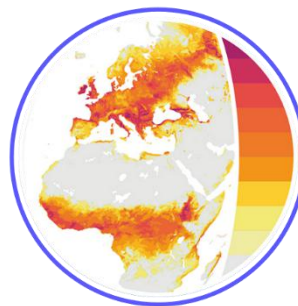


A new SIF (solar-induced chlorophyll fluorescence) product derived from TROPOMI onboard Sentinel-5 Precursor

ESA TROPOSIF project

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Space



Environment

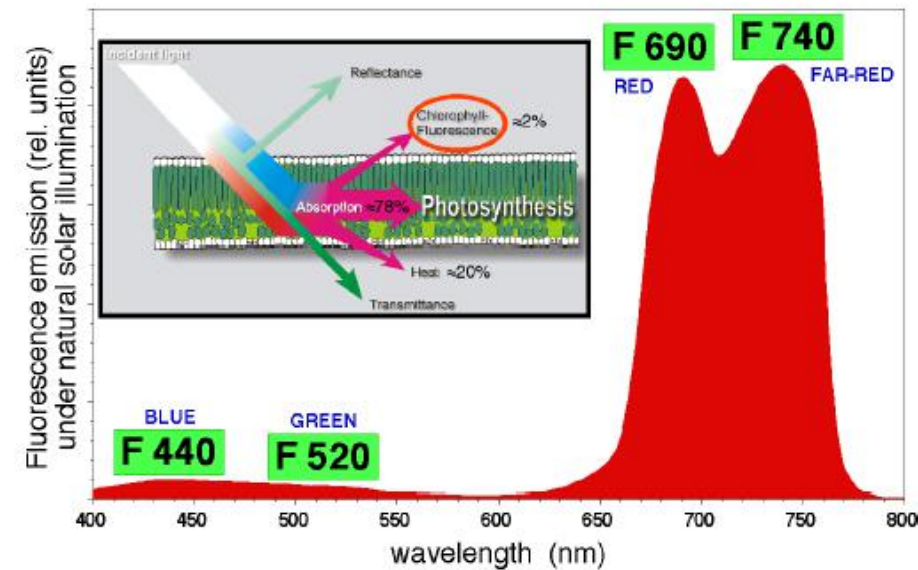


Sustainable development

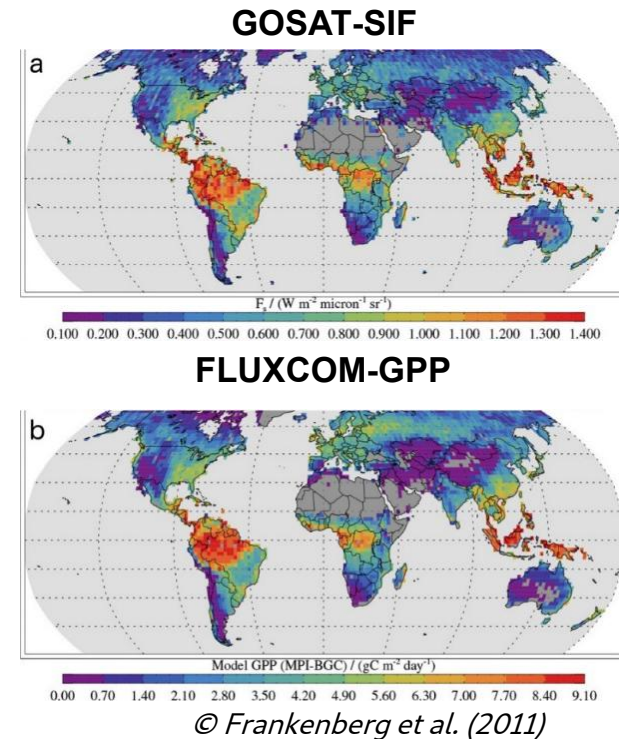


Risk prevention

- 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)

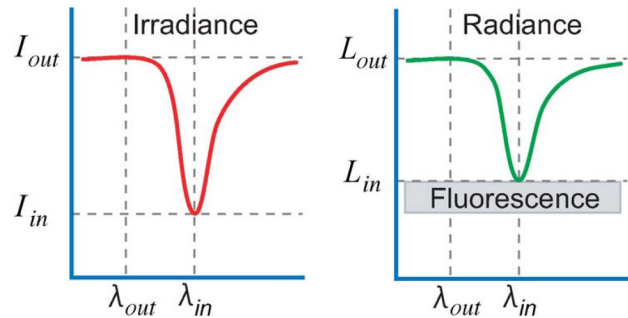


© Frankenberg et al. (2011)

