Comparative analysis of full-spectrum SIF Principal Component Reconstruction versus SpecFit

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Introduction

Photosynthesis releases Solar-Induced Fluorescence (SIF) as a byproduct, a key signal for monitoring vegetation health and climate regulation. Reliable SIF retrieval is constrained to atmospheric absorption bands O_2A (760 nm) and O_2B (687 nm) due to its weakness relative to reflected radiance. Retrieving the full SIF emission spectrum (640–850 nm) remains a major challenge. This study proposes an approach based on fast Principal Component Analysis (PCA) to reconstruct the complete SIF spectrum and compare it with SpecFit in terms of accuracy and speed. In anticipation of the ESA's FLEX mission, robust reconstruction methods need to be developed and validated.

Conclusions

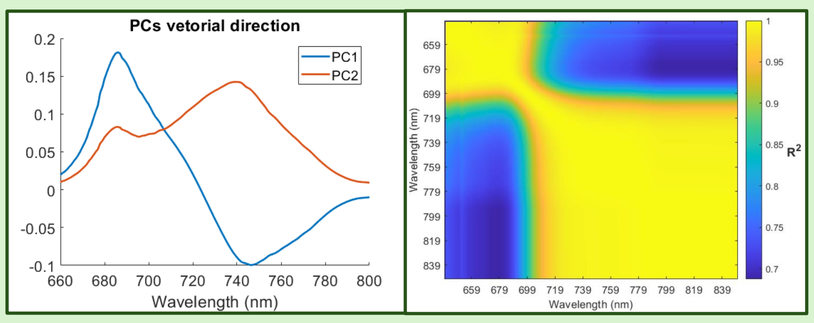
- The results demonstrate the potential of the proposed method to reconstruct a synthetic full-SIF spectrum from the retrieved values in O_2A and O_2B.
- PC reconstructions (PCrec) can obtain a fast and accurate estimation of integrated SIF at canopy level and can be directly applied to HyPlant SFM products.
- A performance comparison of the most used SIF retrieval methods and PCrec shows that PCrec produced better results in O_2B and processed spectra ten times faster.

Materials & Methods

- **Data:**
  - **CKA-Bonn:** Klein-Altendorf campaigns during the years 2021, 2022 and 2023. Fields of wheat and faba bean. Measurements with FLoX, LoX and HyPlant.
  - **IVIA-Valencia:** A three-day field campaign was conducted at Valencian Institute of Agricultural Research (IVIA), on September 27, 29, and October 5, 2021. Healthy and SPLCV-infected Ipomoea batatas were measured diurnally (10:00–18:00). Measurements with QEPRO VNIR + Fluowat leaf clip.
- **Sensors:**
  - **FLoX:** Mobile field device to measure hyperspectral reflectance and canopy fluorescence using a QEPRO spectrometer.
  - **FluoWat:** Leaf clip device design for measurement of SIF reflectance and transmittance.
  - **LoX:** FluoWat leaf clip paired with a Leaf Fluorescence Box QEPRO spectrometer.
  - **HyPlant (FLUO):** SIF-SFM product in O_2A and O_2B with uncertainties. Spatial resolution of 1.7m.
- **Methods:** SCOPE, Principal Component Analysis (PCA), SpecFit.

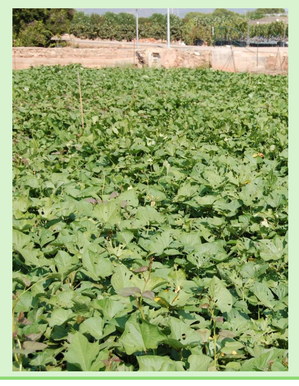
Canopy level

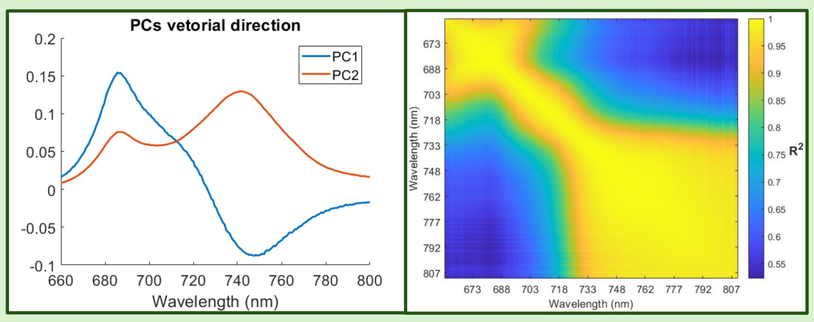
- We generated a SCOPE LUT of 10,000 samples with LHS distribution. Then used this LUT to generate the PCA matrix for PCrec.
- Two PCs represent the 99.38% of the SIF-SCOPE variance.
- Using the SFM values in 687 and 760nm measured by FloX we reconstructed full spectra for all measurements using the PCrec.
- Then we compared PCrec with SpecFit measurements at the canopy level.



Leaf level

- We used a LUT obtained from LoX measurements from the Bonn site and based the PCA matrix transformation on that dataset.
- Using a total of 138 IVIA radiance and irradiance measurements, we applied iFLD, SFM, SpecFit, and PCrec (based on iFLD measurements) to retrieve SIF.
- We compared the results with in-situ SIF measurements obtained from the FluoWat.

