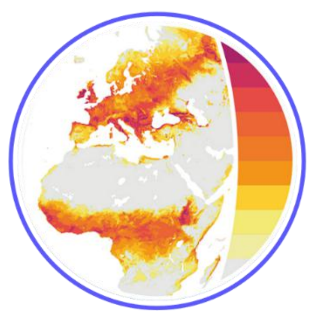
Solutions to protect life

A new SIF (solar-induced chlorophyll fluorescence) product derived from TROPOMI onboard Sentinel-5 Precursor

ESA TROPOSIF project



Consortium:

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UPV: L. Guanter
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LSCE: F. Maignan
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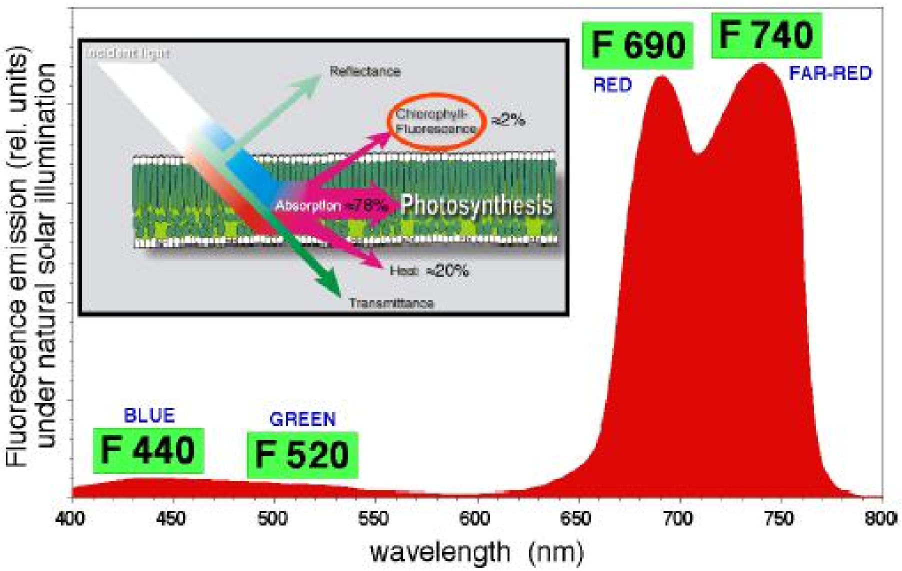
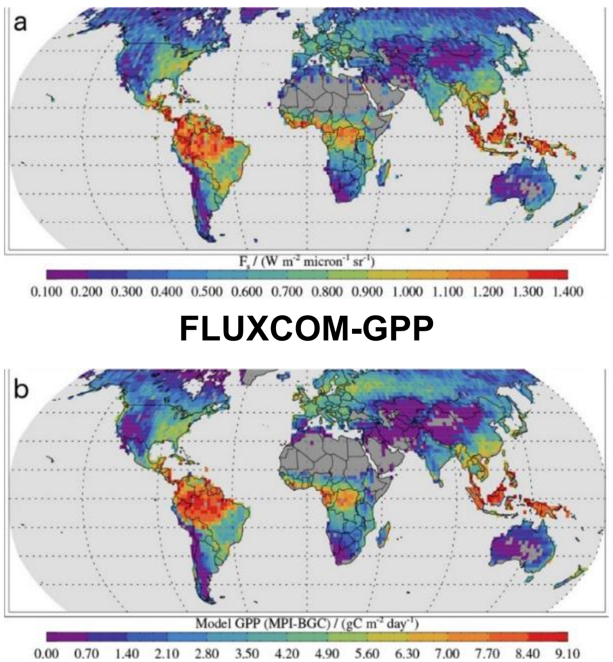
Context of the study

- Chlorophyll fluorescence is an electromagnetic signal emitted by the photosynthetic machinery of green plants that can be linked to instantaneous photosynthesis.
- First global measurements of SIF over land achieved in late 2011 from GOSAT spectra (Frankenberg et al., Joiner et al.).
- It has been proven to be a better **indicator of terrestrial photosynthesis activity** and gross primary production (GPP) than reflectance-based vegetation indices



FLEX Report for Assessment (2008)



R^2=0.8

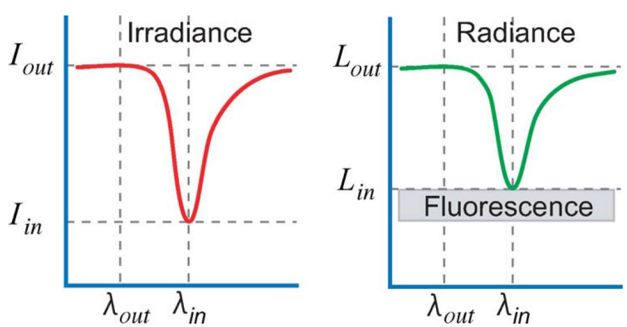
© Frankenberg et al. (2011)

