Prototyping FLEX FLORIS and Sentinel-3 OLCI Vegetation Products in Support of Forthcoming FLEX Photosynthesis Estimates.

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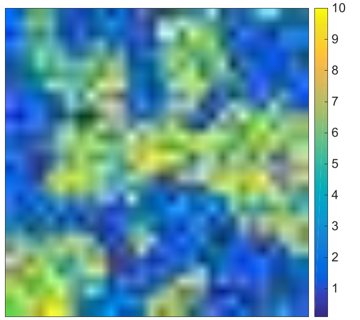
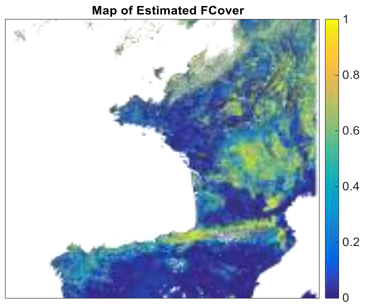
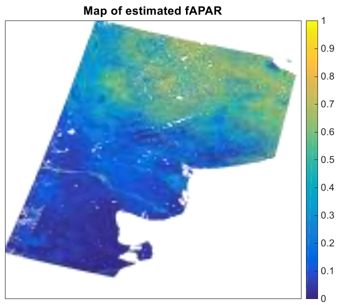
Background

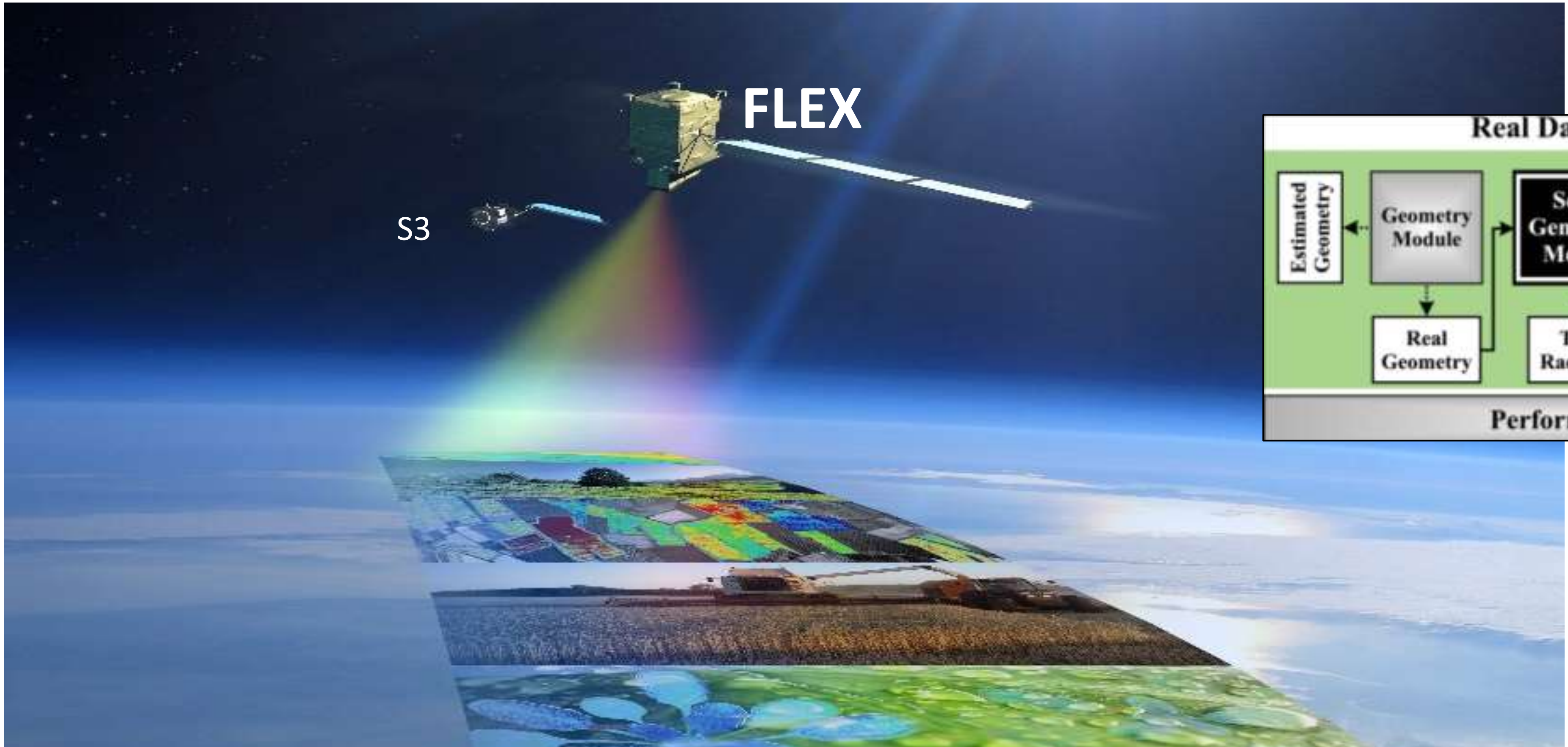
1. **FLEX – Sentinel-3 Tandem Mission** for vegetation monitoring
2. Vegetation **retrieval algorithms developed** for FLEX-Floris and S3-OLCI, and first validated in End-to-End Simulator
3. **OLCI SYN images processed** over Europe and Argentina
4. **Comparison** against S3 L2 OTCI and OGVI and S2-300m products







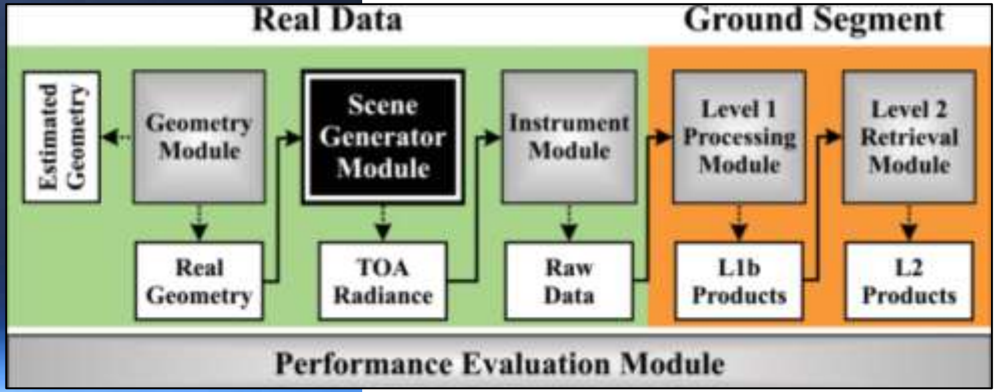
FLEX & S3 tandem mission



FLEX aims to quantify **actual photosynthetic activity** of terrestrial ecosystems from space, accounting for **vegetation health** status and **stress** conditions.

FLEX

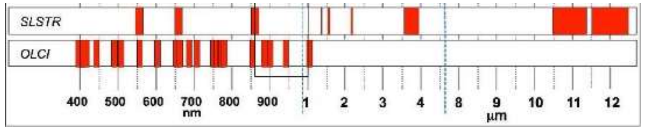
E2E simulator



Sentinel-3

L2 SYN product:
Surface Directional Reflectance (SDR):

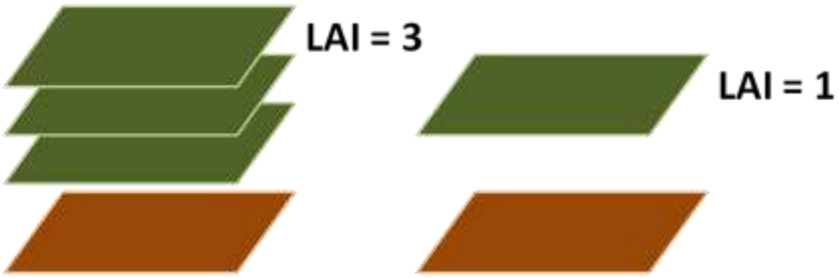
- SLSTR channels (S1 to S6 for both nadir and oblique views) and for
- **All OLCI channels, except for the oxygen absorption bands Oa13-15, and the water vapour band Oa19-20**

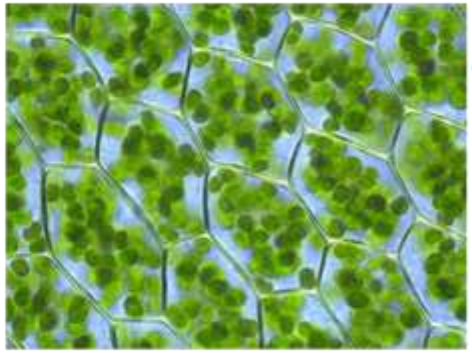


Biophysical variables FLEX/S3

- **LAI** = **L**eaf **A**rea **I**ndex

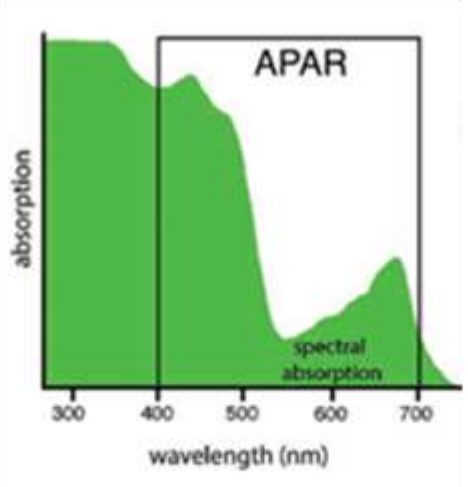
  Range ~ 0 - 10 **(m^{-2}/m^{-2})**





- **Cab** = leaf **C**hlorophyll (**a** + **b**) content

  Range ~ 0 - 100 μg $.cm^{-1}$

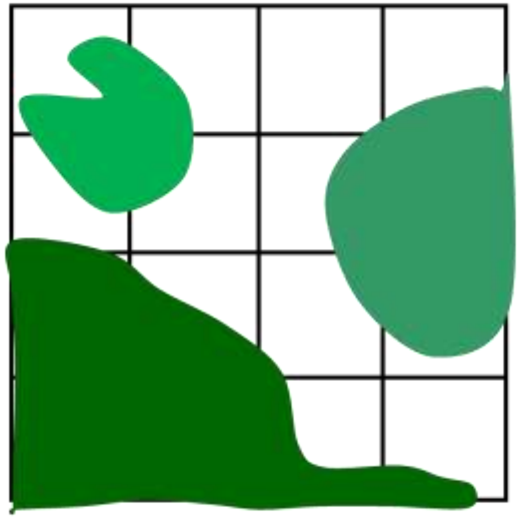


- **fAPAR** = **f**raction of **A**bsorbed **P**hotosynthetically **A**ctive **R**adiation

  Range: 0 - 1

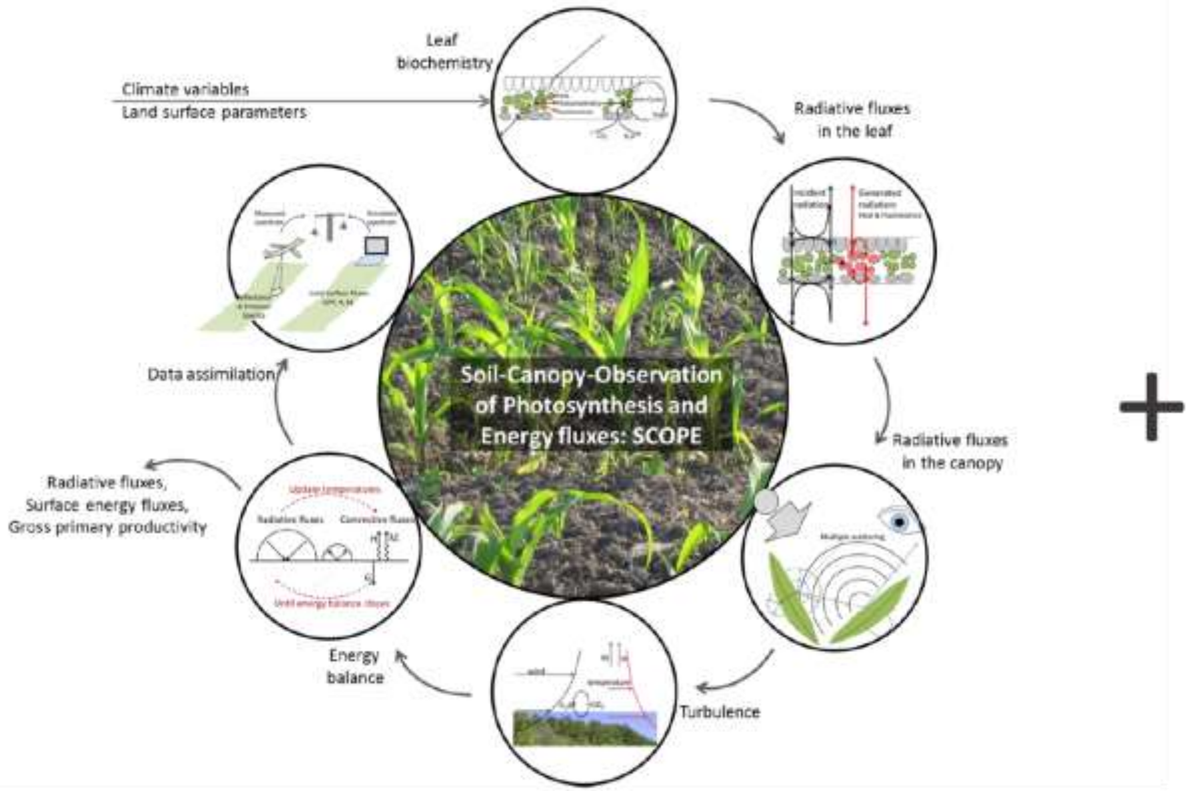
- **FCover** = **F**ractional vegetation **Cover**

  Range: 0 - 1



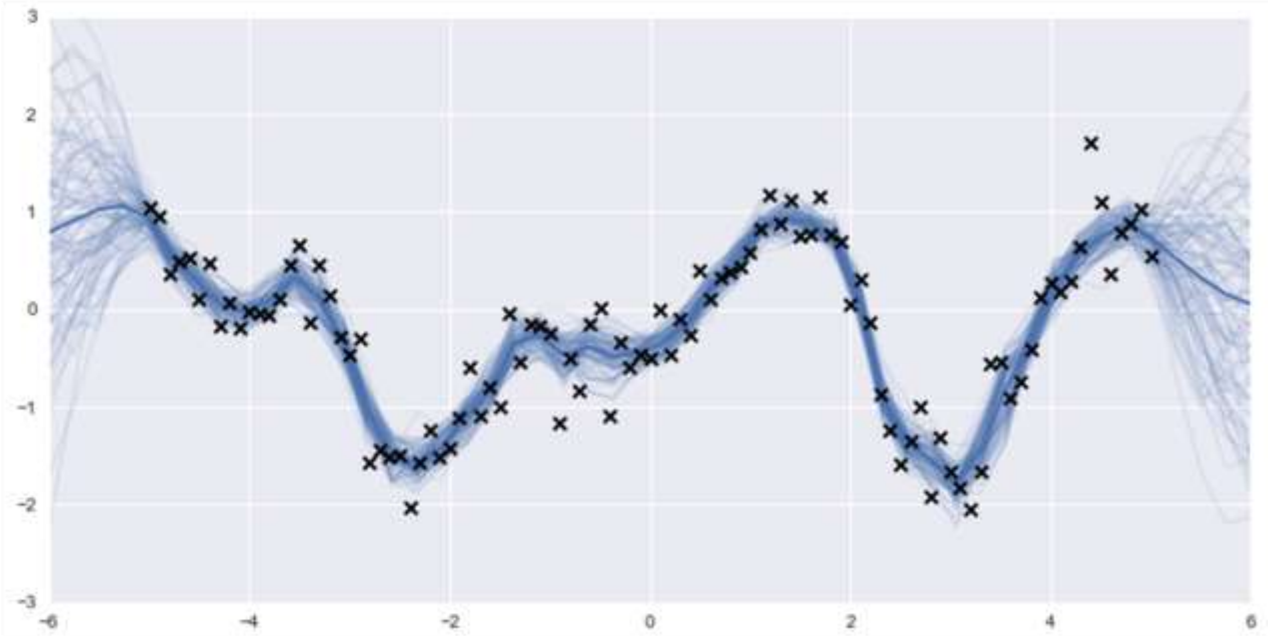
Variables retrieved by FLEX-FLORIS, S3-OLCI and synergy of both

Hybrid retrieval method: SCOPE + GPR



Radiative Transfer Model (RTM):
SCOPE (v 1.70)

+

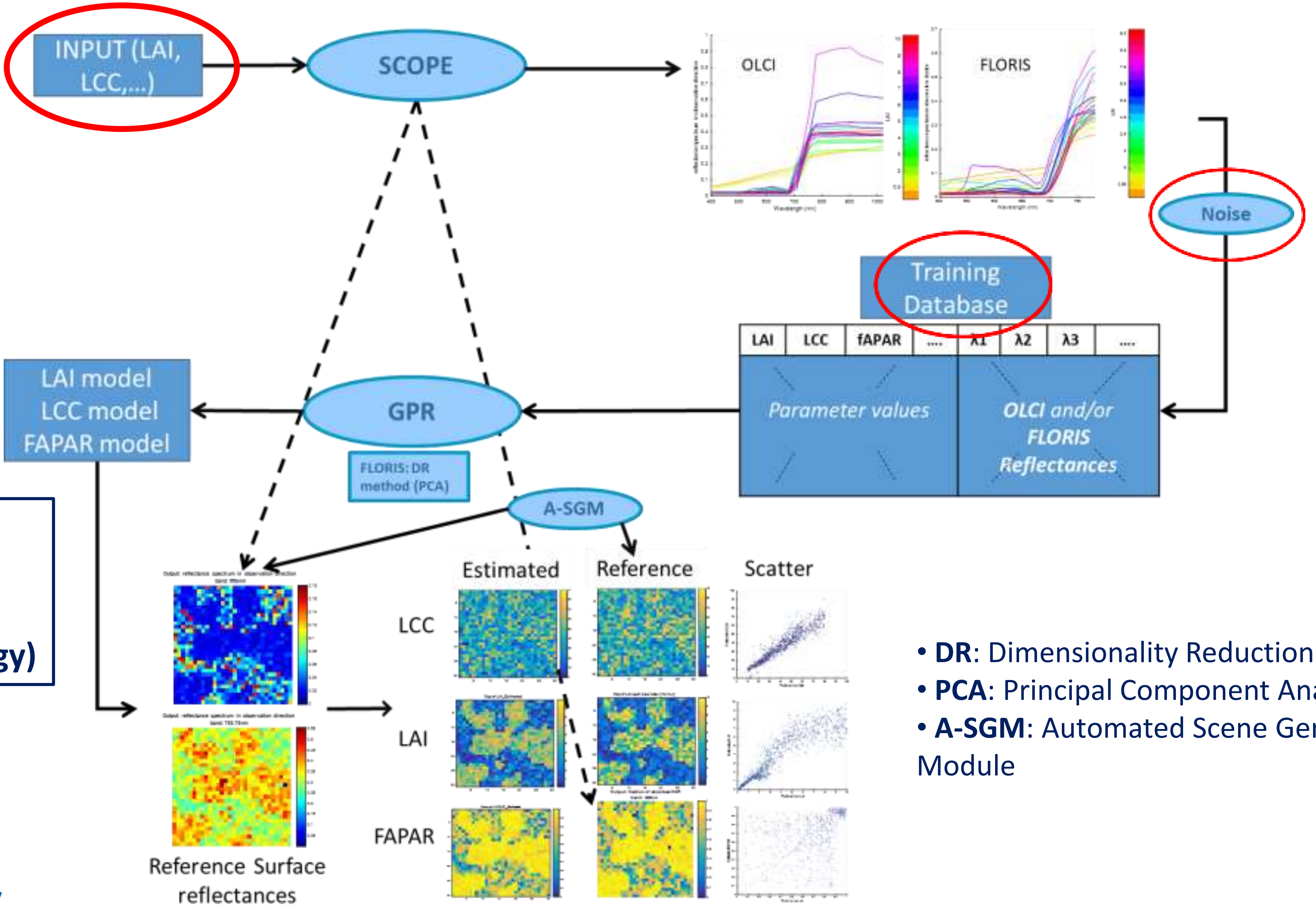


Machine Learning Algorithm:
Gaussian Process Regression (GPR)

