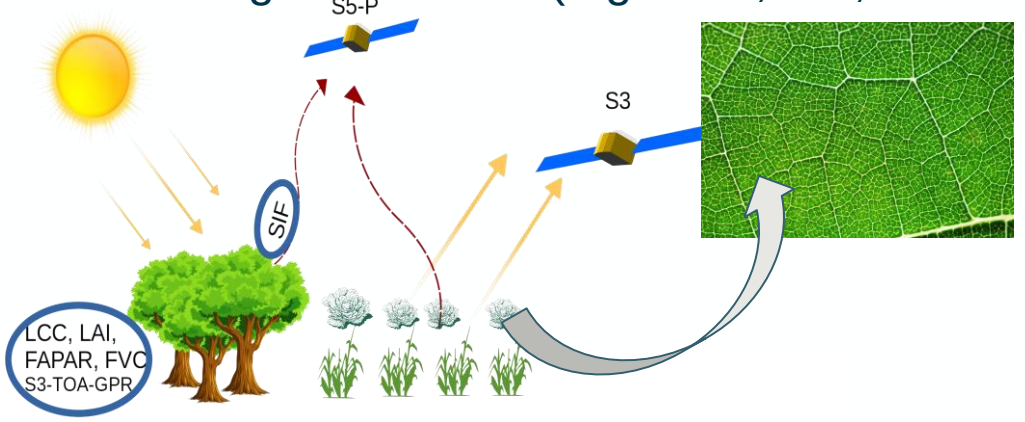
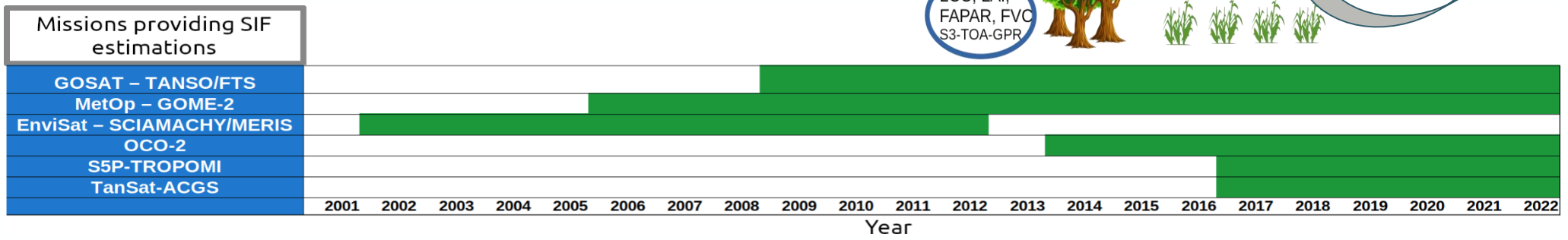
Objectives:

- Assessing the potential of FLEX-S3 tandem for monitoring photosynthesis activity through a proxy satellite: TROPOMI
- Development of prototype models based on machine learning for estimating terrestrial carbon fluxes (TCF): Future applications for FLEX
- Evaluating the predictive power of SIF jointly with quantitative vegetation traits (e.g. LCC, LAI, FAPAR)
- Performing benchmarking activities

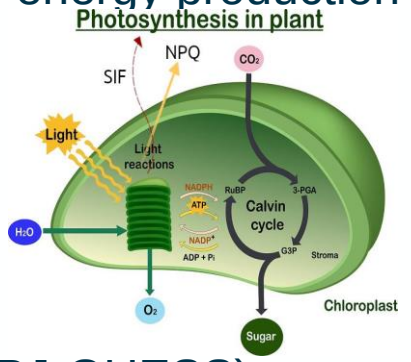
(MOD17A2H and LPJ-GUESS)

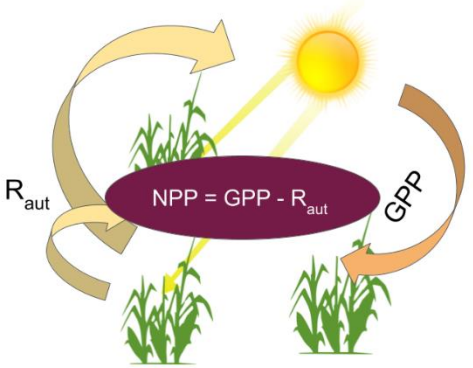


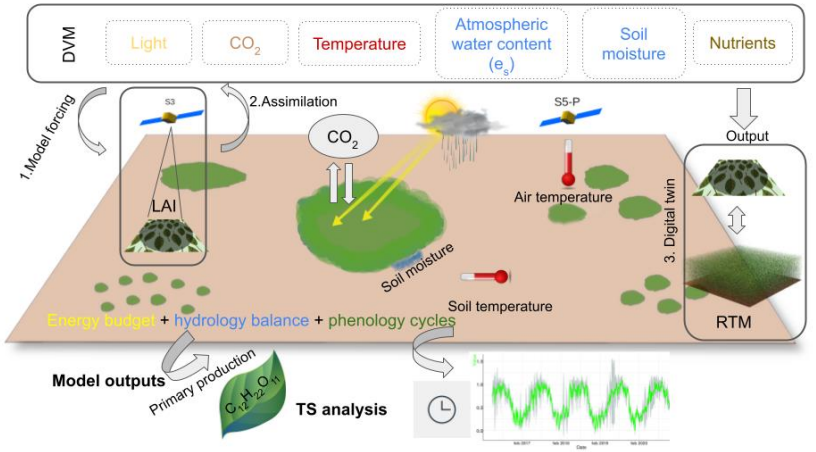


Introduction

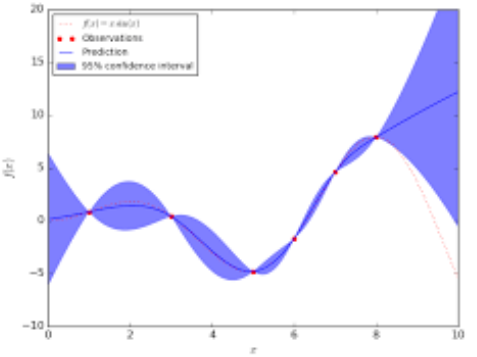
- **Monitoring of TCF**: applications to account for carbon sinks, ecosystem services, food and energy production -> GPP: rate of photosynthetic carbon assimilated by vegetation.
- Net primary production: NPP = GPP – R_a
  - Estimated from different approaches:
    - LUE models - > empirical coefficients and APAR
    - Process-based models -> Dynamic global vegetation models DGVMs (LPJ-GUESS)
    - Data-driven methods -> machine learning