Context of the study

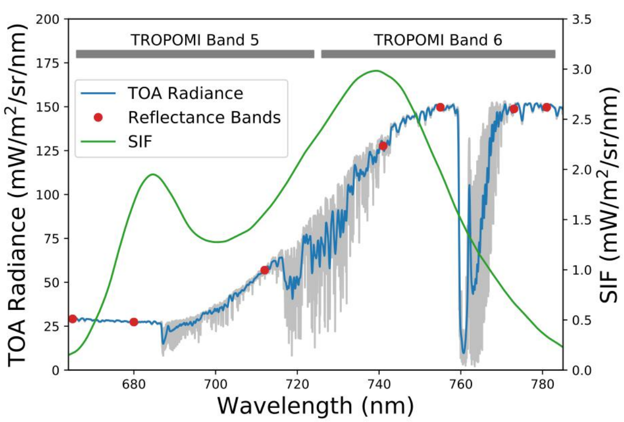
- SIF can be retrieved in the solar and atmospheric absorption lines, which facilitates the retrieval of the weak SIF signal from the surface reflectance
- Atmospheric spectrometers provide the required spectral and radiometric resolutions

	GOME-2	SCIAMACHY	GOSAT	OCO-2	TROPOMI
Spatial resolution	40x40 km²	30x60 km²	0.5x0.5 km²	1.3x2.25 km²	3 km x 7 km²
Revisit frequency	3 days	6 days	3 days	16 days	~ 1 day
Overpass time	9:30	10:00	13:00	13:30	13:30
Spectral range	650-790 nm **SIF@685nm** **SIF@740 nm**	650–790 nm	755-775 nm	Micro windows at **757 nm** and 770 nm	675–775 nm **SIF@740nm** SIF@683nm
Spectral resolution	~ 0.5 nm	~ 0.5 nm	~ 0.025 nm	~ 0.05 nm	0.38 nm

- Challenge: to decouple SIF from the solar radiation reflected by the surface and the atmosphere
- Evaluation of the fractional depth of solar Fraunhofer lines → not affected by atmospheric scattering, simple modelling.



@Alonso et al. GRSL, 2008



TROPOMI SIF retrieval scheme

- Data-driven retrieval implemented for far-red fitting windows (743-758 nm and 735-758 nm) based on *Guanter et al. (2015)*
- Linear Forward model based on Singular Vectors derived from vegetation-free areas
- Easy implementation and fast processing (~5 min/orbit in a desktop computer)

- Input data: only L1B_RAD and cloud fraction (L2_Cloud) products

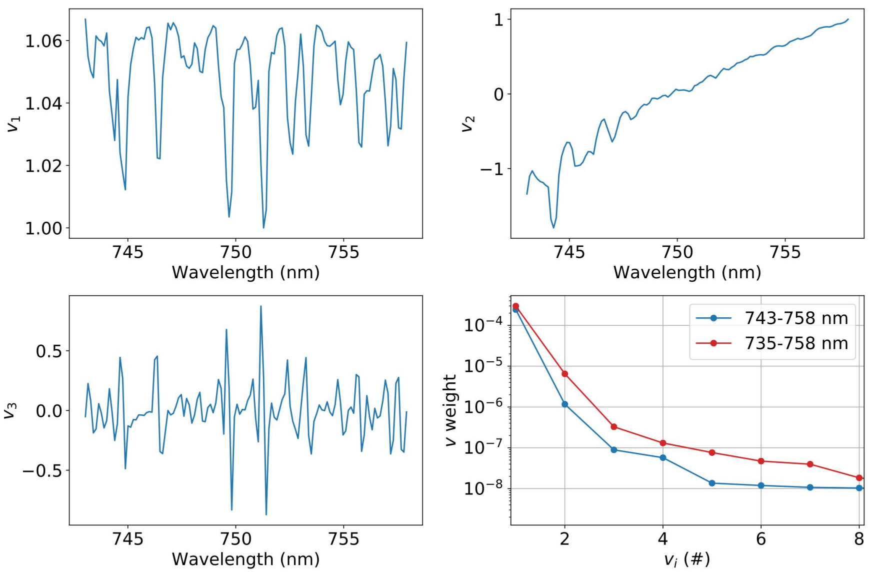
$$L_{\mathrm{TOA}} = \frac{\mu_{\mathrm{s}} I_{\mathrm{sc}}}{\pi}\left[\rho_0 + \frac{\rho_{\mathrm{s}} T_{\downarrow\uparrow}}{1 - S\rho_{\mathrm{s}}}\right] + \frac{F_{\mathrm{s}} T_{\uparrow}}{1 - S\rho_{\mathrm{s}}}$$

$$\boldsymbol{F}\left(\boldsymbol{a}, \boldsymbol{\alpha}, F_{\mathrm{s}}\right) = \left(\sum_{i=0}^{n_{\mathrm{p}}} a_i \boldsymbol{\lambda}^i\right) \cdot \left(\sum_{j=1}^{n_{\mathrm{v}}} \alpha_j \boldsymbol{v}_j\right) + F_{\mathrm{s}} \boldsymbol{h}_{\mathrm{F}} \cdot \boldsymbol{T}_{\uparrow}^{\mathrm{e}}$$

$$\boldsymbol{F}'\left(\boldsymbol{a}, \boldsymbol{\alpha}, F_{\mathrm{s}}\right) = \boldsymbol{v}_1 \sum_{i=0}^{n_{\mathrm{p}}} a_i \boldsymbol{\lambda}^i + \sum_{j=2}^{n_{\mathrm{v}}} \alpha_j \boldsymbol{v}_j + F_{\mathrm{s}} \boldsymbol{h}_{\mathrm{F}} \cdot \boldsymbol{T}_{\uparrow}^{\mathrm{e}}$$

