CNRS, CNES, INRAE, IRD, Univ. Toulouse III

Cover crops for climate change mitigation: analysis of their benefit through their soil organic carbon storage and albedo effects by combining remote sensing and modelling approaches

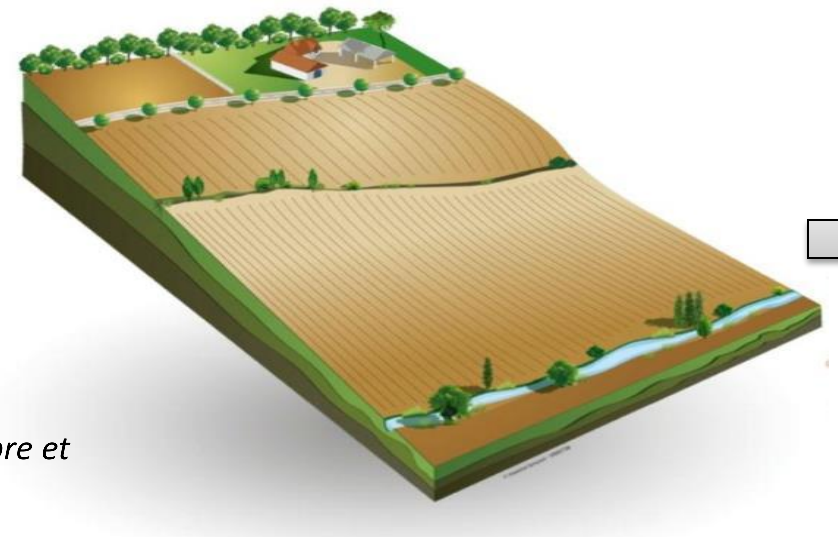
Eric Ceschia, INRAE senior scientist at CESBIO

Earth & Life Talks

Louvain, 04/05/2023

Context/Societal challenges

Questioning of the **durability of conventional agriculture** ➔ food security, resilience, climatic & other environmental impacts)



<u>Agro-ecological practices</u>

No till

Cover crops

Agroforestery

C storage, water cycle… albedo effects

Illustrations: Arbre et Paysage 32

Lack of large scale tools to quantify cropland C and energy budgets and their components (e.g. biomass, CO_2 fluxes, albedo effects) at plot level and to analyse the effect of management practices on them

Need for methods & tools adapted to different context (CAP, C market) combining crop modelling and high resolution remote sensing

What is a cover crop ?

Definition of the French agroecology dictionary :

It is a crop implanted between the harvest of a main crop and the sowing of the next crop for a more or less long period called fallow (most often between autumn and spring, sometimes in summer). **Cover crops are intended to be returned to the soil**.

If exported:

- Bioenergy crop ➔ biofuel,
- Fodder ➔ to feed livestock

What is the benefit of growing cover crops?

They help to improve soil structure, reduce water and/or wind erosion, maintain biodiversity (soil + vegetation), limit N losses by leaching, fight against global warming (storage C = 4/1000, albedo effects...) and it's much more beautiful than bare ground!!

But are sometimes destroyed with herbicides (pollution), can reduce water availlability for the following cash crop, additional cost & work for the farmer,

Some examples of cover crops

Féverole

Phacélie

Vesce-Avoine

Moutarde blanche

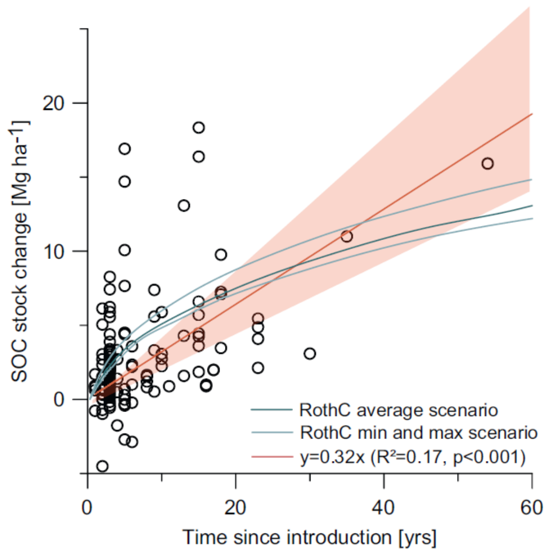
Radis fourrager

Mélange sorgho, tournesol, vesce, colza…

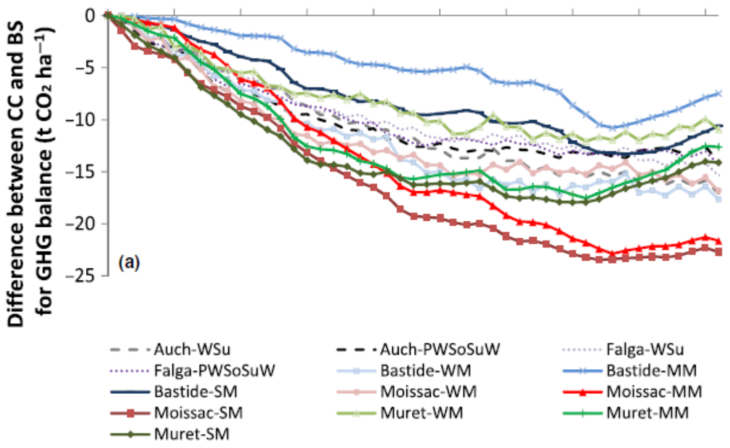
Effects of cover crops on climate

- Numerous studies have highlighted the effect of CC on soil organic C storage (more biomass returned to the soil) and the improvement of the GHG budgets ➔ main lever for storing C in arable lands in France (Pellerin et al. 2019)

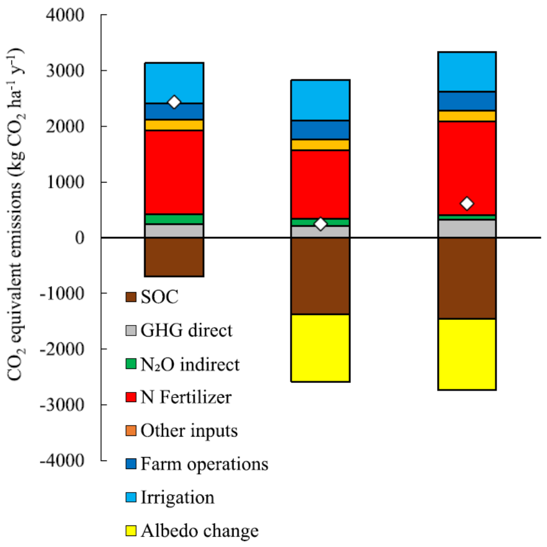
Meta-analysis based on in-situ data
(*Poeplau & Don, 2015*)