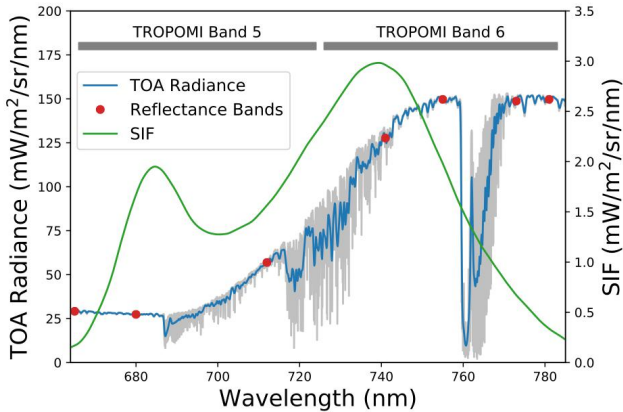
- SIF can be retrieved in the solar and atmospheric absorption lines, which facilitates the retrieval of the weak SIF signal from the surface reflectance
- Atmospheric spectrometers provide the required spectral and radiometric resolutions

	GOME-2	SCIAMACHY	GOSAT	OCO-2	TROPOMI
Spatial resolution	40x40 km ²	30x60 km ²	0.5x0.5 km ²	1.3x2.25 km ²	3 km x 7 km ²
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



- 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

$$L_{\text{TOA}} = \frac{\mu_s I_{\text{sc}}}{\pi} \left[\rho_0 + \frac{\rho_s T_{\downarrow\uparrow}}{1 - S\rho_s} \right] + \frac{F_s T_{\uparrow}}{1 - S\rho_s}$$

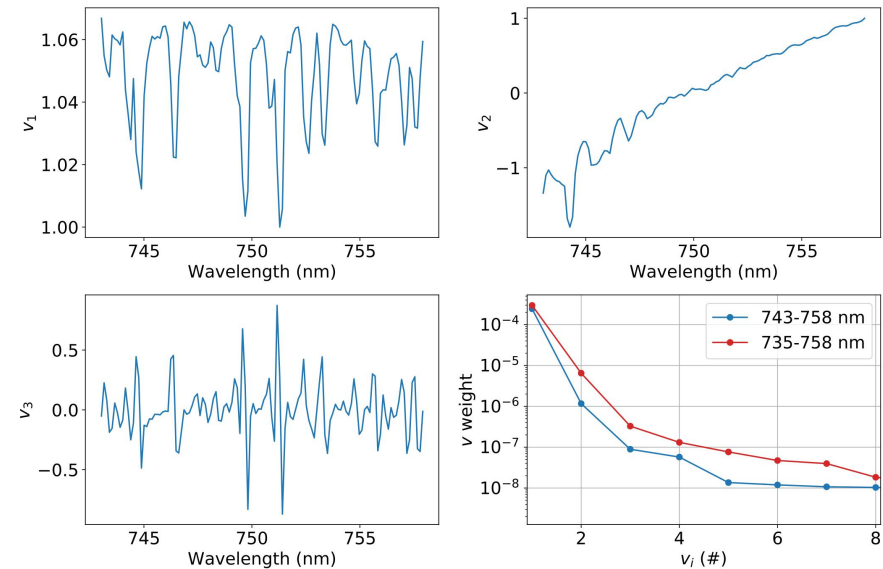
$$F(a, \alpha, F_s) = \left(\sum_{i=0}^{n_p} a_i \lambda^i \right) \cdot \left(\sum_{j=1}^{n_v} \alpha_j v_j \right) + F_s h_F \cdot T_{\uparrow}^e$$

$$F'(a, \alpha, F_s) = v_1 \sum_{i=0}^{n_p} a_i \lambda^i + \sum_{j=2}^{n_v} \alpha_j v_j + F_s h_F \cdot T_{\uparrow}^e$$

Number of eigenvectors n_v :