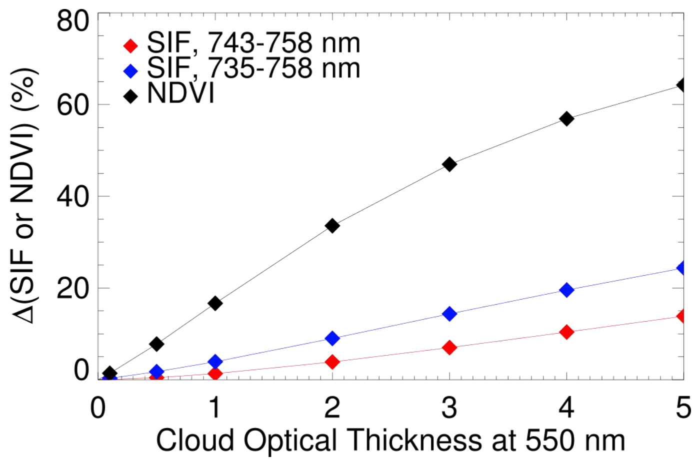
Number of eigenvectors n_v:
- 743-758 nm fitting window: 4
- 735-758 nm fitting window: 7

Singular vectors



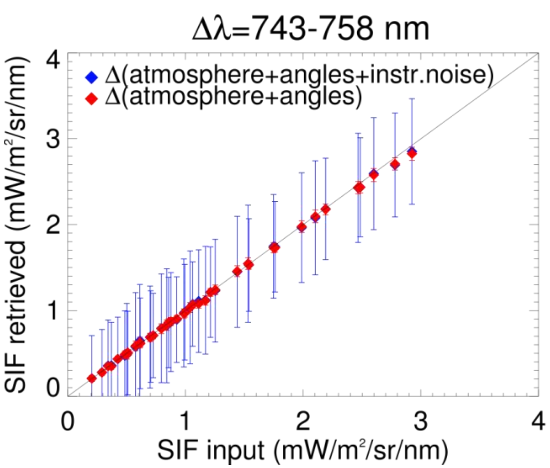
TROPOMI SIF retrieval scheme

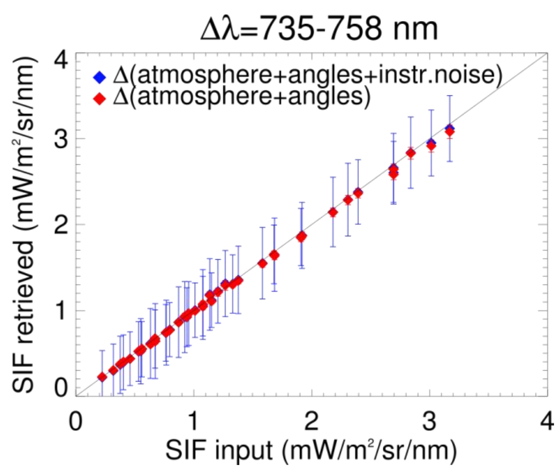
- **Measurement noise is the main error source**: variations in atmospheric conditions (cloud aside), angles or surface reflectance are negligible for the two fitting windows
- Width of the fitting window drives 1-sigma errors
- SIF (esp. from 743-758 nm) is much less sensitive to clouds than reflectance-based indices.

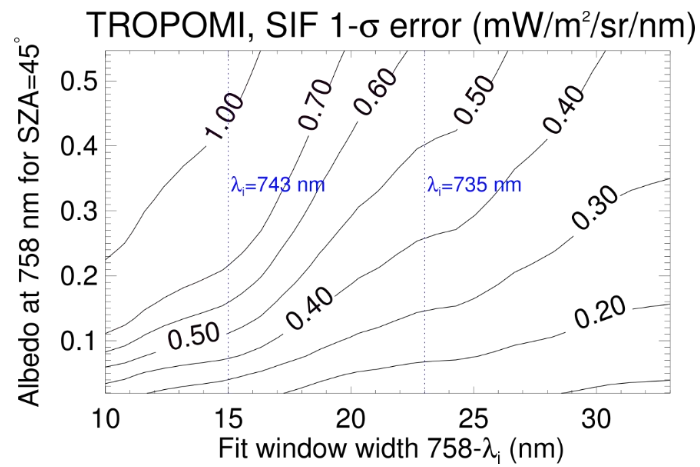


Fitting window selection:

- Compromise between random error (favours 735-758 nm) and sensitivity to clouds (favours 743-758 nm)
- Retrievals from the 743-758 nm window is the primary SIF product