GPR

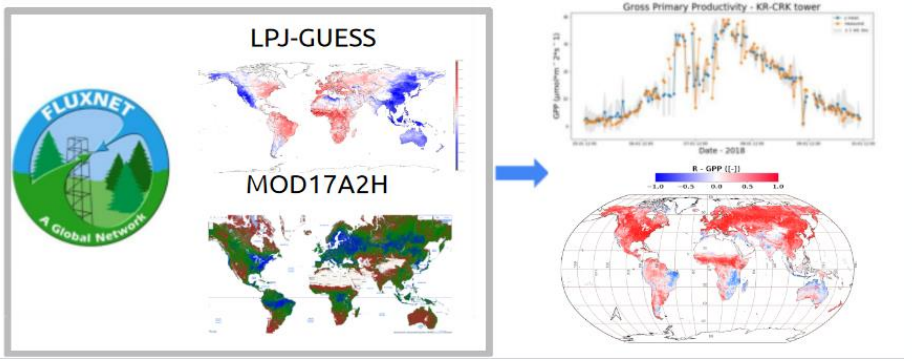


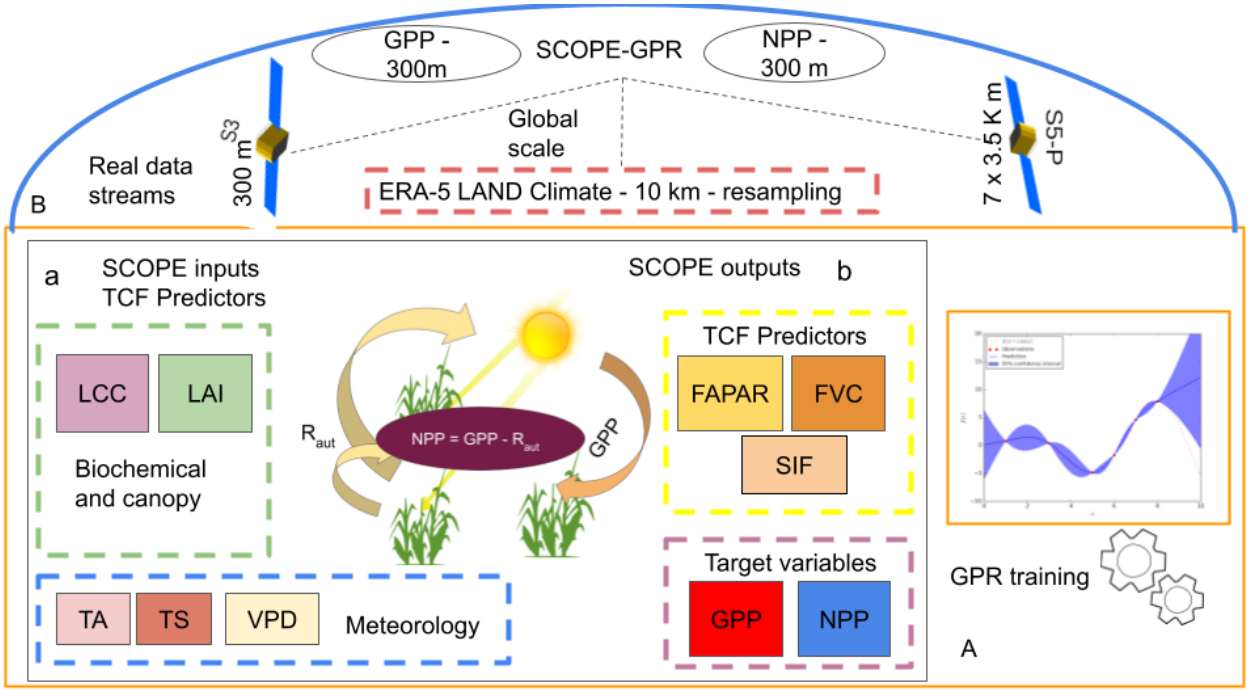
Methods

- **Hybrid methods** for estimating geophysical variables: SCOPE + GPR
  - Machine learning efficiency built on physical principles
  - SCOPE: Soil Canopy Observation, Photochemistry and Energy fluxes (vertical 1-D)
  - GPR: Non linear non parametric regression algorithm – kernel based

$$f(x) \sim GP(m(x), k(x, x'))$$

  - Implementation of GPR on cloud computing
  - Validation against reference products



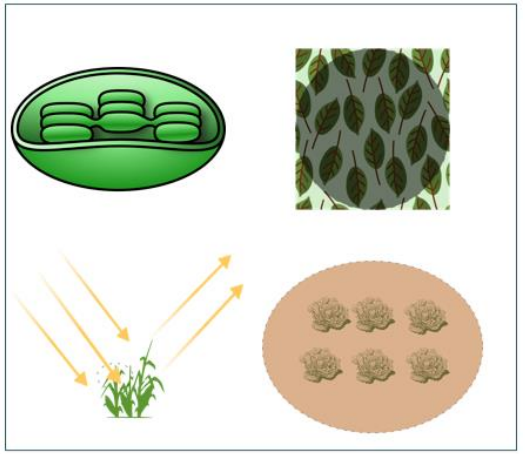


Methods

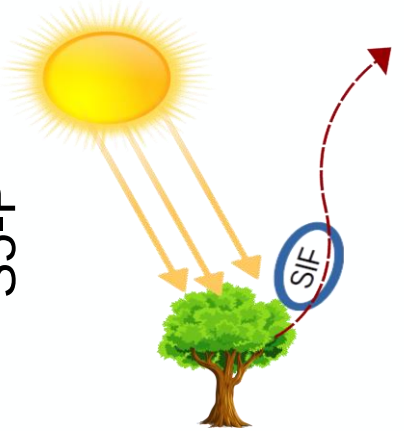
Global data streams predictors to estimate TCF

- S3-TOA-GPR products[1]: **LCC, LAI, FAPAR, FVC ->** Retrievals from OLCI (400 nm - 1020 nm, 21 bands)
  - Spatial resolution: 300 m - Temporal resolution: ~ daily (middle and high latitudes)
- S5P-TROPOMI: **SIF-TROPOSIF[2]** (743 - 758 nm windows)
  - Spatial resolution: 7 km x 3.5 km^2 - Temporal resolution < 1 day -> daily length scaled
- ERA5-LAND reanalysis models -> Surface solar radiation, Air temperature, Atmospheric vapor pressure
  - Spatial resolution 0.1ºx0.1º - Temporal resolution: Hourly to monthly aggregations.

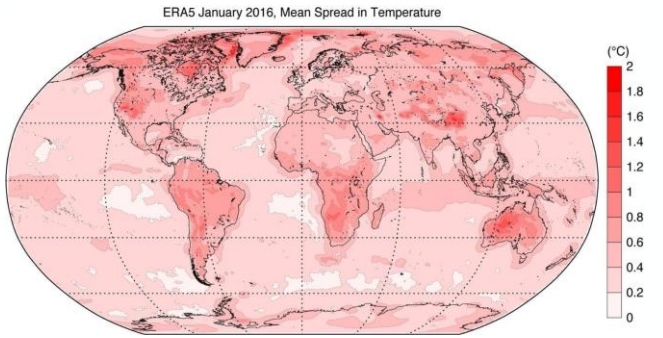
S3 products



S5-P



ERA-5



1. Kovàks et al., 2023
2. Guanter et al., 2021

Methods

Mapping strategy: Different temporal aggregation

- Instant scenes

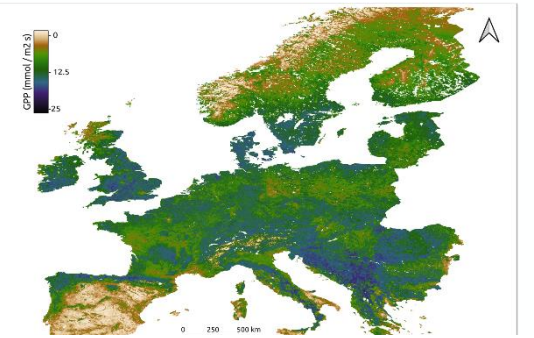
$$y_h = f(x^D) + \epsilon; x^D : \left(X_{8d}^{LCC} \quad X_{8d}^{LAI} \quad X_{8d}^{FAPAR} \quad X_{8d}^{FVC} \quad X_h^{SW} \quad X_h^{Ta} \quad X_h^{ea} \quad X_h^{SIF_{743}}\right)$$

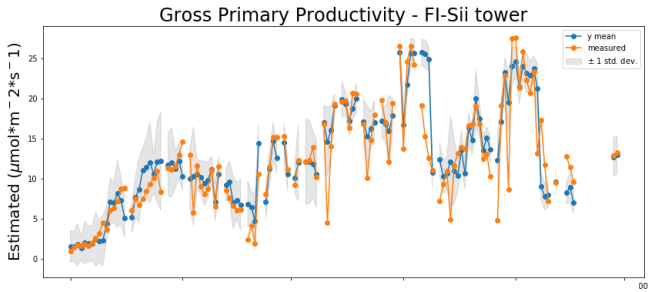
- Time series

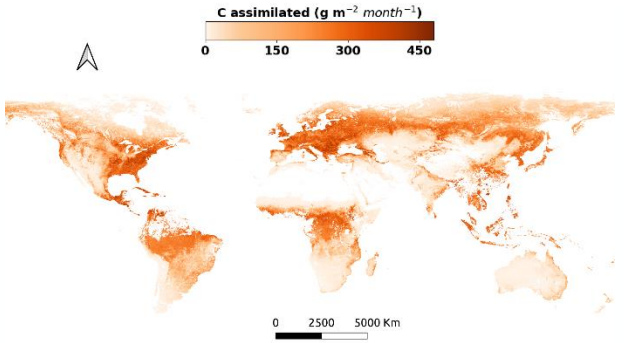
$$y_{8d} = f(x_{\bar{8d}^D}) + \epsilon; x^D : \left(X_{8d}^{LCC} \quad X_{8d}^{LAI} \quad X_{8d}^{FAPAR} \quad X_{8d}^{FVC} \quad X_{8d}^{SW} \quad X_{8d}^{Ta} \quad X_{8d}^{ea} \quad X_{8d}^{SIF_{743}}\right)$$

- Monthly aggregations

$$y_m = f(x_{\bar{m}^D}) + \epsilon; x^D : \left(X_{\bar{m}}^{LCC} \quad X_{\bar{m}}^{LAI} \quad X_{\bar{m}}^{FAPAR} \quad X_{\bar{m}}^{FVC} \quad X_{\bar{m}}^{SW} \quad X_{\bar{m}}^{Ta} \quad X_{\bar{m}}^{ea} \quad X_{\bar{m}}^{SIF_{743}}\right)$$







