Sentinel-2 potential for Gross Primary Production estimation in forests by considering memory effects

David Montero[a,★], Miguel D. Mahecha[a], Khalil Teber[a], Alexander Knohl[b], and Sebastian Wieneke[a]

ABSTRACT

Forests play a major role in the global carbon cycle and the mitigation of climate change effects. Gross Primary Production (GPP), the gross uptake of CO_2, is a key variable that needs to be accurately monitored to understand terrestrial carbon dynamics.

Even though GPP can be derived from Eddy Covariance (EC) measurements at ecosystem scale (e.g., the FLUXNET network), the corresponding monitoring sites are sparse and unevenly distributed throughout the world. Data-driven techniques are among the most used methods to estimate GPP and its spatio-temporal fluctuations for locations where local measurements are unavailable. These methods entail developing an empirical model based on ground-truth GPP measurements and have been a primary tool for upscaling the GPP derived from EC measurements by using traditional Machine Learning methods with satellite imagery and meteorological data as inputs.

Current data-driven carbon flux models utilize traditional models like Linear Regression, Random Forests, Support Vector Machines or Gaussian Processes, while Deep Learning approaches that leverage the temporal patterns of predictor variables are underutilised. Short- and long-term dependencies on previous ecosystem states are complex and should be addressed when modeling GPP. These temporally lagged dependencies of vegetation states, hereinafter memory effects, can be considered in traditional Machine Learning approaches, but must be encoded in hand-designed variables that lose their sequential structure.

Here we show that the estimation of GPP in forests can be improved by considering memory effects using Sentinel-2 imagery and Long Short Term Memory (LSTM) architectures.

We found that the accuracy of the model increased by considering the long-range correlations in time series of Sentinel-2 satellite imagery, outperforming single state models. Furthermore, the additional information contributed from Sentinel-2, such as its high spatial resolution (10-60 m), as well as the vegetation reflectance in the Red Edge bands (703-783 nm), boosted the accuracy of the model.

Our results demonstrate that long-term correlations are a key factor for GPP estimation in forests. Moreover, the Red Edge reflectance enhances the sensitivity of the model to photosynthetic activity and the high spatial resolution of the imagery allows to account for local spatial patterns.

These results imply that novel data-driven models should account for long-term correlations in remote sensing data. Additionally, the information provided by Sentinel-2 imagery demonstrated to increase the accuracy of the model and further investigation should be carried out. For example, local spatial patterns (e.g., tree mortality or deforestation in certain spots in the image) can be further exploited by Deep Learning methods such as Convolutional Neural Networks (CNN).

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INTRODUCTION

Gross Primary Production (GPP) is a key variable that is affected by extreme events (e.g. drought) and needs to be accurately monitored to understand terrestrial carbon dynamics under climate extremes.

Current data-driven models utilize traditional single state methods while Deep Learning approaches that leverage the temporal patterns of predictor variables are underutilised.

QUESTIONS

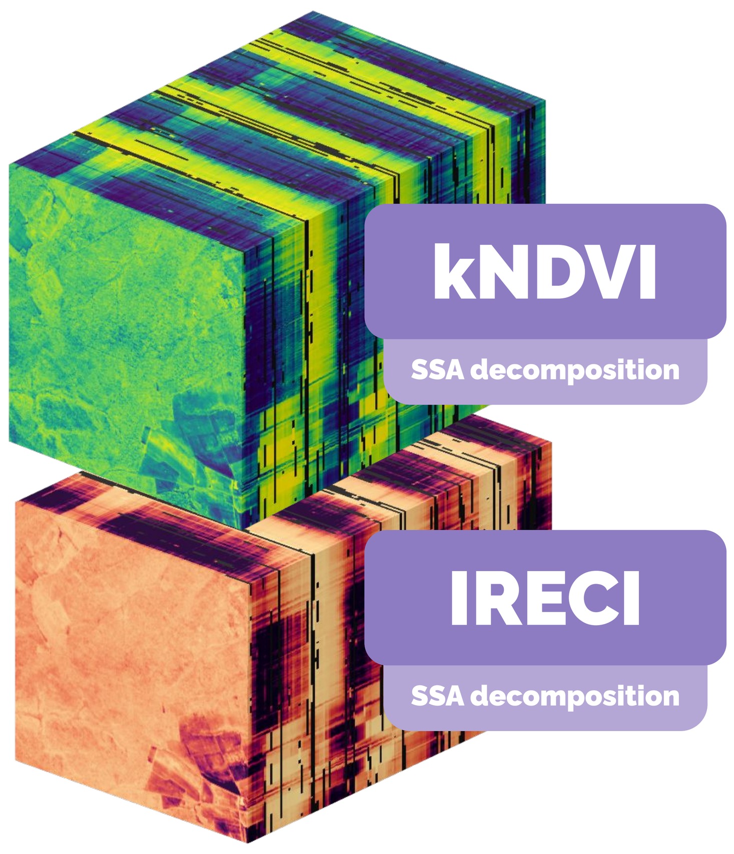
- Can the GPP estimation accuracy be improved by considering memory effects using LSTM architectures and Sentinel-2 spectral indices?
- Do the red edge bands (by means of a red edge spectral index) improve the GPP estimation using these architectures?