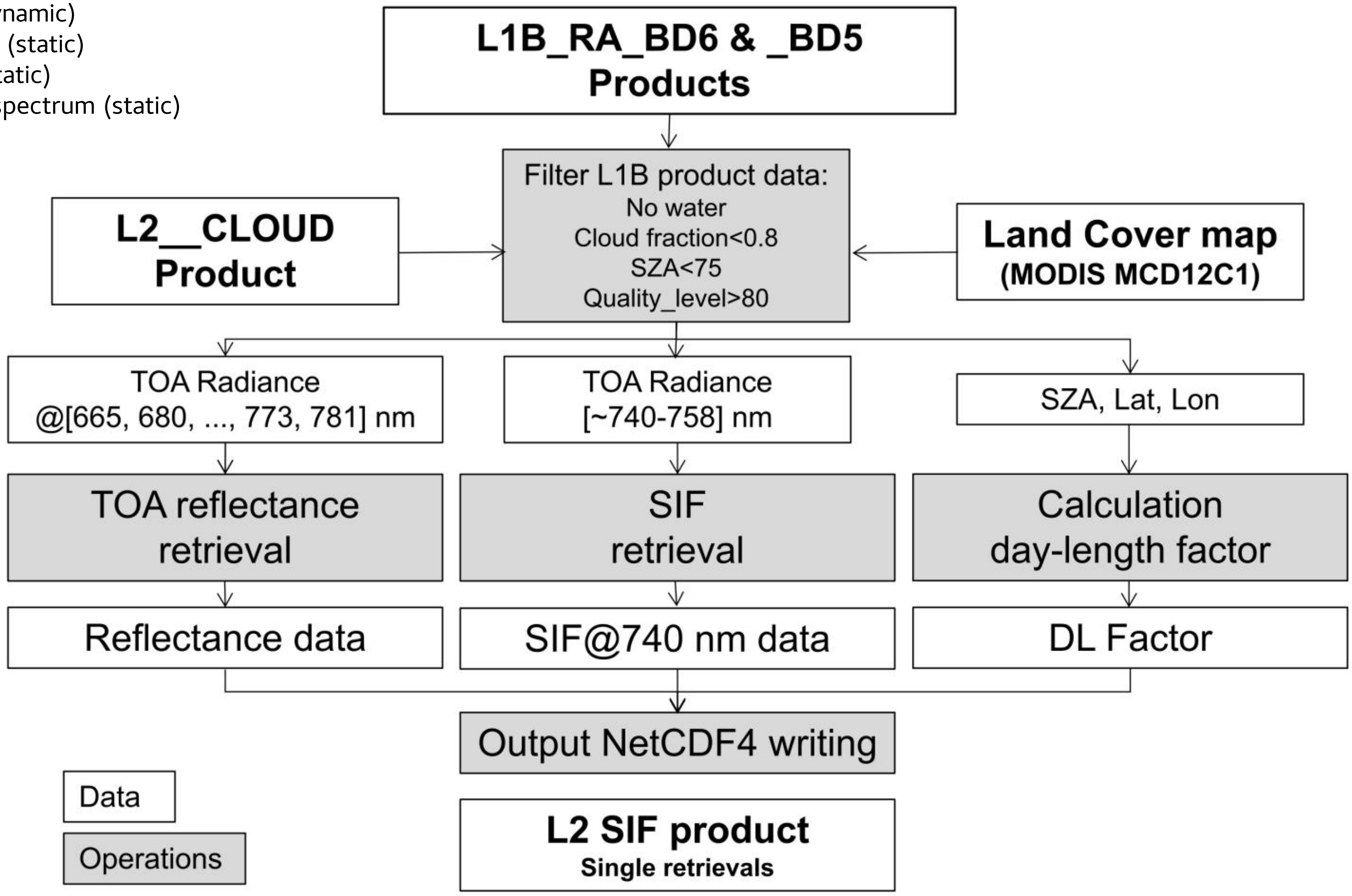


- The calculation of 1-sigma retrieval errors based on empirical SIFerr - TOA Radiance curves

Processing workflow

Input data summary

- L1B_RA_BD6 (dynamic)
- L2__CLOUD (dynamic)
- Land Cover Map (static)
- SIF spectrum (static)
- TOA irradiance spectrum (static)



Data format and availability

Data Format

- netCDF-4
- **L2 product:**
  - Ungridded data available for each TROPOSIF orbit
  - SIF estimates at 740 nm from the two fitting windows and associated retrieval error
    - **743-748 nm** : baseline product
    - **735-748 nm** : more «experimental»
  - Daily corrected SIF in the two fitting windows
  - Surface reflectance at 665, 680, 712, 741, 755, 773 and 781 nm
  - Solar and view angles, TOA radiance, Cloud fraction
  - Quality flag

- **L2B product:**
  - Ungridded daily files (similar to the Caltech product *Köhler et al. (2018)*)
  - Contains only the valid retrievals

- Covered time period: **May 2018 to December 2020**

Data availability

- project web site: https://s5p-troposif.noveltis.fr/
- L2B data (for now): ftp://ftp.sron.nl/open-access-data-2/TROPOMI/tropomi/sif/v2.0/l2b/

- The TROPOSIF product will be generated and distributed to users by S5P-PAL in an operational manner in the near- future.

Characterization of the mean error and bias over Sahara

- **Comparison against Caltech and OCO-2 SIF products**
  - estimates aggregated at 0.1 ° / daily , CF < 0.05
  - *SIF(OCO2) = 1.56 × (SIF@757nm + 1.8 × SIF@771nm)/2.* *(Köhler et al. (2018))*

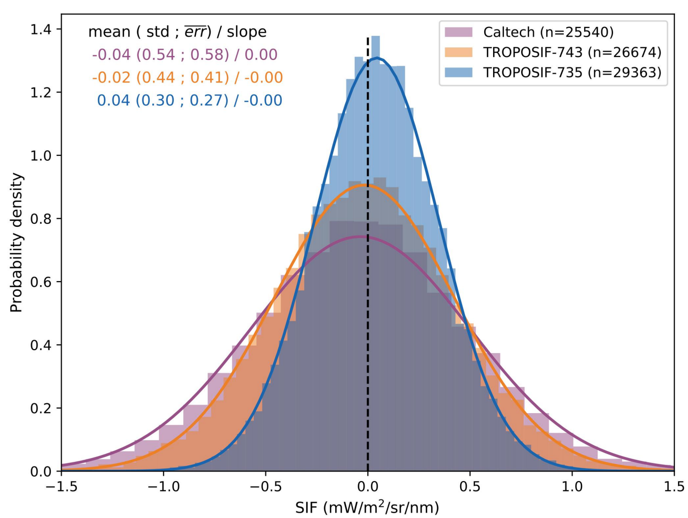
Mean bias ($mW.m^{-2}.sr^{-1}.nm^{-1}$)