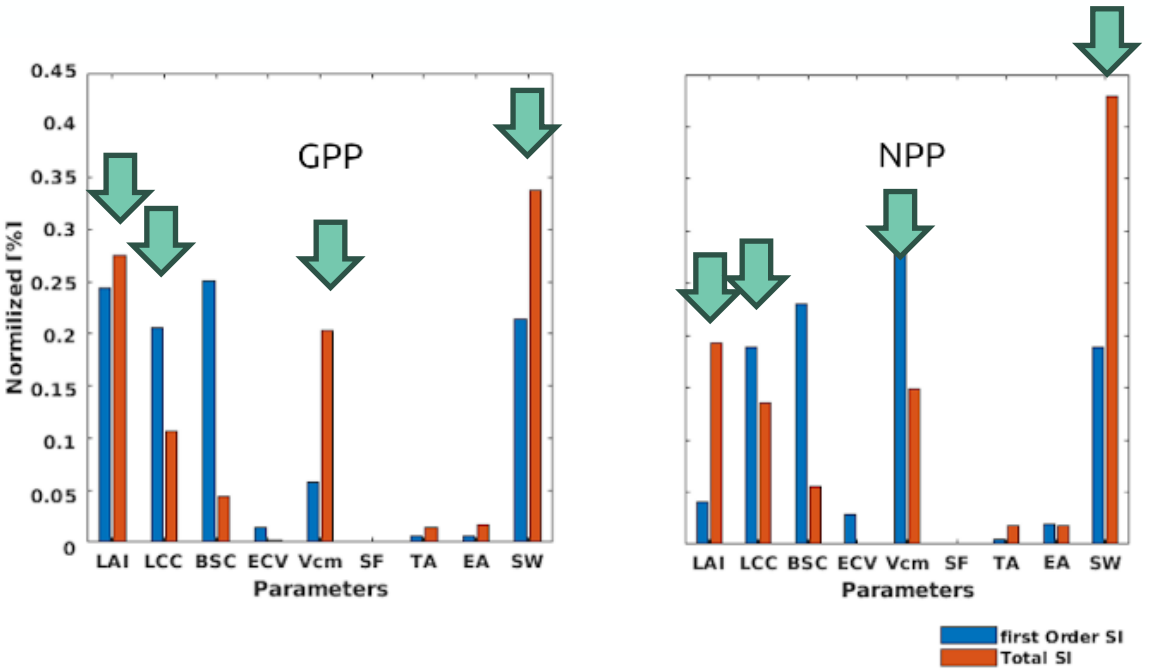
Results

Analysis of predictors strength:

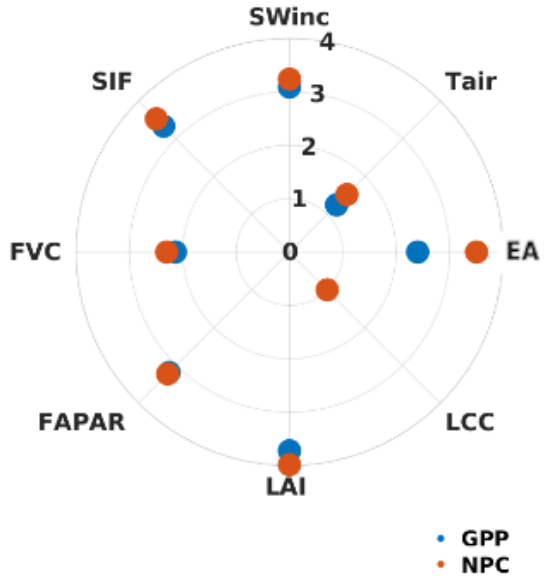
The global sensitivity analysis carried out from SCOPE simulations revealed that **Vcmax, LAI and Short-wave incident radiation** were the predictors with maximal influence.

The analysis of GPR-ranking models (after trained) shows that **LAI, SIF, FAPAR and SW** were the variables more important after trained.

Global Sensitivity Analysis calculated from SCOPE inputs



GPR-training input ranking



Results

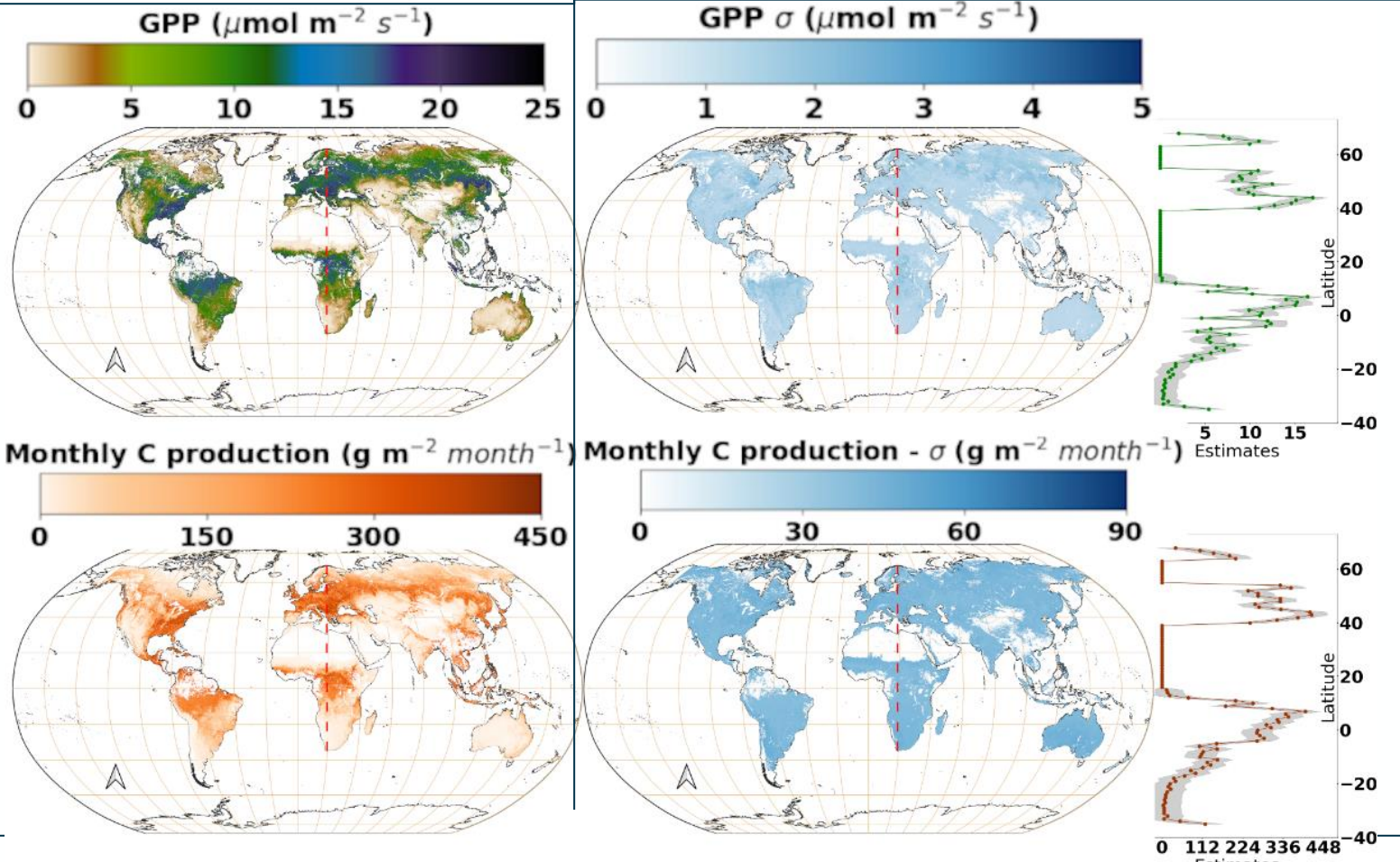
Spatial distribution:

Tropical forests, Taiga and temperate forests reaching peaks of GPP (25 micro mols·m-2·s-1). Latitudinal profile showing peaks at the equator and middle latitudes

Uncertainties uniformly distributed across the globe: Values relative to estimates in the range **10-40%**

Estimates on 16-06-2019–13:00:00 (first row). Monthly accumulated values (06-2019) (second row)

Uncertainties on 16-06-2019–13:00:00 (first row). Monthly accumulated values (06-2019) (second row)