- 743-758 nm fitting window: 4
- 735-758 nm fitting window: 7

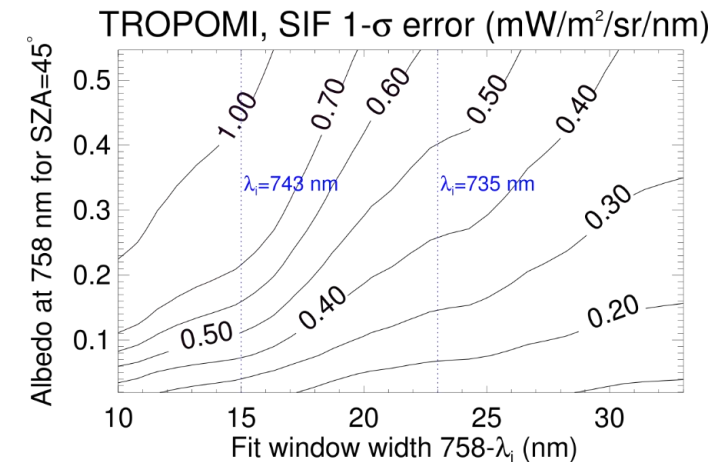
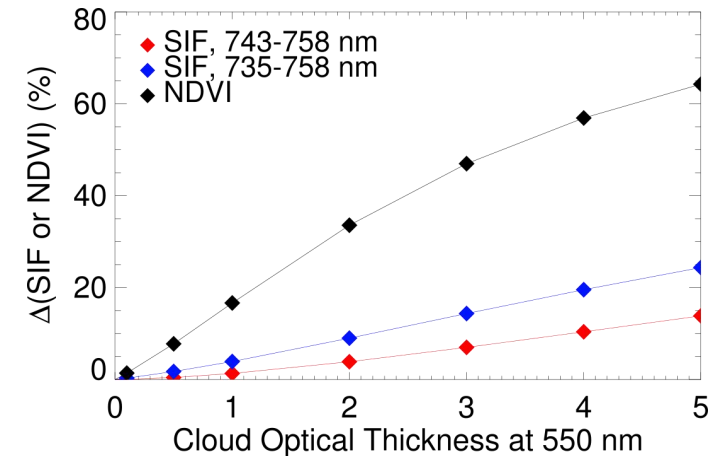
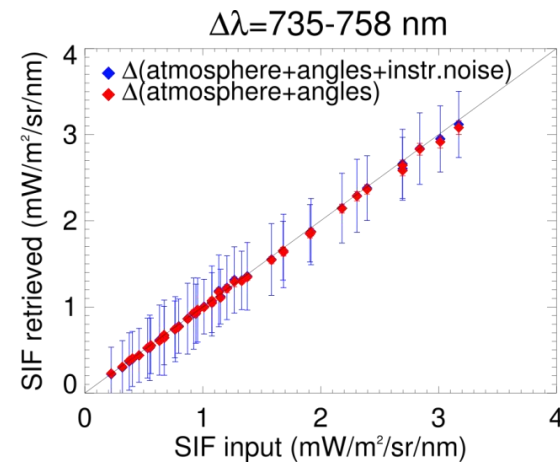
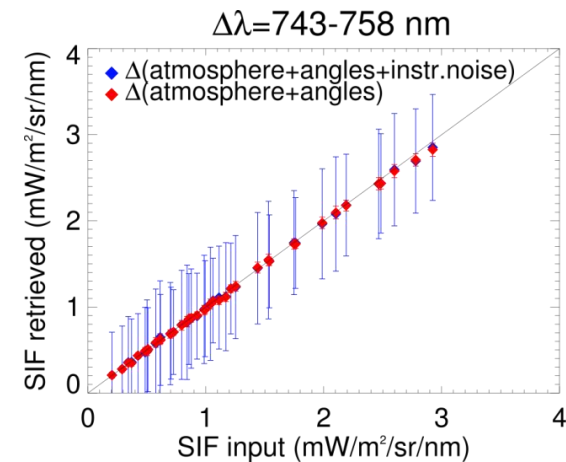
Singular vectors



- **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:

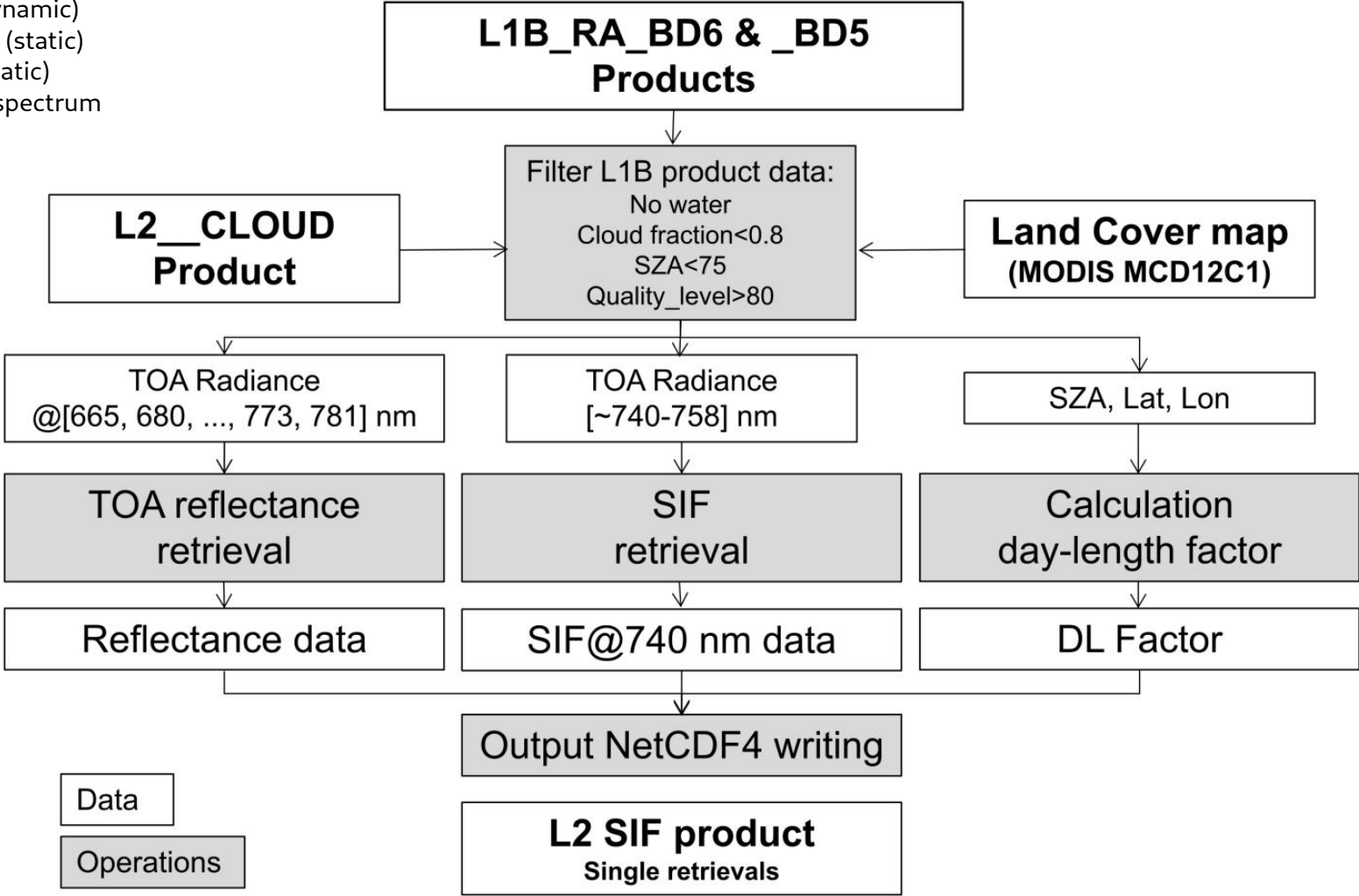
- Compromise between random error (favours 735-758 nm) and sensitivity to clouds (favours 743-758 nm)
- Retrievals from the 743-758 nm window is the primary SIF product



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

Input data summary

- L1B_RA_BD6 (dynamic)
- L2_CLOUD (dynamic)
- Land Cover Map (static)
- SIF spectrum (static)
- TOA irradiance spectrum (static)



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 March 2021**

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/v2.1/l2b/>
- The TROPOSIF product will be generated and distributed to users by S5P-PAL
- The full TROPOMI SIF time series is planned to be available on S5P-PAL by Q3 of 2021

Detail of the L2B TROPOMI SIF product

TROPOSIF_L2B_2021-02-07.nc	TROPOSIF_L2B	Local File
▼ METADATA	METADATA	—
▼ ALGORITHM_SETTINGS	METADATA/	—
▼ PRODUCT	PRODUCT	—
delta_time	offset from the reference start time of m...	1D
latitude	latitude	1D
longitude	longitude	1D
SIF_735	retrieved SIF@740 (735-758nm)	GeoTraj
SIF_743	retrieved SIF@740 (743-758nm)	GeoTraj
SIF_Corr_735	daylength-corr SIF@740 (735-758nm)	GeoTraj
SIF_Corr_743	daylength-corr SIF@740 (743-758nm)	GeoTraj
SIF_ERROR_735	1-sigma SIF retrieval error (735-758nm)	GeoTraj
SIF_ERROR_743	1-sigma SIF retrieval error (743-758nm)	GeoTraj
▼ SUPPORT_DATA	PRODUCT/	—
▼ DETAILED_RESULTS	PRODUCT/SUPPORT_DATA/	—
Mean_TOA_RAD_735	Mean TOA Radiance in 735-758 nm fittin...	GeoTraj
Mean_TOA_RAD_743	Mean TOA Radiance in 743-758 nm fittin...	GeoTraj
TOA_RFL	TOA Reflectance at atmospheric windows...	GeoTraj
WVL_RFL	Spectral points at which TOA RFL is calc...	1D
▼ GEOLOCATIONS	PRODUCT/SUPPORT_DATA/	—
latitude_bounds	latitude bounds	Geo2D
longitude_bounds	longitude bounds	Geo2D
relative_azimuth_angle	relative azimuth angle	GeoTraj
solar_zenith_angle	solar zenith angle	GeoTraj
viewing_zenith_angle	viewing zenith angle	GeoTraj
▼ INPUT_DATA	PRODUCT/SUPPORT_DATA/	—
cloud_fraction_L2	cloud fraction	GeoTraj
LC_MASK	Land Cover Map	GeoTraj

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
 - $SIF(OCO2) = 1.56 \times (SIF@757nm + 1.8 \times SIF@771nm) / 2.$ (Köhler et al. (2018))