	OCO-2 @740nm	Caltech	TROPOSIF - 743nm	TROPOSIF - 735nm
Sahara	0.0098 (0.0308)	-0.0357 (-0.1047)	-0.0277 (-0.0805)	-0.0059 (-0.0173)

daily corrected SIF
(raw SIF)

Mean random error ($mW.m^{-2}.sr^{-1}.nm^{-1}$)

	Caltech	TROPOSIF - 743nm	TROPOSIF - 735nm
Sahara	0.61	0.52	0.42

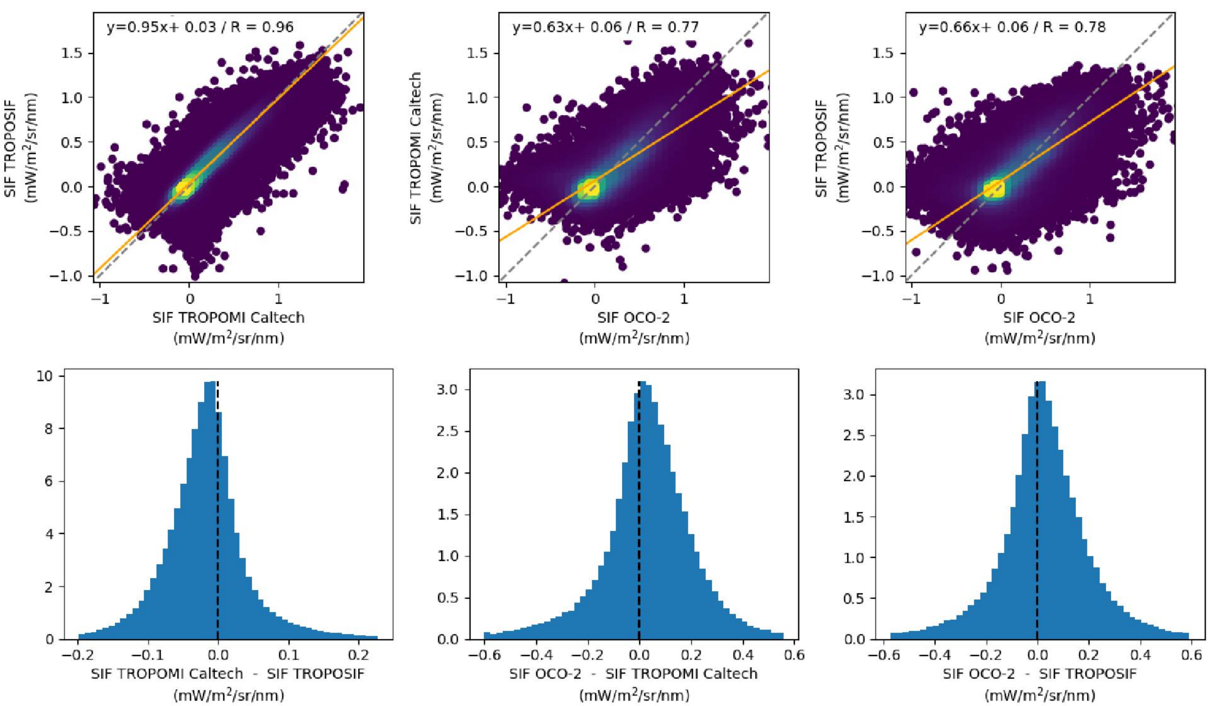


- Distribution of the daily SIF estimates from Caltech and TROPOSIF products over 10 Pseudo-Invariant Calibration Sites (*Bacour et al., 2019*)
- The slope of the temporal variation of the SIF data over 2018-2020 is close to 0 ; no temporal drift was detected for any of the sites

Global scale evaluation

- Cross-comparison between TROPOSIF (743 nm), Caltech and OCO-2
- Daily data / 0.1° resolution, Cloud Fraction (CF) < 0.2
- Daily corrected SIF

August 2019



We generally observe that:

- SIF(TROPOSIF) > SIF(Caltech)
- SIF(OCO2) > SIF(Caltech)
- SIF(OCO2) ~ SIF(TROPOSIF)

Biome scale evaluation

- Time series comparison for an ensemble of "homogeneous" pixels - biome representative (*Bacour et al., 2019*)
- Several clusters for each biome (14 Plant functional Types)
- Weekly / 0.5 °aggregation ; CF < 0.2 ; VZA < 40°