- Van der Tol, C., Berry, J.A., Campbell, P.K.E., Rascher, U., (2014). Models of fluorescence and photosynthesis for interpreting measurements of solar-induced chlorophyll fluorescence. Journal of Geophysical Research: Biogeosciences, 119: 2312-2327
- Gaussian Processes for Machine Learning, Carl Edward Rasmussen and Chris Williams, the MIT Press, 2006
- Verrelst, J., Malenovský, Z., Van der Tol, C., Camps-Valls, G., Gastellu-Etchegory, J.P., Lewis, P., Moreno, J. (2018). Quantifying Vegetation Biophysical Variables from Imaging Spectroscopy Data: A Review on Retrieval Methods. Surveys in Geophysics

Scheme training models and validation

Optimization steps



3 types of models:

- **OLCI**
- **FLORIS**
- **OLCI + FLORIS (synergy)**

- **DR**: Dimensionality Reduction
- **PCA**: Principal Component Analysis
- **A-SGM**: Automated Scene Generator Module

https://artmotoolbox.com/

Input SCOPE

Variable type	Variable	Distribution	Min	Max	Mean	SD
Leaf structure	N	Gaussian*	1	2.7	1.5	0.5
	Cab (μg.cm^{-2})	Uniform	1	100		
	Cca (μg.cm^{-2})	Gaussian*	0	30	10	5
	Cdm (g.cm^{-2})*	Gaussian*	0.002	0.02	0.005	0.003
	Cw**	Gaussian*	0.005	0.035	0.012	0.006
Canopy structure	LAI	Uniform	0.1	10		
	LIDFa (rad)***	Uniform	-1	1		
	LIDFb (rad)***	Uniform	-1	1		
Soil	SMC (%)	Gaussian	5	55	25	12.5
	BSM Brightness	Gaussian	0.5	1.5	1	0.5
	BSM lat (°)	Gaussian	20	40	25	12.5
	BSM long (°)	Gaussian	45	65	50	10
Geometry	SZA (°)	Uniform	0	80		
	OZA (°)	Uniform	-25	25		
	RAA (°)	Uniform	0	180		

N: Leaf mesophyll structure; **Cab**: Leaf chlorophyll content; **Cdm**: Leaf dry matter content; **Cw**: Leaf water thickness; **Cant**: Leaf anthocyanin content; **Cs**: Leaf senescent material content; **Cca**: Leaf carotenoid content; **LAI**: Leaf Area Index; **LIDFa**: Average leaf angle; **LIDFb**: Variation in leaf angle; **SMC**: Soil Moisture Content; **BSM**: Brightness - Shape - Moisture spectral soil model; **SZA**: Solar Zenith Angle; **OZA**: Observer Zenith Angle; **RAA**: Relative Azimuth Angle; * truncated Gaussian; ** Constraint: Cw/(Cw+Cdm) between 0.45 and 0.93; *** constraint: |LIDFa|+ |LIDFb| < 1

- Based on global sensitivity analysis
- Based on leaf optical properties databases (OPTICLEAF)
  < S. Jacquemoud, L. Bidel, C. François, G. Pavan (2003); B. Hosgood, G. Andreoli, S. Jacquemoud, A. Pedrini, G. Schmuck, J. Verdebout (1993)
- Based on literature (e.g. García-Haro et al., 2018; Weiss and Baret, 2016; Croft et al., 2015; Houborg et al., 2015; Verrelst et al., 2015; Houborg and Boegh, 2008; Lauvernet et al., 2008)
- To cover all geometrical configurations and canopy realizations
- Fixed variables: default SCOPE values

Apart from simulated LUT, additional bare soil samples are added to account for not-vegetated surfaces

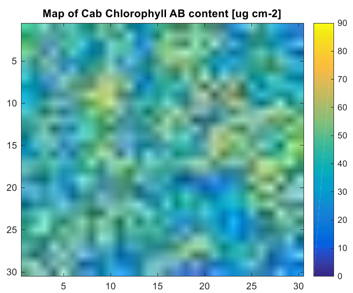
E2E Validation setup

- Reference images simulated with an Automated Scene Generator Module (A-SGM)
- Small image (30 x 30 pixels) with 2 land cover (LC) classes to create a LC map
- Generated by SCOPE with varying input variables for each class

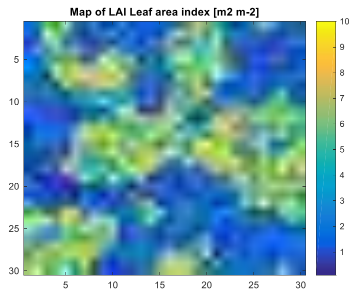
Variable type	Variable	Distribution	Min	Max	Mean	SD
Leaf structure	N	Gaussian*	1	2.7	1.5	0.5
	Cca (μg.cm^{-2})	Gaussian*	0	30	10	5
	Cdm (g.cm^{-2})*	Gaussian*	0.002	0.02	0.005	0.003
	Cw**	Gaussian*	0.005	0.035	0.012	0.006
Canopy structure	LIDFa (rad)***	Uniform	-1	1		
	LIDFb (rad)***	Uniform	-1	1		
Soil	SMC (%)	Gaussian	5	55	25	12.5
	BSM Brightness	Gaussian	0.5	1.5	1	0.5
	BSM lat (°)	Gaussian	20	40	25	12.5
	BSM long (°)	Gaussian	45	65	50	10

Variable	class 1	class 2
Cab (μg.cm^{-2})	1 - 60	15 - 100
LAI	0.1 – 3	3 – 10

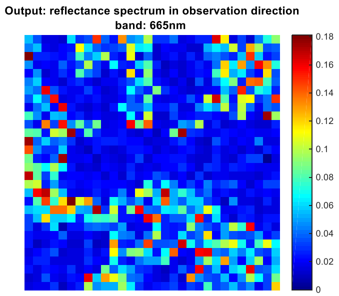
- Cab and LAI images: uniform sampling distribution, random spatial distribution
- Selection of the mapped SCOPE output (reflectances, fAPAR) with noise



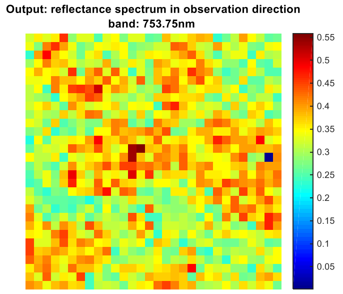
Cab



LAI



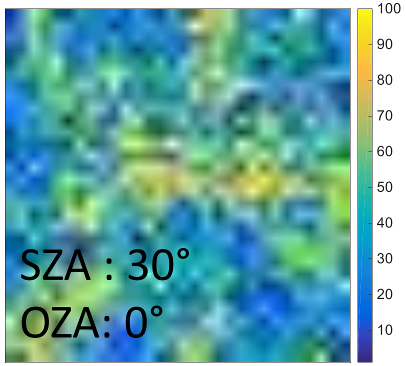
Reflectance in the Red (665 nm)

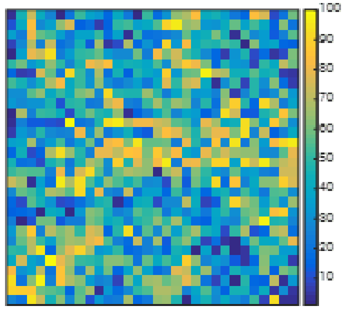
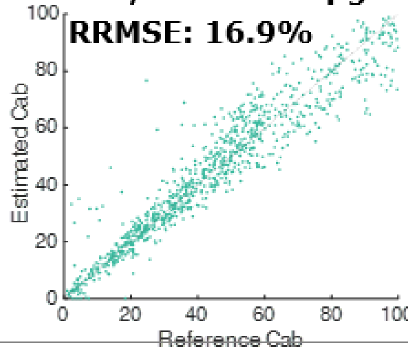
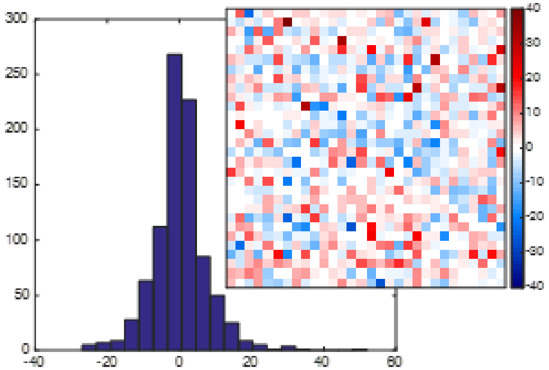
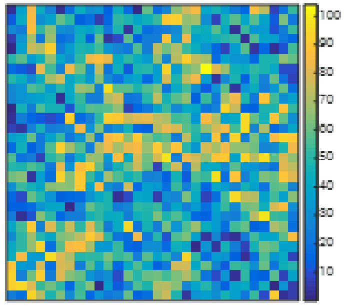
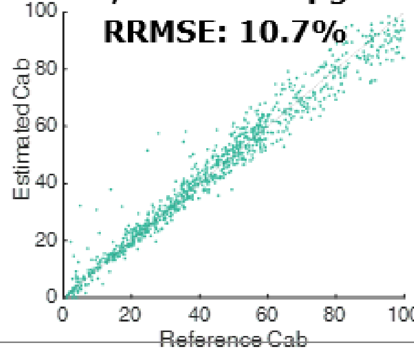
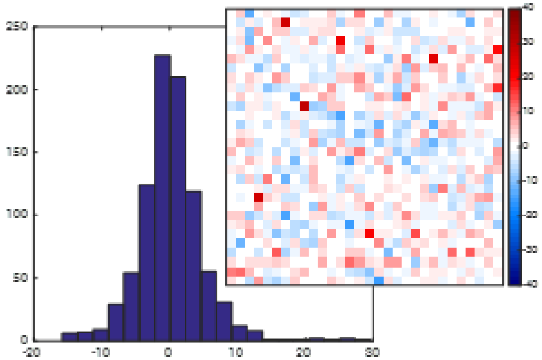
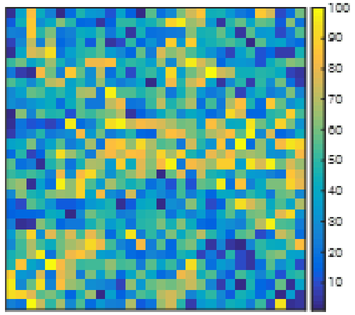
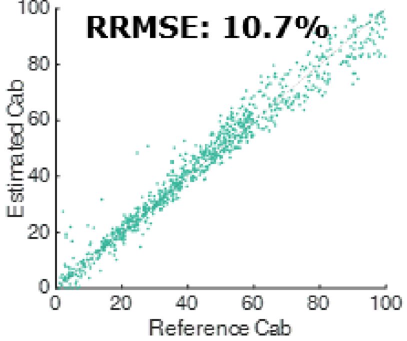
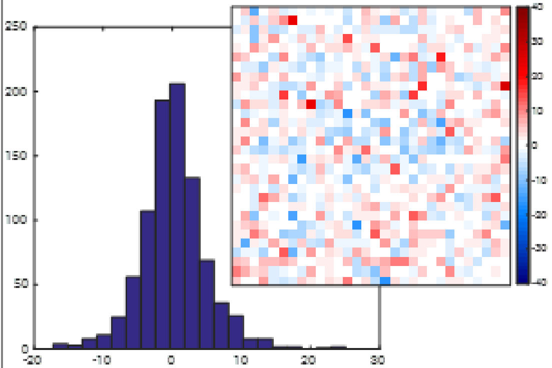


Reflectance in the Red Edge (754 nm)

E2E Validation results - Cab

Reference

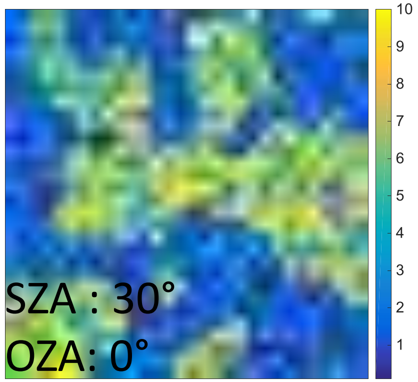


Cab	Estimated image	Validation (Estim. vs. Ref.)	Absolute error per pixel
OLCI		R^2: 0.91; RMSE: 7.6 µg.cm^{-2}; RRMSE: 16.9% 	
FLORIS		R2: 0.96; RMSE: 4.8 µg.cm^{-2}; RRMSE: 10.7% 	
Synergy (OLCI + FLORIS)		R2: 0.96; RMSE: 4.8 µg.cm^{-2}; RRMSE: 10.7% 	

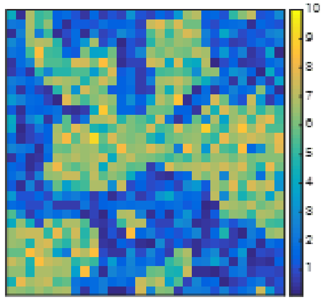
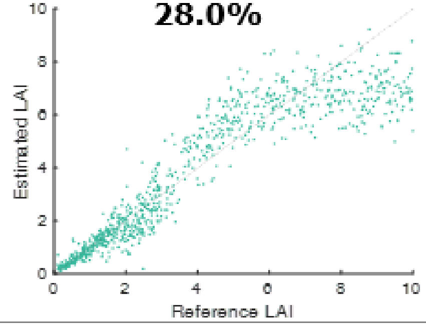
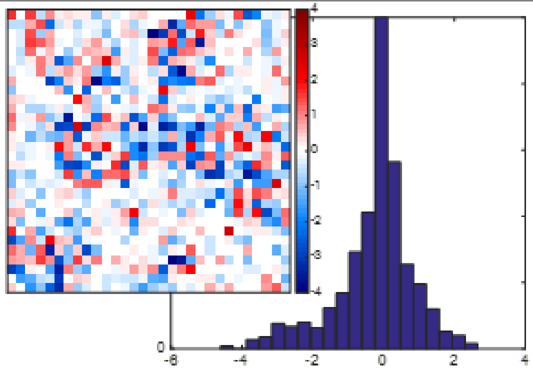
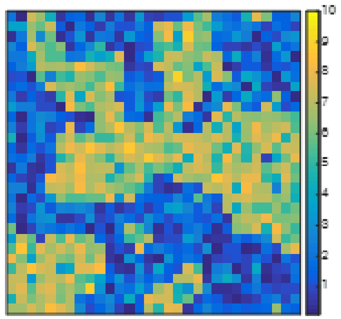
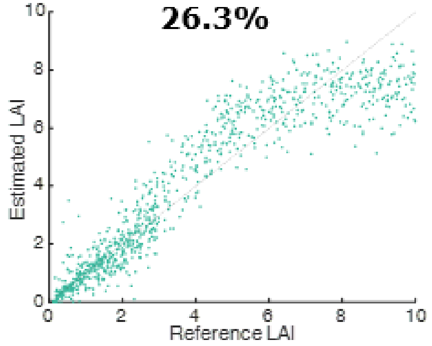
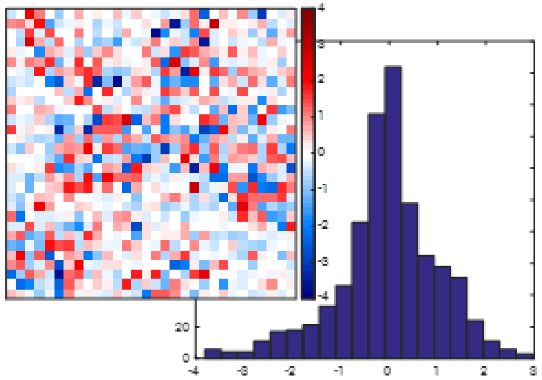
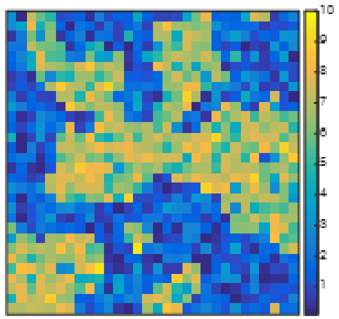
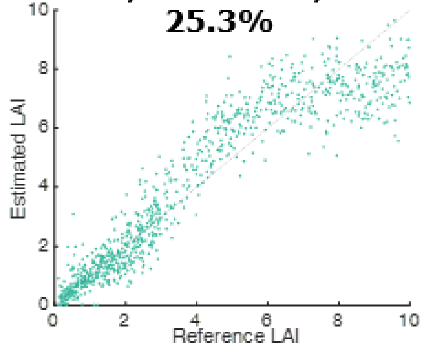
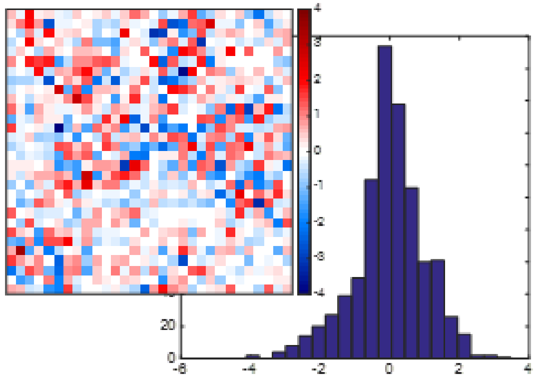
$$RRMSE\ (\%) = 100 * \frac{RMSE}{V_{obs}^{mean}}$$

E2E Validation results - LAI

Reference

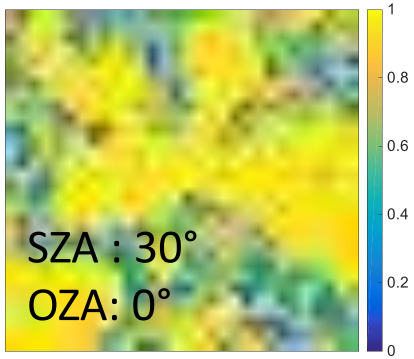


$$RRMSE\ (\%) = 100 * \frac{RMSE}{V_{obs}^{mean}}$$

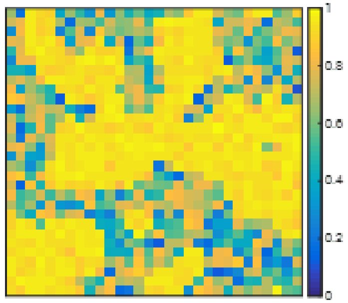
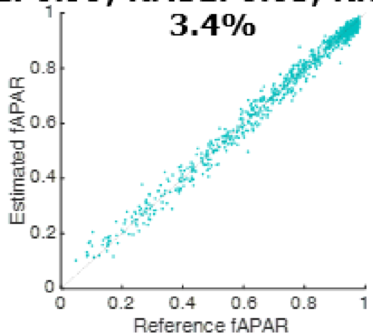
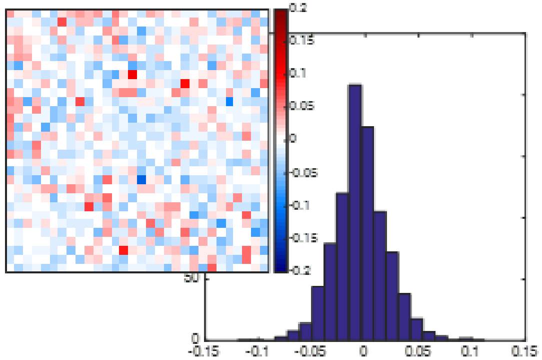
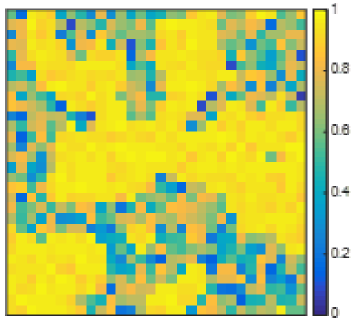
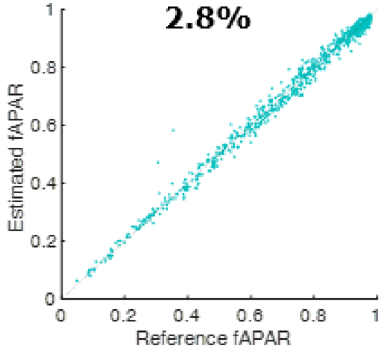
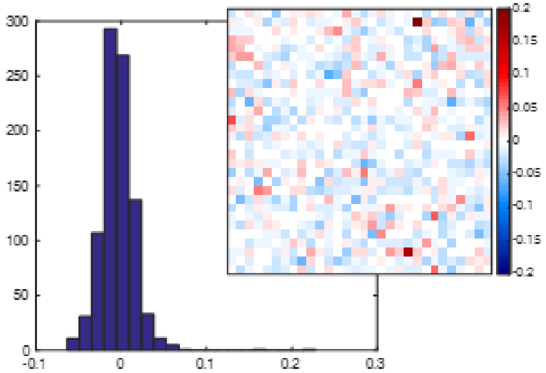
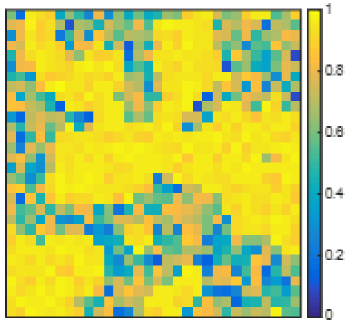
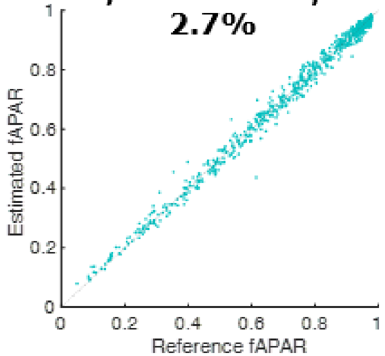
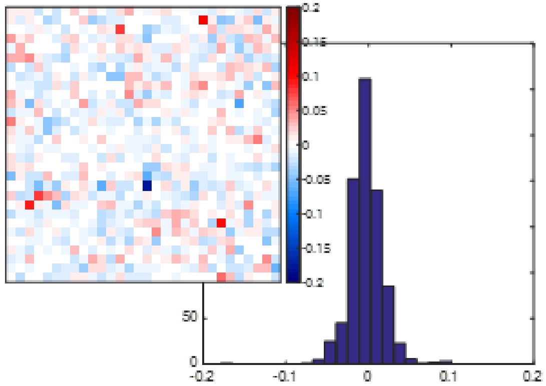
LAI	Estimated image	Validation (Estim. vs. Ref.)	Absolute error per pixel
OLCI		R2: 0.86; RMSE: 1.1; RRMSE: 28.0% 	
FLORIS		R2: 0.87; RMSE: 1.1; RRMSE: 26.3% 	
Synergy (OLCI + FLORIS)		R2: 0.88; RMSE: 1.0; RRMSE: 25.3% 	