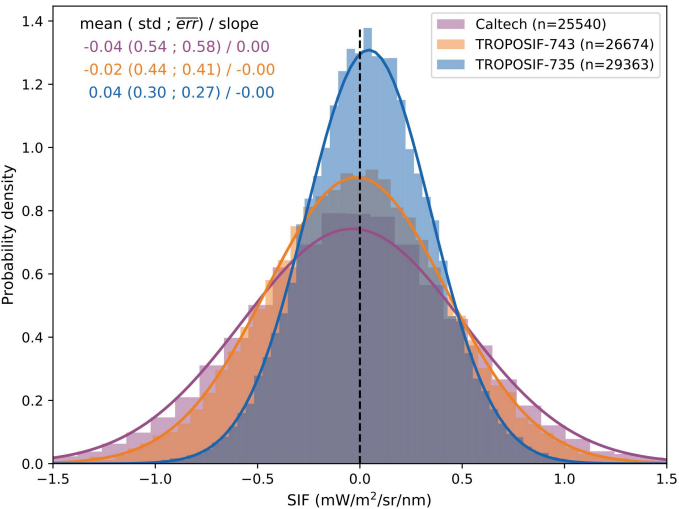
Mean bias (mW.m⁻².sr⁻¹.nm⁻¹)

	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

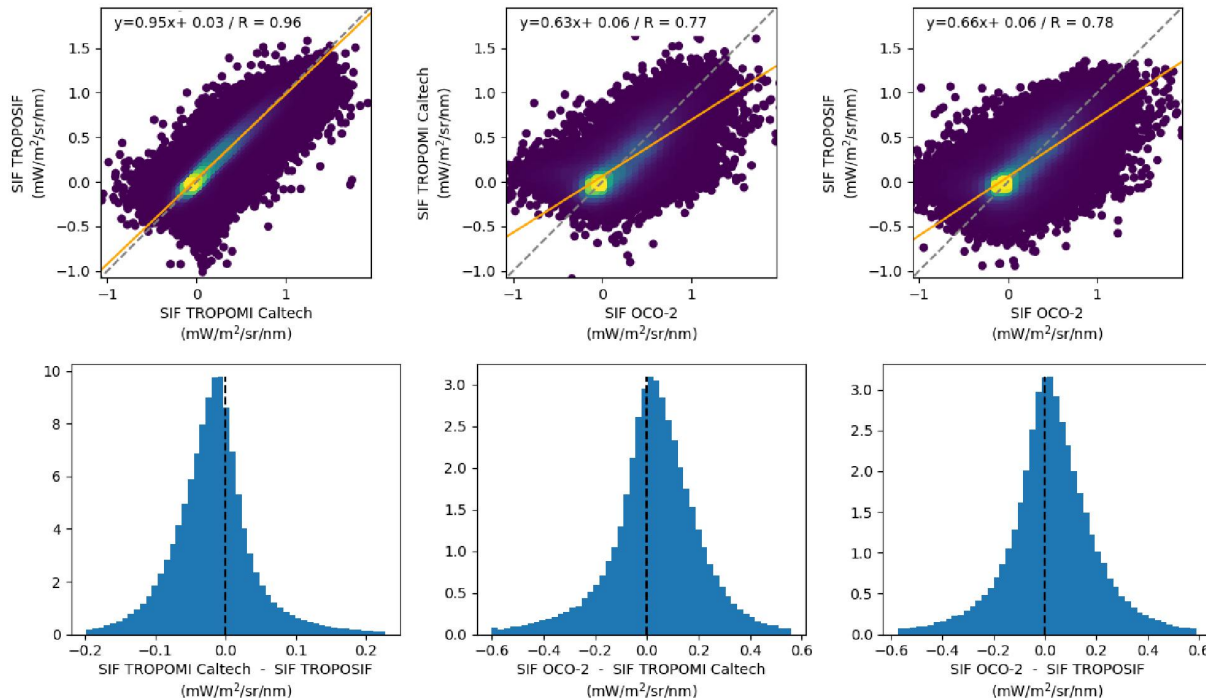


- Distribution of the daily SIF estimates from Caltech and TROPOSIF products over 10 Pseudo-Invariant Calibration Sites (Bacour et al., 2019)
- The slope of the temporal variation of the SIF data over 2018–2020 is close to 0 ; no temporal drift was detected for any of the sites

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:

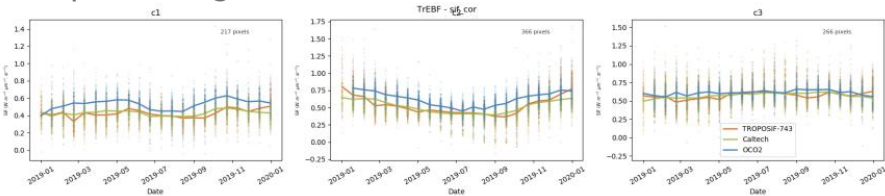
- SIF(TROPOSIF) > SIF(Caltech)
- SIF(OCO2) > SIF(Caltech)
- SIF(OCO2) ~ SIF(TROPOSIF)

