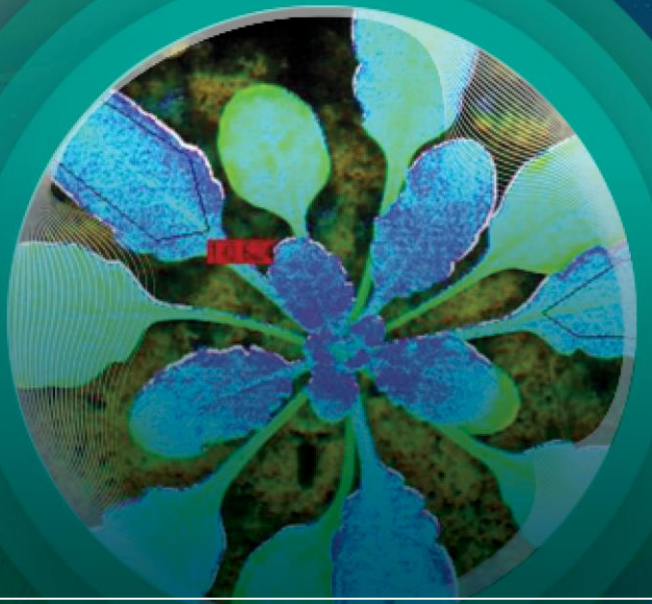
FLEX-Fluorescence 2026 Workshop

03 – 06 March | Bonn University, Germany



Bridging the Gap to the FLEX Era: A Cloud-Computing Framework for 300 m Global SIF Retrieval from Sentinel-3 and TROPOSIF

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Motivation & Research Gap

Why do we need S3-based 300 m SIF products?

Coarse Resolution

Most satellite SIF products (e.g., OCO-2, TROPOMI, GOME-2, and their downscaled datasets) are limited by their spatial resolution or regional coverage, preventing their effective use in fine-scale ecosystem studies and precision agriculture.

FLEX Not Yet Available

ESA's FLEX mission will provide dedicated 300 m SIF. The scientific community urgently needs preparatory sub-km datasets NOW to maximize FLEX's impact.

Scalability Challenge

Generating and managing large-scale high-resolution SIF datasets is computationally intensive—traditional local workflows cannot handle petabyte-scale S3 archives.

Our Solution: Fuse Sentinel-3 OLCI (300 m) with TROPOSIF$_{743}$ via Random Forest on Google Earth Engine → first global 300 m, 4-day SIF product operational from 2016.

Research Objectives

01

Generate S3-SIF$_{743}$

First global 300 m, 4-day SIF product derived from Sentinel-3 OLCI fused with TROPOSIF$_{743}$ via Random Forest on Google Earth Engine.

02

Validate the Product

Validate against ground-based tower SIF observations across diverse ecosystems (savanna, cropland, mixed vegetation) and compare to TROPOSIF

03

Demonstrate Spatial Heterogeneity

Show the ability of the 300 m product to resolve sub-kilometer variability — irrigated croplands, climate zones, ecosystem boundaries.

04

Bridge to ESA FLEX

Provide a preparatory dataset and operational framework for the upcoming FLEX mission (launch 2026) at matching 300 m spatial resolution and using Sentinel-3 data that FLEX will fly in tandem with.

Methodology: Downscaling Framework

S3 OLCI Bands

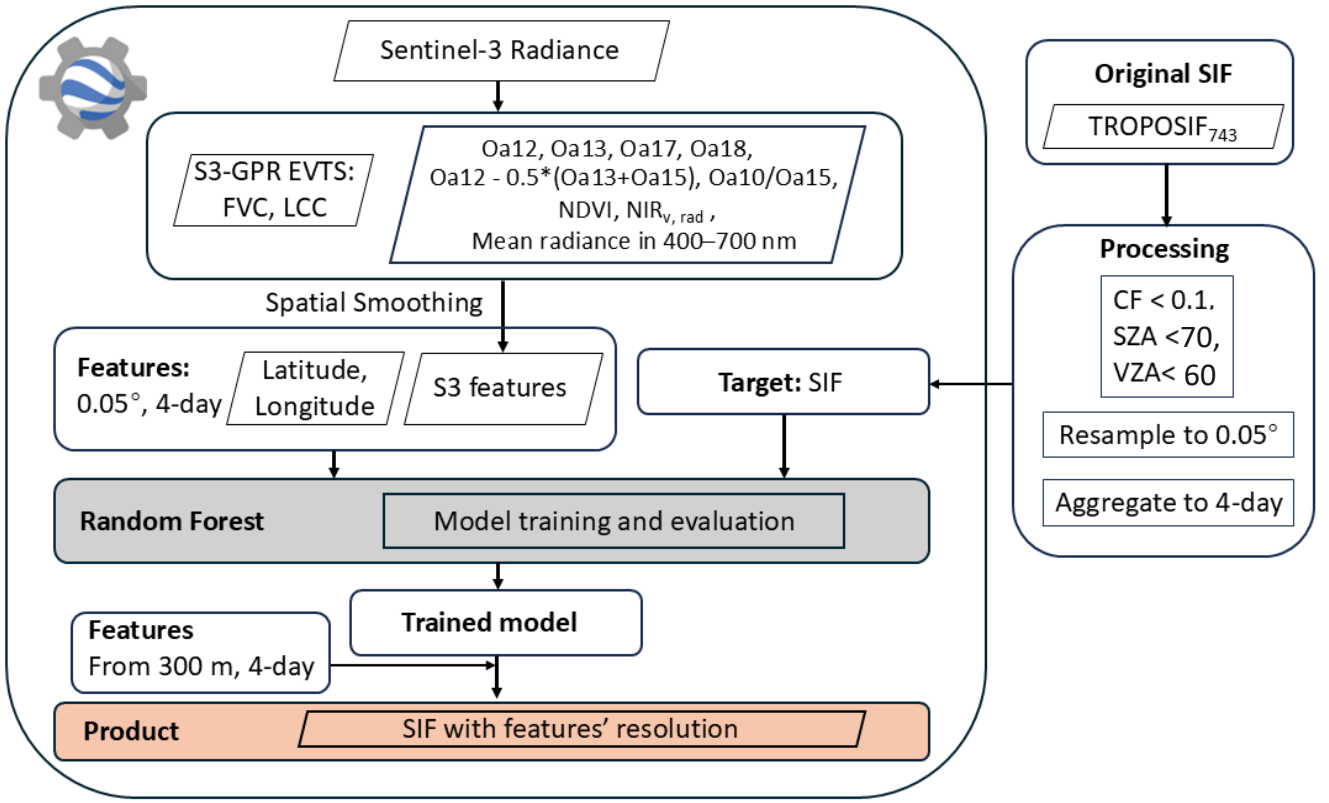
- **Oa12 (753.75 nm)**
  Within $TROPOSIF_{743}$ retrieval window
- **Oa13 (761.25 nm)**
  O_2-A absorption — fluorescence proxy
- **Oa17 (865 nm)**
  Atmospheric/background correction
- **Oa18 (885 nm)**
  Atmospheric/background correction
  Vegetation monitoring