E2E Validation results - fAPAR

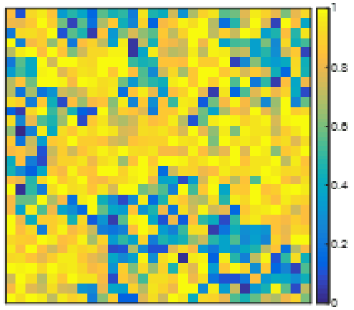
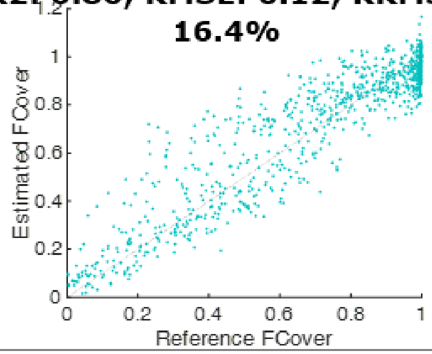
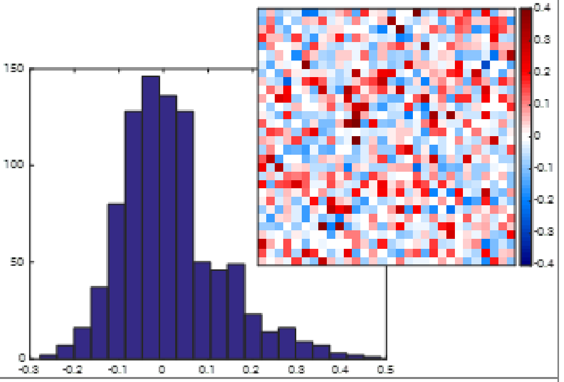
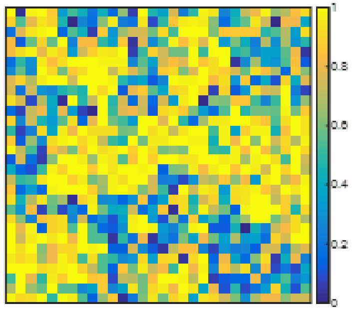
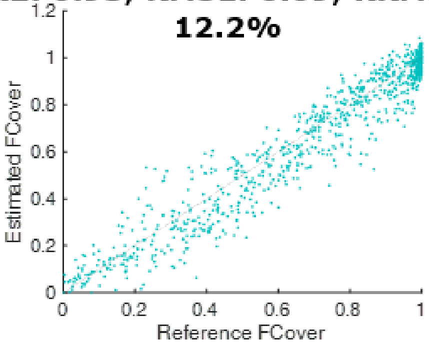
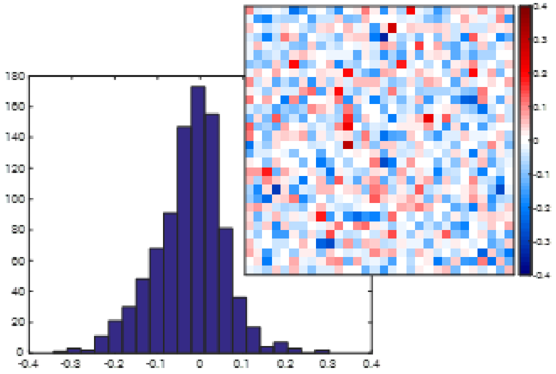
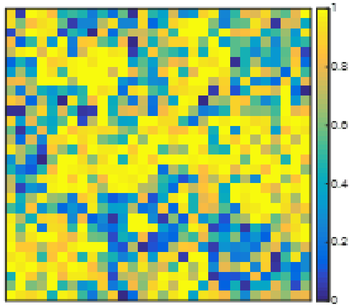
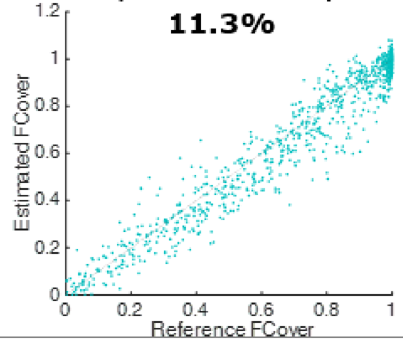
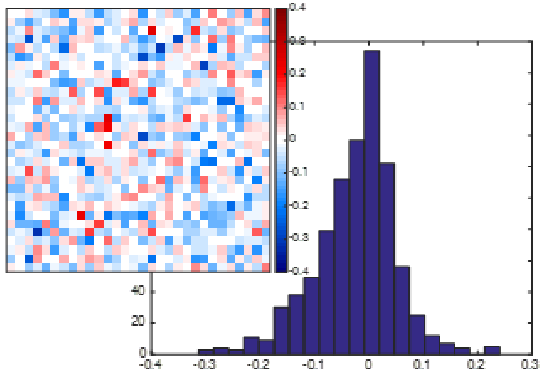
Reference



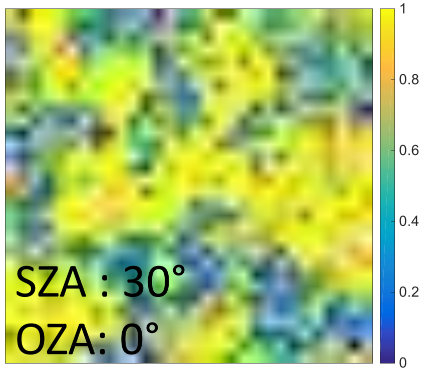
$$RRMSE\ (\%) = 100 * \frac{RMSE}{V_{obs}^{mean}}$$

fAPAR	Estimated image	Validation (Estim. vs. Ref.)	Absolute error per pixel
OLCI		**R2: 0.99; RMSE: 0.03; RRMSE: 3.4%** 	
FLORIS		**R2: 0.99; RMSE: 0.02; RRMSE: 2.8%** 	
Synergy (OLCI + FLORIS)		**R2: 0.99; RMSE: 0.02; RRMSE: 2.7%** 	

E2E Validation results - FCover

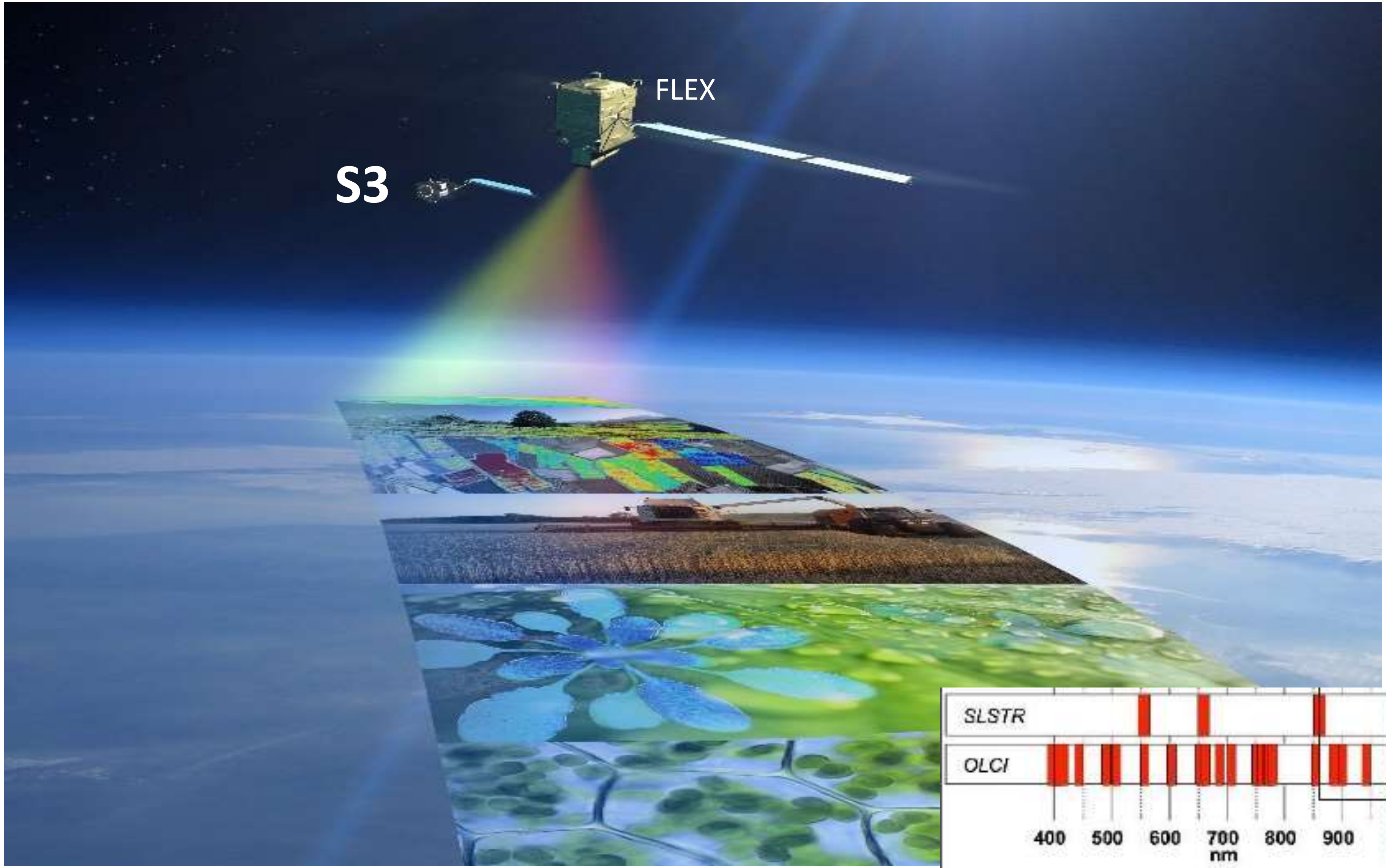
FCover	Estimated image	Validation (Estim. vs. Ref.)	Absolute error per pixel
OLCI		**R2: 0.86; RMSE: 0.12; RRMSE: 16.4%** 	
FLORIS		**R2: 0.93; RMSE: 0.09; RRMSE: 12.2%** 	
Synergy (OLCI + FLORIS)		**R2: 0.94; RMSE: 0.08; RRMSE: 11.3%** 	

Reference



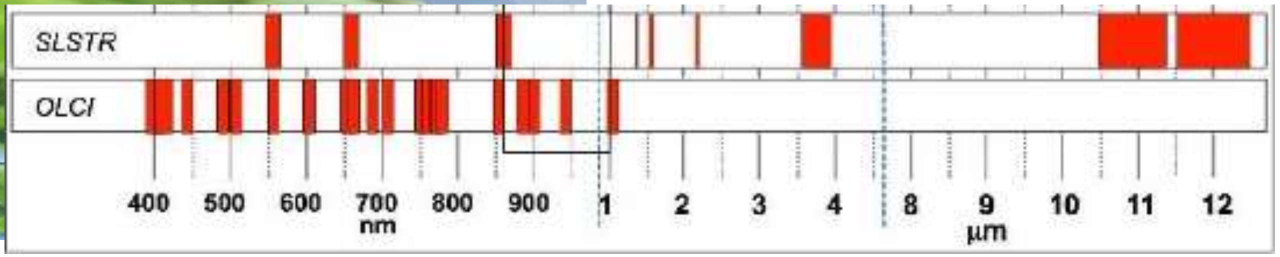
$$RRMSE\ (\%) = 100 * \frac{RMSE}{V_{obs}^{mean}}$$

S3 & FLEX tandem mission

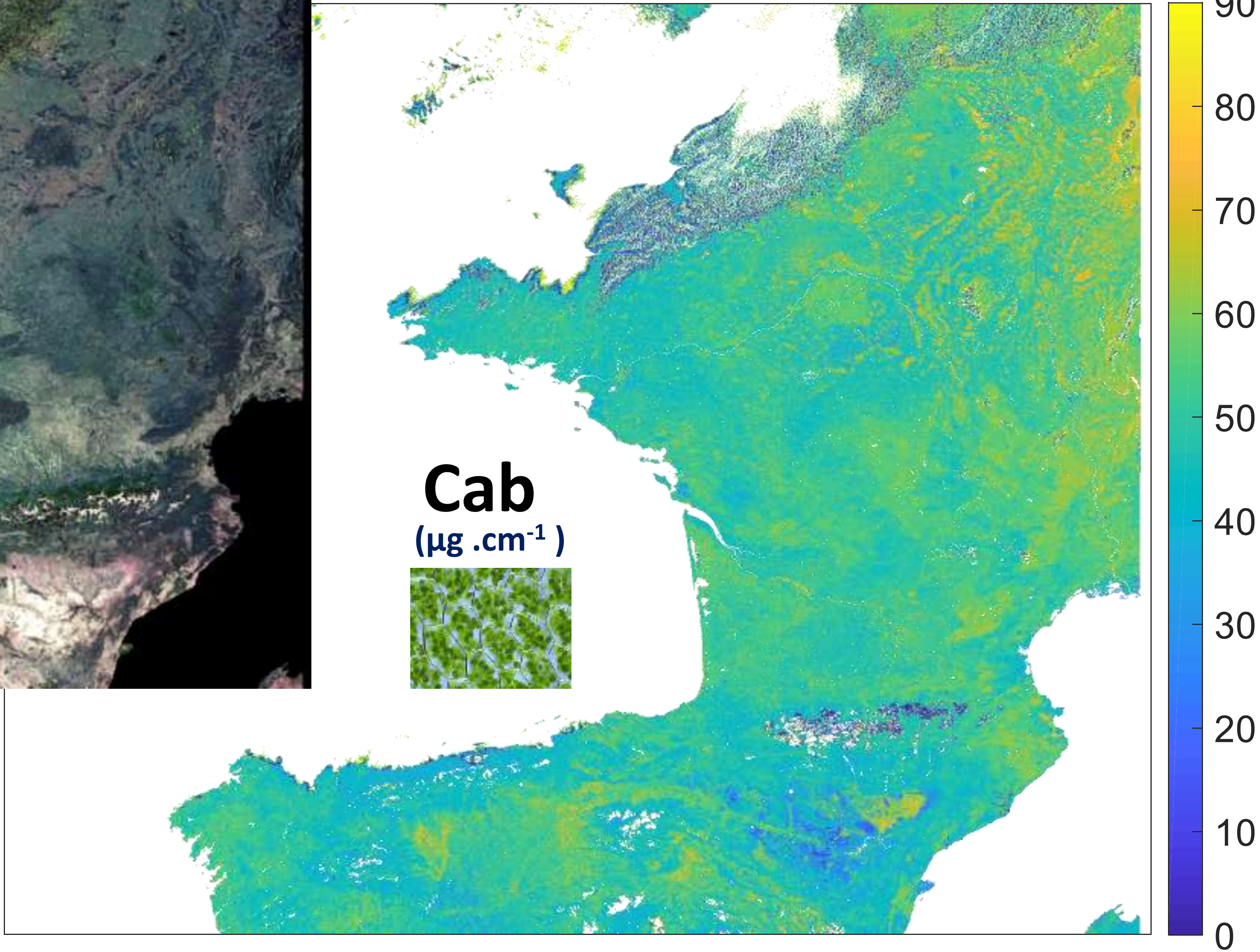


L2 SYN product: Surface Directional Reflectance (SDR):

- SLSTR channels (S1 to S6 for both nadir and oblique views) and for
- **All OLCI channels, except for the oxygen absorption bands Oa13-15, and the water vapour band Oa20-21**