Biome scale evaluation

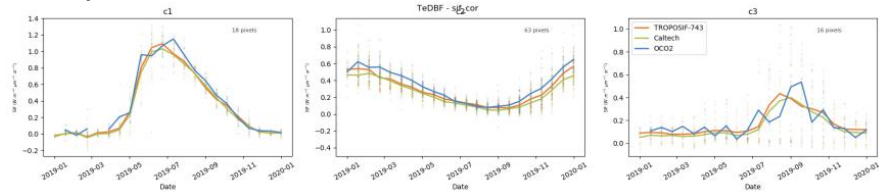
- Time series comparison for an ensemble of “homogeneous” pixels - biome representative (*Bacour et al., 2019*)
- Several clusters for each biome (14 Plant functional Types)
- Weekly / 0.5 °aggregation ; CF < 0.2 ; VZA < 40°

Illustration of compared SIF seasonal variations for 3 PFTs

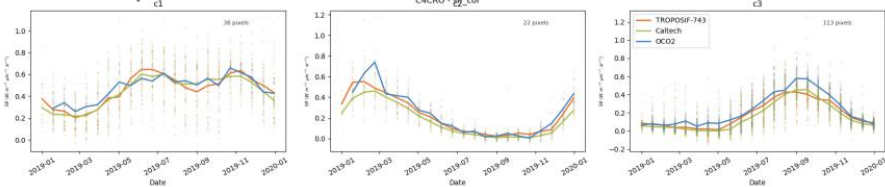
Tropical Evergreen Broadleaf Forest



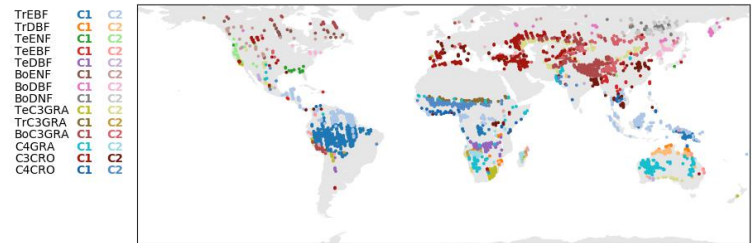
Temperate Deciduous Broadleaf Forest



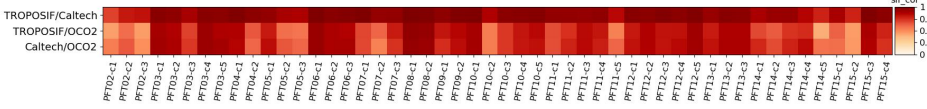
C4 Crops



Distribution of 2 clusters for each PFT



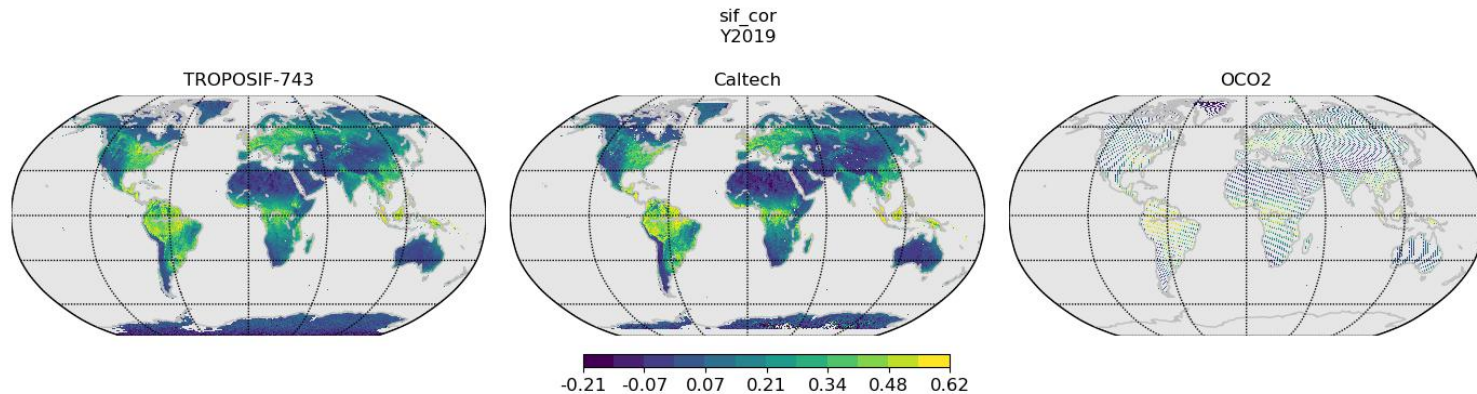
Temporal correlation



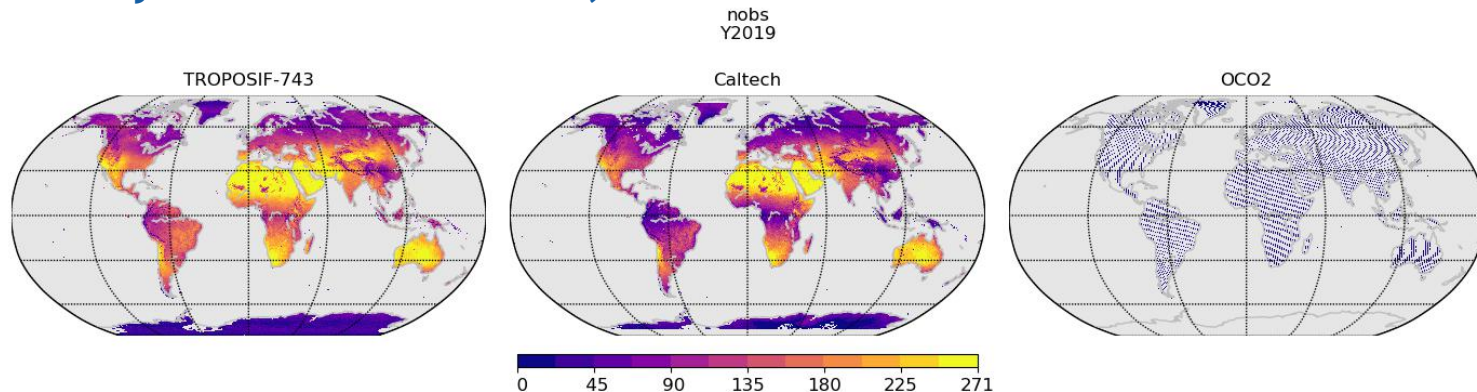
- higher agreement between the 2 TROPOMI products than with OCO-2 (similar sampling for the TROPOMI products and higher number of observations within the 0.5° pixels that reduces the retrieval error)
- OCO-2 in closer agreement with TROPISIF than with Caltech