Distribution of 2 clusters for each PFT

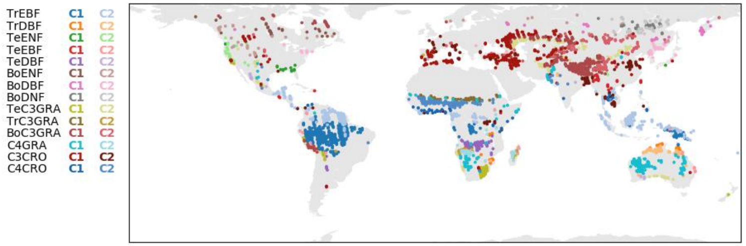
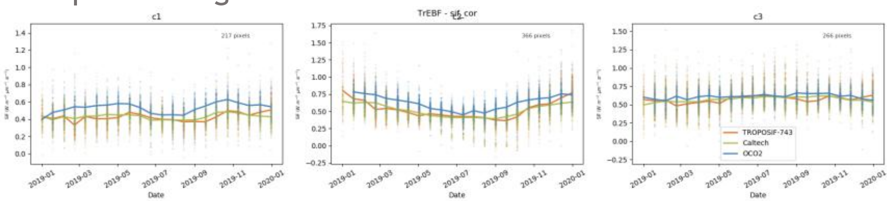
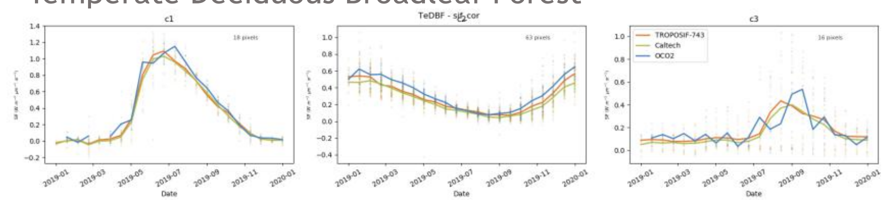


Illustration of compared SIF seasonal variations for 3 PFTs

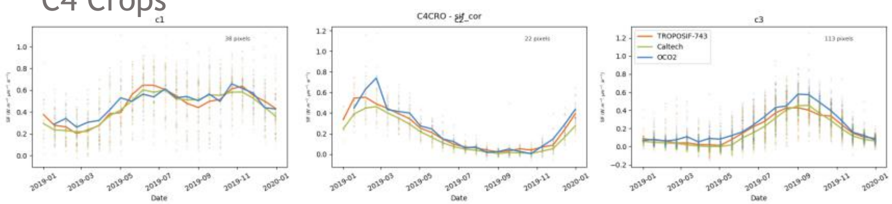
Tropical Evergreen Broadleaf Forest



Temperate Deciduous Broadleaf Forest

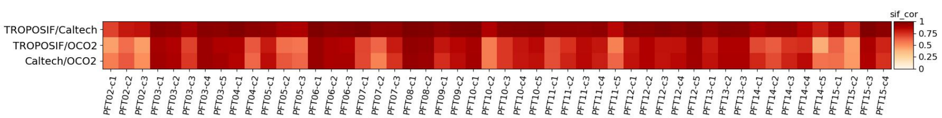


C4 Crops



TROPOSIF-743
Caltech
OCO-2

Temporal correlation



- higher agreement between the 2 TROPOMI products than with OCO-2 (similar sampling for the TROPOMI products and higher number of observations within the 0.5° pixels that reduces the retrieval error)
- OCO-2 in closer agreement with TROPOSIF than with Caltech

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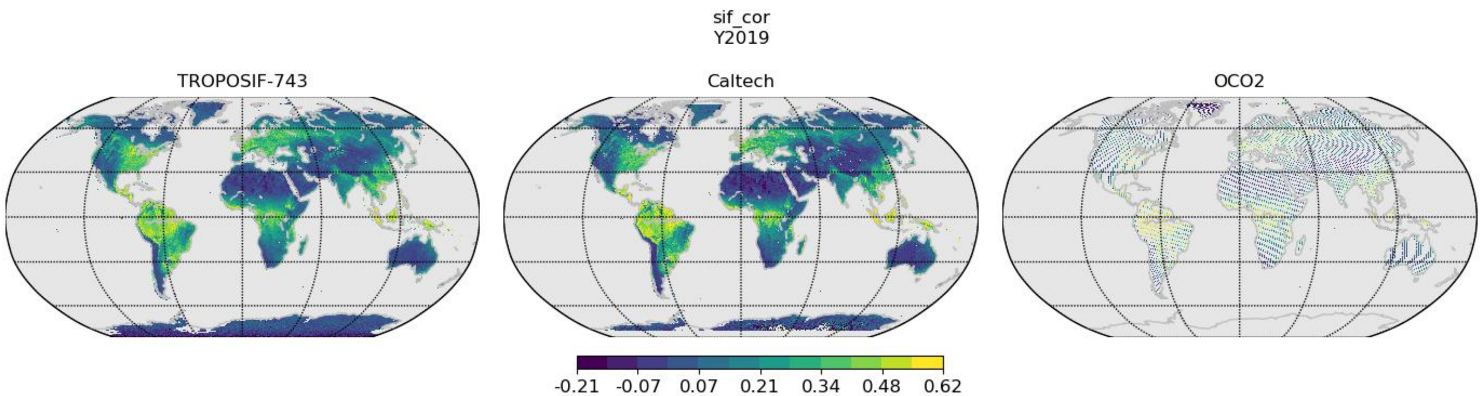
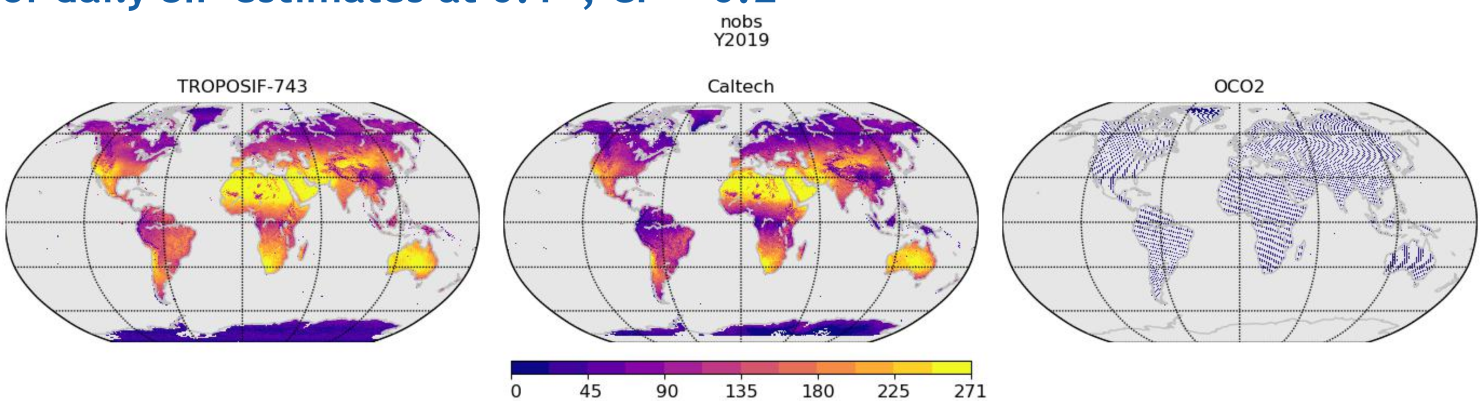
Overview of the TROPOSIF products