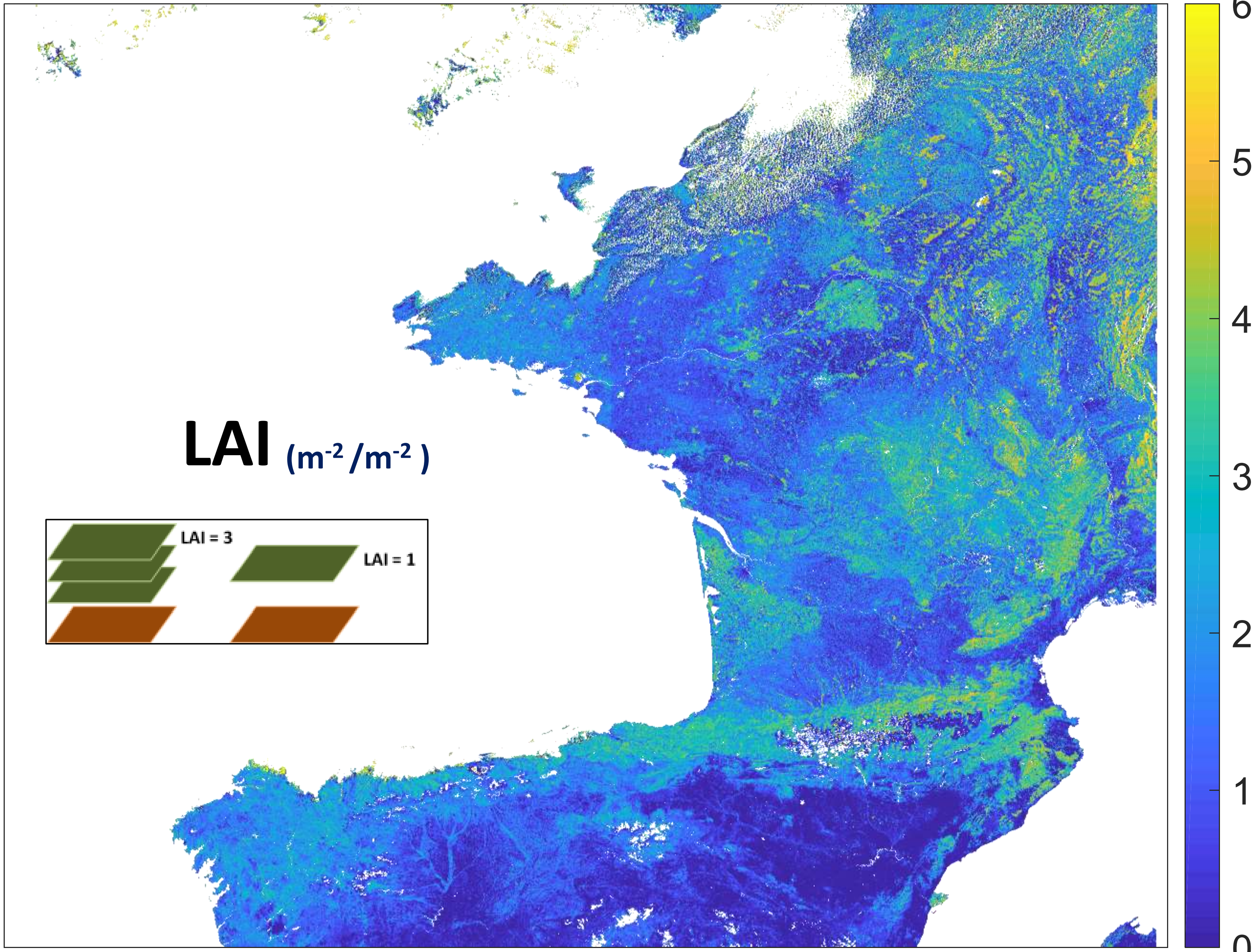


Map of Cab_Estimated



FAST PROCESSING

Map of LAI_Estimated

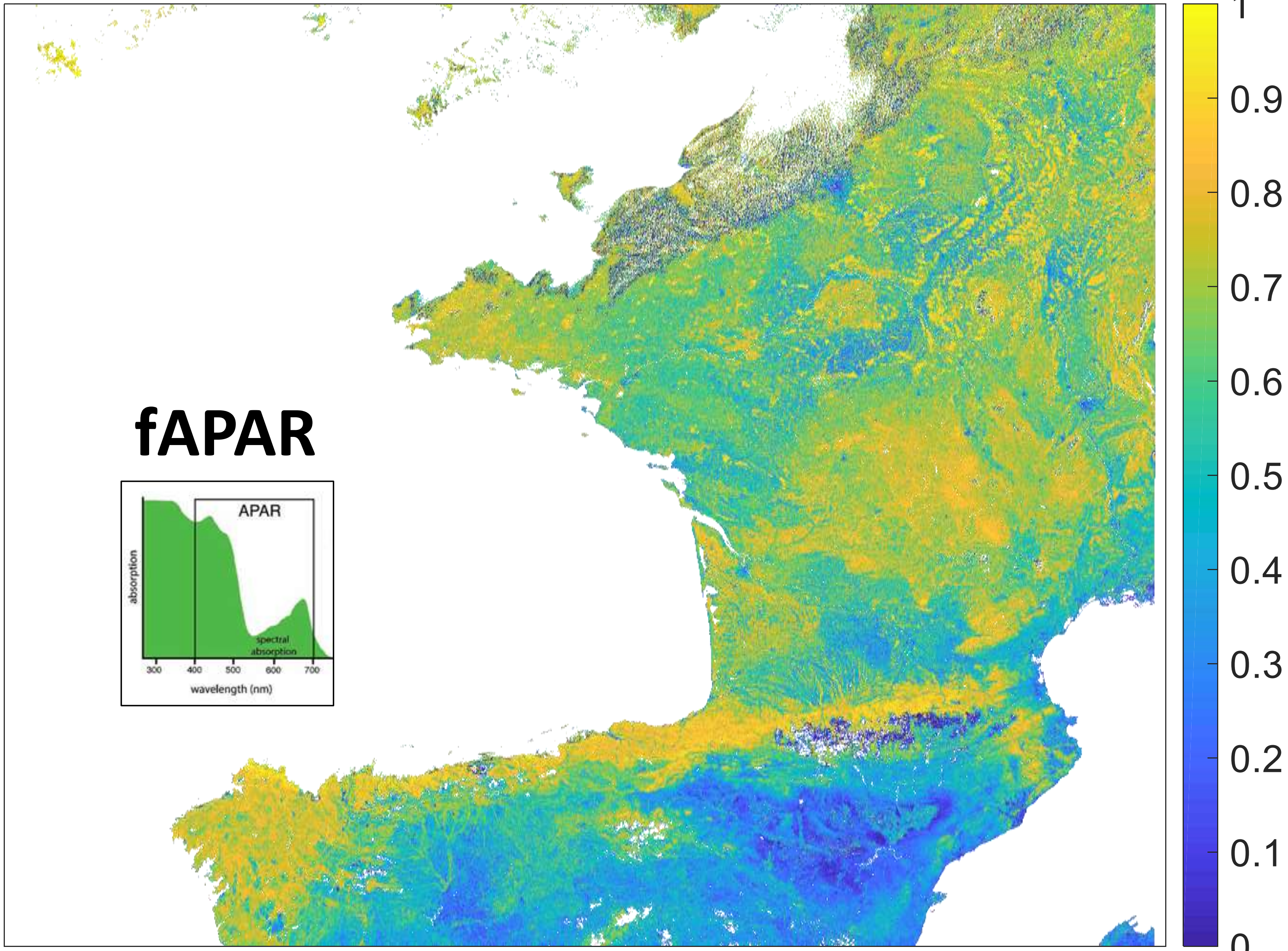


LAI (m^{-2} /m^{-2})

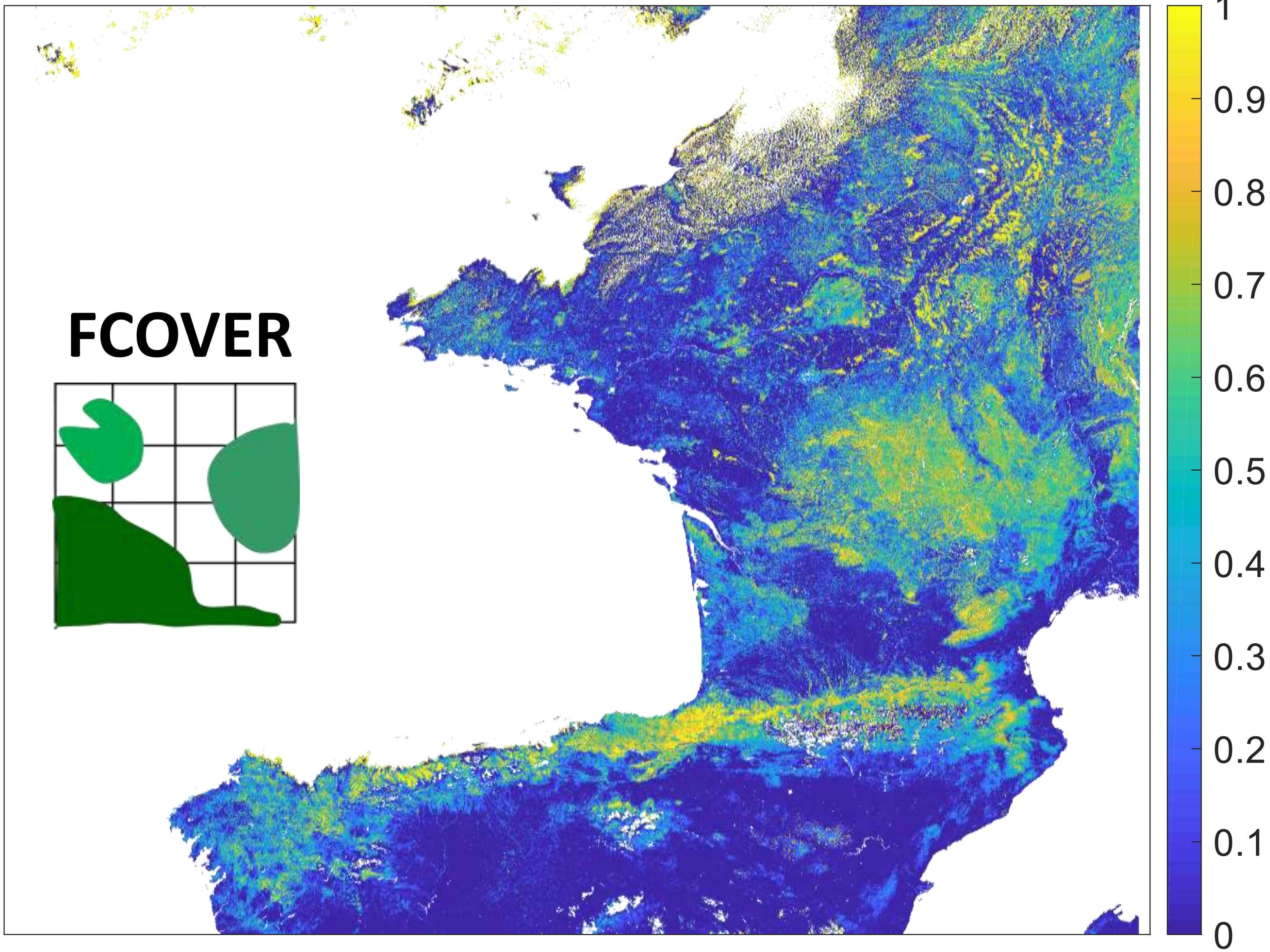
LAI = 3

LAI = 1

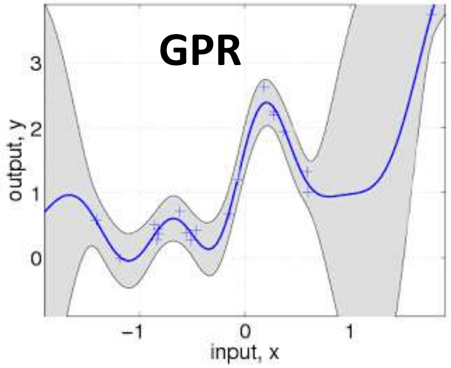
Map of fAPAR_Estimated

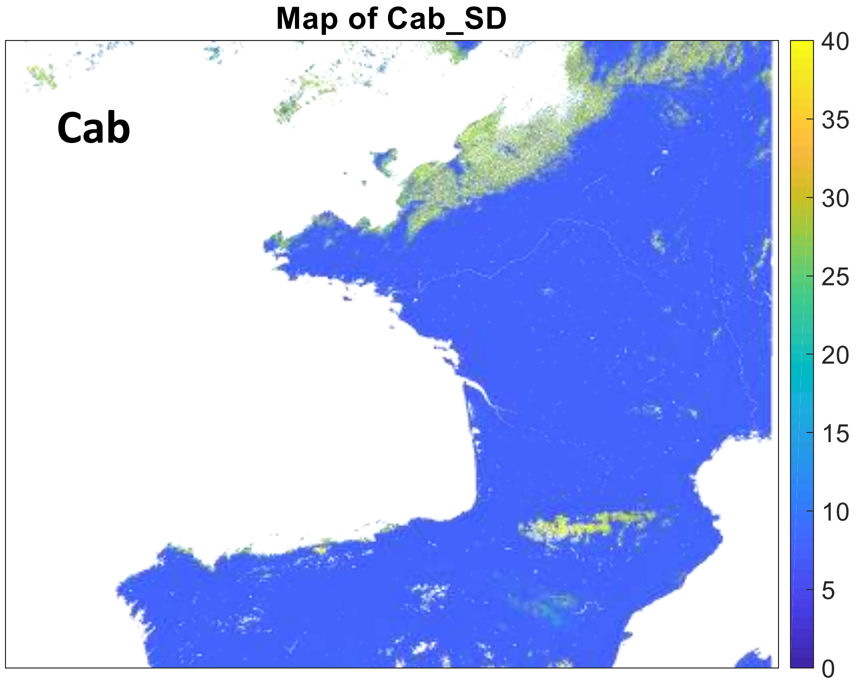


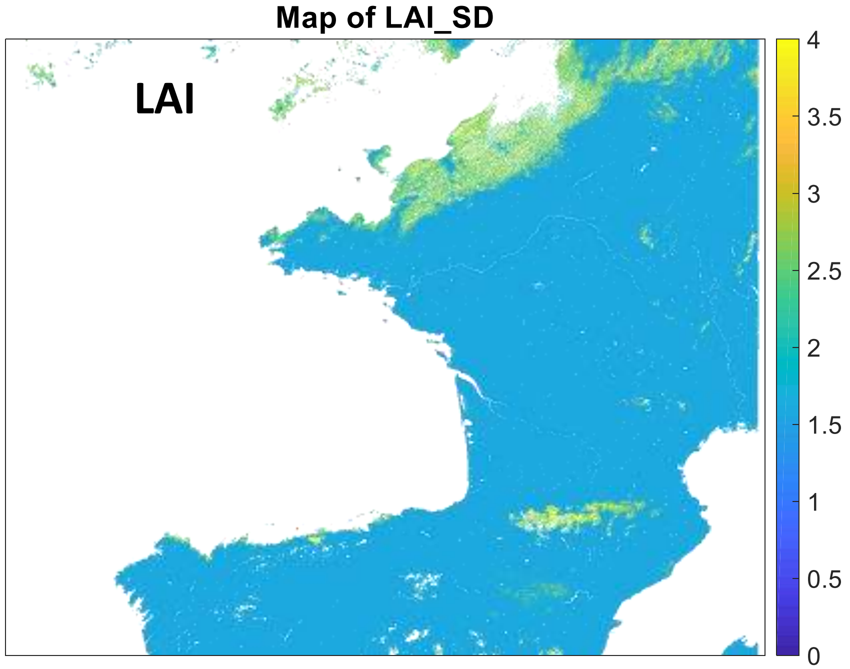
Map of FCover_Estimated

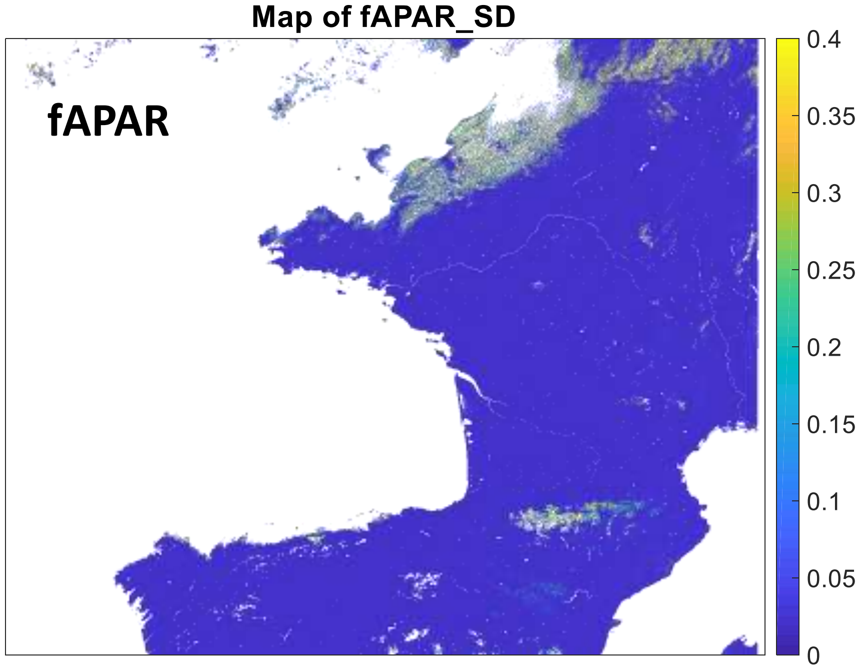


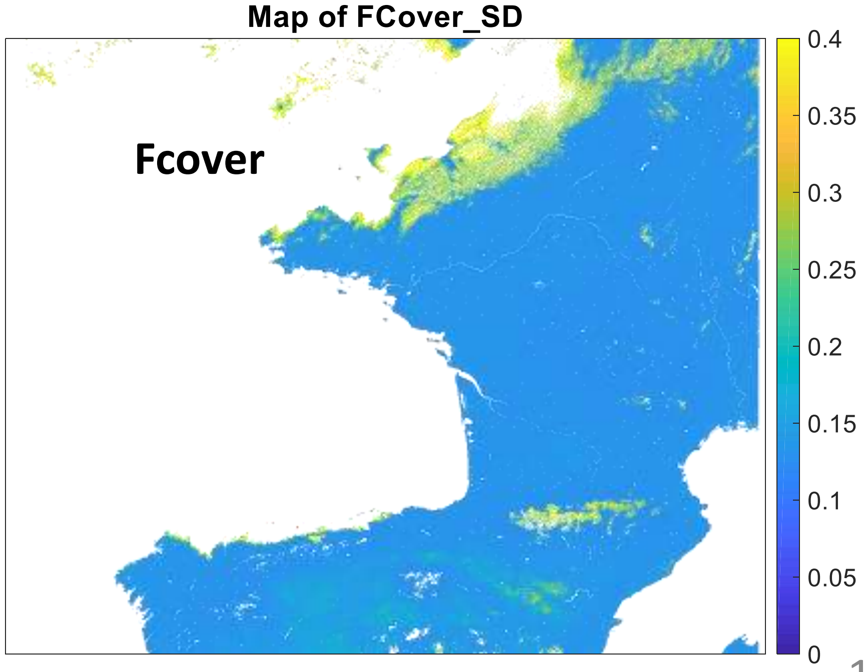
Absolute Uncertainties (SD)