Spectral Indices

- **k = Oa10 / Oa15**
  SIF-sensitive ratio (681 nm / 767 nm)
- **L = Oa12 – 0.5×(Oa13+Oa15)**
  O_2-A absorption depth
- **NDVI**
  Vegetation greenness (Oa17 vs Oa08)
- **NIRvR = NDVI × Oa17**
  Near-infrared radiance of vegetation

Ancillary Features

- **Mean rad 400–700 nm**
  Photosynthetically active radiation band
- **FVC (GPR model)**
  Fractional Vegetation Cover from S3-GPR
- **LCC (GPR model)**
  Leaf Chlorophyll Content from S3-GPR
- **Latitude & Longitude**
  Geographic context for global generalization



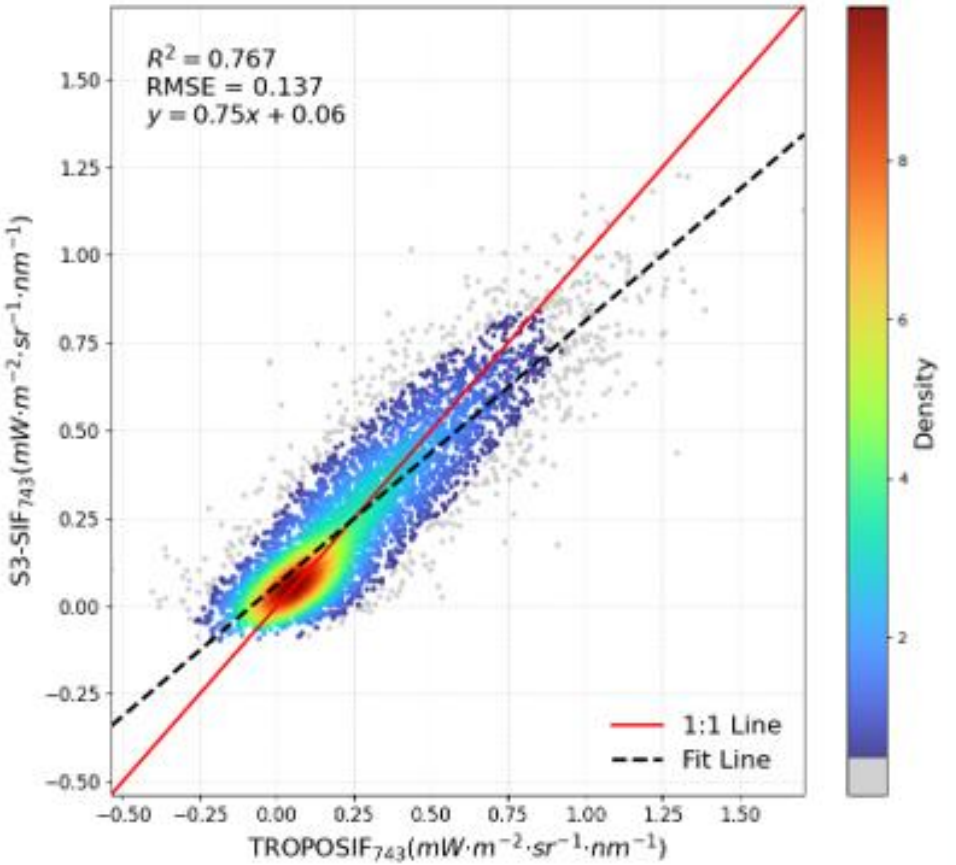
Workflow for downscaled 300 m resolution S3-SIF_{743} generation integrating S3 OLCI and$TROPOSIF_{743}$.