STICS simulations in France
(*Tribouillois et al., 2018*)



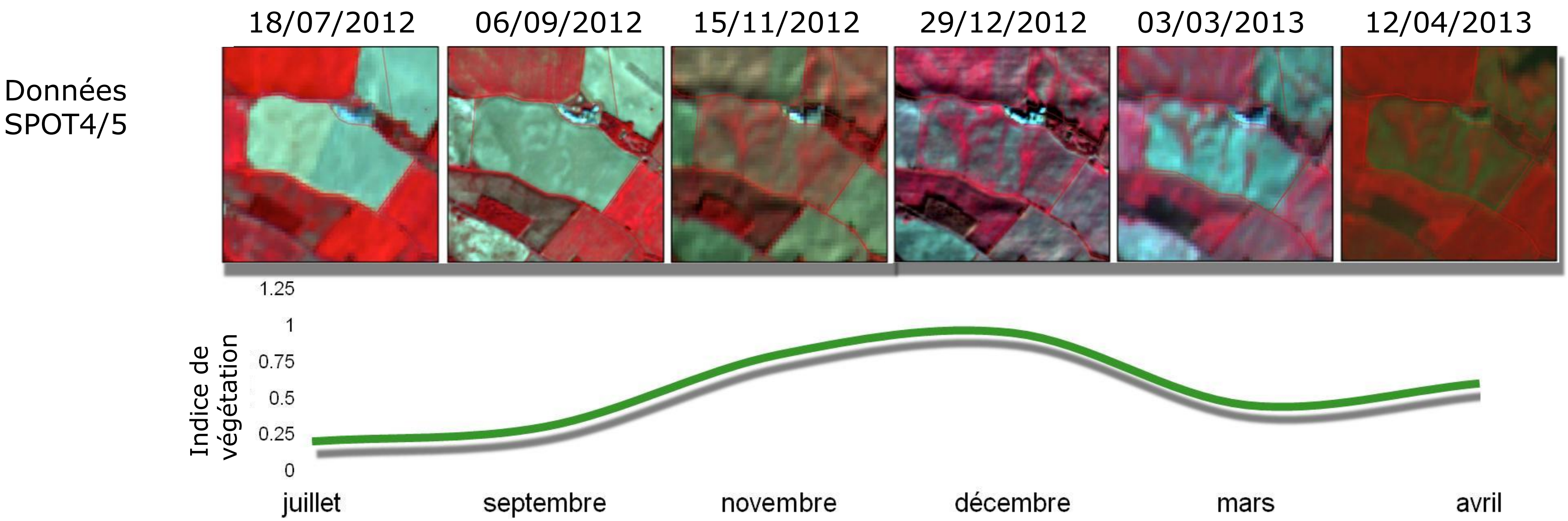
In-situ data in Spain
(*Guardia et al. 2019*)



➔ These studies are based only on agronomic trials or at plot level

Benefit of high resolution multi-temporal EO data

- For mapping the growth dynamics of crops and cover crops



NO AGRONOMIC MODEL CAN PREDICT THIS DEVELOPMENT HETEROGENEITY AND THE CONSEQUENCES IN TERMS OF CARBON STORAGE AND OTHER CLIMATIC EFFECTS

➔ EO DATA COMBINED WITH CROP MODELS MAY HELP TO OBJECTIFY THESE EFFECTS

Remote sensing to estimate the impact of cover crops on soil organic C storage

Concrete application example: Naturellement Popcorn project in collaboration with the Nataïs company

2012 — 2022 — 2024 — 2025

Field survey conducted by Nataïs with its partner farmers

Cover crop: Yes/No

Fixed C bonus payed by Nataïs

Biomass estimation by satellite

Empirical estimation of stored carbon

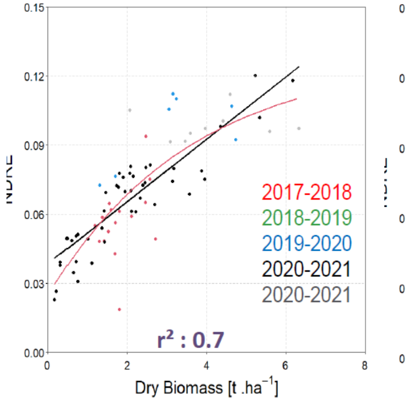
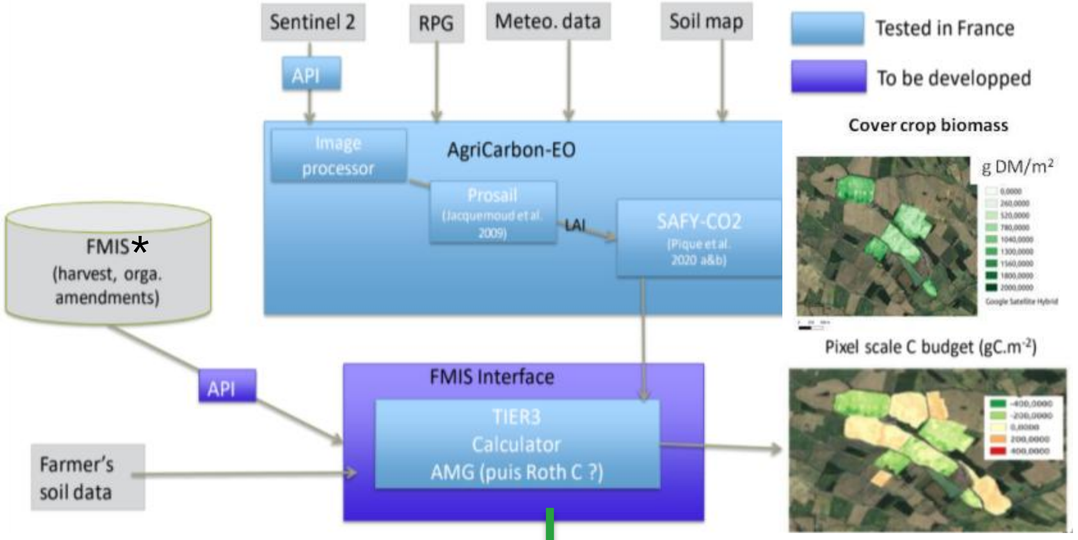