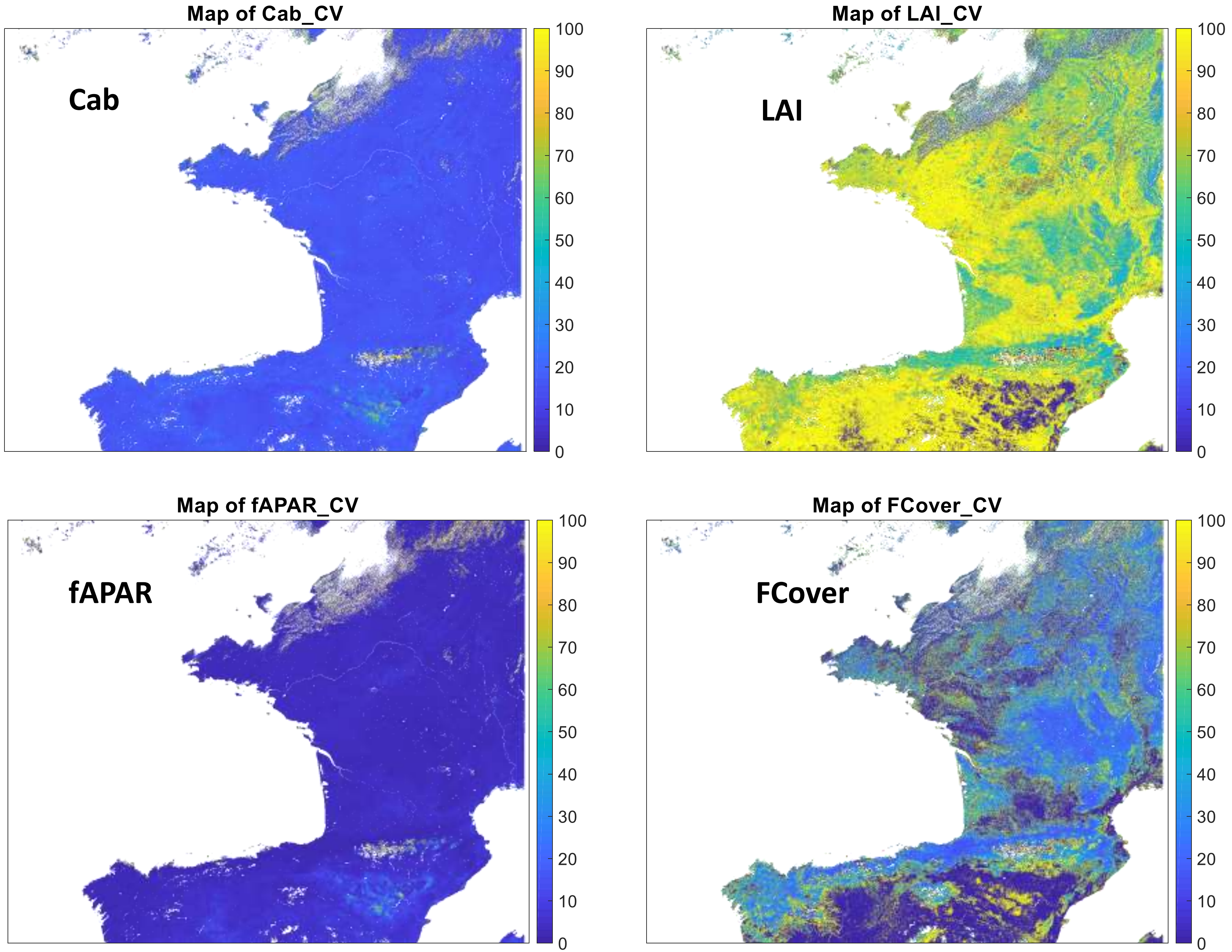






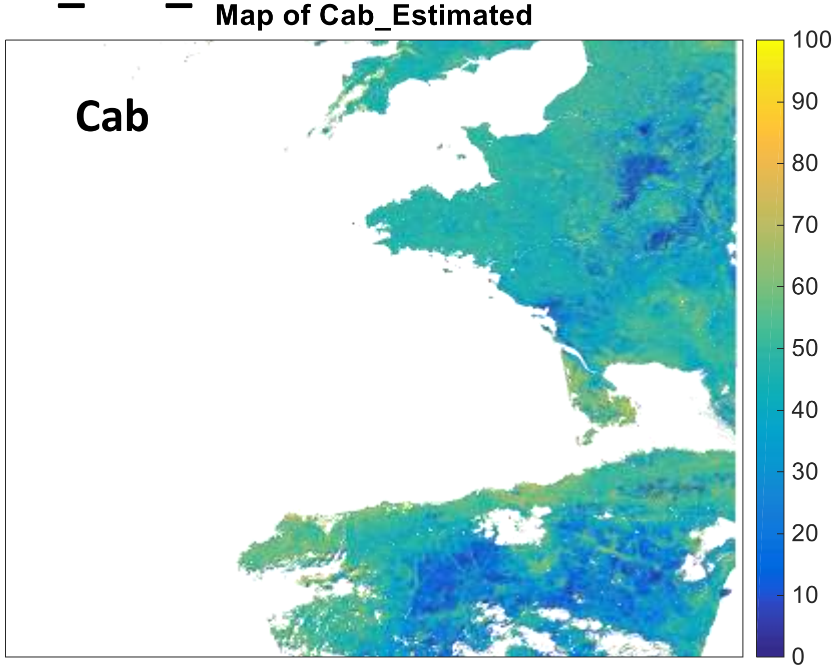


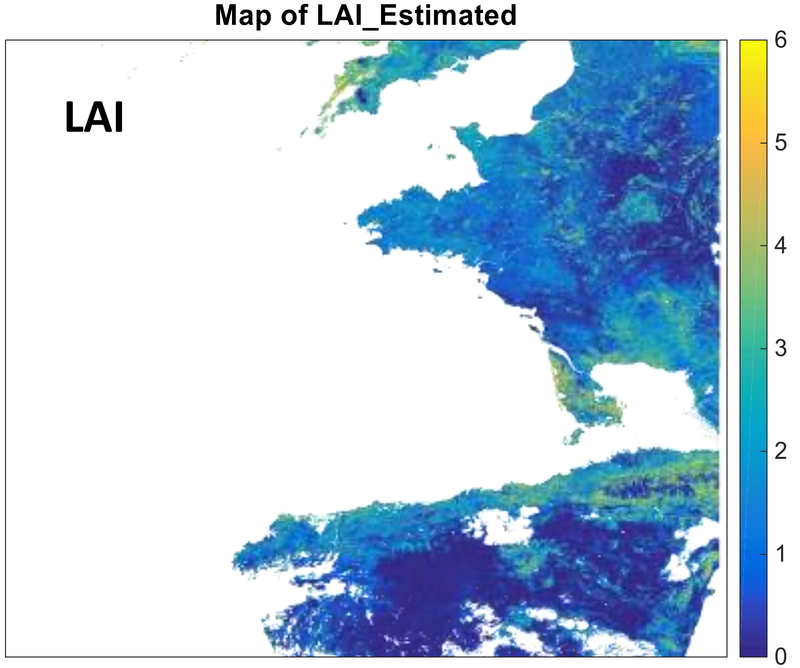
Relative Uncertainties $CV=SD/\mu*100$

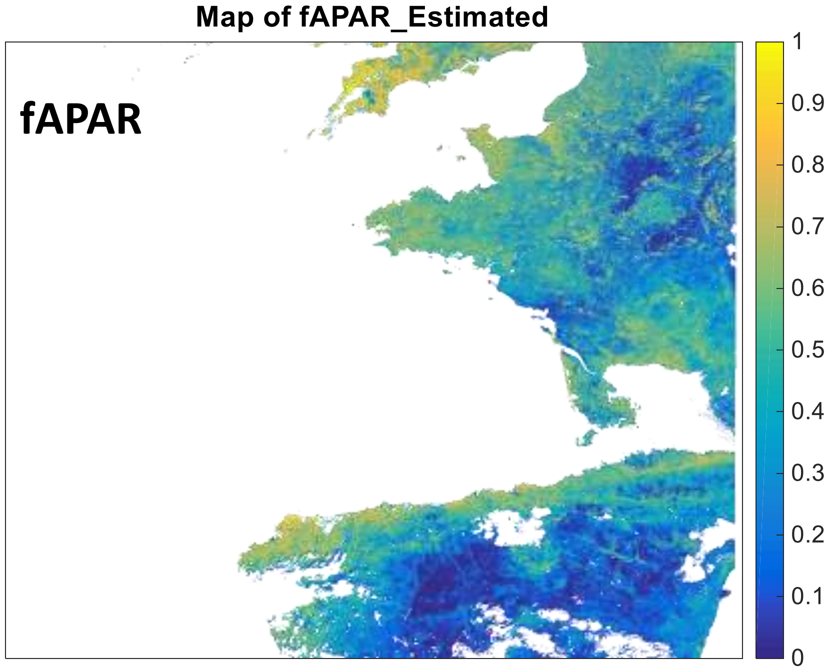


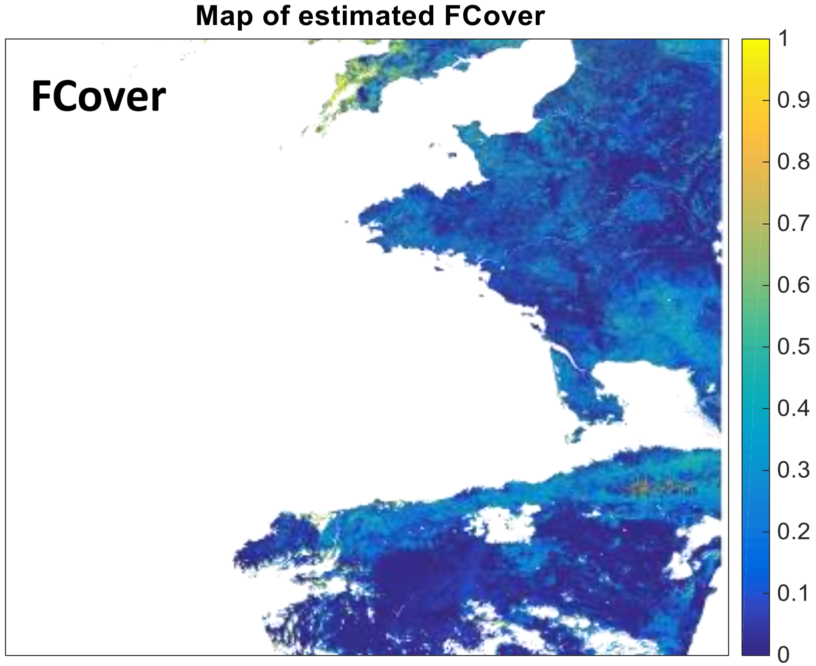
S3A_SY_2_SYN_20181021T103913_0179_037_108

21 Oct 2018





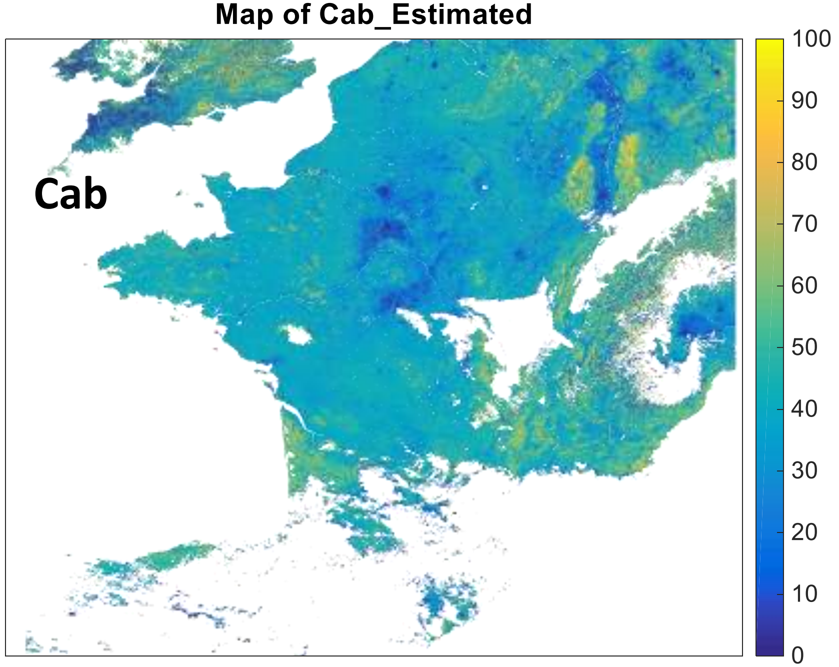


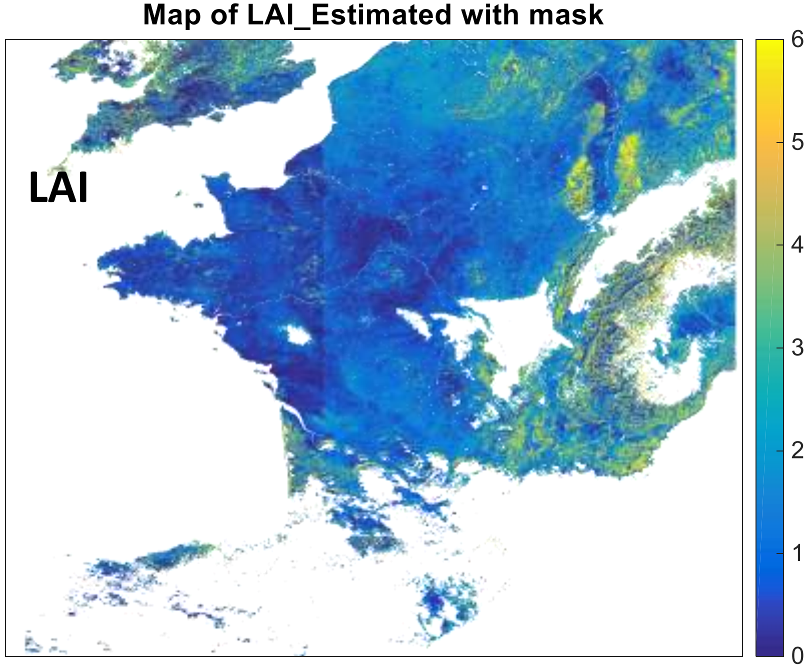


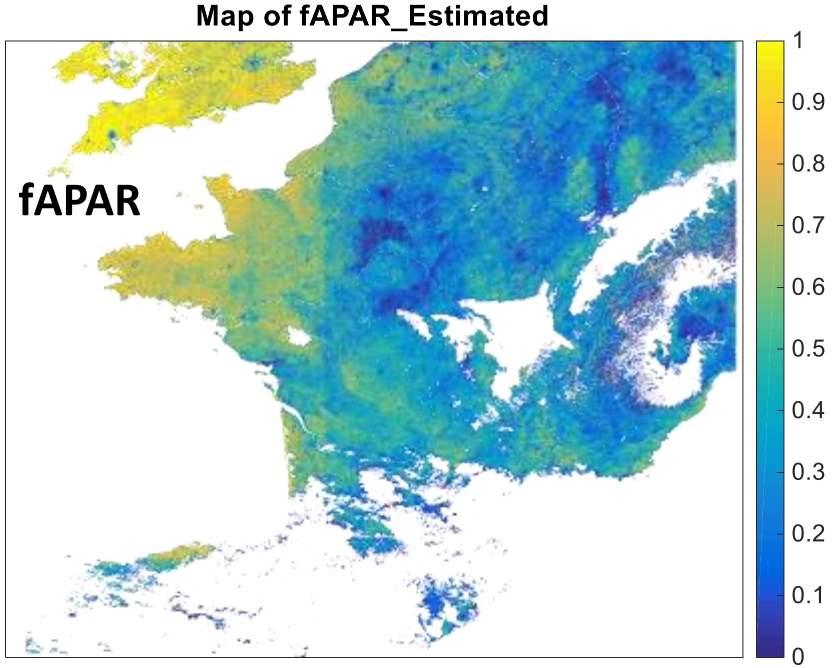
- fAPAR best estimated (lowest uncertainties)
- Probably some overestimation Cab
- Some underestimation LAI and FCover

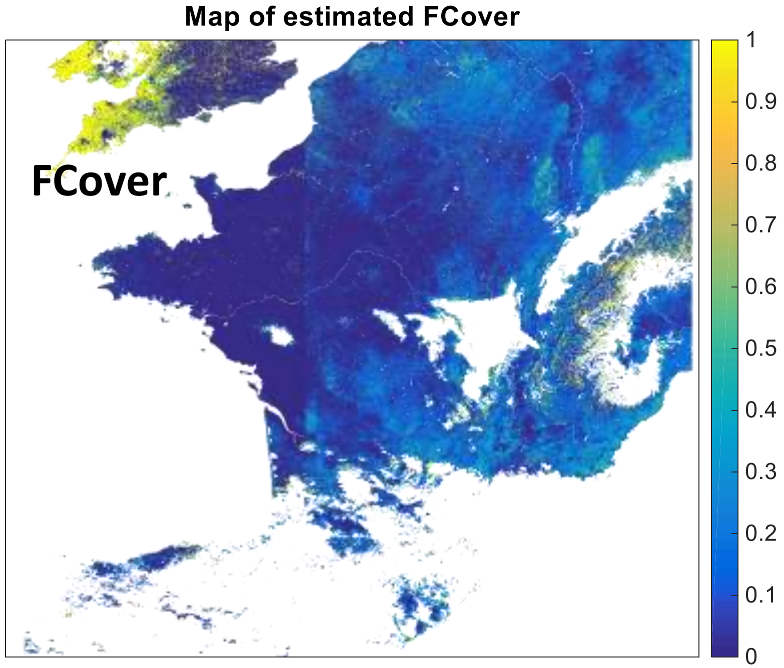
S3A_SY_2_SYN_20181118T101301_0180_038

18 Nov 2018









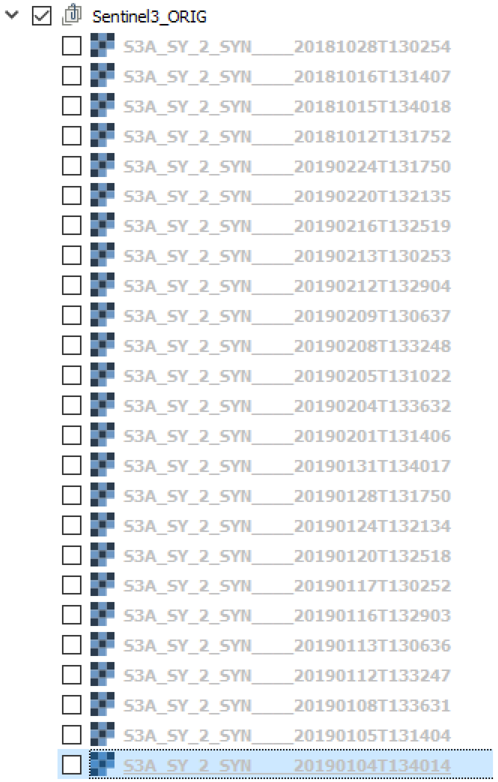
- fAPAR best estimated (lowest uncertainties)
- Probably some overestimation Cab
- Some underestimation LAI and FCover

SYN product faces artifact due to atm. Correction using SLSTR Nadir/Oblique

Assessment SYN product over Argentina from hub

SYN Data available from October 2018

Crop area in South Hemisphere (Argentina) for significant phenology changes



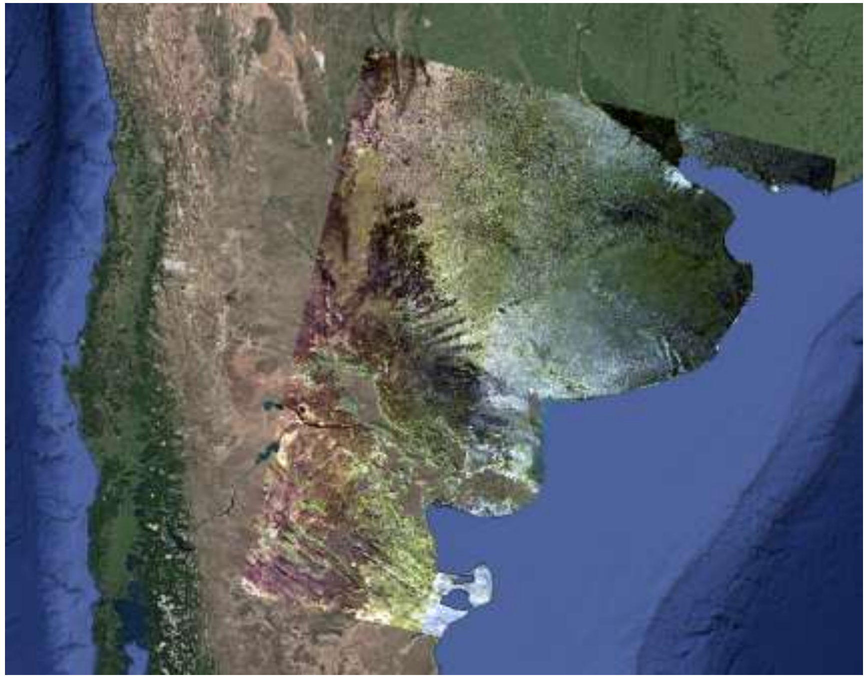
Collection of S3 SYNERGY images with cloud percentage <50%

October 2018- February 2019

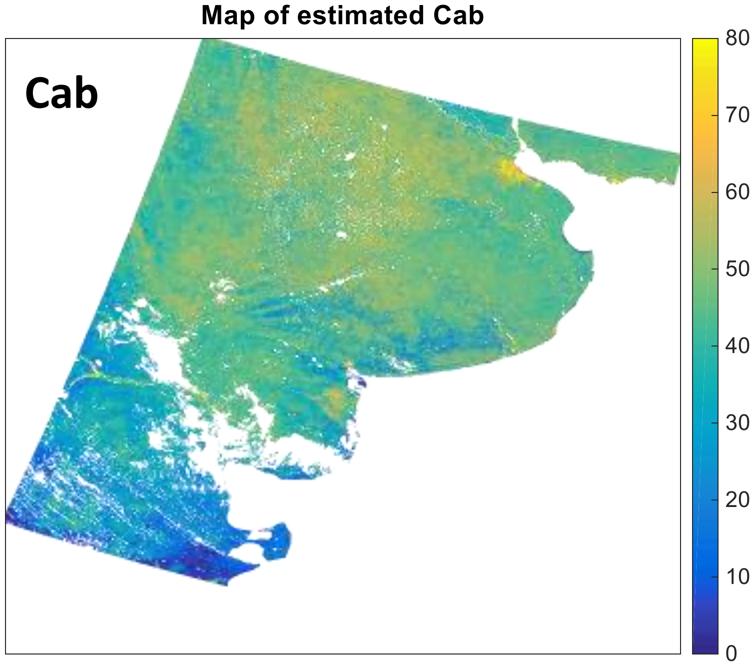
Oa01 (400.0nm)	**Oa10** (708.75nm)
Oa02 (412.5nm)	**Oa11** (753.75nm)
Oa03 (442.5nm)	**Oa12** (778.75nm)
Oa04 (510.0nm)	**Oa16** (865.0nm)
Oa05 (555.0nm)	**Oa17** (865.0nm)
S1N (555.0nm)	**S3N** (65.0nm)
S1O (560.0nm)	**S3O** (885.0nm)
Oa06 (620.0nm)	**Oa18** (1020.0nm)
Oa07 (659.0nm)	**Oa21** (1610.0nm)
S2N (659.0nm)	**S5N** (1610.0nm)
S2O (665.0nm)	**S5O** (2250.0nm)
Oa08 (673.75nm)	**S6N** (2250.0nm)
Oa09 (681.25nm))	**S6O** (2250.0nm)