Training: Europe, April–November 2019 | Prediction: Global, 2016–

Model Performance: European Test Set

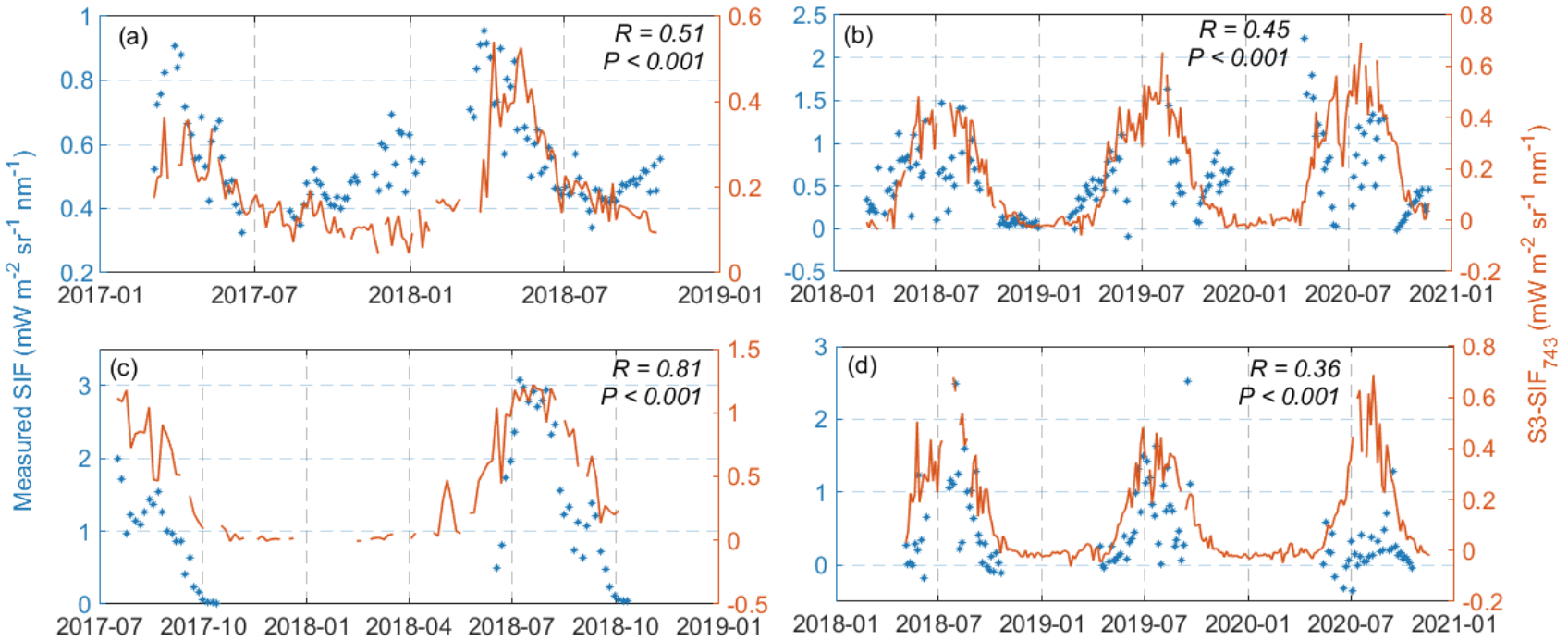
Key Observations

- Strong positive linear relationship with $TROPOSIF_{743}$.
- Good agreement across the dominant value range when $TROPOSIF_{743} > 0$.
- Underestimation at high SIF values (>0.8 mW m^{-2} sr^{-1} nm^{-1}) — typical RF regression-to-mean behavior.
- Limited reproduction of negative $TROPOSIF_{743}$ values (noise-driven artifacts).



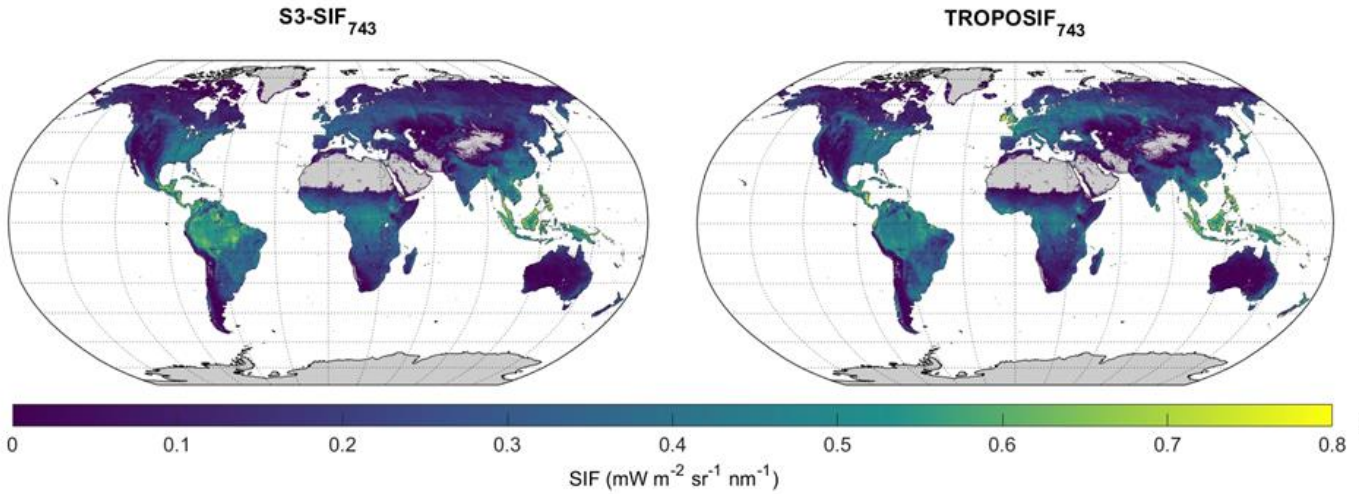
Scatter Plot: S3-SIF$_{743}$ vs TROPOSIF$_{743}$