Image acquises à ± 2j de la date de prélèvement

Premium paid by Nataïs based on C stored by cover crops

SAFYE-CO2 model/AgriCarbon-EO processing chain



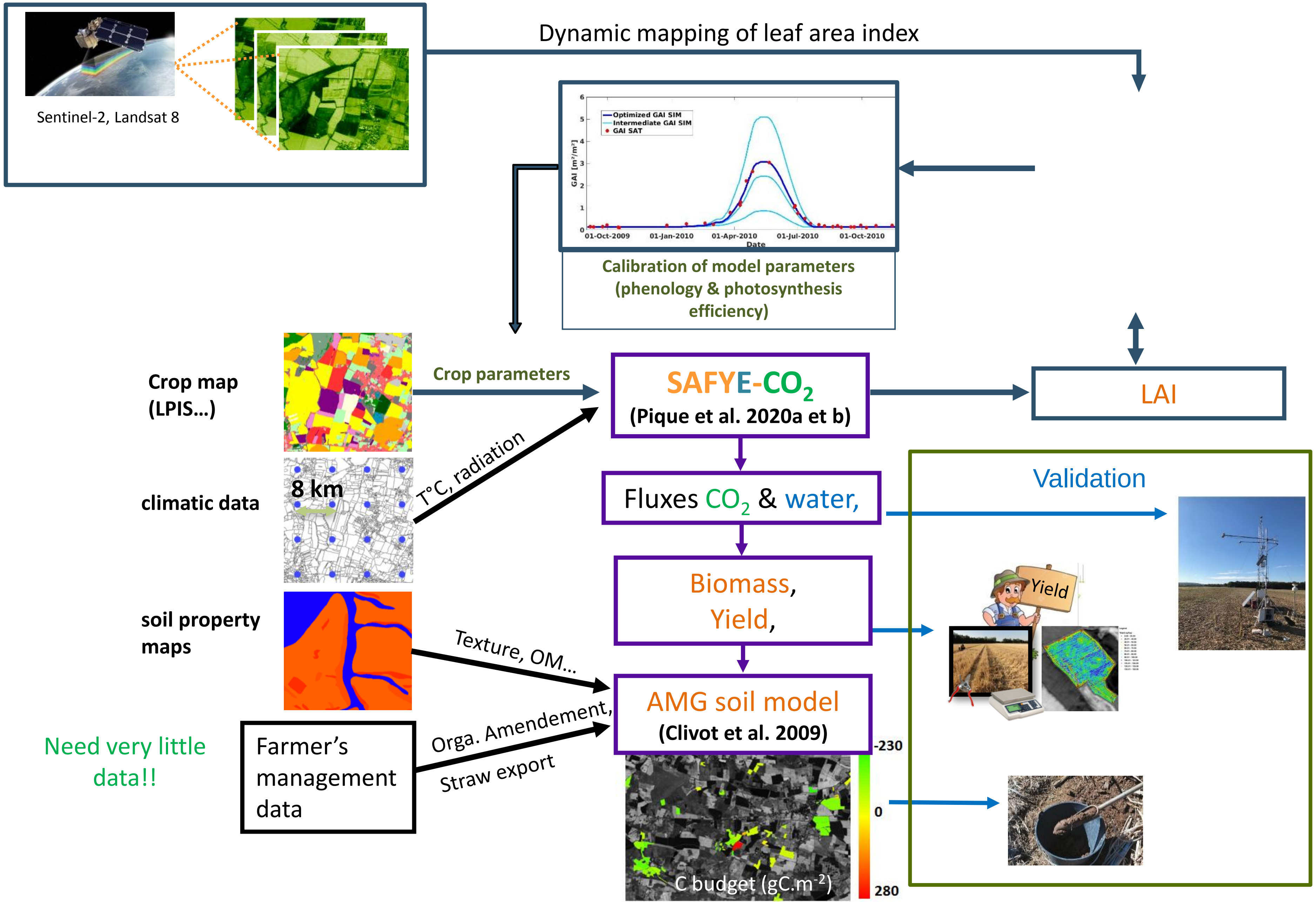
Carbon source
Carbon sink

Annual C budget

Payment of farmers according to their C budget

* Farm Management

SAFYE-CO2 model



Started 10 yrs ago

Objective :

1) Force the crop model (SAFYE-CO2) to reproduce the dynamics and development intensity of the crop/**cover crops** as seen by satellite ➔ more precise and objective biomasses, implicit consideration of stress (N, water, etc.) and of some practices,

2) At first, modelling of SOC mineralisation very simple on purpose (empirical approach function of T°C and SWC) because high uncertainty in soil properties of soil products (GSM, SoilGrids)

More recently ➔ coupling with the soil C module (AMG) activated when accurate soil data availlable