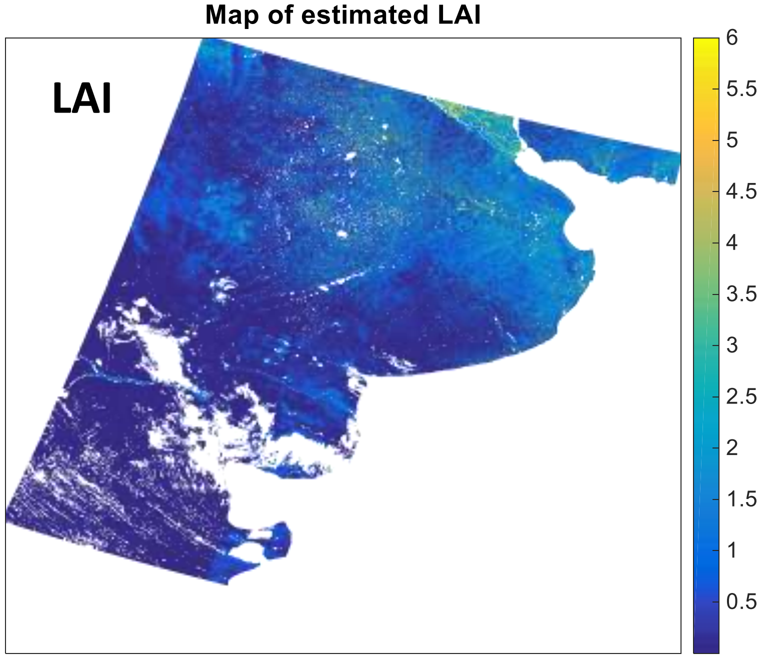
S3A_SY_2_SYN___20181224T132515

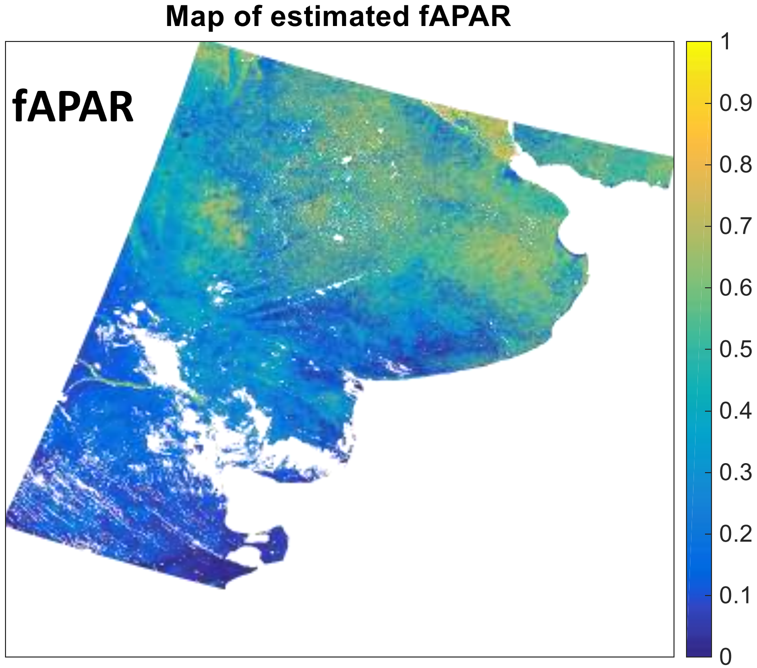
22 Dec 2018

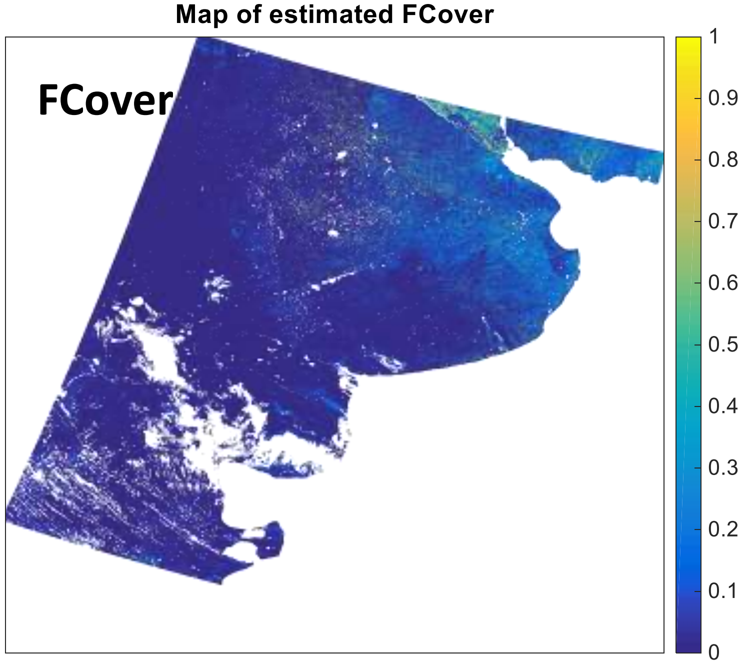


- fAPAR best estimated (lowest uncertainties)
- Probably some overestimation Cab
- Underestimation LAI and FCover