Results

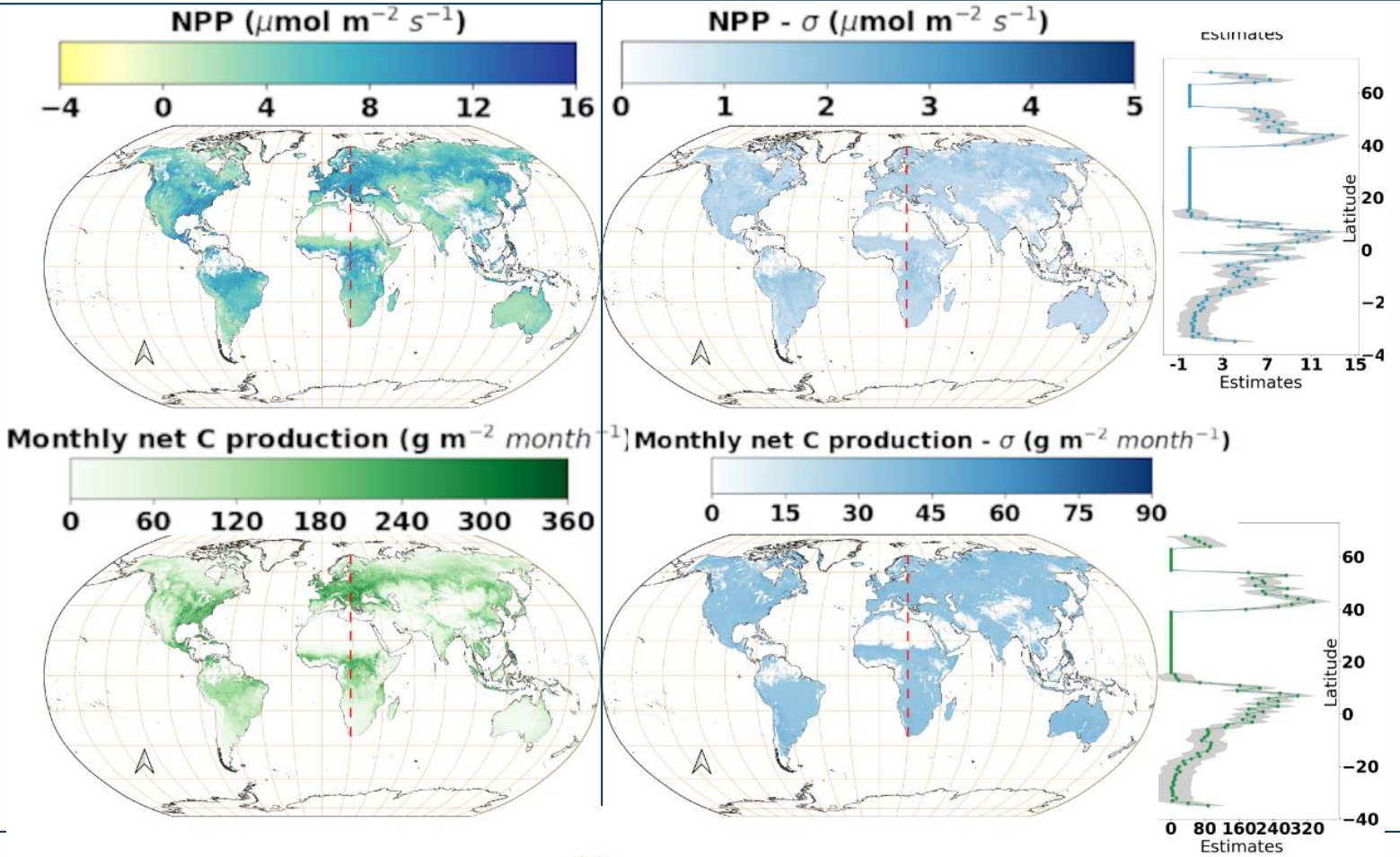
Spatial distribution:

Tropical forests, Taiga and temperate forests reaching peaks of NPP. Latitudinal profile showing peaks at the equator and middle latitudes. Negative values where Ra > GPP

Uncertainties uniformly distributed across the globe: Values relative to estimates in the range **10-40%**

Estimates on 16-06-2019–13:00:00 (first row). Monthly accumulated values (second row)

Uncertainties on 16-06-2019–13:00:00 (first row). Monthly accumulated values (second row)



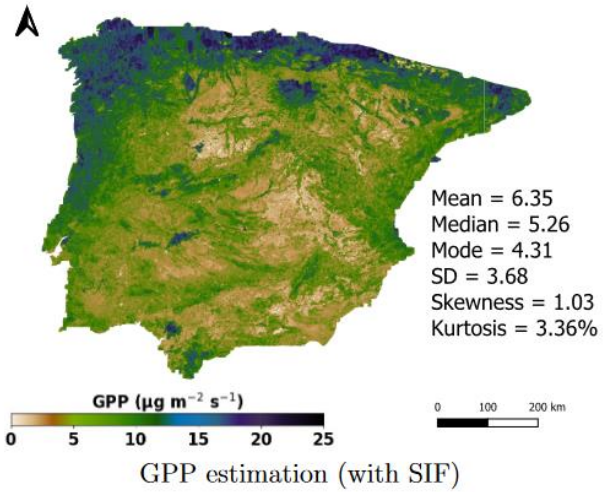
Results

Regional scale:

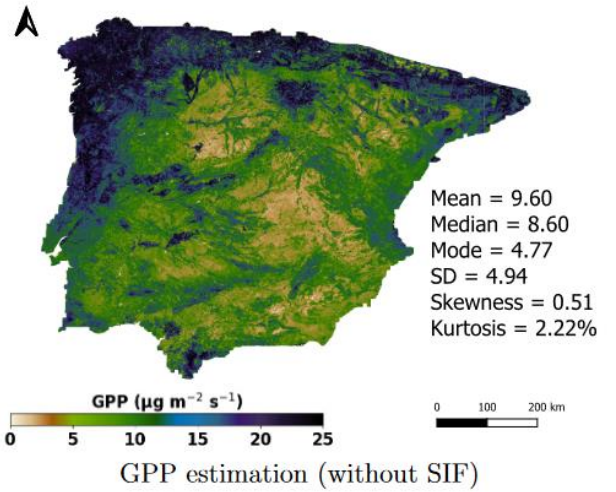
An analysis at higher resolution shows the impact of **SIF** after removed from the list of predictors -> Uncertainties mean and SD were 25% and 142% superior for the non-SIF version.

Forest and crop fields (e.g. rice fields) presenting peaks of GPP

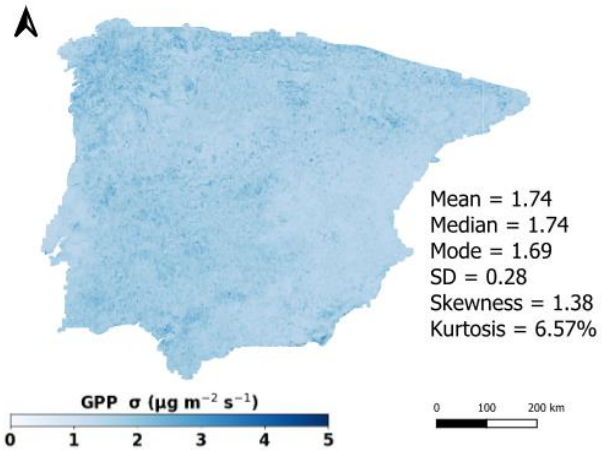
Estimates and uncertainties on 16-06-2019–13:00:00 (8 vars model with SIF)	Estimates and uncertainties on 16-06-2019–13:00:00 (7 vars model no-SIF)

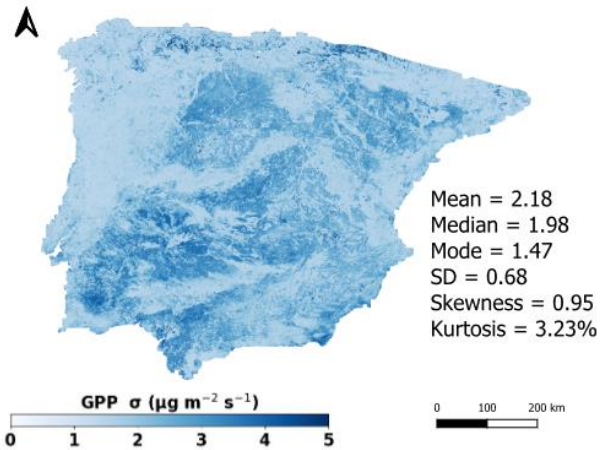


GPP estimation (with SIF)



GPP estimation (without SIF)