Temporal Validation Against Tower-Based SIF

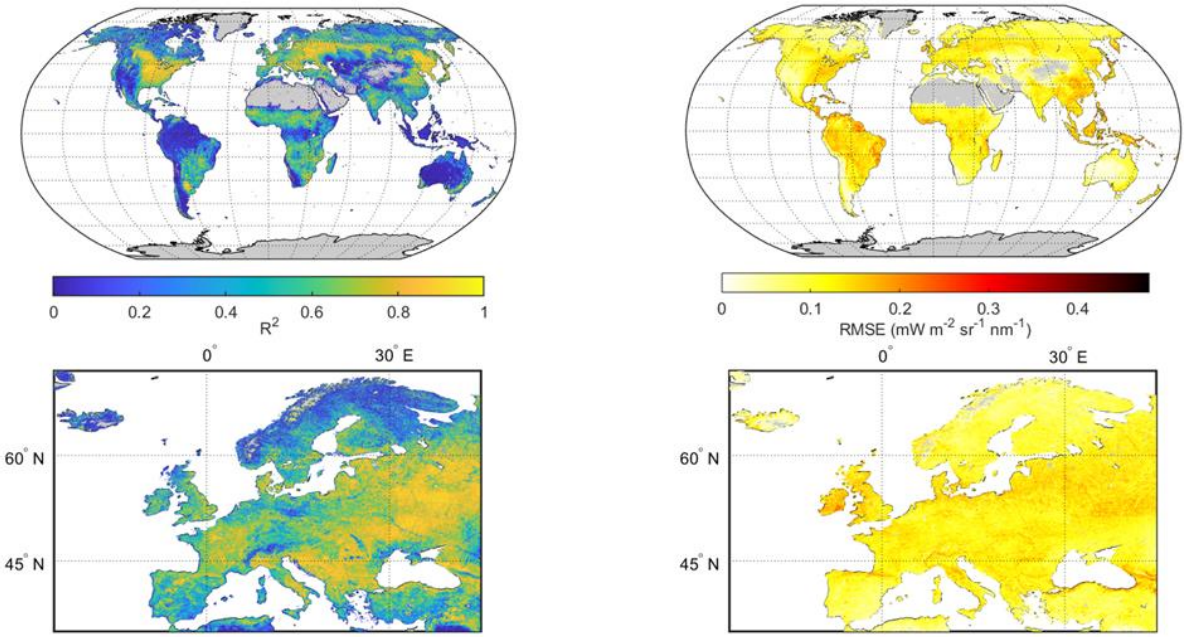


Site	Time period	Position	Observation system	Ecosystem type
(a) Majadas de Tiétar	2017/03 - 2018/10	39.9°N, 5.8°W (Spain)	FloX	Savanna
(b) XiaoTangshan	2018/03 - 2020/11	40.2°N, 116.4°E (China)	AutoSIF	Cropland (winter wheat and maize rotation)
(c) US-Ne2	2017/07 - 2018/10	41.2°N, 96.5°W (USA)	FluoSpec2	Cropland (Corn-soy rotation)
(d) HuaiLai	2018/05 - 2020/11	40.3°N, 115.8°E (China)	AutoSIF	Mixture of grassand crabapple trees

Spatial Distribution (0.05°, 2020 annual)



Spatial patterns of yearly-averaged S3-SIF$_{743}$ and TROPOSIF$_{743}$ at 0.05° in 2020.



Intra-annual R^2 and RMSE between S3-SIF$_{743}$ and TROPOSIF$_{743}$ in 2020

SIF Hotspots

Highest SIF >0.6 mW m^{-2} sr^{-1} nm^{-1}: Amazon, Central Africa, SE Asia, US Corn Belt

S3-SIF$_{743}$ vs TROPOSIF$_{743}$

Slightly higher Amazonian values; slightly lower in Europe

Low-SIF regions:

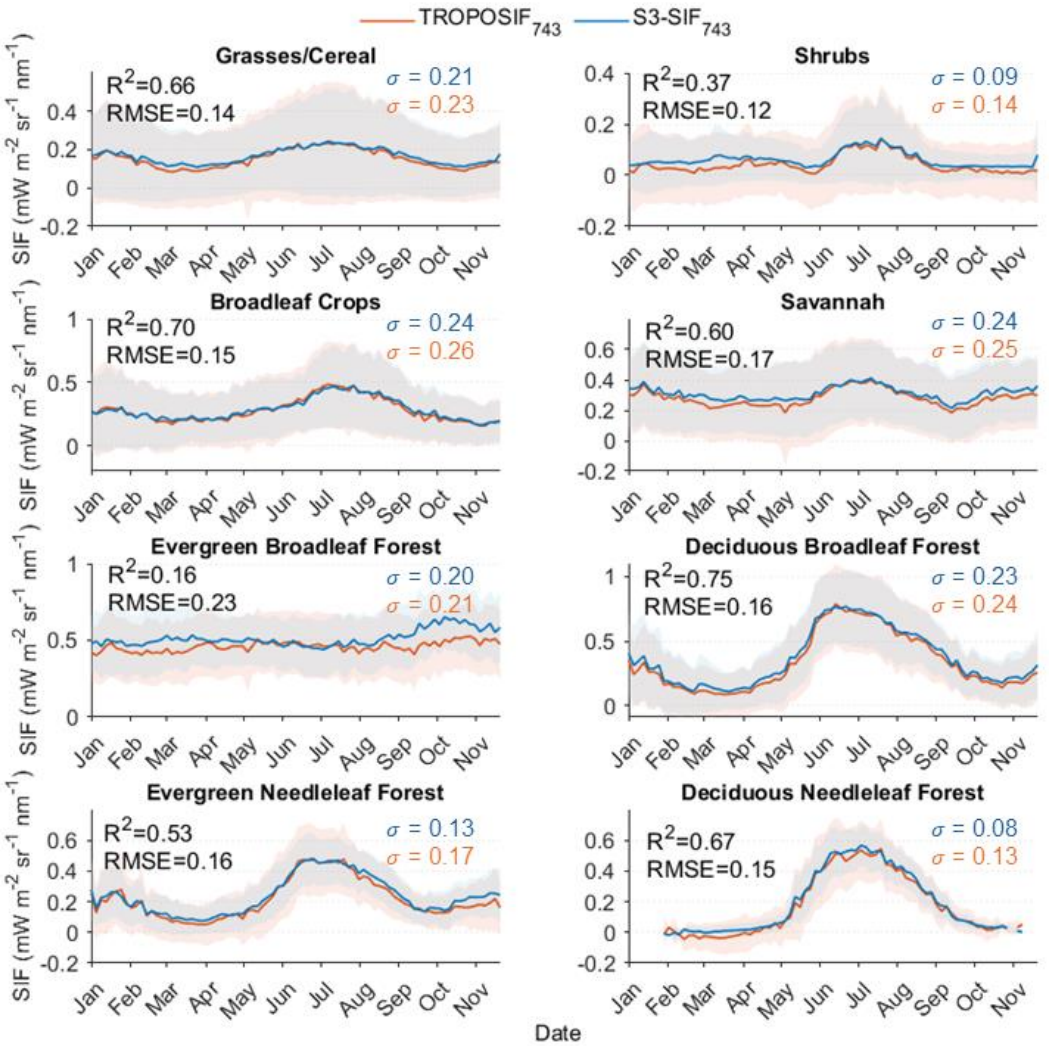
Sahara, Arabian Peninsula, Arctic/Antarctic (< 0.2 mW m^{-2} sr^{-1} nm^{-1})

Pixel-wise Agreement

Temperate Croplands	**R^2 > 0.8**
Boreal Forests Grasslands	**R^2 0.4–0.6**
Arid Regions Tropical Forests	**R^2 < 0.4**

RMSE < 0.1 mW m^{-2} sr^{-1} nm^{-1} across most global regions

Seasonal Cycles by Vegetation Type



Comparison between S3-SIF$_{743}$ and TROPOSIF$_{743}$ for each vegetation type.

Vegetation Type	R^2	RMSE	σ S3-SIF$_{743}$	σ TROPOSIF$_{743}$	Agreement
Deciduous Broadleaf Forest	0.75	0.16	**0.23**	0.24	**High**
Deciduous Needleleaf Forest	0.67	0.15	**0.08**	0.13	**High**
Broadleaf Crops / Croplands	0.70	0.15	**0.24**	0.26	**High**
Grasses / Cereal	0.66	0.14	**0.21**	0.23	**Good**
Savannah	0.60	0.17	**0.24**	0.25	**Good**
Evergreen Needleleaf Forest	0.53	0.16	**0.13**	0.17	**Moderate**
Shrubs	0.37	0.12	**0.09**	0.14	**Moderate**
Evergreen Broadleaf Forest	0.16	0.23	**0.20**	0.21	**Low**

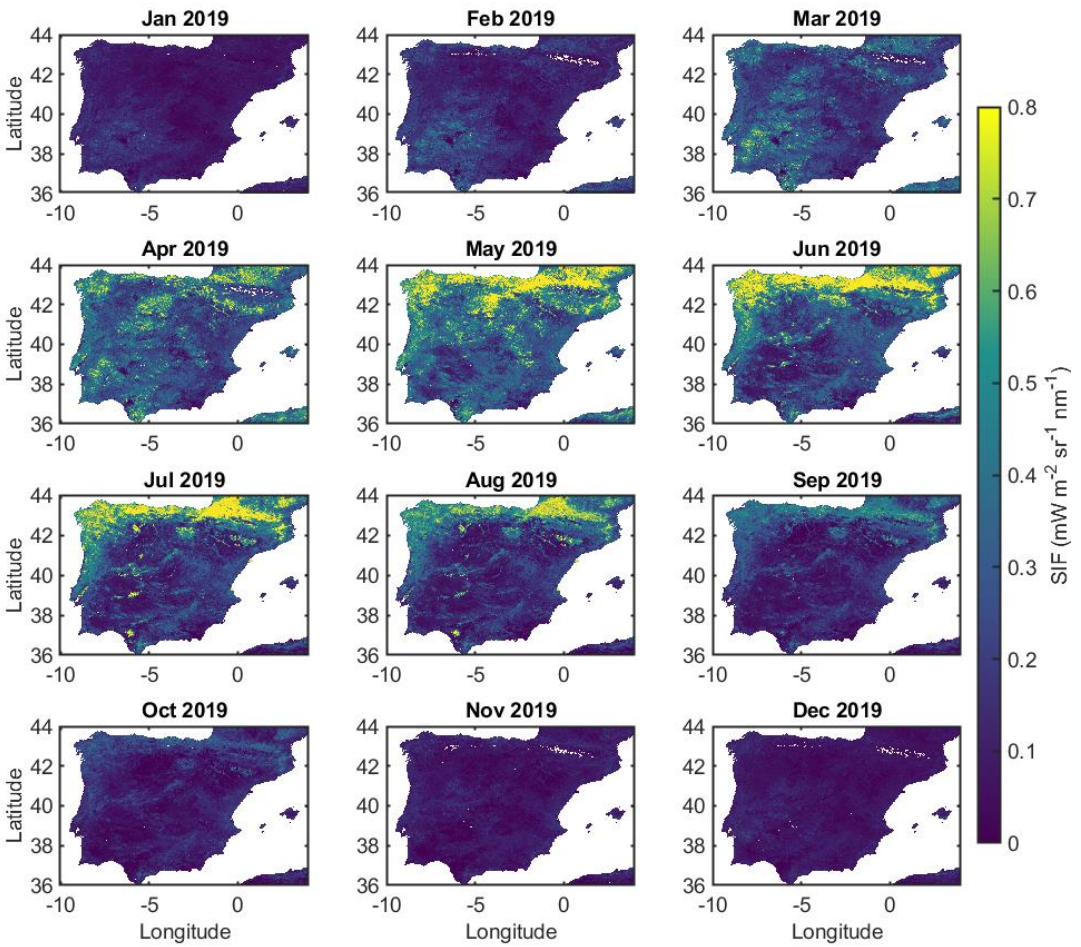
S3-SIF$_{743}$ consistently exhibits lower spatial std. deviation, indicating reduced retrieval noise across all biomes.