Plot level, a few thousands plots, no uncertainty…

AgriCarbon-EO

Agri carbon-EO [ACEO]
An end-to-end pre-operational processing chain

ACEO

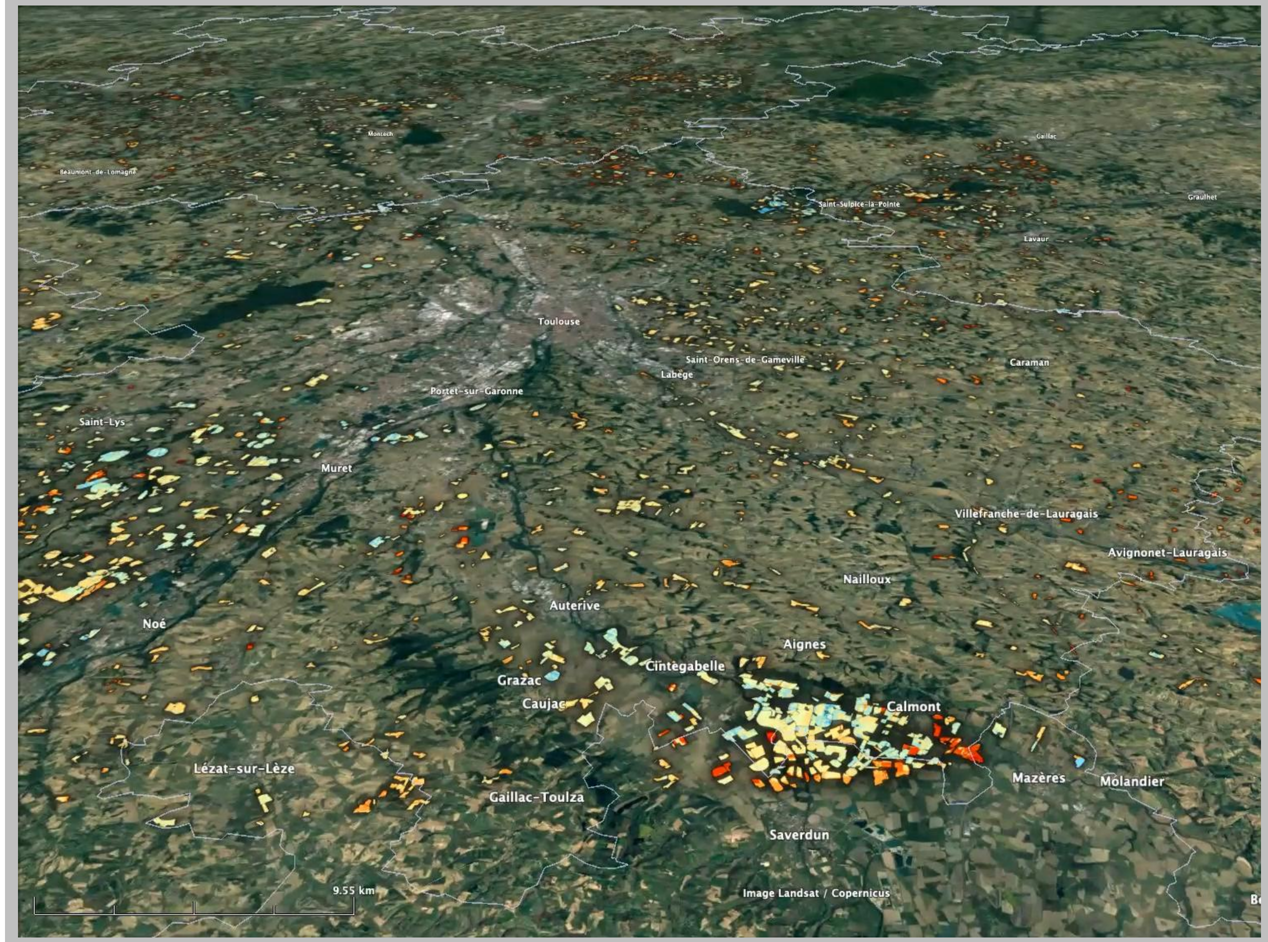
BASALT

Bayesian Normalised Importance Sampling using Look-out Table
&
Bayesian Assimilation Method

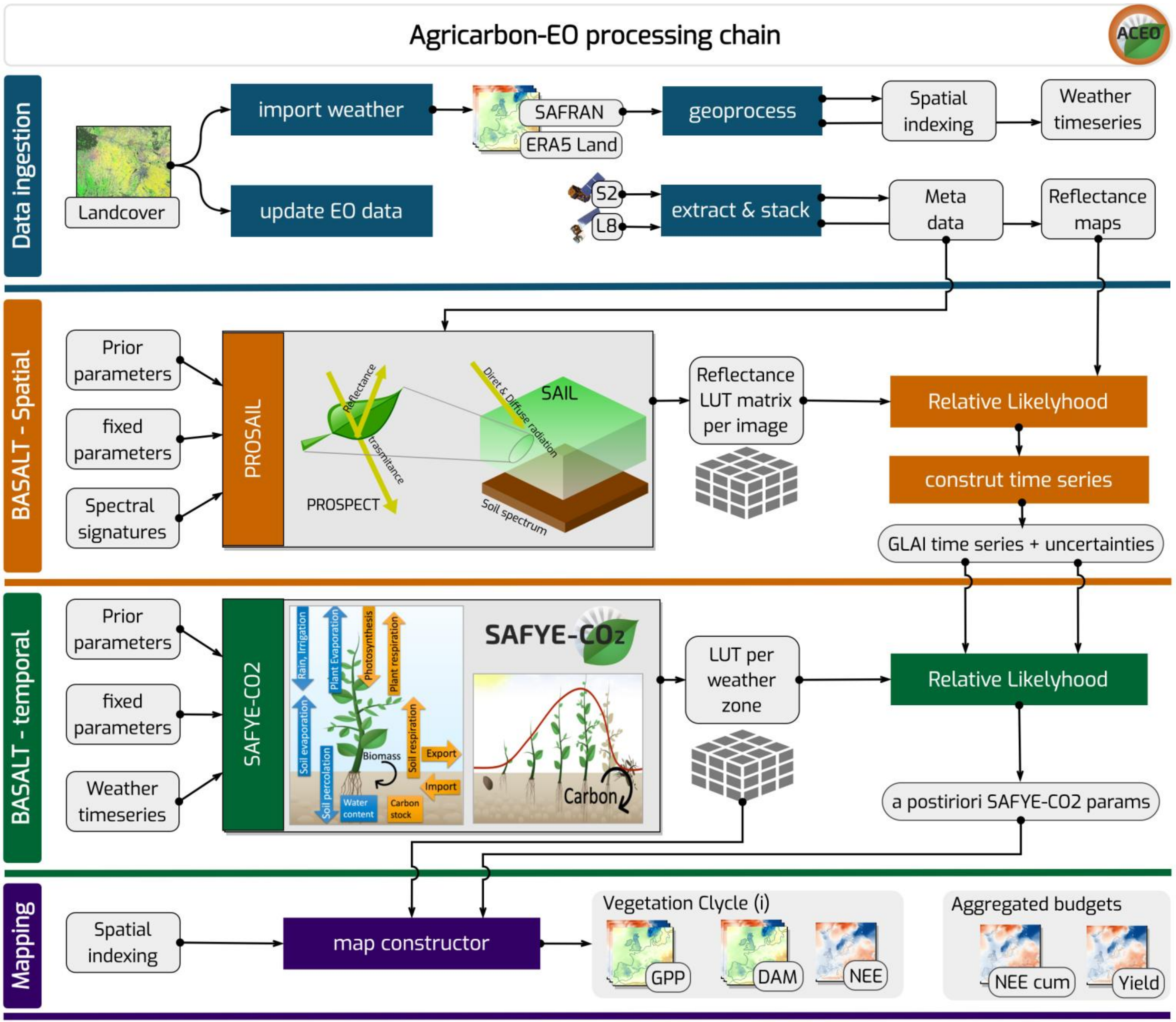
SAFYE-CO2

Parsimonious Agronomic model

Net Ecosystem Exchange over Wheat for 110x110 km at 10m (in France)



AgriCarbon-EO – overview



AgriCarbon-EO v1.0.1: Large Scale and High Resolution Simulation of Carbon Fluxes by Assimilation of Sentinel-2 and Landsat-8 Reflectances using a Bayesian approach