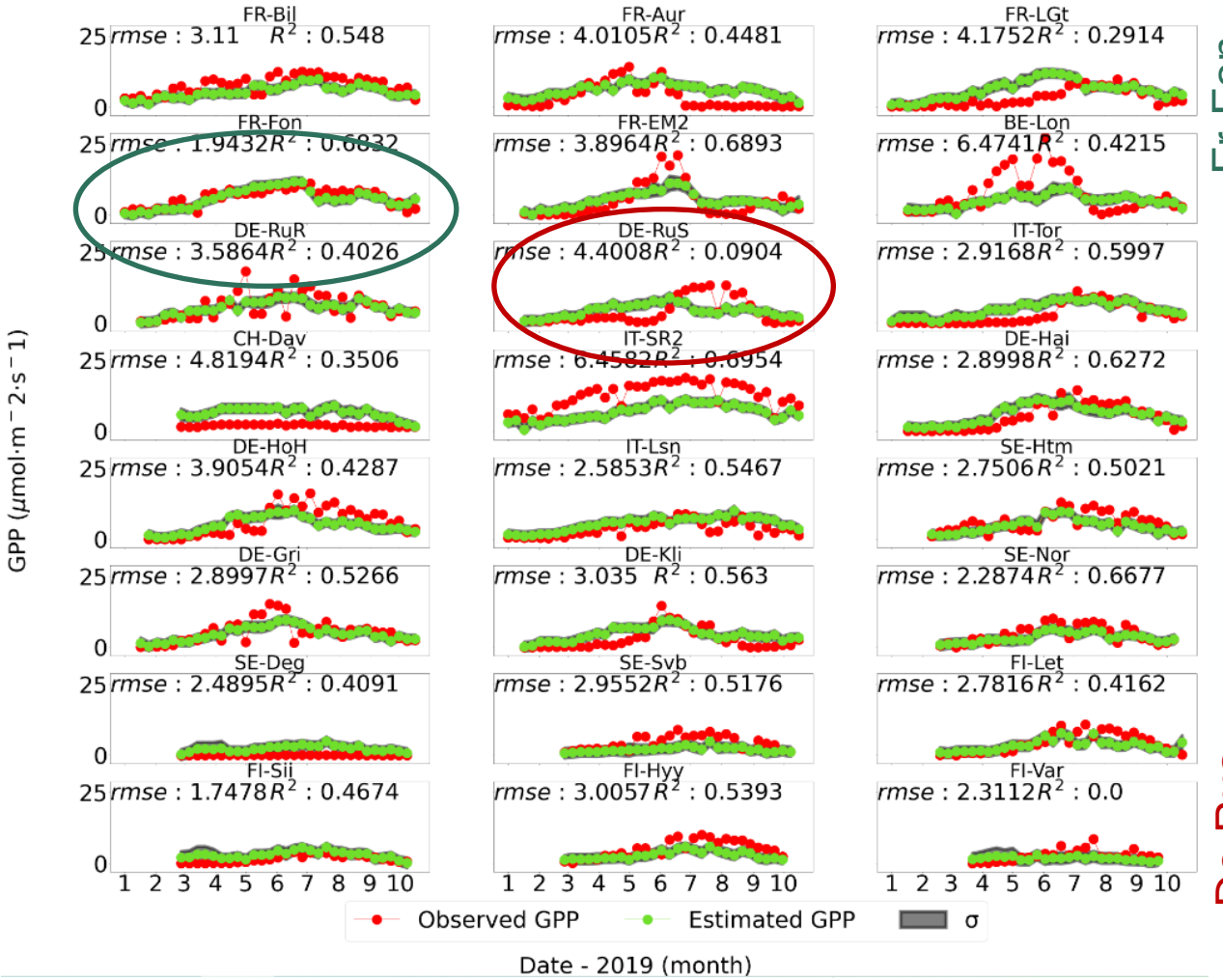


Results

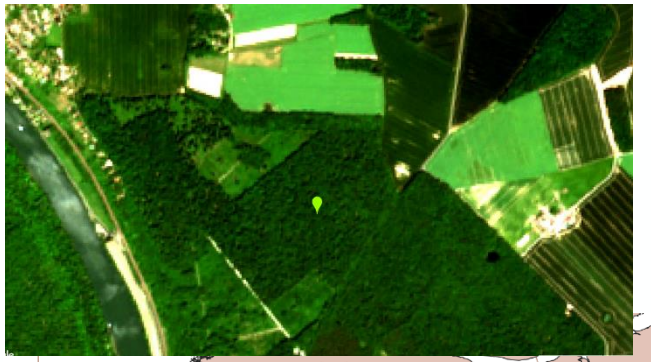
Validation and benchmarking - tower observations:

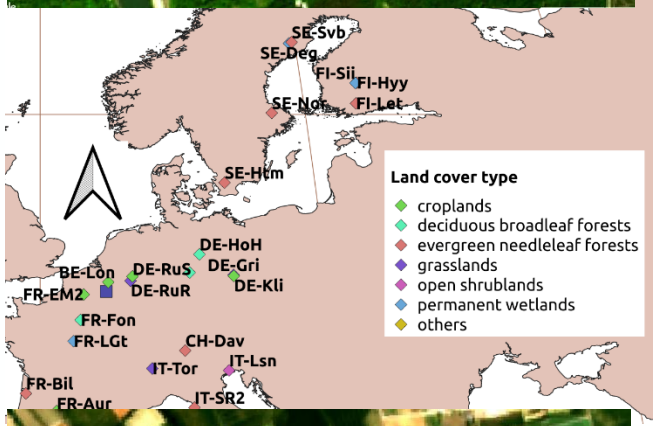
Temporal correlation against FLUXNET GPP product -> Best match for Fr-fon tower (deciduous broad leaf forest) with R^2=0.68 and rmse=1.94µmolm^{-2}s^{-1}

Worst match on DE-RuS (crop land)



Fr-Fon



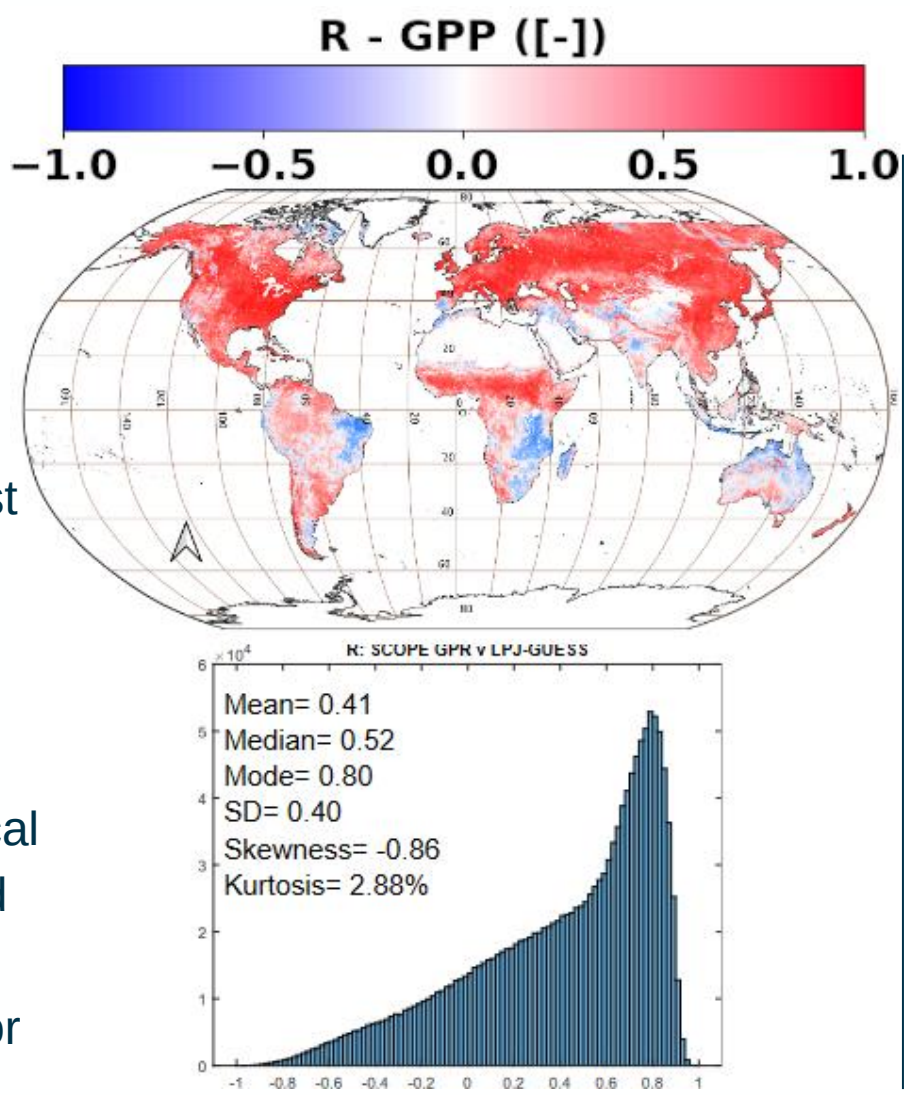


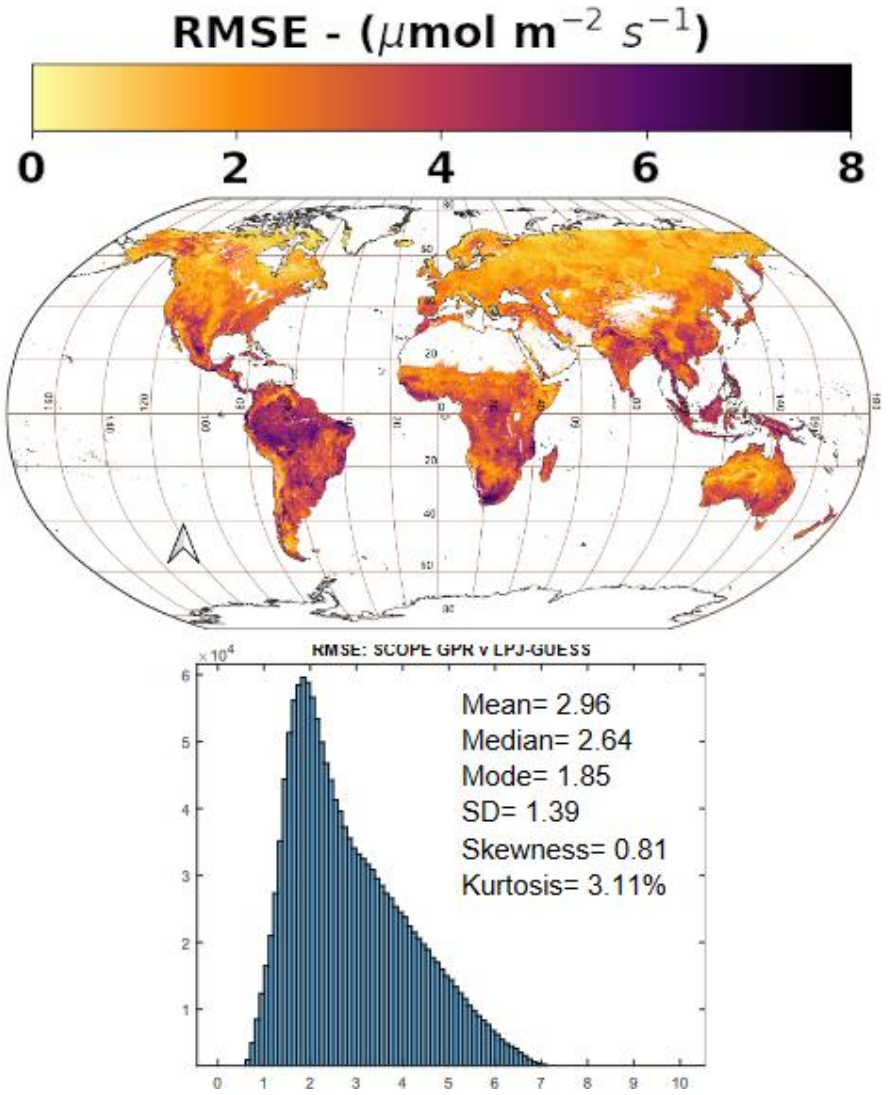
De-Rus

Results

Validation and benchmarking – global intercomparison:

Best intra-annual Pearson cross-correlation (R) against LPJ-GUESS is produced in middle latitudes (northern hemisphere): **Taiga and temperate forests** are well correlated meanwhile tropical areas and scarce vegetated areas in the southern hemisphere present weak or negative correlations.

