OPTIMIZING HYBRID MODELS FOR CANOPY NITROGEN MAPPING FROM SENTINEL-2 IN GOOGLE EARTH ENGINE

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HIGHLIGHTS

- **Sentinel-2** (S2) bands can estimate **canopy nitrogen content** (CNC) over **croplands**.
- **PROSAIL-PRO** RTM based training data is optimized with **Euclidean distance-based active learning** (AL).
- CNC can be estimated with the **protein-N** and with the **chlorophyll-N relation**.
- CNC is quantified and mapped over cropland using a **Gaussian processes regression** (GPR) model with **uncertainties**.
- **Operational monitoring** of CNC becomes possible with hybrid models implemented in **Google Earth Engine** (GEE).

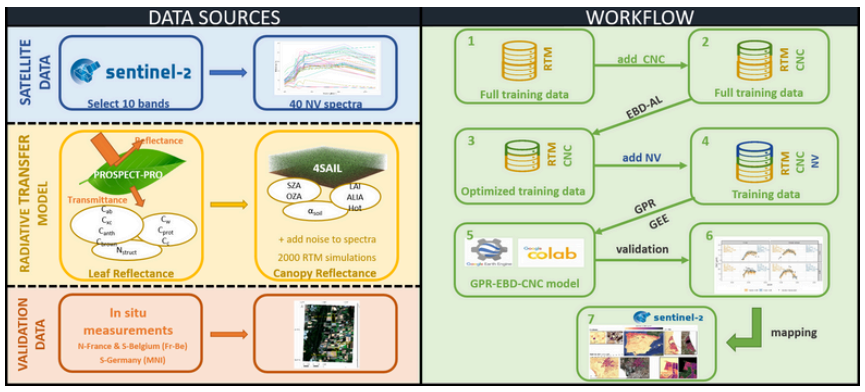
1 INTRODUCTION

Problem: High-spatial-resolution CNC estimation is crucial for local plant health monitoring, optimizing agricultural practices, and assessing ecosystem dynamics.

Challenge: There are no scalable, fine-resolution CNC products from multi-spectral satellite data that capture CNC and can be applied operationnally across large areas.

Objective: To develop and validate accurate and scalable hybrid GPR models for CNC mapping from S2 data, specifically evaluating both protein-N and chlorophyll-N relationships, and implementing them for cloud deployment in GEE.

2 MATERIALS AND METHODS

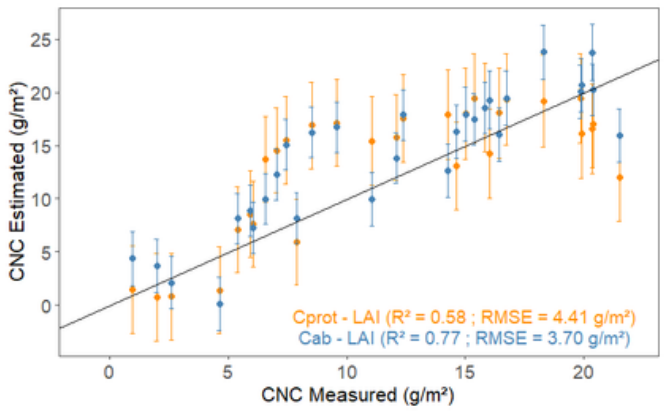


- **Data**
  - **Sentinel-2** surface reflectance: high-spatial resolution optical imagery.
  - **PROSAIL-PRO Radiative Transfer Model**: Generated a generic simulated training dataset (2000 samples).
  - **In-situ CNC data**: Field measurements (Fr-Be, MNI sites) for model tuning and independent validation.
- **Hybrid GPR approach**
  - **CNC approximations**: Evaluated both protein-based and chlorophyll-based relations.
  - **AL**: Optimized PROSAIL-PRO training data to reduce training data size and improve efficiency.
  - **GPR**: Bayesian machine learning with uncertainty. Evaluated against other machine learning algorithms.
- **Application**
  - Implementation of S2-GPR models in GEE and pyEOGPR package for **cloud-computing**.
  - Tested model consistency over growing seasons with **timeseries** analysis.
  - Showcased large-scale CNC **mapping** with associated uncertainties over the Iberian Peninsula.