Taeken Wijmer[1,2,*], Ahmad Al Bitar[1,*], Ludovic Arnaud[1], Remy Fieuzal[1], and Eric Ceschia[1]

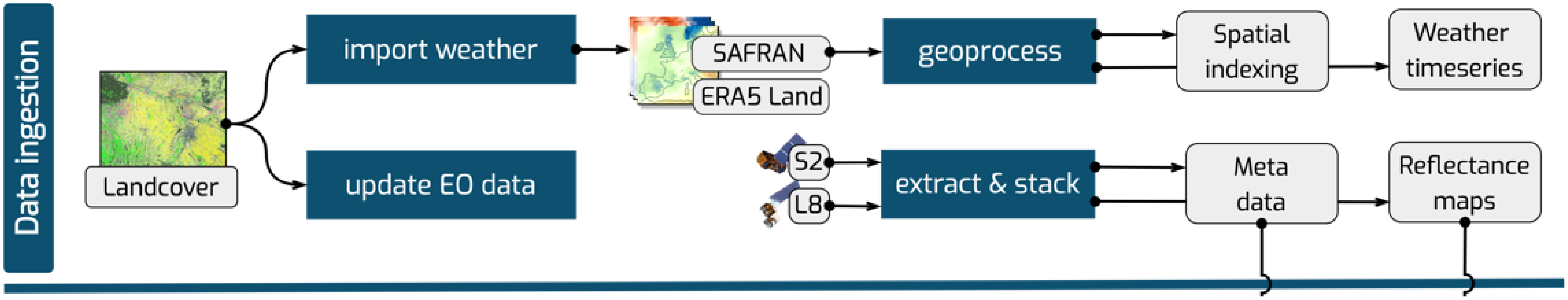
[1]CESBIO, Université de Toulouse, CNES/CNRS/INRAE/IRD/UPS, 18 Avenue Edouard Belin, bpi 2801, CEDEX 09, 31401 Toulouse, France

[2]DYNAFOR, Université de Toulouse, INRAE, INPT, INP-PURPAN, Castanet-Tolosan, France

Correspondence: Taeken Wijmer (taeken.wijmer@inrae.fr) and Ahmad Al Bitar (ahmad.albitar@gmx.com)

1

« Data ingestion » - download and preprocessing



Land cover map

LPIS

Vectorised OSO map

remote sensing data

multispectral reflectance L2A
(MAJA).
10m resolution

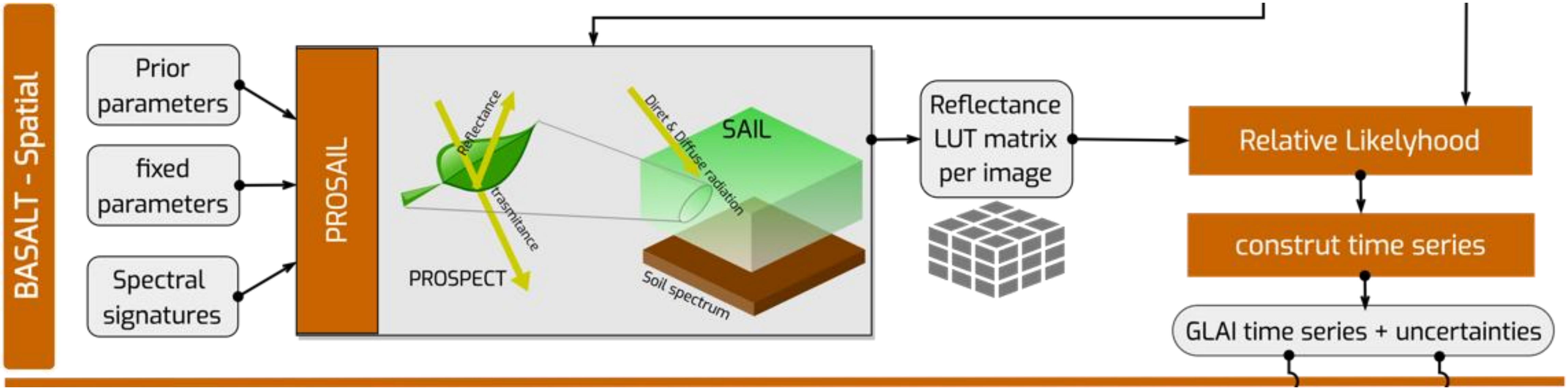
Sentinel-2, Landsat8, Venus
(coming Planet, Sentinel-1)

meteorological data

- Rg: Incoming global radiation
- 2m air temperature

ERA5-Land par api
or
SAFRAN Météo France

2 GLAI & associated uncertainty

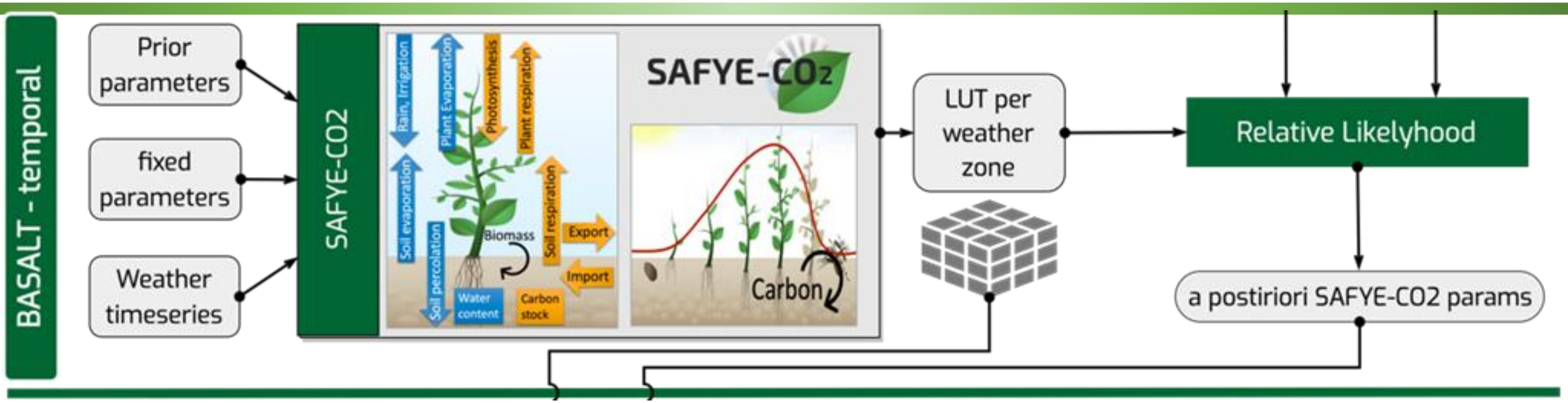


Inversion of PROSAIL to obtain the Green Leaf Area Index (GLAI) + its uncertainty.