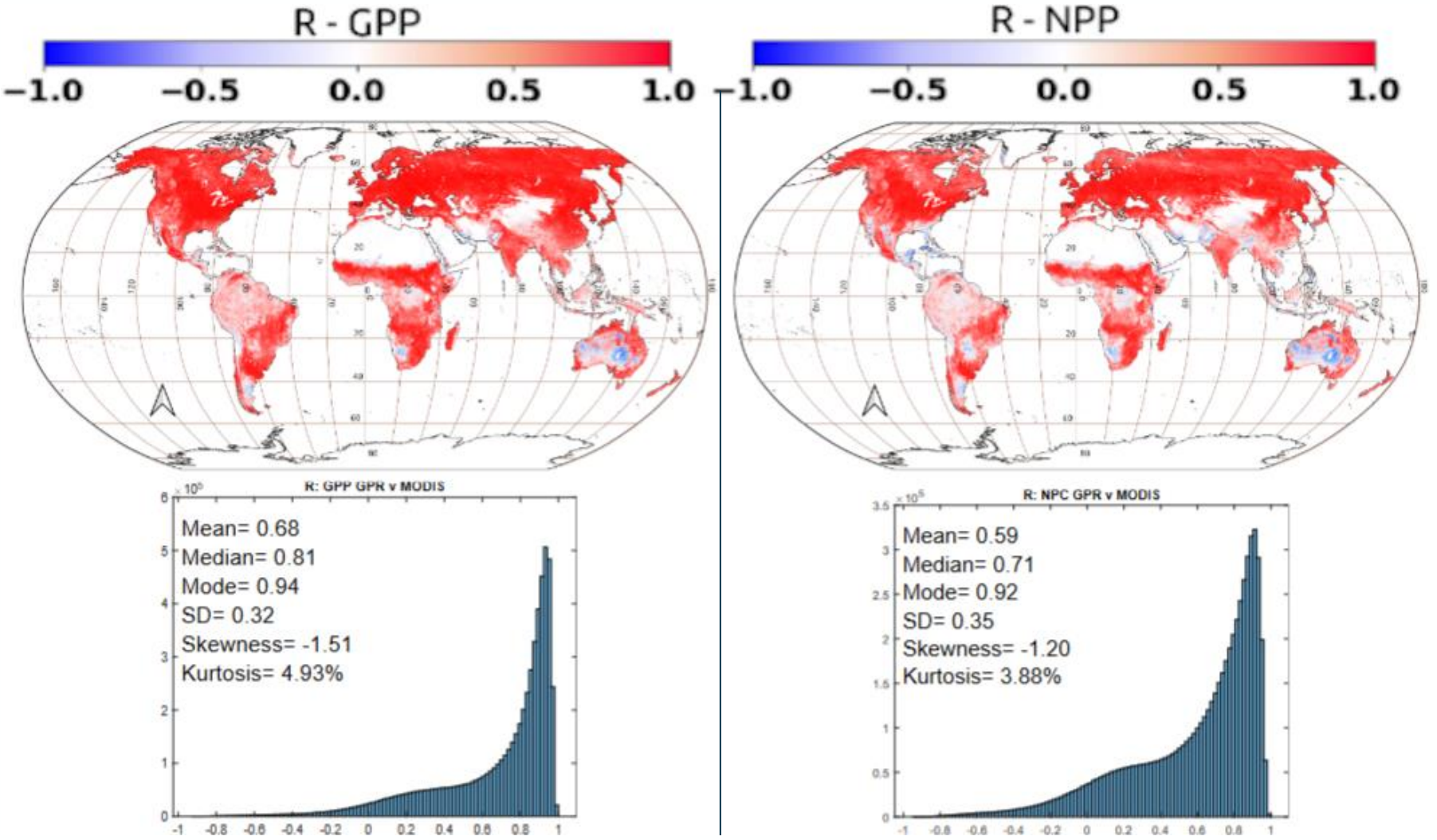




Results

Validation and benchmarking – global intercomparison

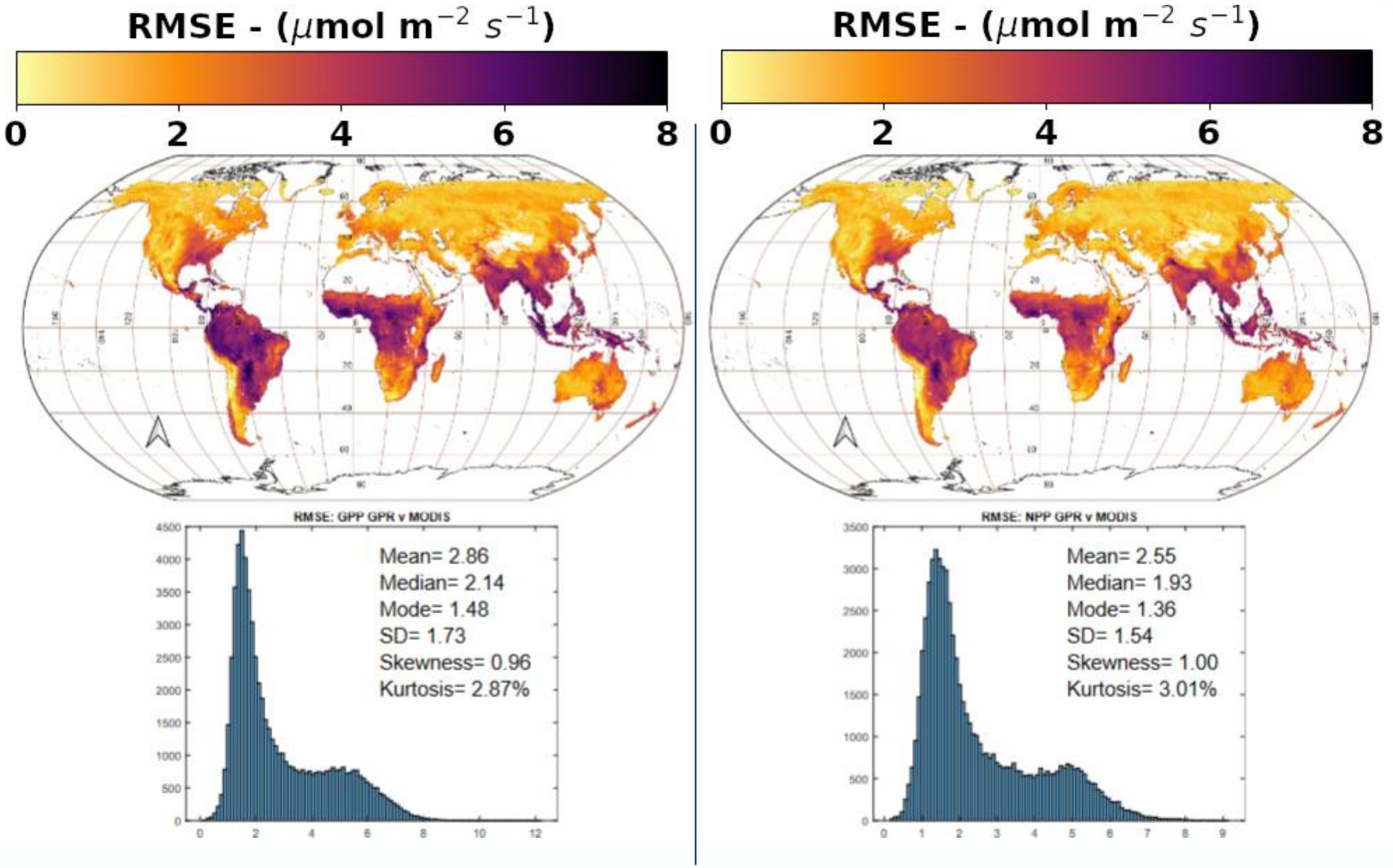
Intra-annual cross-correlation (R) against MOD17A2H was higher than in the case of LPJ-GUESS. Mean biomes of the Earth correlated well except tropical forests and dry areas (e.g. Inner Australia).