Fine-Scale Spatial Heterogeneity — Iberian Peninsula

Annual Phenological Cycle (Monthly S3-SIF$_{743}$)

Jan–Mar	Dormant — Near-zero SIF
Apr–May	Green-up — Rapid SIF increase
June	Peak — Regional maximum
Jul–Aug	Drought stress — Sharp decline (Med. interior)
Sep–Oct	Recovery — Gradual decrease
Nov–Dec	Senescence — Return to dormancy

Irrigated croplands remain green islands during summer drought



Monthly-averaged S3-SIF$_{743}$ in the Iberian Peninsula at 300 m resolution in 2019.

Fine-Scale Spatial Heterogeneity — Iberian Peninsula

Köppen Climate Types — Iberian Peninsula 2019

Csa

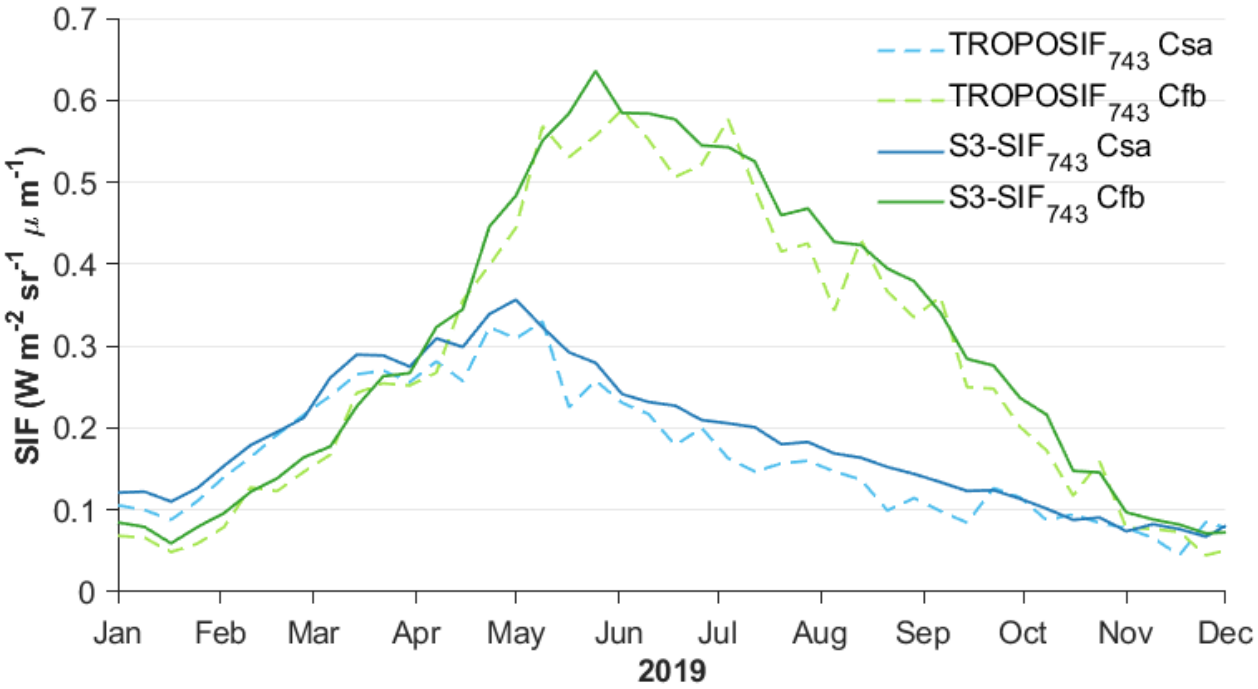
Hot-Summer Mediterranean

- **S3-SIF$_{743}$: Sharp spring peak (Apr–May), pronounced summer decline**
- TROPOSIF$_{743}$: Dampened peak, less-defined summer decline