Yearly SIF average (2019) / daily / 0.1°, Cloud Fraction < 0.2



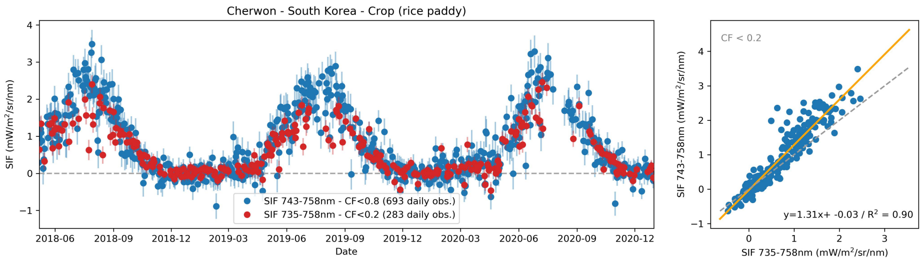
Number of daily SIF estimates at 0.1°, CF < 0.2

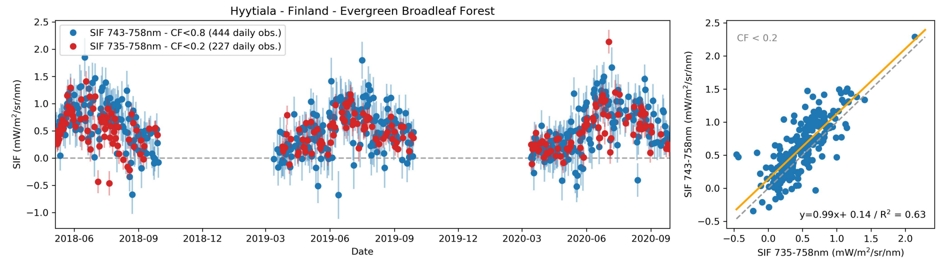


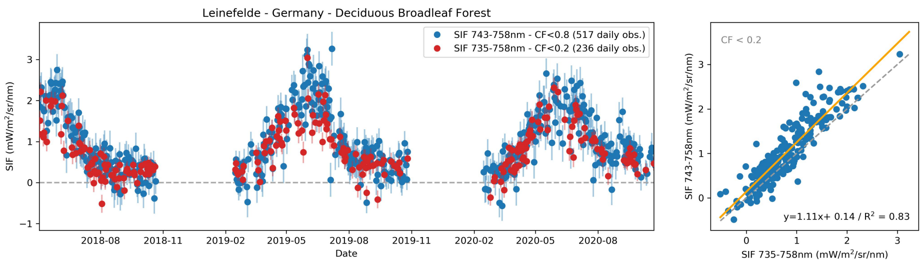
- The difference between Caltech and TROPOSIF are largely explained by the different Cloud Fraction products used :
  - Caltech: VIIRS
  - TROPOSIF: TROPOMI L2_Cloud