Results

Validation and benchmarking – global intercomparison

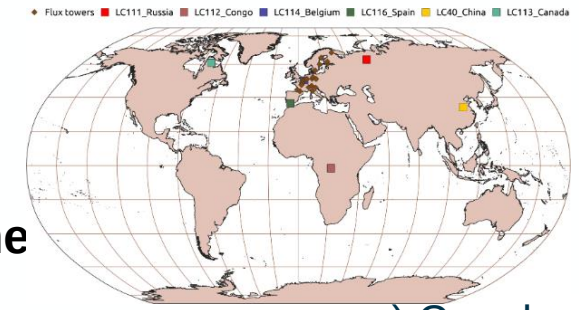
RMSE (against MOD17A2H) presents a similar distributions with smoother values obtained on the northern hemisphere (meanly middle latitudes), meanwhile sharpest differences found along the tropics



Results

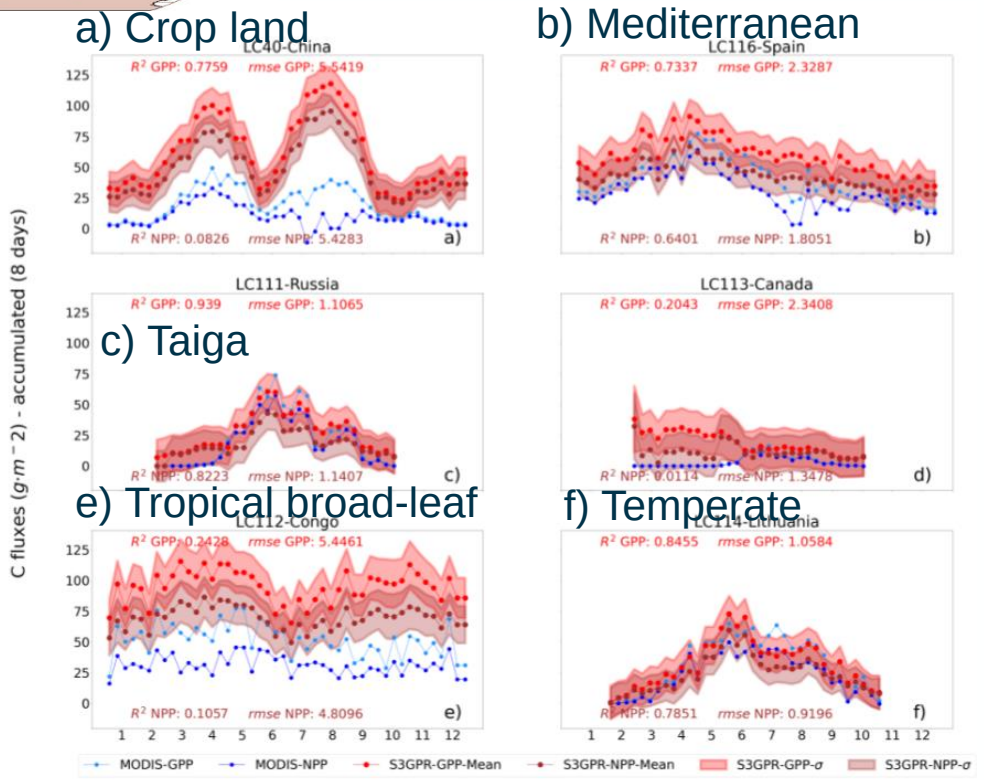
Validation and benchmarking – time Series analysis

An additional intercomparison against MOD17A2H (spatial resolution of 500 m) shows the time series spatially-averaged on different land cover types across the globe. **Highest correlation** is obtained on the **Taiga** and lowest in the equator. Croplands in China shows a discrepant phenological cycle



a)

b)



c)

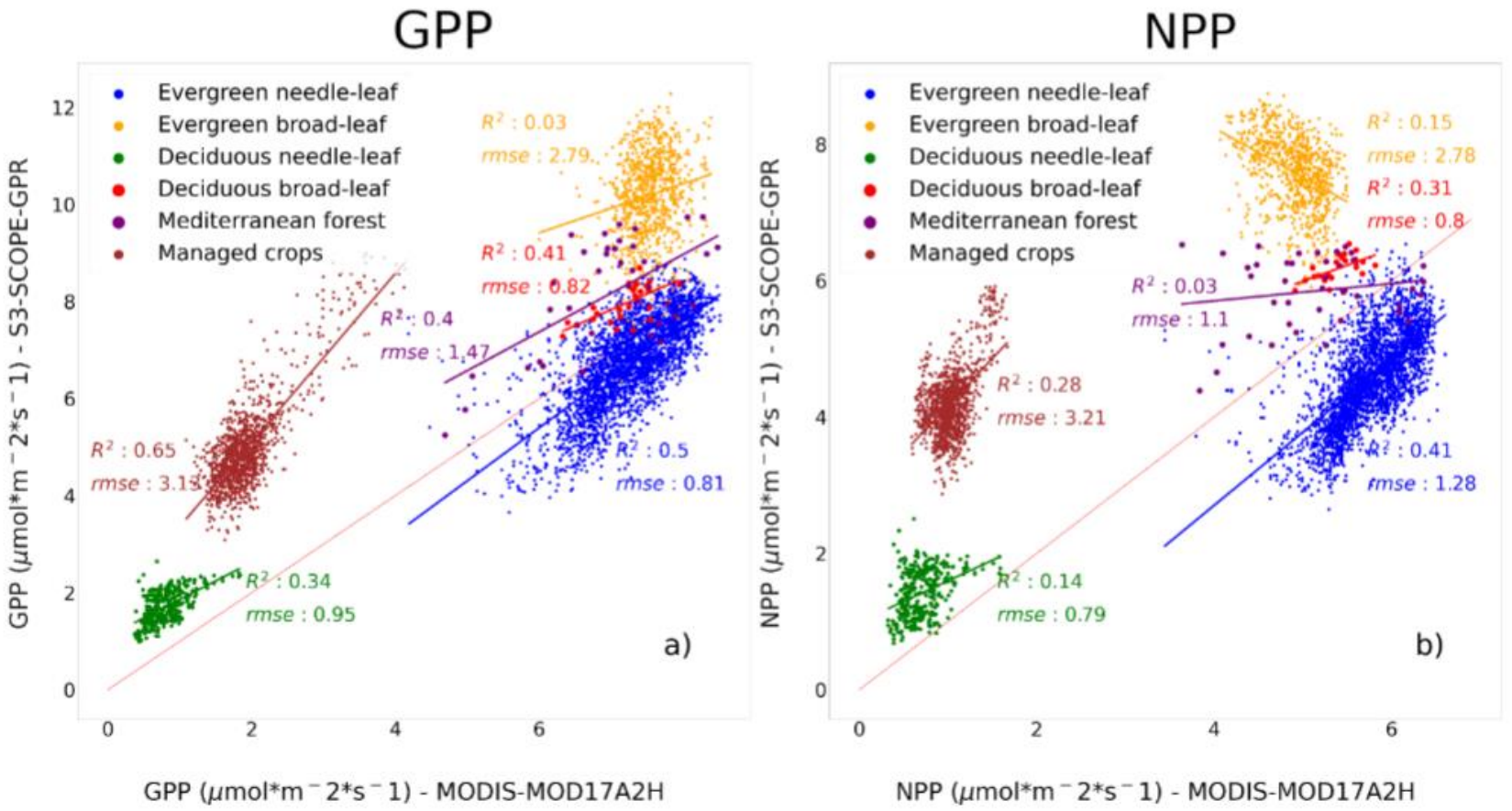
e)

f)

Results

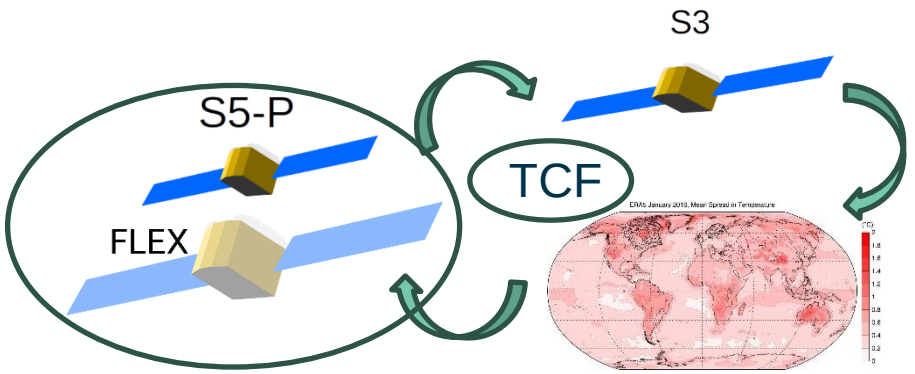
Validation and benchmarking – spatial correlation against MOD17A2H

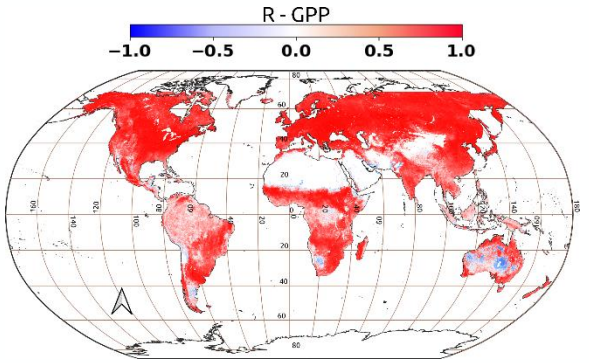
Analysis of spatial inter-correlation (June 2019) show higher match on the Taiga (blue), temperate forests (red) and crop area (brown). Evergreen tropical forests present worst inter-correlation.
Best match for GPP than for NPP



Conclusions:

- The S3&S5P&ERA-5 data synergy allows for global estimation of TCF, generally consistent with reference products (FLUXNET, LPJ-GUESS and MOD17A2H) .
- LAI, FAPAR and SIF, measurable from satellite data are key variables for quantification of TCF
- Cross-correlation against reference products is meanly driven by seasonality and spatial homogeneity
- The lack of spatial resolution explain the worst results against the towers measurements on small crop parcels: a gap potentially solvable with FLEX.
- The versatility of the GPR models allows for improvements counting on new predictors data sets (e.g. FLEX).