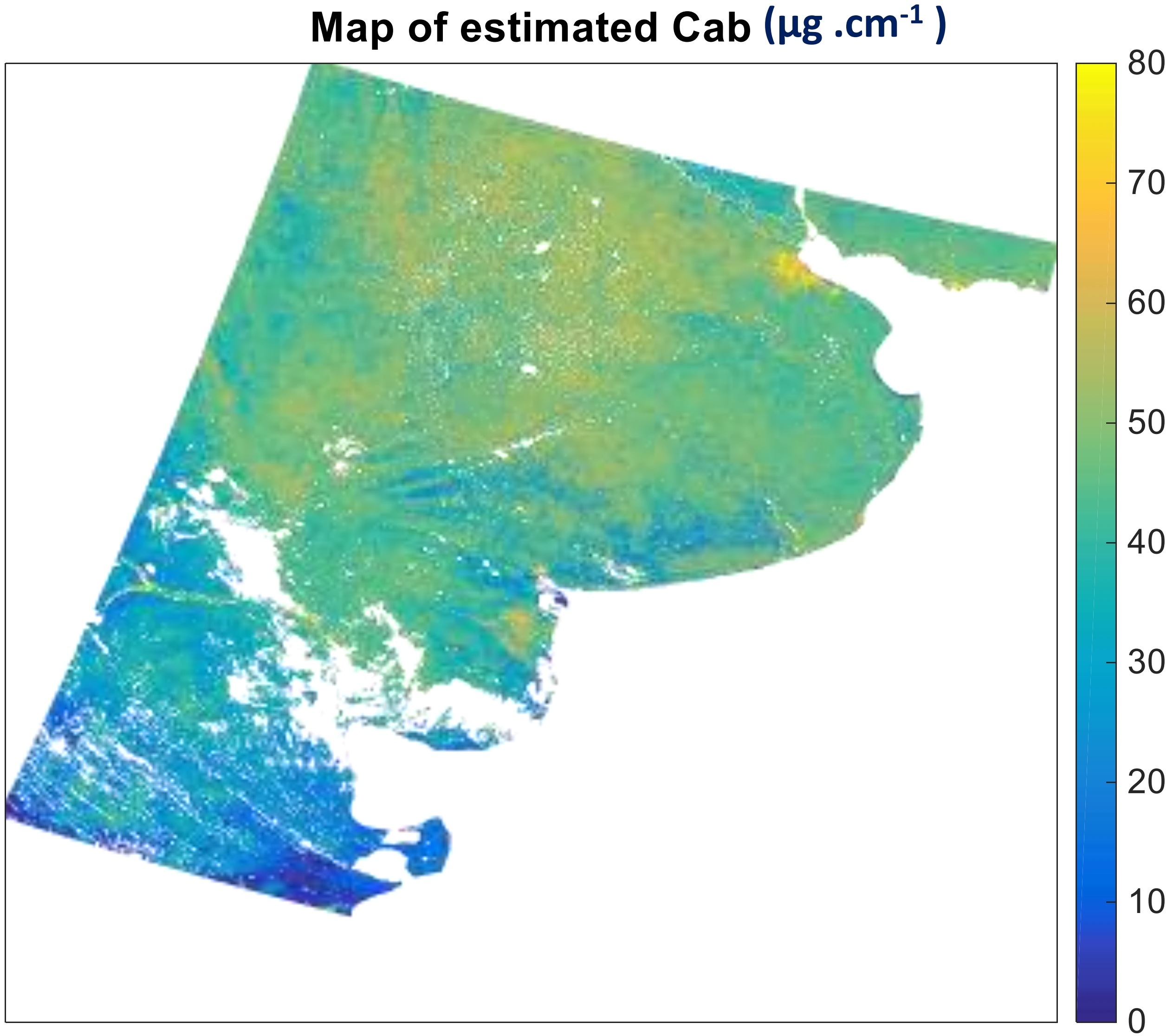


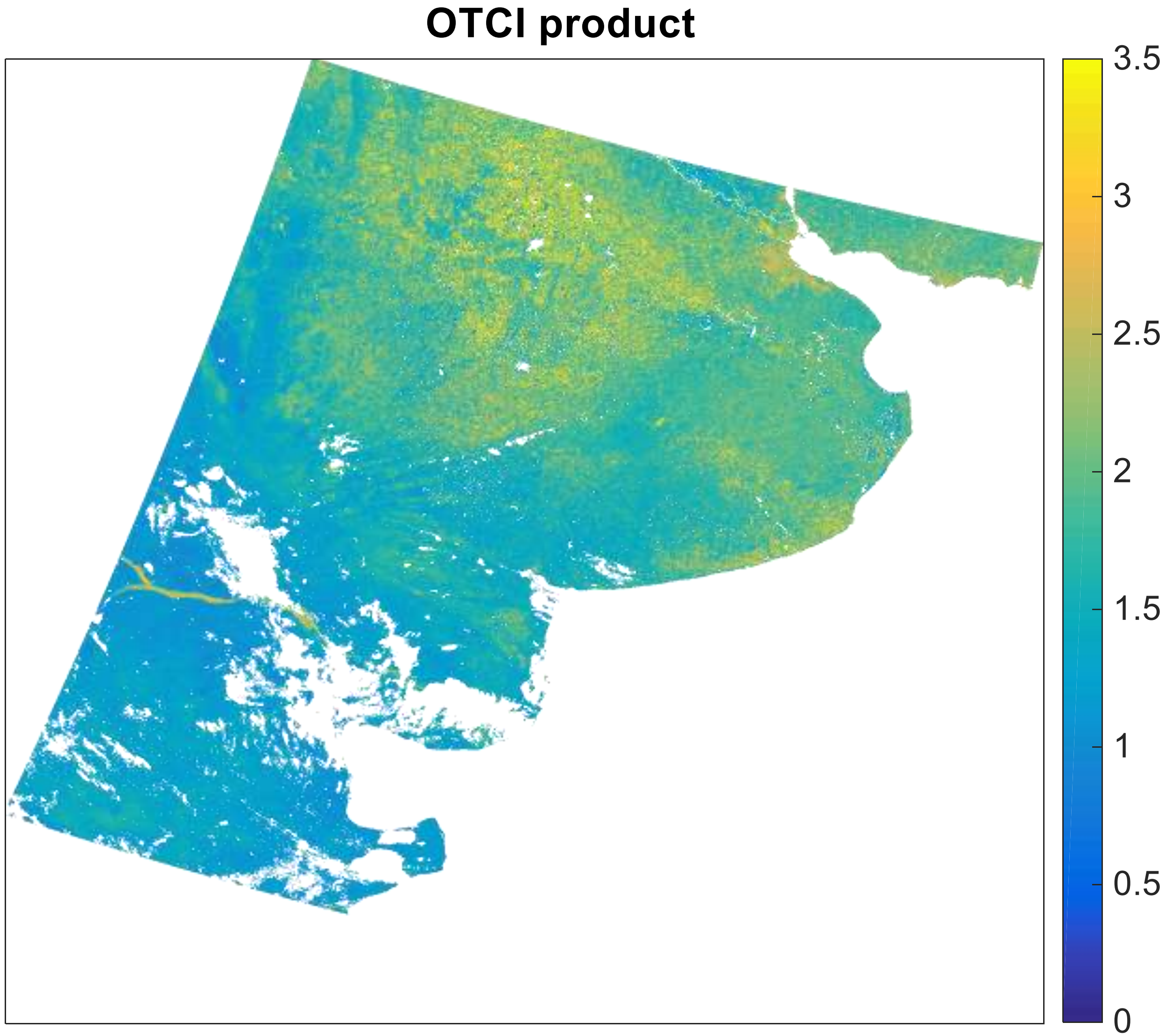




Comparison against L2 OTCI product

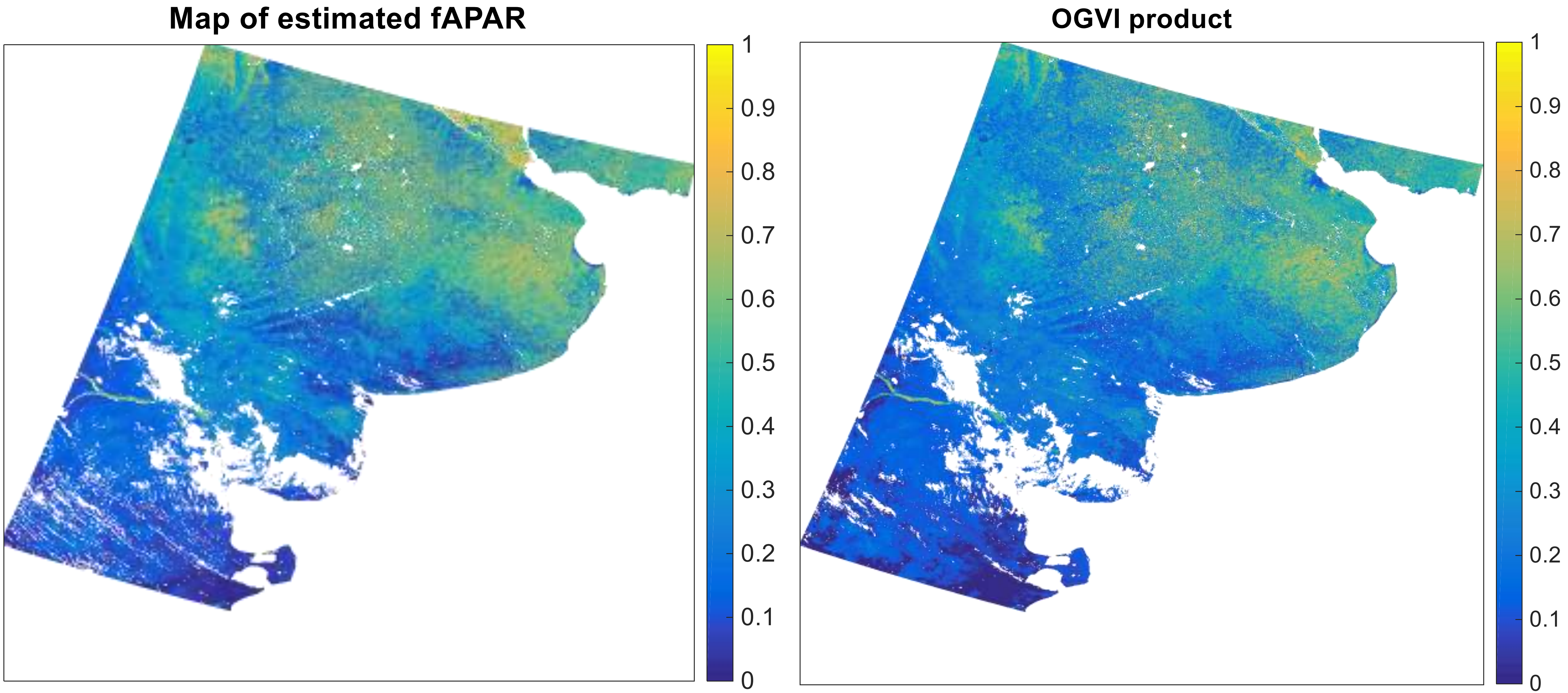
S3A_SY_2_SYN____20181224T132515





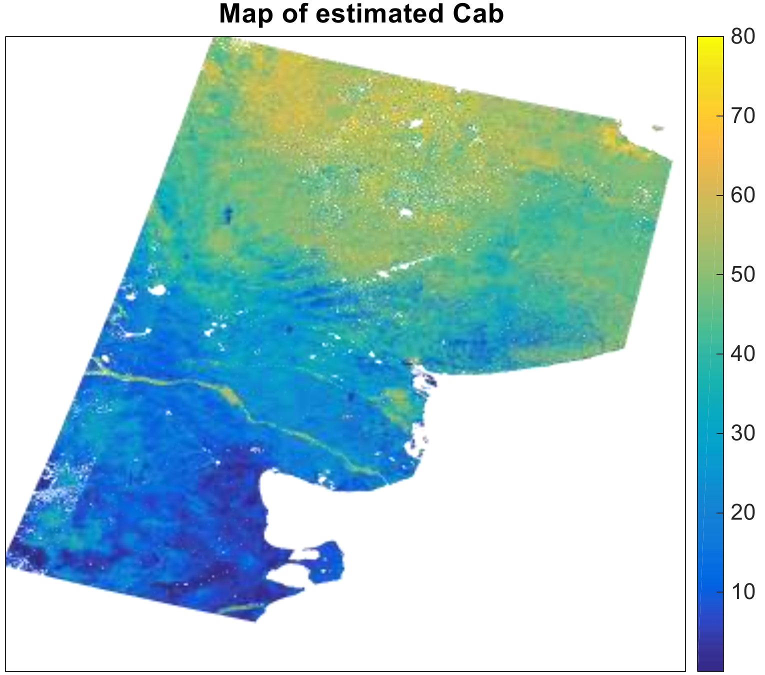
Comparison against L2 OGVI product

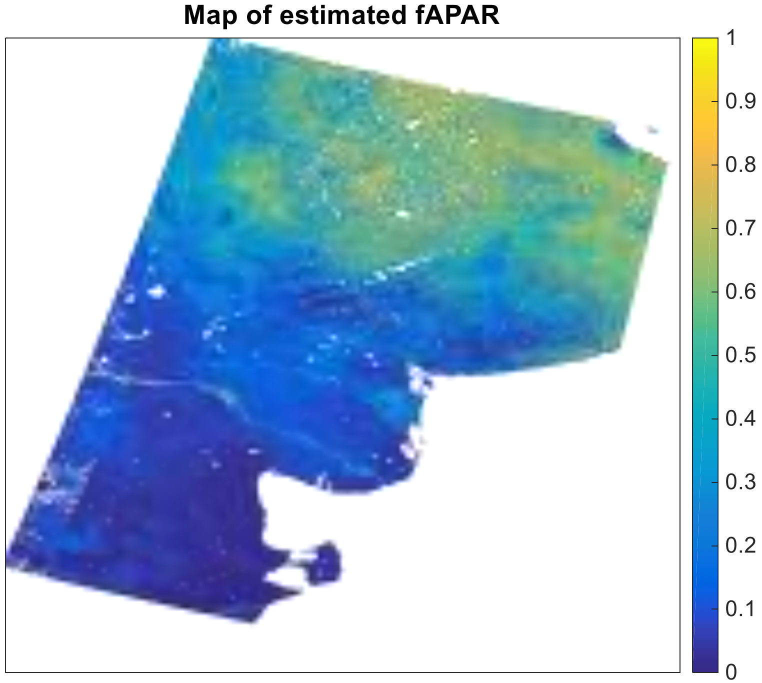
S3A_SY_2_SYN____20181224T132515

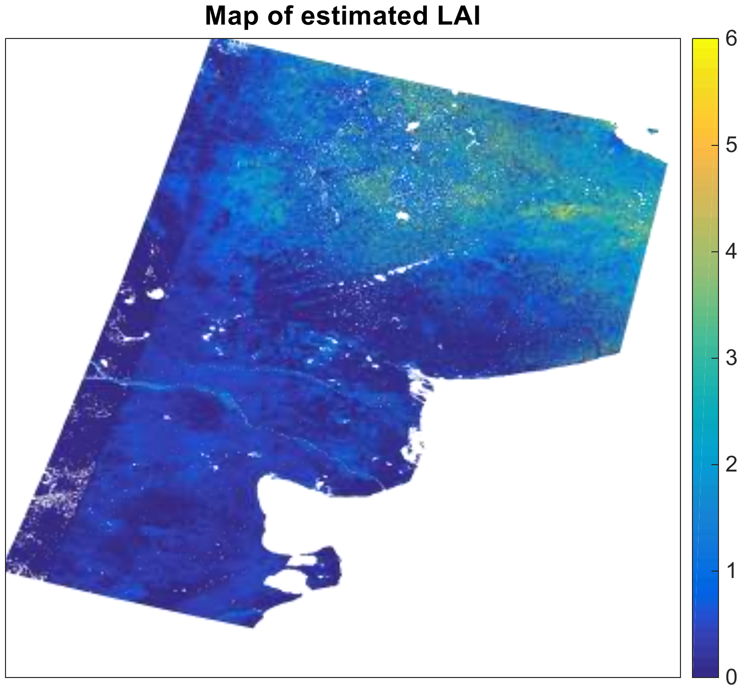


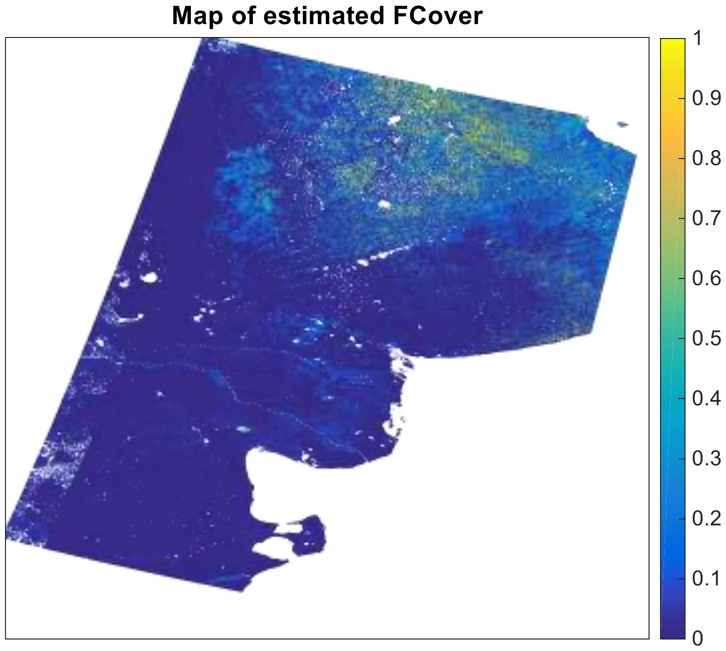
S3A_SY_2_SYN____20190104T134014

04 Jan 2019







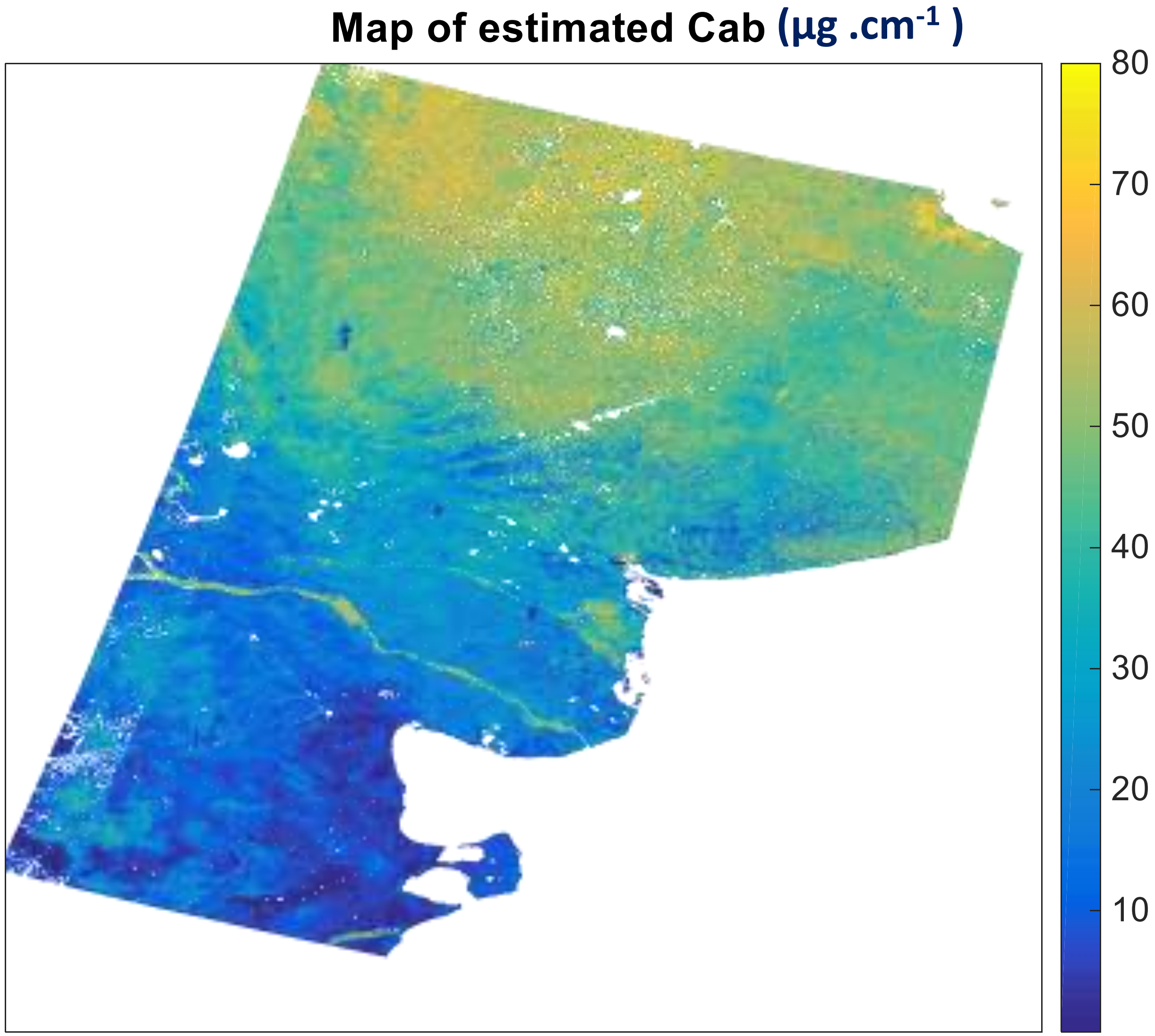


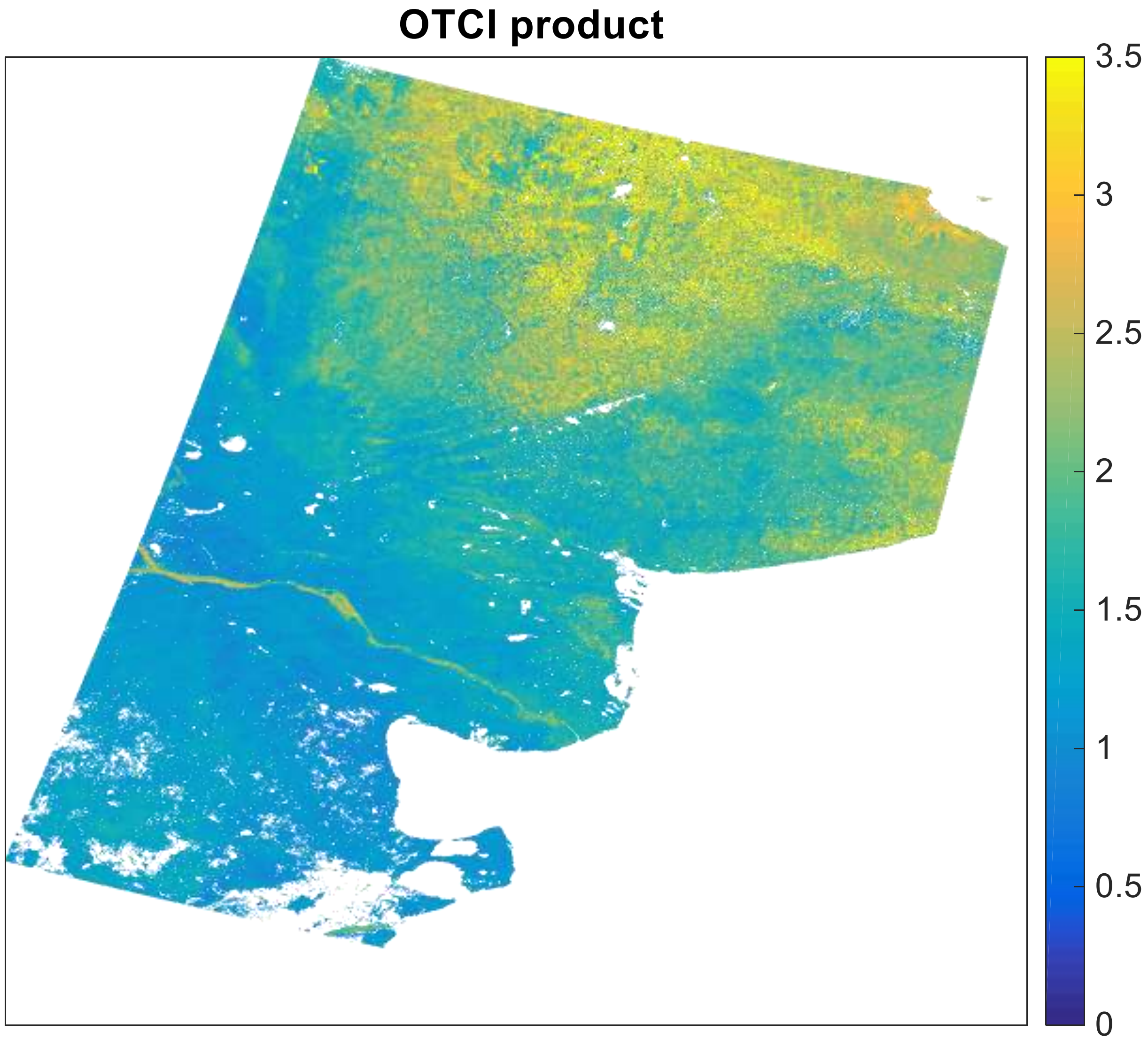
- fAPAR best estimated (lowest uncertainties)
- Probably some overestimation Cab
- Underestimation LAI and FCover

SYN product faces artifact due to atm. Correction using SLSTR N/O

Comparison against L2 OTCI product

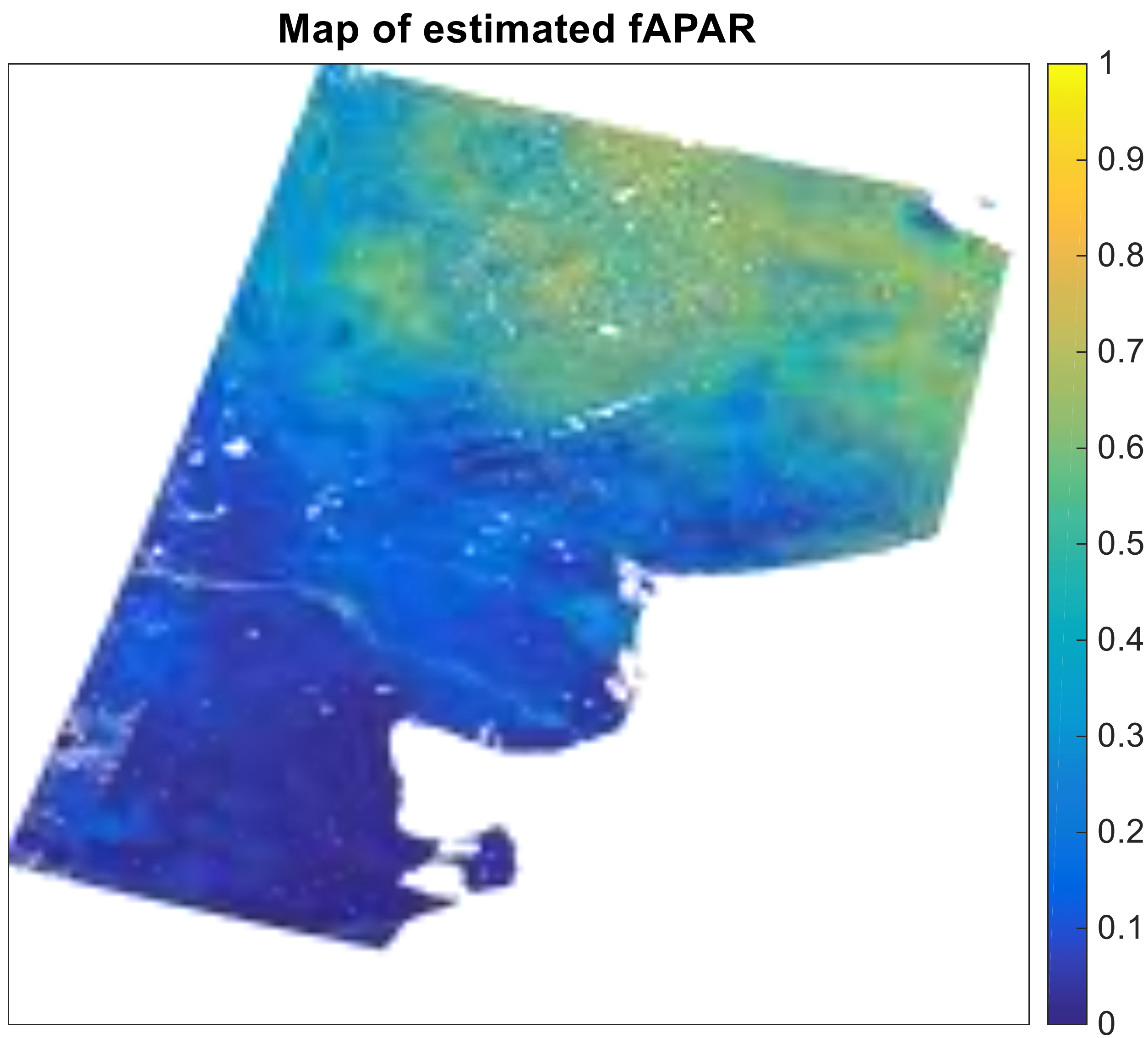
S3A_SY_2_SYN____20190104T134014

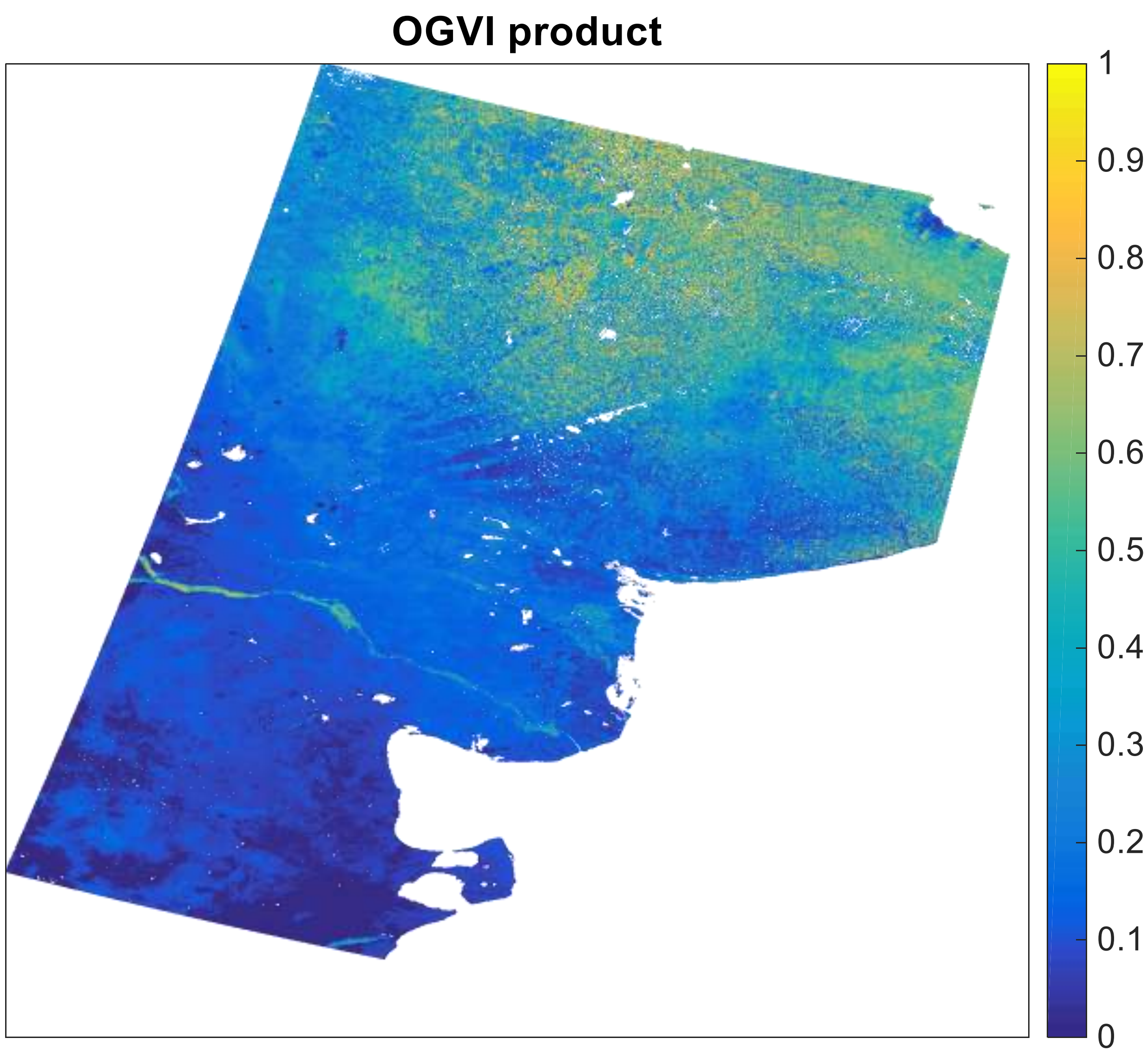




Comparison against L2 OGVI product

S3A_SY_2_SYN____20190104T134014



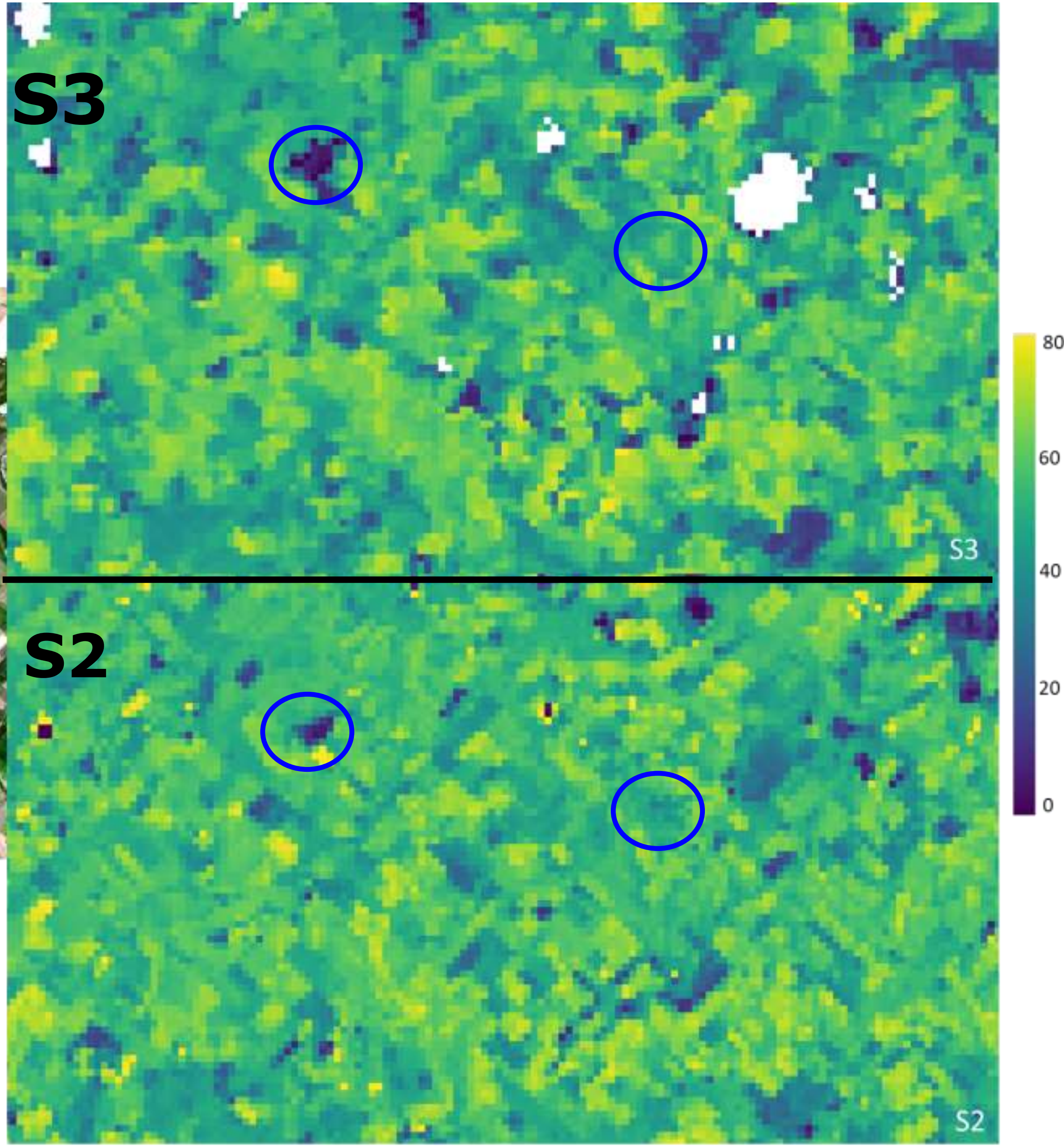


Comparison against S2 resampled to 300m

Cab

(µg .cm^{-1})