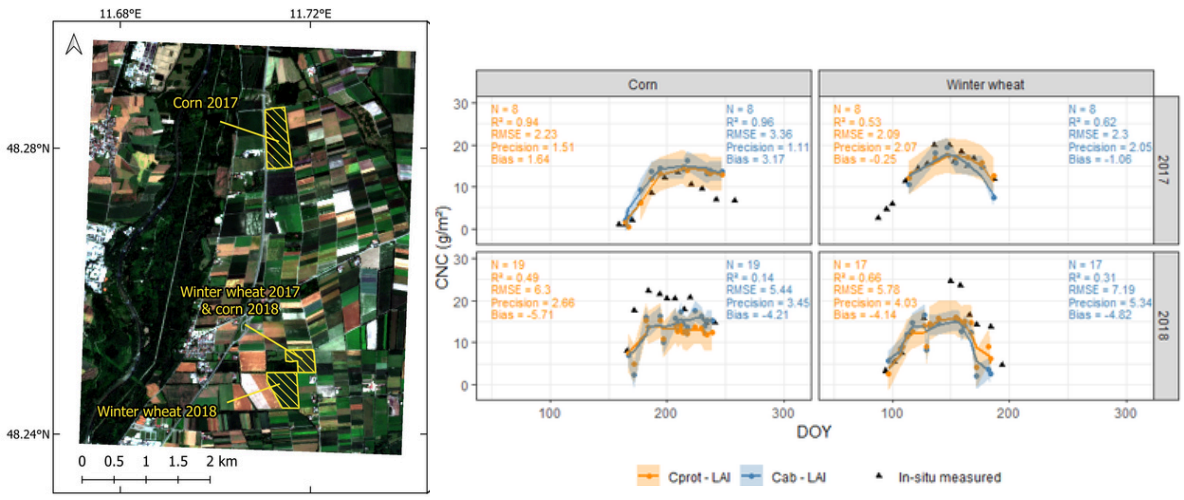
3 RESULTS AND DISCUSSION

MODEL PERFORMACE & ACCURACY

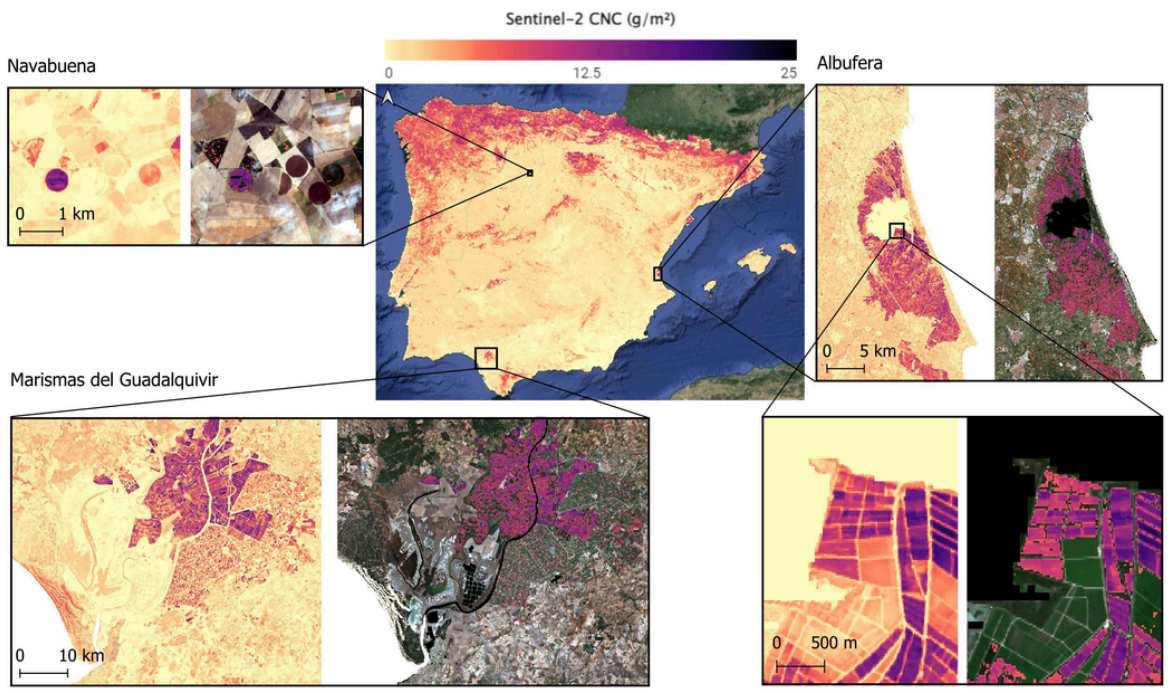
- Both **protein-based (C_{prot}-LAI) and chlorophyll-based (C_{ab}-LAI)** GPR models accurately estimated CNC, with NRMSE of 21.47% and 20.17%, respectively.
- They significantly **outperformed other benchmarked ML methods** (e.g., KRR, PCR, neural network), and regression algorithms (PLSR,, nearest neighbor).
- Analysis of GPR hyperparameters revealed **key S2 bands** for CNC estimation, highlighting the red-edge and SWIR bands.



INDEPENDENT VALIDATION



MAPPING APPLICATION



4 CONCLUSIONS

- We developed scalable hybrid GPR models for S2-based CNC mapping.
- Both protein-N and chlorophyll-N relationships proved viable for CNC estimation, with the chlorophyll-based model showing slightly higher independent validation accuracy.
- Implementation in GEE enables operational, large-scale monitoring of crop nitrogen dynamics with associated uncertainty estimates.
- This work provides a powerful, accessible tool for CNC quantification, crucial for precision agriculture and ecosystem management.

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REFERENCES

De Clerck, E., Kovács, D. D., Berger, K., Schlerf, M., & Verrelst, J. (2024). Optimizing hybrid models for canopy nitrogen mapping from Sentinel-2 in Google Earth Engine. ISPRS Journal of Photogrammetry and Remote Sensing, 218, 530-545.

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