MATERIALS AND METHODS

Warm Winter 2020 Dataset
Daily GPP
Weekly mean
DBF, ENF, MF

26 train sites
4 validation sites
1 test site
DE-Hai (DBF)

Sentinel-2
Cloud masking
BRDF correction
Weekly mean



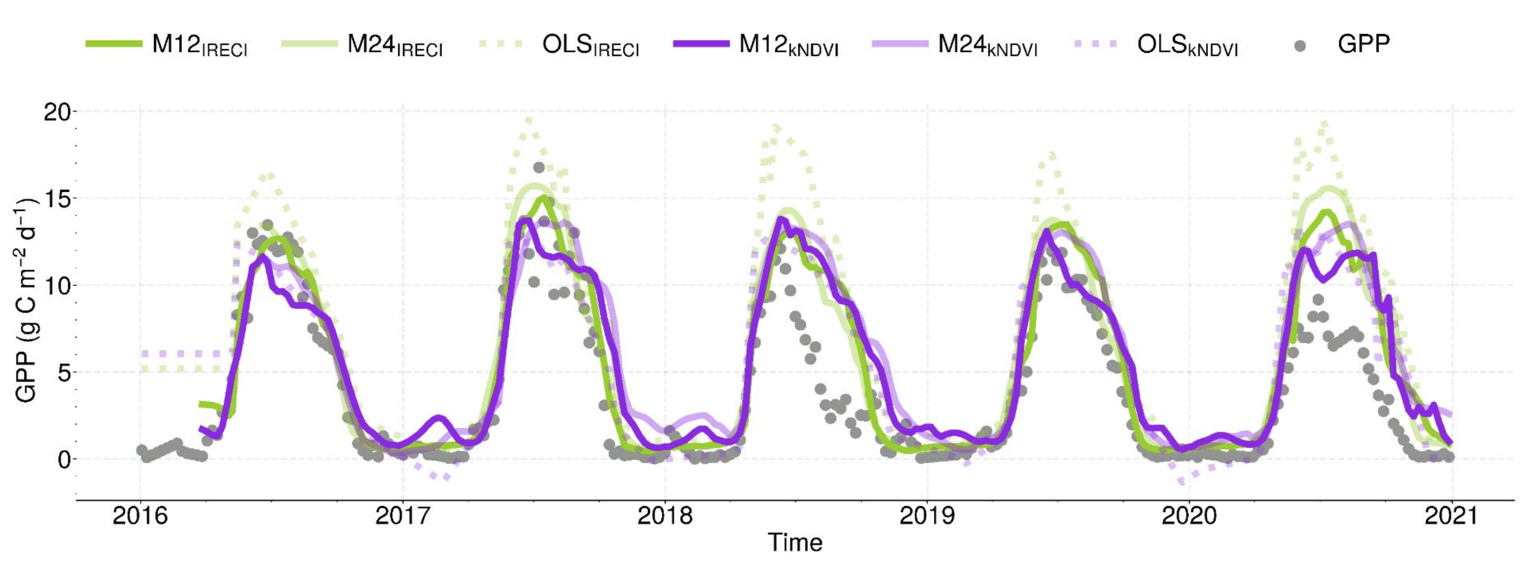
Models
LSTM architectures
3 models per index
Baseline: OLS (no lag)

M12	M24
12 timesteps	**24** timesteps
32 units, recurrent dropout = 0.5, dropout = 0.1	**32** units, recurrent dropout = 0.5, dropout = 0.1
64 units, recurrent dropout = 0.5, dropout = 0.1	**64** units, recurrent dropout = 0.5, dropout = 0.1
output **GPP**	output **GPP**

Training
same setup per model

Adam optimizer
MSE loss
LLO validation

RESULTS



	M12	M24	OLS
IRECI	2.48 RMSE, 0.84 R^2	2.85 RMSE, 0.84 R^2	4.26 RMSE, 0.82 R^2
kNDVI	2.69 RMSE, 0.77 R^2	3.03 RMSE, 0.77 R^2	2.55 RMSE, 0.74 R^2

CONCLUSIONS

The accuracy of GPP estimation increases by taking memory effects into account using LSTM architectures. However, the accuracy did not improve by using a lookback of 24 weeks instead of 12 weeks.

By using the red edge bands, IRECI inputs show a higher accuracy than kNDVI inputs.

Although GPP estimation accuracy increased and the prediction error was lowered, big discrepancies are still visible in periods were GPP was impacted by extreme events.

Further investigation is required to improve GPP estimation by using DL architectures and Sentinel-2 data, especially for periods where GPP was impacted by extreme events.

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