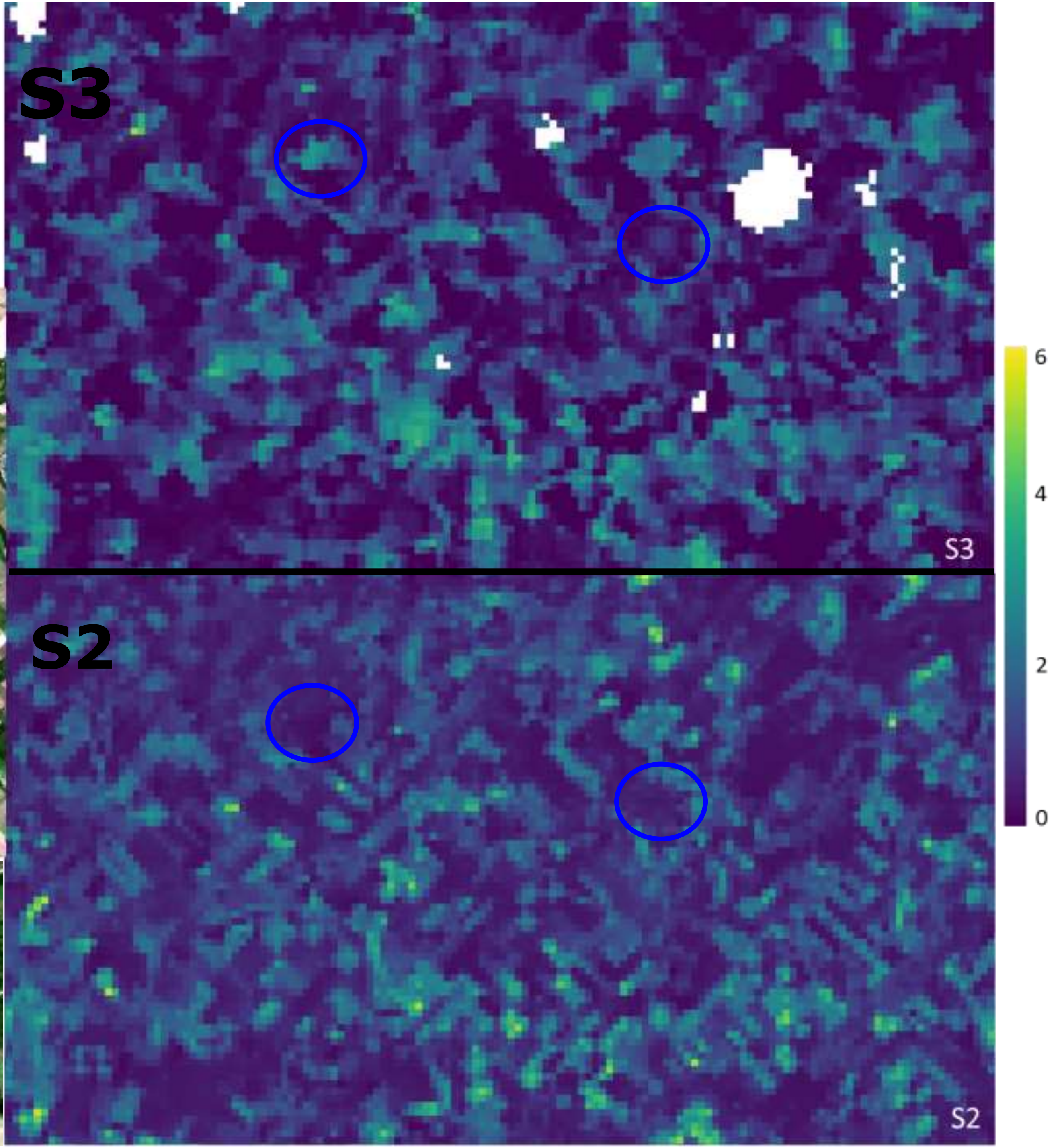
Sentinel 2 RGB mosaic of **18/02/2019,** zoom in Argentina
S2 vegetation products derived in SNAP and resampled to 300 m
S3 vegetation products derived from S3A_SY_2_SYN from **20/02/2019**



- Similar products
- Low values for not masked out water spots
- Too high values for man-made surfaces for both products
- Probably too high values for some bare soil (but even worse for S2 product)

Comparison against S2 resampled to 300m

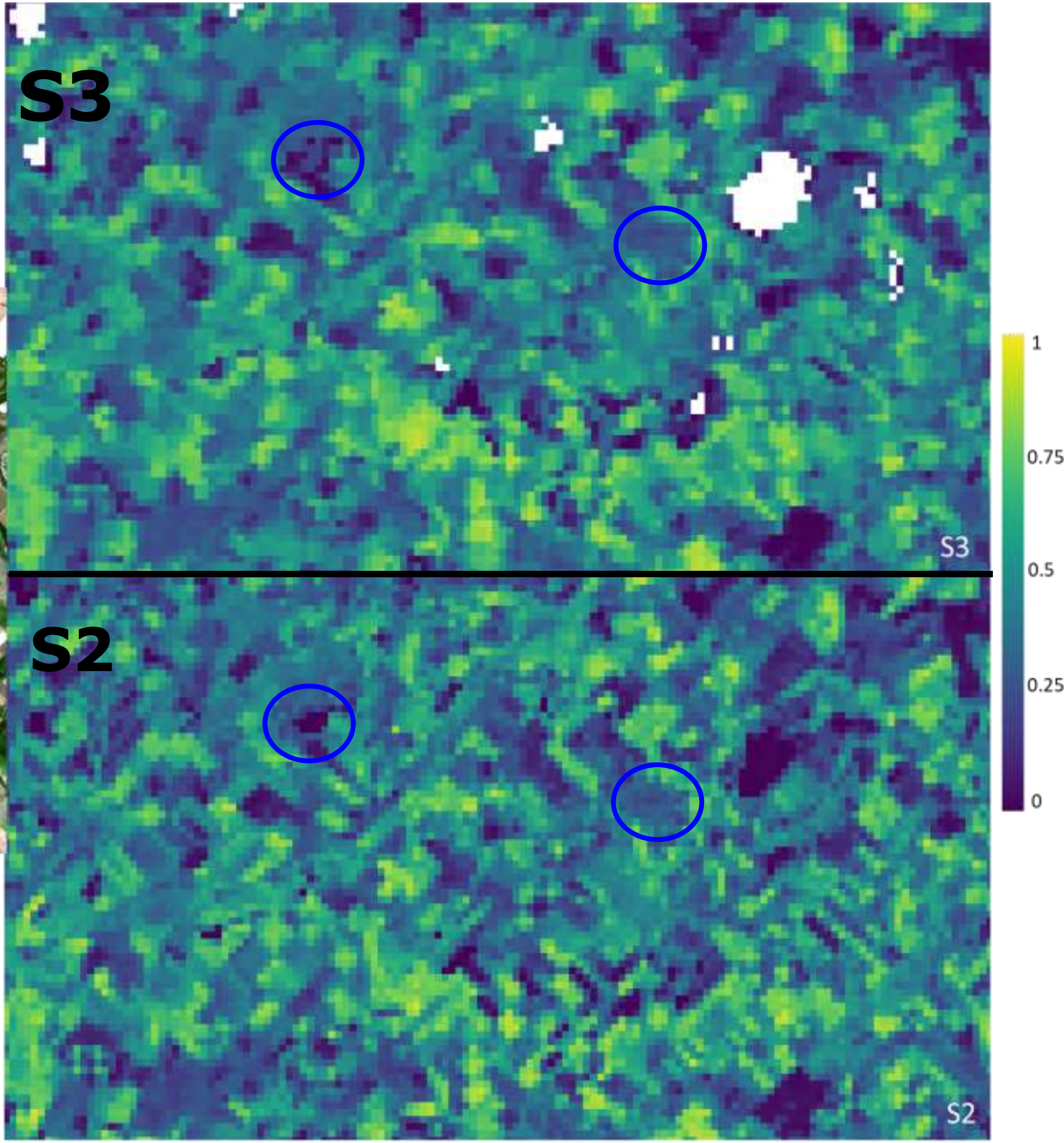
LAI
(m^{-2} /m^{-2})



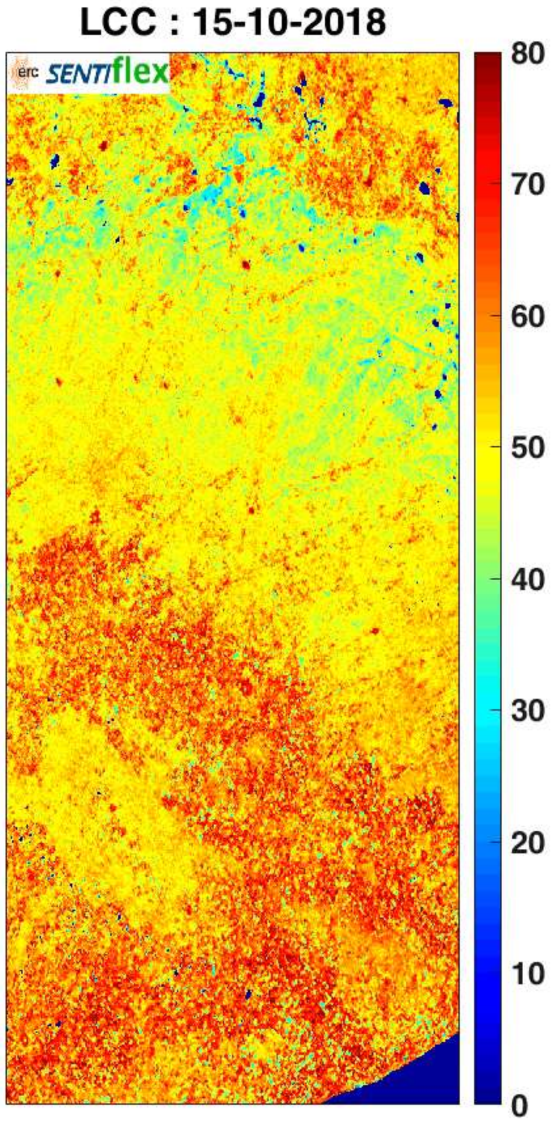
- Similar products
- S3 overestimation for not masked out water spots
- S3 Bare soil areas larger and “darker” (really at 0)

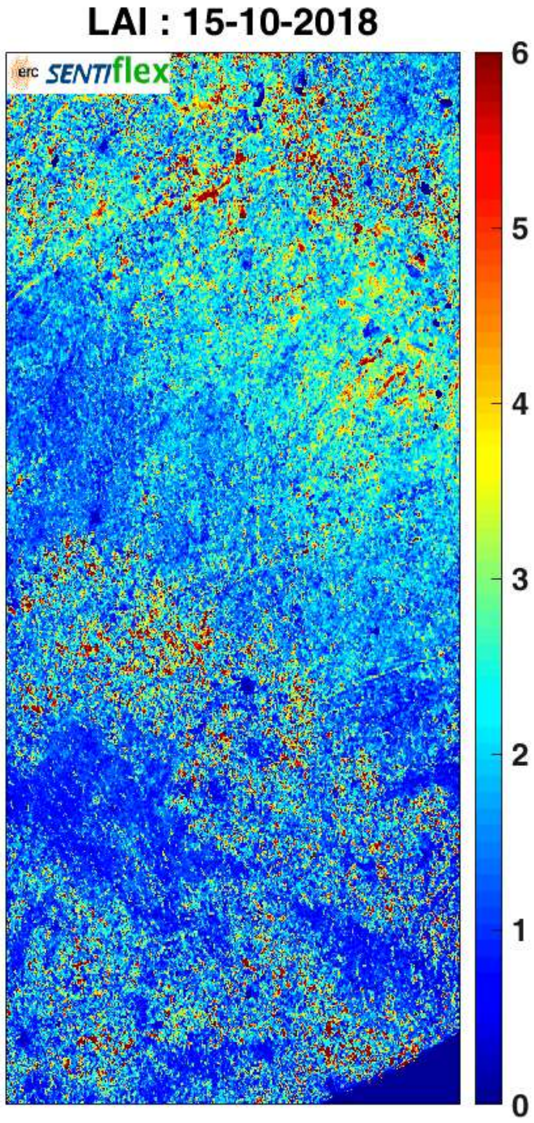
Comparison against S2 resampled to 300m

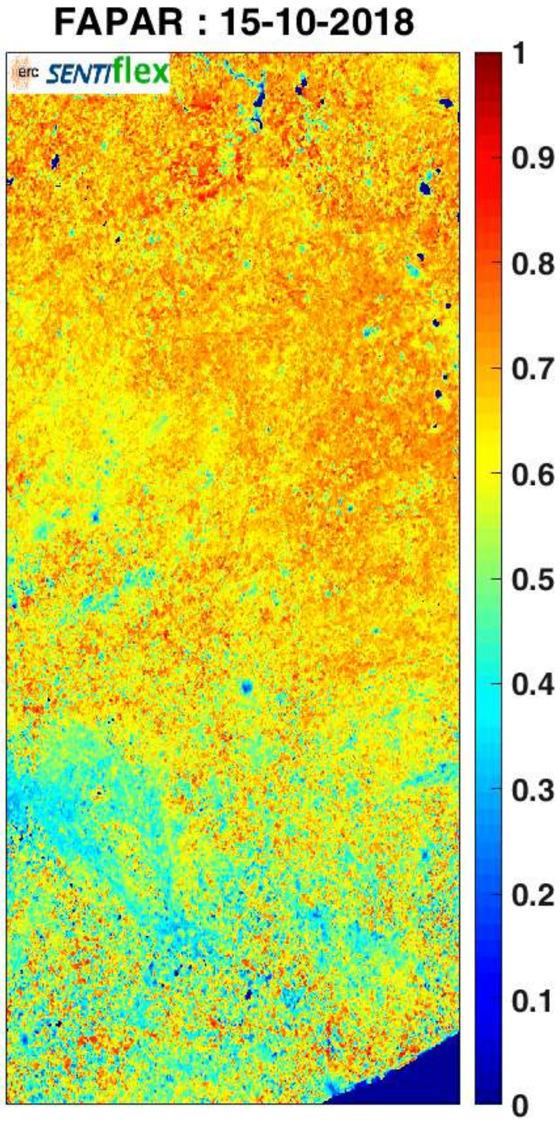
fAPAR



- Similar products
- Low values for not masked out water spots
- Low values for urban area





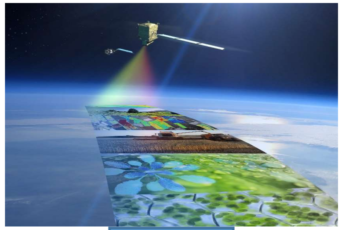


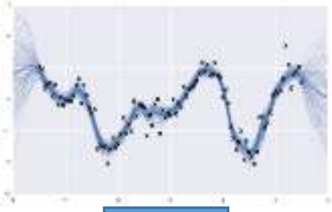
DATimeS, a new toolbox for time series analysis: opportunities for Sentinels time series processing

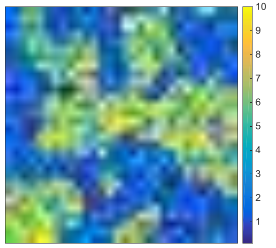
Santiago Belda et al., A3.17: Agriculture (3,4,5,6) Poster Session; Wednesday

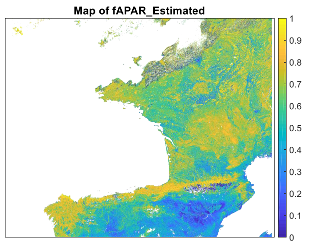
Conclusions

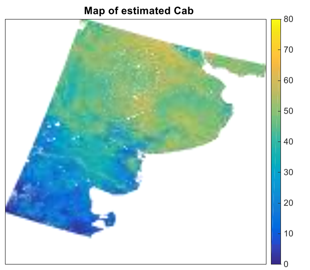
- **Retrieval models for vegetation products developed** for both **FLEX-FLORIS, S3-OLCI** and **synergy**
- **Hybrid method using GPR**: provision of **uncertainty estimates**
- **Models validated by E2E**. Comply requirements. **Synergy of FLEX-S3 data leads to most accurate retrievals**
- **S3 models tested to SYN product** over Europe & Argentina
- **Cab and fAPAR consistent** against L2 OTCI and OGVI
- **LAI consistent** against S2-300m
- Improvements are pending











2 announcements….

SENSECO

http://www.senseco.eu/

Optical synergies for spatiotemporal sensing of scalable ecophysiological traits

COST Action CA17134

The main aim of the **SENSECO** Action is to ensure that the practices of optical earth observations for ecophysiology are **compatible at various scales**, **enabling synergistic multi-sensor use** and **transferability** to guarantee the **knowledge exchange on scaling methods** in a European context.

SENSECO is divided into four working groups:

[WG1] Scaling gap
[WG2] Temporal gap
[WG3] Sensor synergies
[WG4] Data quality

Get involved ! Become a SENSECO Member.
To join SENSECO follow simple instructions provided at:
https://www.senseco.eu/join-us/how-to-join/

Do you want to know more? Contact**:**
Martin Schlerf (martin.schlerf@list.lu)
Jochem Verrelst (jochem.verrelst@uv.es)

COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

COST is supported by the EU Framework Programme Horizon 2020 remote sensing

an Open Access Journal by MDPI

Special Issue

Applications of Spectroscopy in Agriculture and Vegetation Research

Special Issue Editors:

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Dr. Karolina Sakowska University of Innsbruck, Austria

Submission Deadline: 31 May 2019

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48 days
Article Processing Time

IMPACT FACTOR 3.406

18 days
Submission to Frist Decision

5 days
Acceptance to publication

This *Special Issue* aims to address **fundamental and applied research relating the spectral properties of vegetation to agronomic and biophysical variables**, genetic and phenotypic parameters, as well as diurnal and seasonal dynamics linked to light harvesting and photoprotection.

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