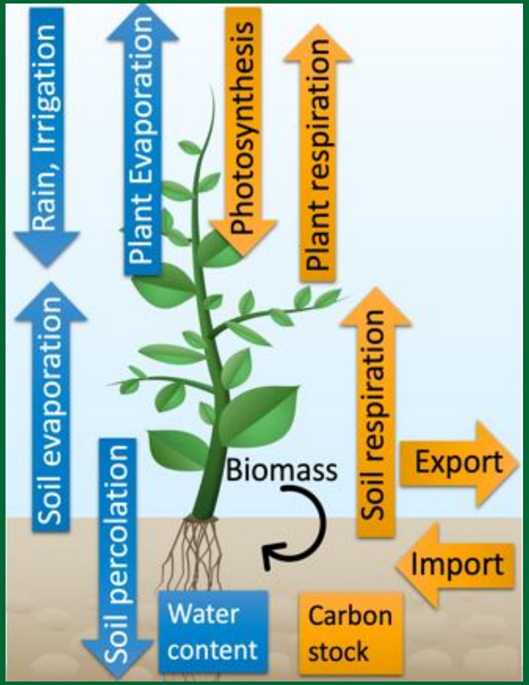
$$P(\vec{\theta}, x) = \frac{P(x|\vec{\theta})P(\vec{\theta})}{P(x)}$$

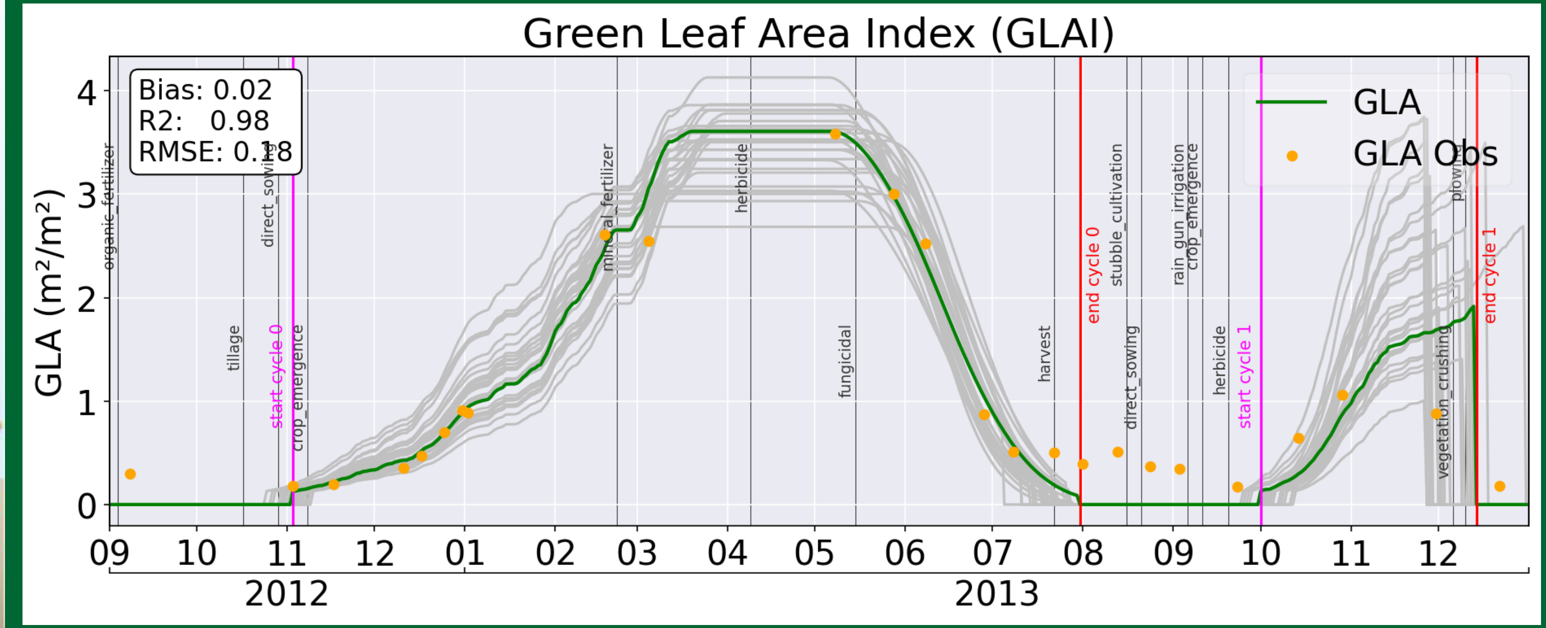
- Posteriori Prob. distribution
- Conditional probability likelihood
- Probability distribution of prior parameters
- Probability distribution of observation