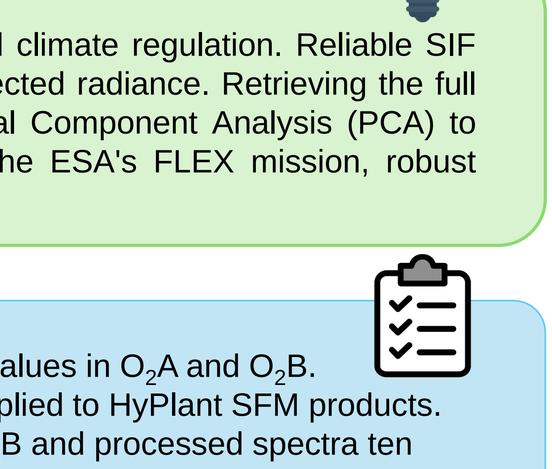


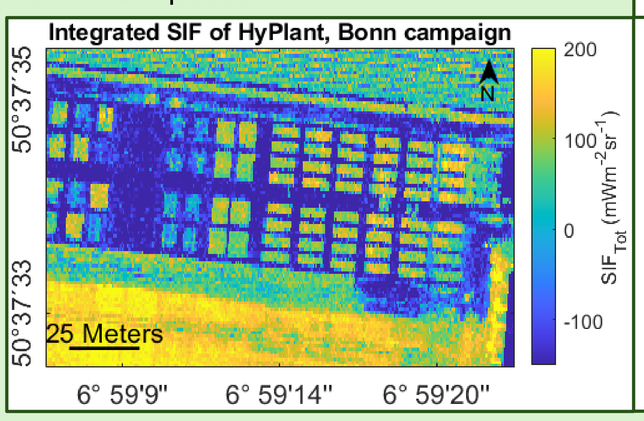


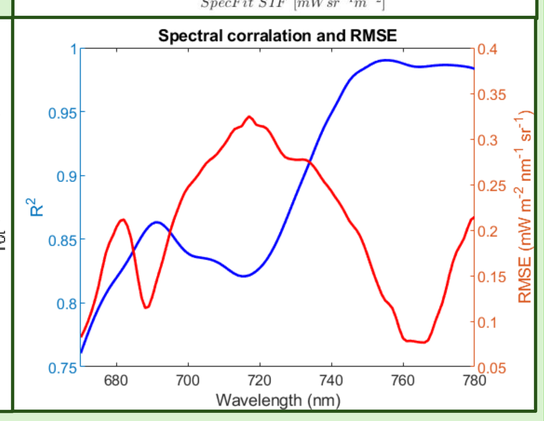
Results

Canopy level

- Integrated SIF with PCrec obtained an R^2 of 0.98 and an RMSE of 11.5 $mWm^{-2}sr^{-1}$ in comparison with SpecFit.
- Consistent estimator of Integrated SIF.
- Consistent spectral correlation with SpecFit, with R^2 upper than 0.75 and RMSE lower than 0.3 $mWm^{-2}sr^{-1}nm^{-1}$ in the full spectral range.
- Consistent correlation in the right region of the spectra and a bit lower in the left region.
- Easy application to the HyPlant SFM product through ARTMO, producing full-SIF images.
- Fast processing in the Bonn image at 10^{-5} seconds/spectrum.

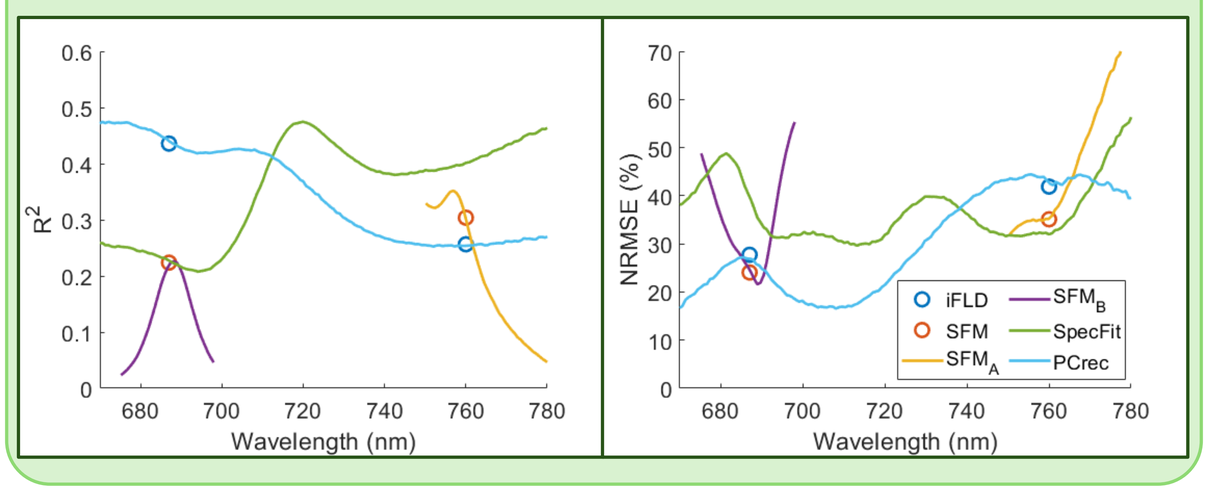






Leaf level

- The explained variance of PC from the leaf-clip dataset was of 98.70% for only 2PCs.
- The residuals (unexplained variance) caused by the reduced dimensionality SIF shapes were below 0.1 $mWm^{-2}sr^{-1}nm^{-1}$.
- The low resolution of sensors causes low performances for all methods, but we can compare between them.
- SpecFit process at 10^{-2} seconds/spectrum, while iFLD + PCrec process at 10^{-3} seconds/spectrum.



Morata et al. (2025). On the potential of principal component analysis for the reconstruction of full-spectrum SIF emission and emulated airborne-to-satellite upscaling. Remote Sensing of Environment, 328, 114865

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