TROPISIF-743
Caltech
OCO-2

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

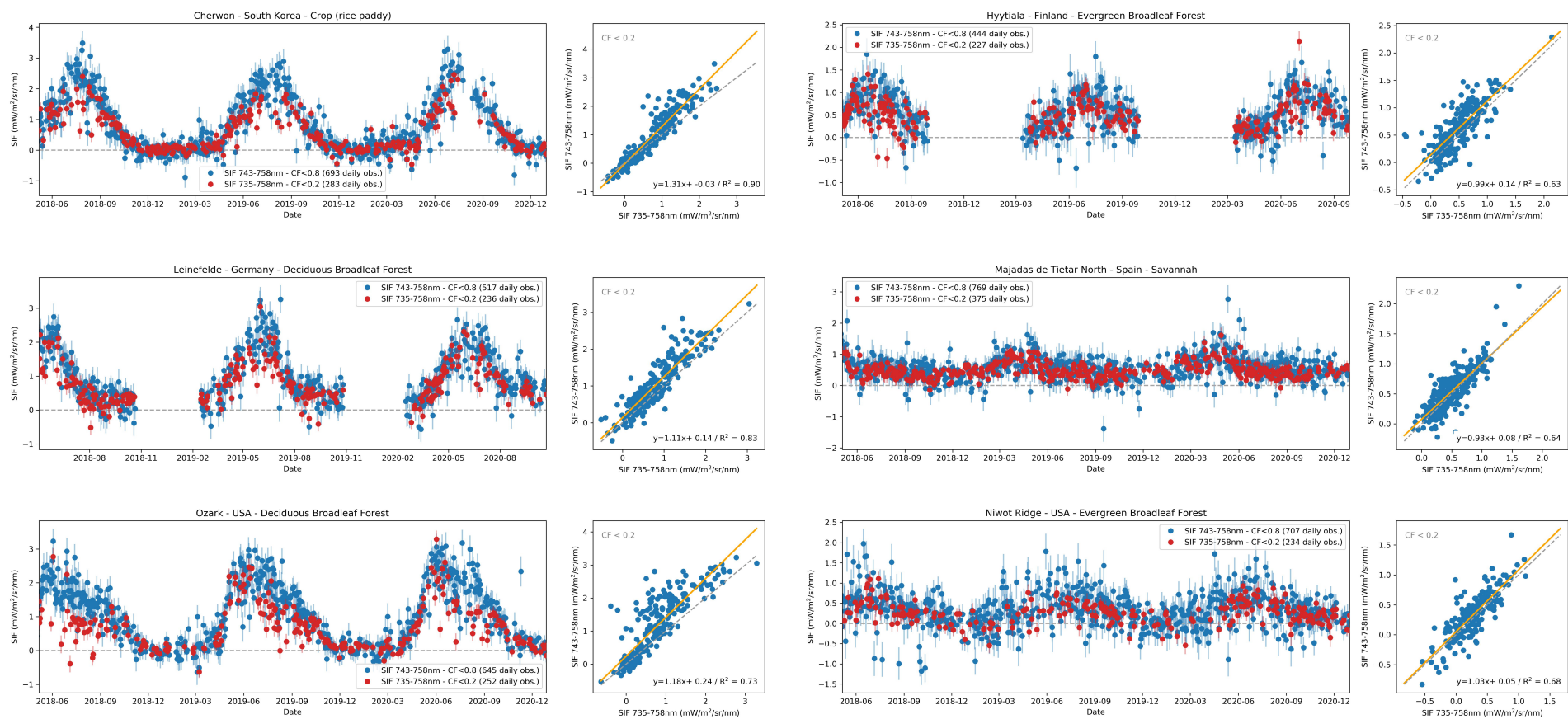


Number of daily SIF estimates at 0.1°, CF < 0.2

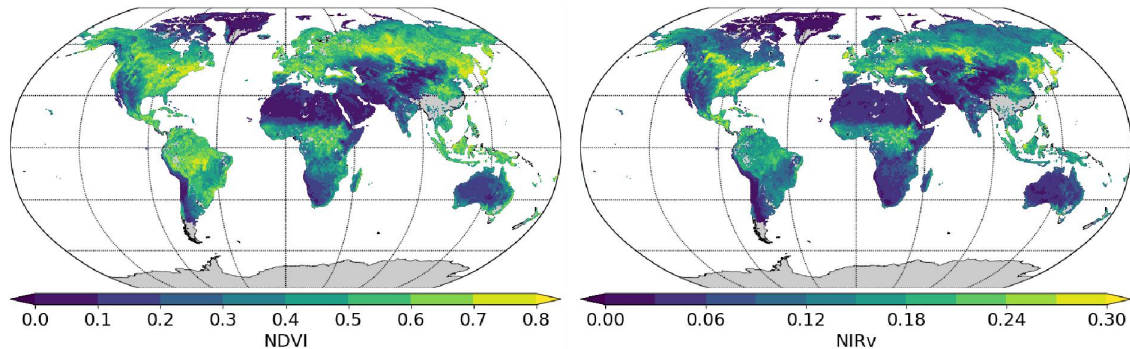


- The difference between Caltech and TROPOSIF are largely explained by the different Cloud Fraction products used :
 - Caltech: VIIRS
 - TROPOSIF: TROPOMI L2_Cloud

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