2 *Inversion of the SAFYE-CO2 model*



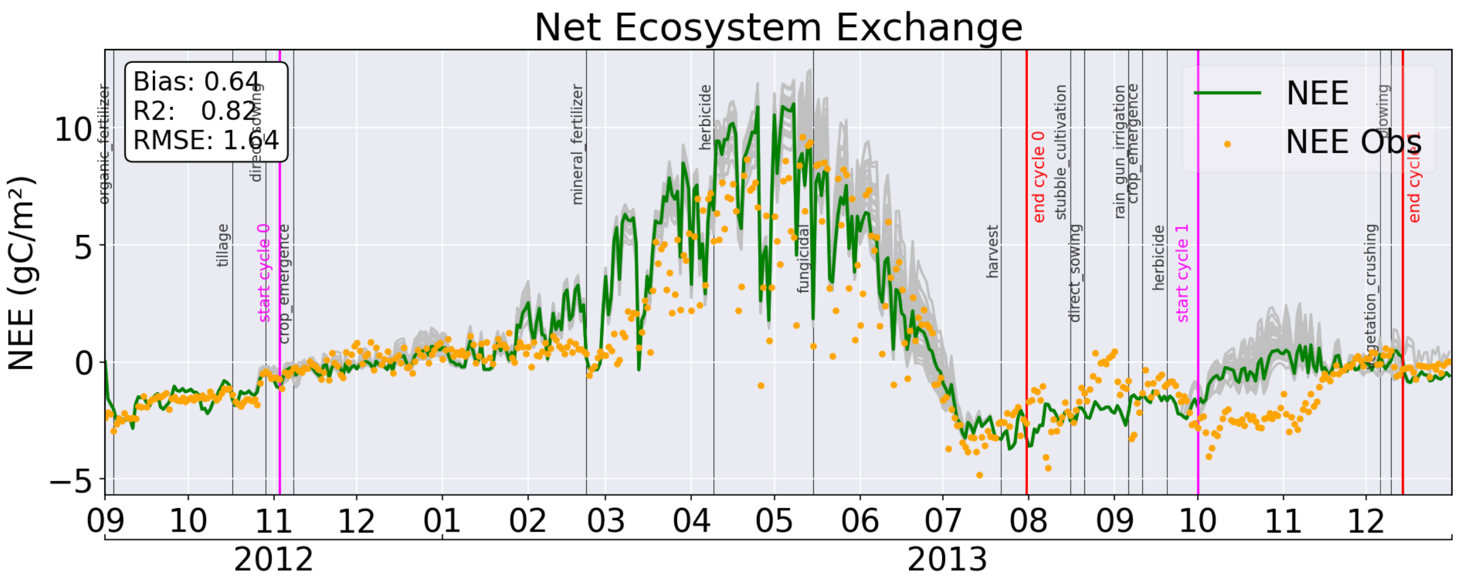
Safye-CO2



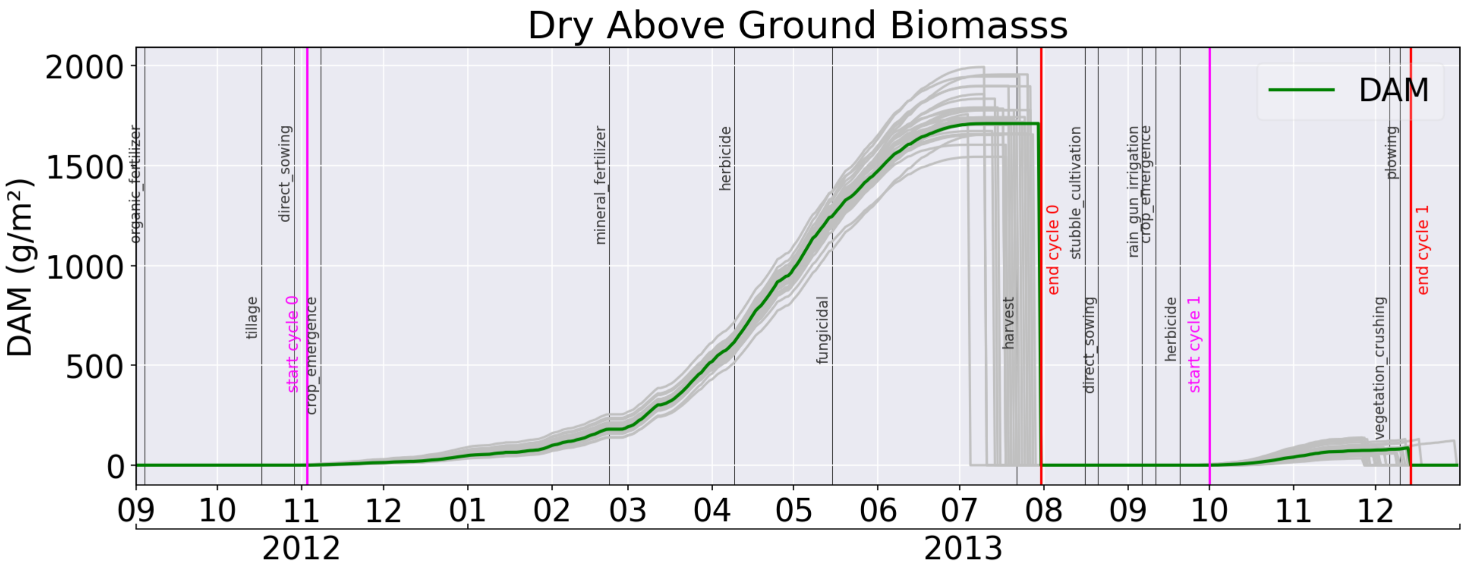


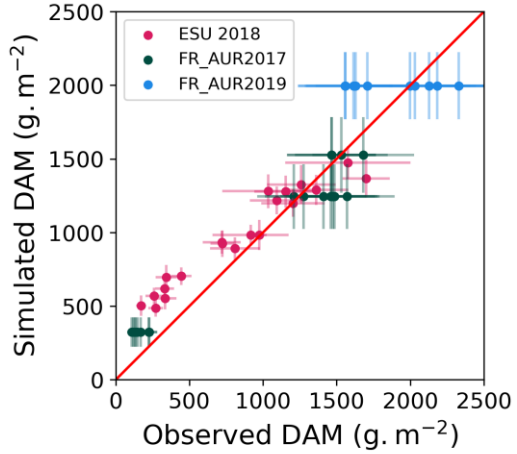
SAFYE-CO2. *Parcimonious agronomic model*