Cfb

Temperate Oceanic

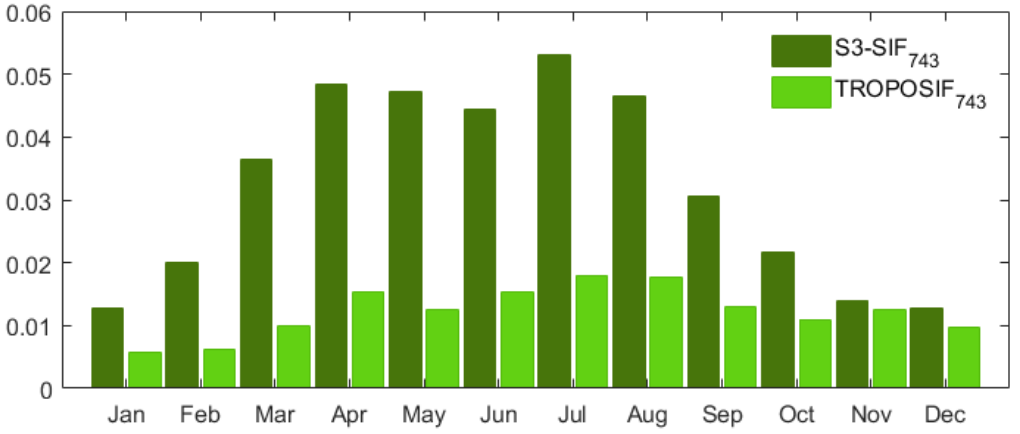
- **S3-SIF$_{743}$: Higher peak magnitude, sustained plateau, rapid senescence**
- TROPOSIF$_{743}$: Prolonged persistence, masks climatic sensitivity



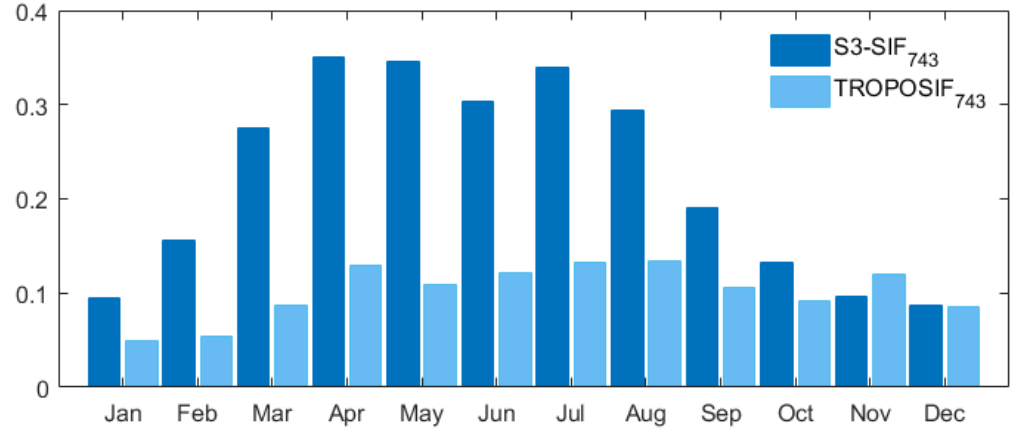
SIF in the Iberian Peninsula for different climate types in 2019.

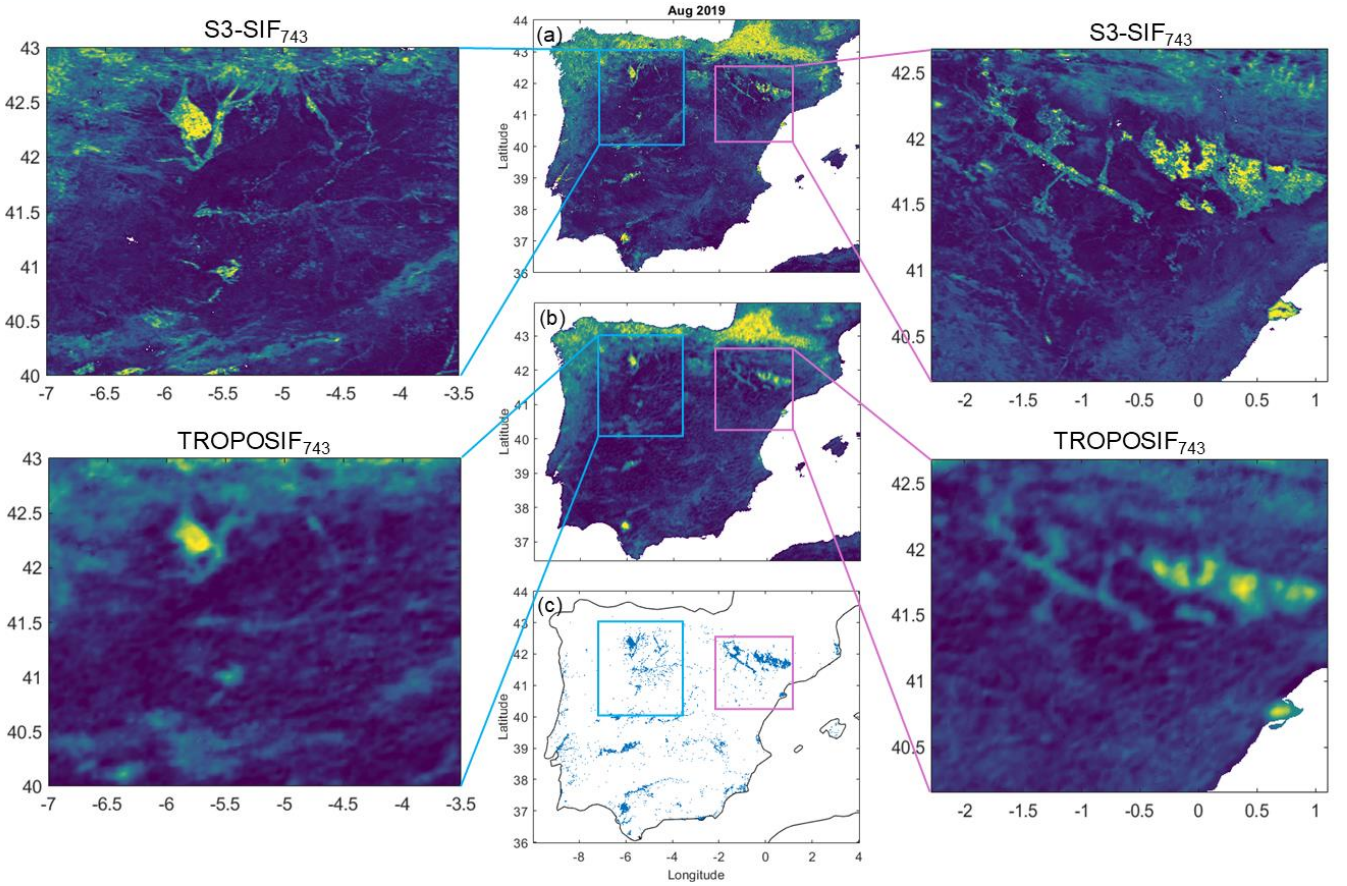
Fine-Scale Spatial Heterogeneity — Iberian Peninsula