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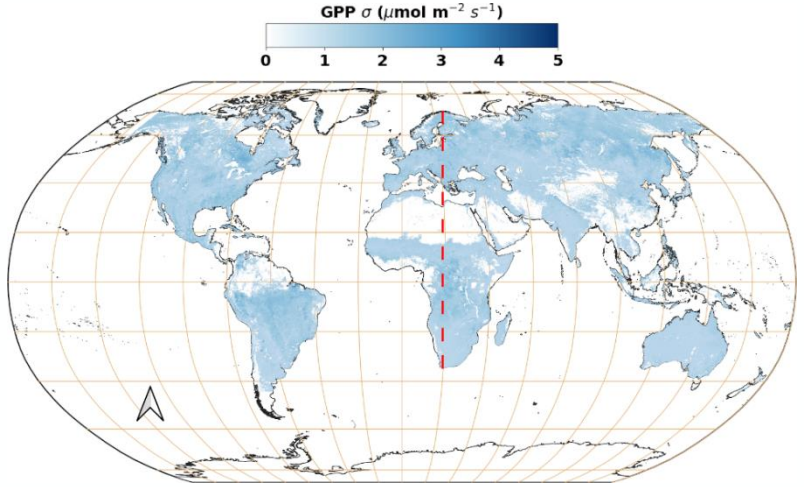

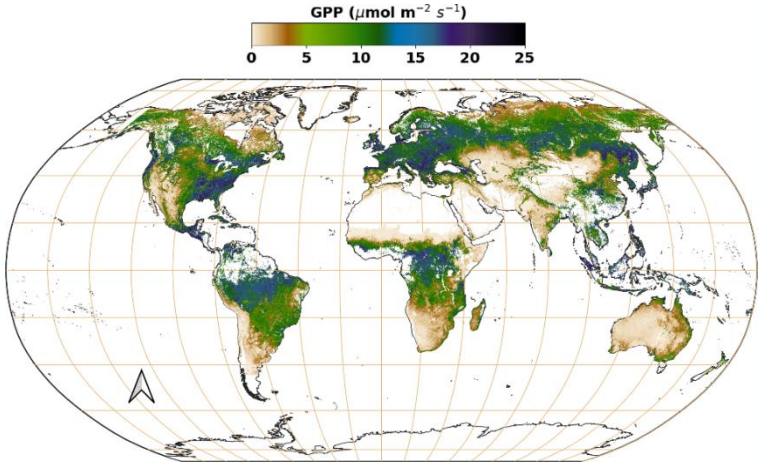

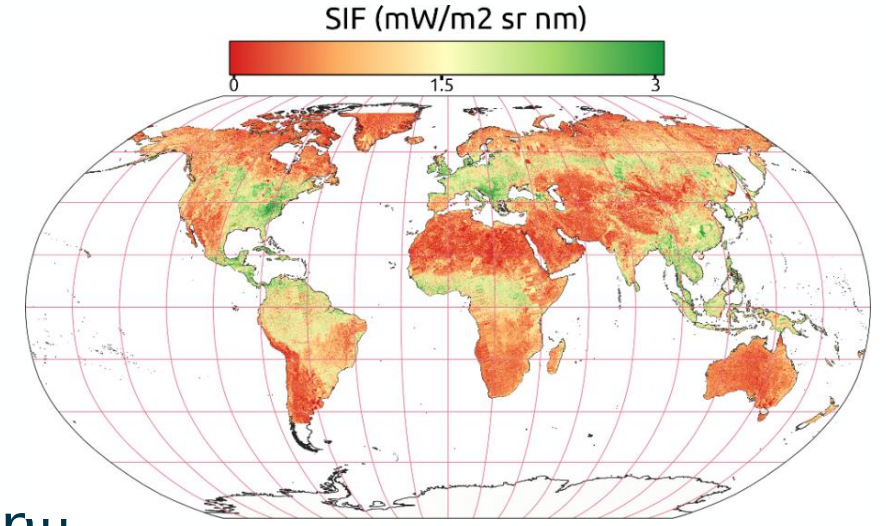
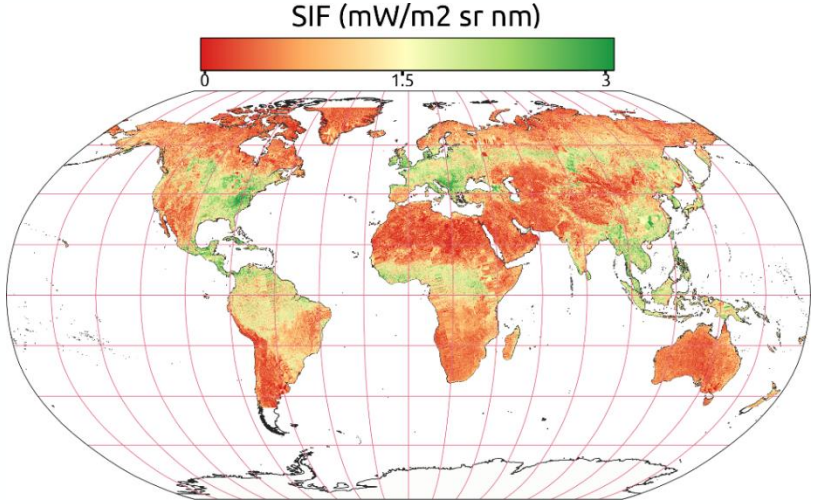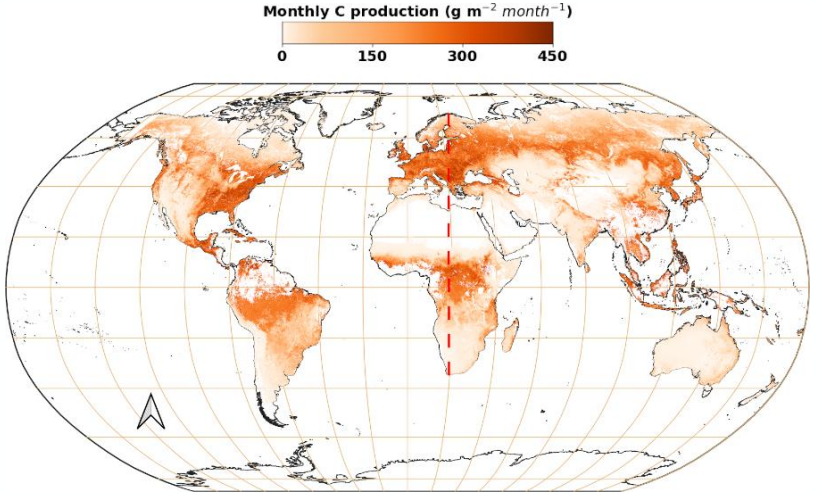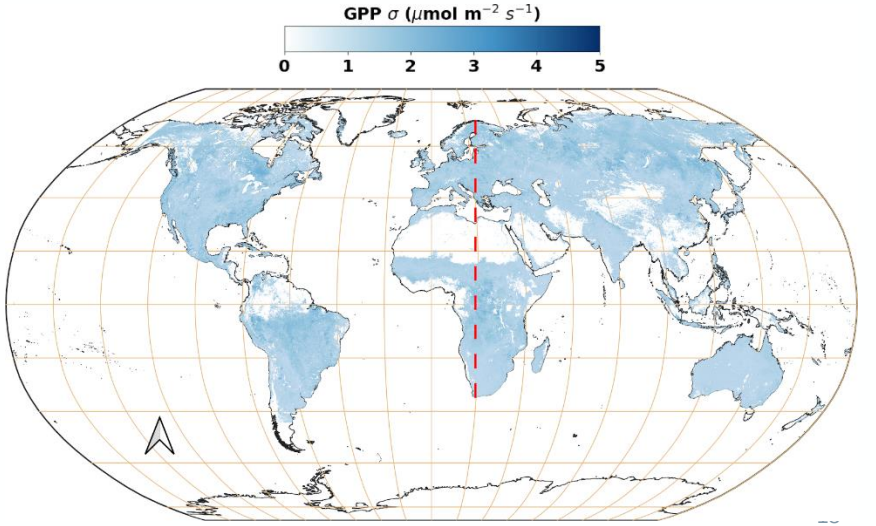
Thanks for your attention!!