NDVI and NIRv
8-15 July 2019

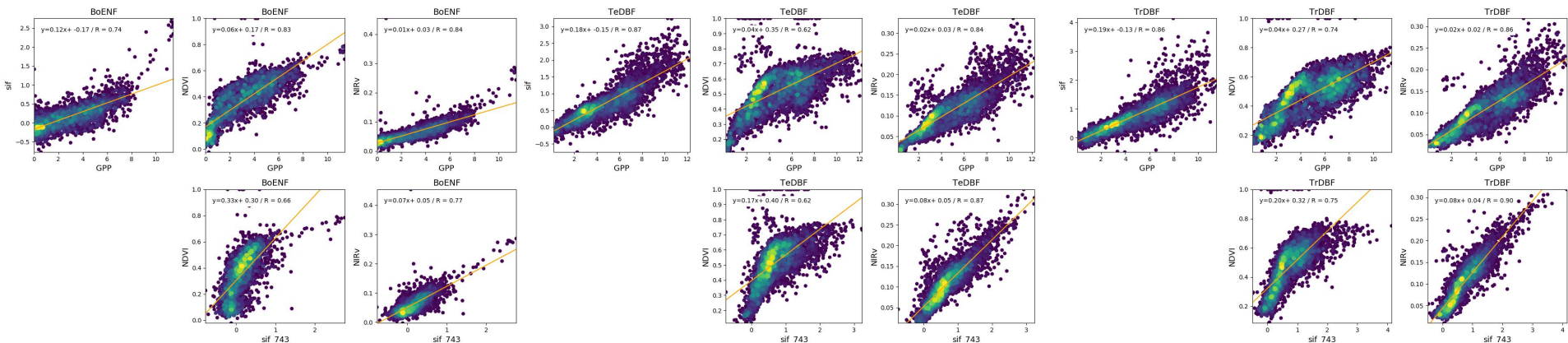


Relationships between SIF(743nm), NDVI and NIRv, and with FluxSat-GPP

Boreal Evergreen Needleleaf Forests

Temperate Deciduous Broadleaf Forests

Tropical Deciduous Broadleaf Forests



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

Please visit the projet web site: <https://s5p-troposif.noveltis.fr/>

For more information, send an email to s5p-troposif@noveltis.fr