$\bar{\sigma}_{area}$ *(Internal variability)*



$\bar{G}_{edge}$ *(Boundary sharpness)*





Monthly-averaged SIF in the Iberian Peninsula in Aug, 2019. (a) S3-SIF$_{743}$ (b) TROPOSIF$_{743}$ (c) Irrigated or post-flooding croplands in the Iberian Peninsula

Strengths, Limitations & Future Work

Methodological Advantages

- First global 300 m SIF product built entirely within GEE — scalable, reproducible, open-access
- Finer spatial resolution (300 m) vs. all existing products that rely on MODIS (~500 m–5 km)
- S3 OLCI spectral richness (21 bands) + FVC/LCC vegetation traits improve model predictors
- Scalable: can generate 2016–present global time series operationally

Known Limitations

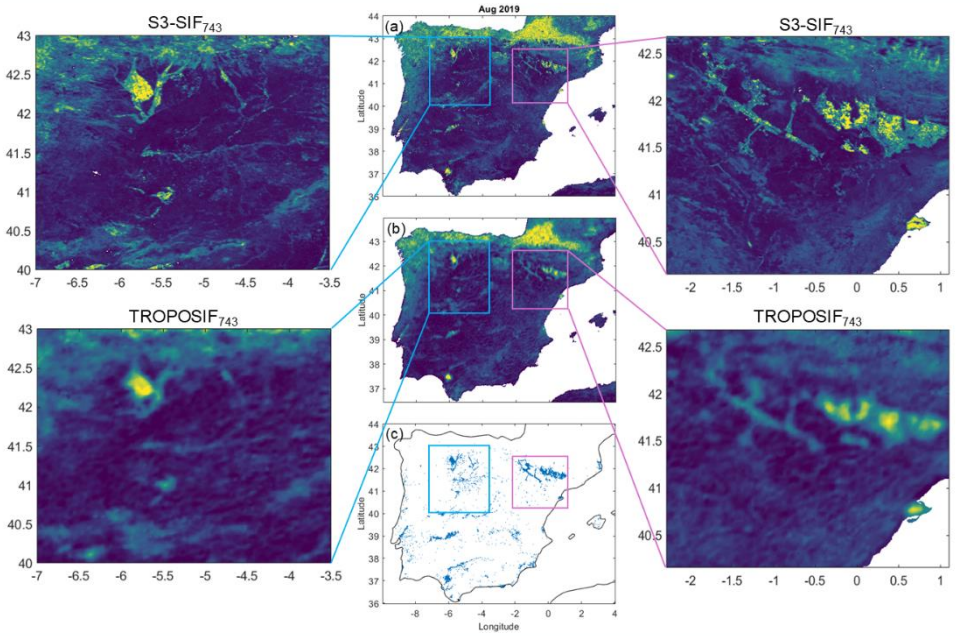
- RF regression-to-mean: underestimates very high SIF (> 0.8 mW m^{-2} sr^{-1} nm^{-1})
- Training limited to Europe: potential bias in tropical & arid extrapolation
- Inherits $TROPOSIF_{743}$ 743–758 nm window; no full spectrum
- S3 data quality on GEE degraded post-2021, limiting temporal continuity

Future Work

- Extend to full-spectrum SIF
- OpenEO / CDSE for greater transparency & reproducibility
- Synergistic integration with ESA FLEX data (launch 2026)

Conclusions

1. First global 300 m, 4-day SIF product (S3-SIF$_{743}$) derived from Sentinel-3 OLCI via Random Forest on Google Earth Engine — operational 2016–present
2. Good temporal agreement with ground-based towers across 4 sites and spatial consistency with TROPOSIF$_{743}$
3. Resolves sub-kilometer heterogeneity: irrigated croplands, climate boundaries
4. Reduced retrieval noise vs TROPOSIF$_{743}$ across all biomes
5. Direct bridge to ESA FLEX mission: matching 300 m footprint provides a historical SIF baseline for upcoming FLEX cross-validation



github.com/YuxinZhang1998/S3-SIF

Thank You

Questions & Discussion Welcome

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