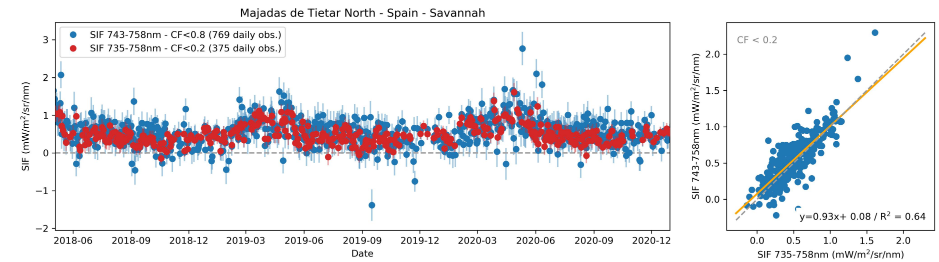
Overview of the TROPOSIF products

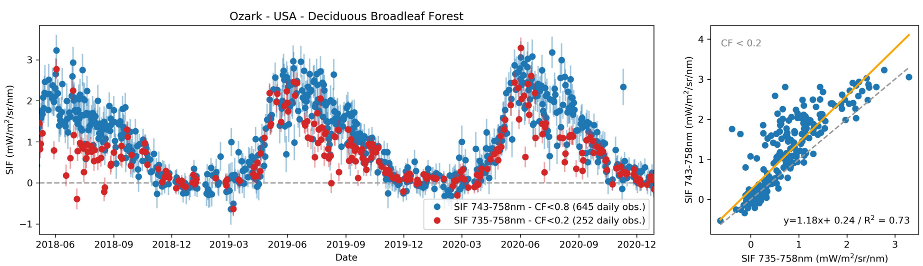
Comparison between TROPOSIF-743nm and TROPOSIF-735nm at sites

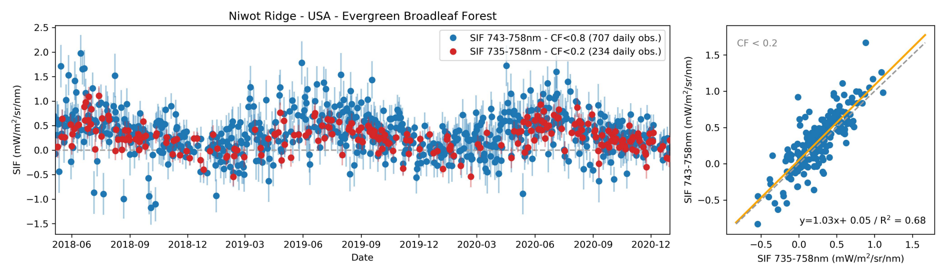




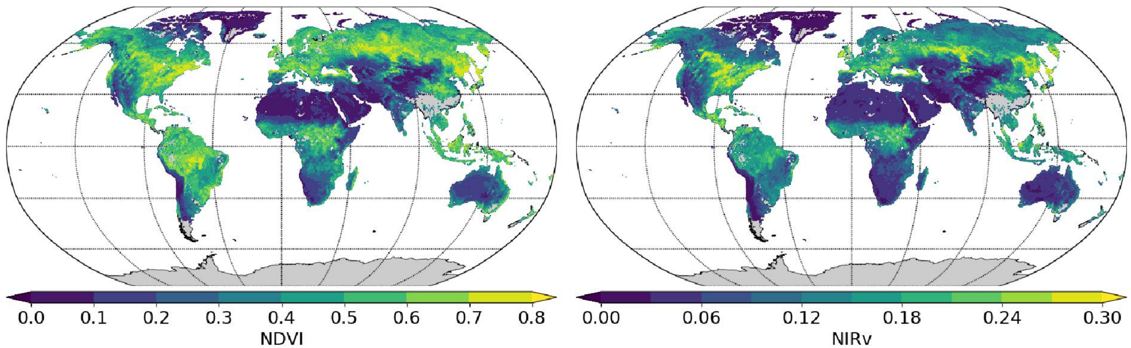






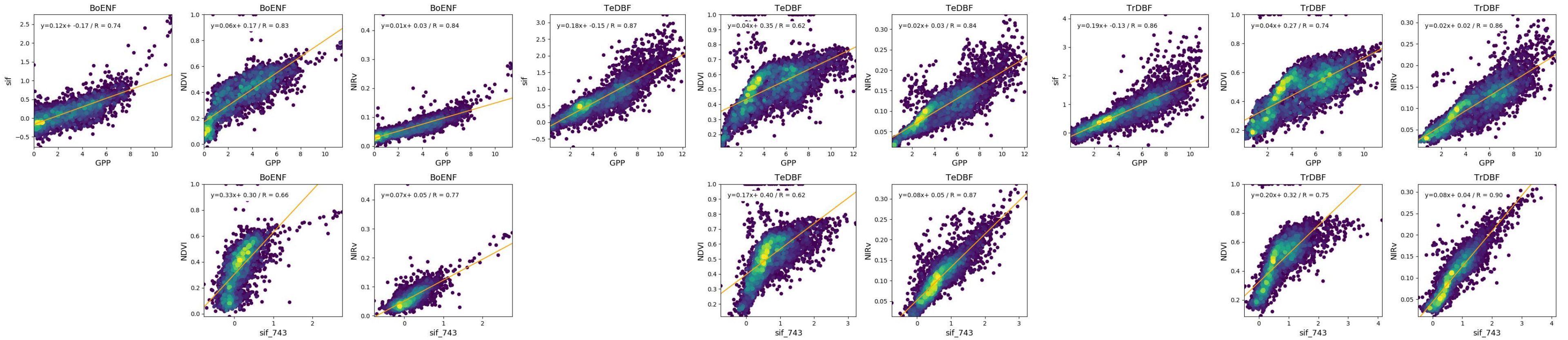


NDVI and NIRv
8-15 July 2019



Relationships between SIF(743nm), NDVI and NIRv, and with FluxSat-GPP

Boreal Evergreen Needleleaf Forests | Temperate Deciduous Broadleaf Forests | Tropical Deciduous Broadleaf Forests



FluxSat-GPP from *Joiner et al. (2018)*