Net Ecosystem Exchange

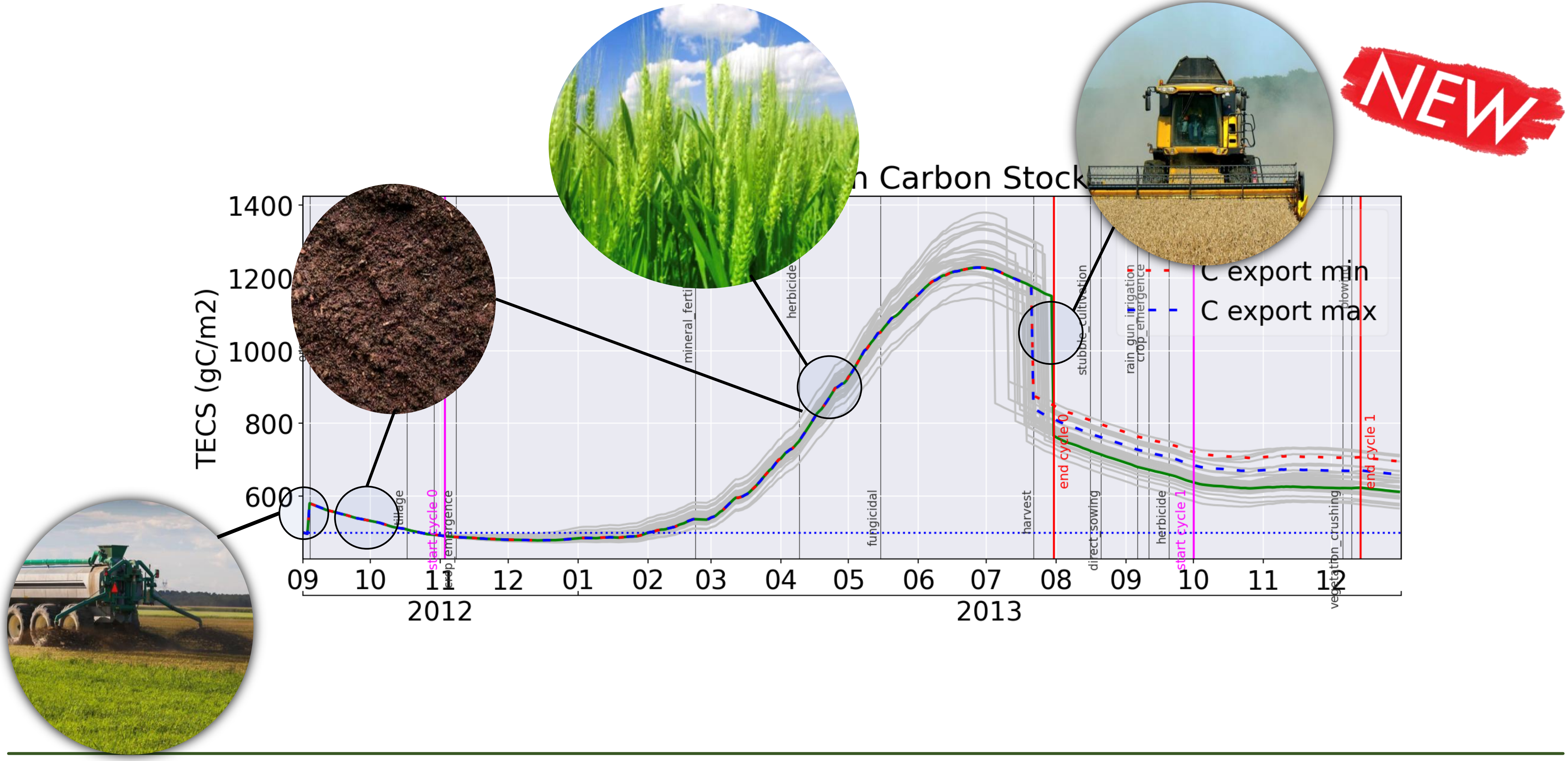


Biomass

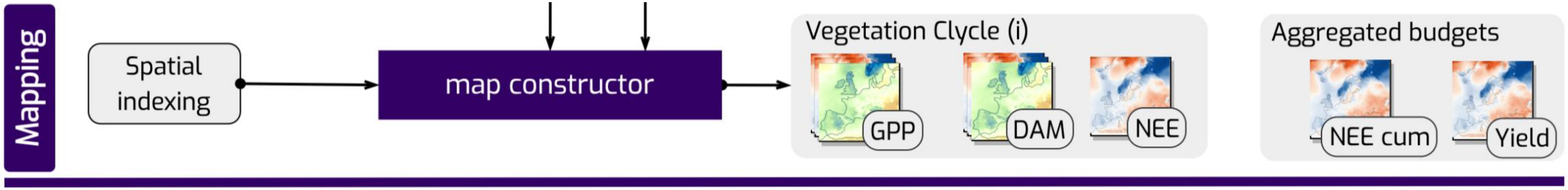




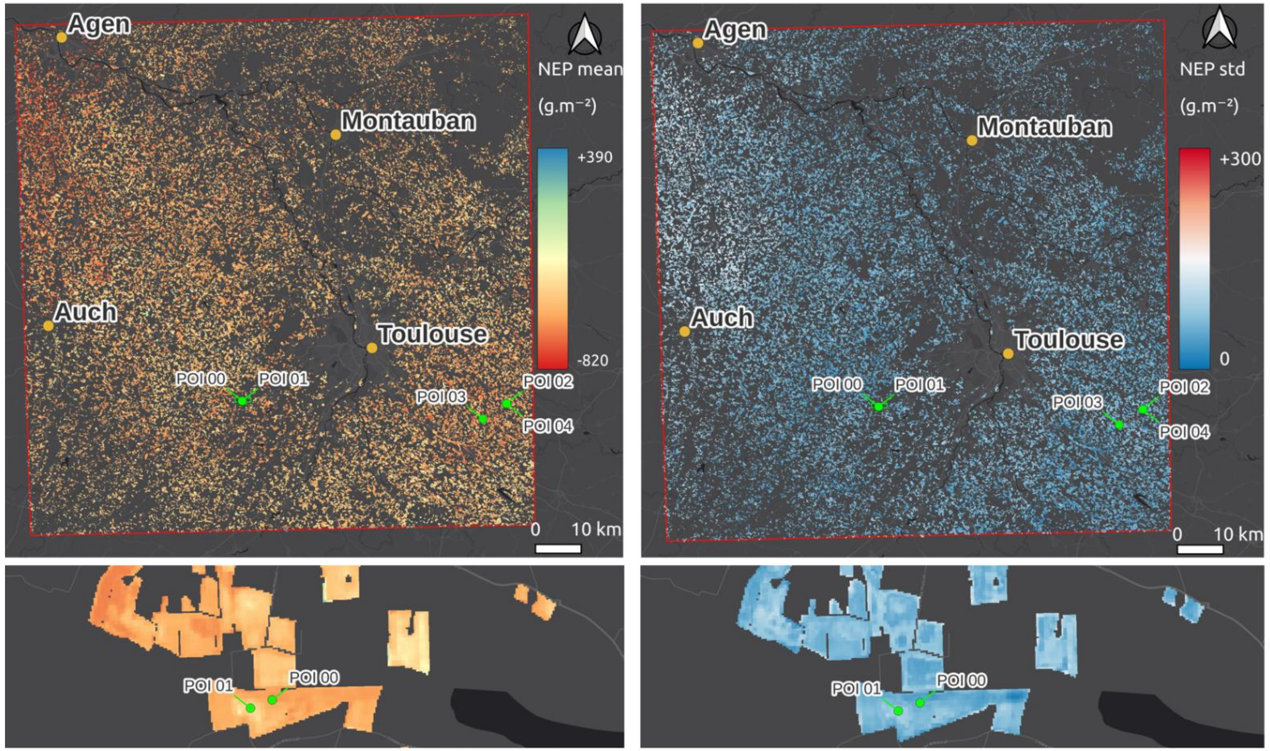
Dynamics of the ecosystem's carbon stock



Mapping

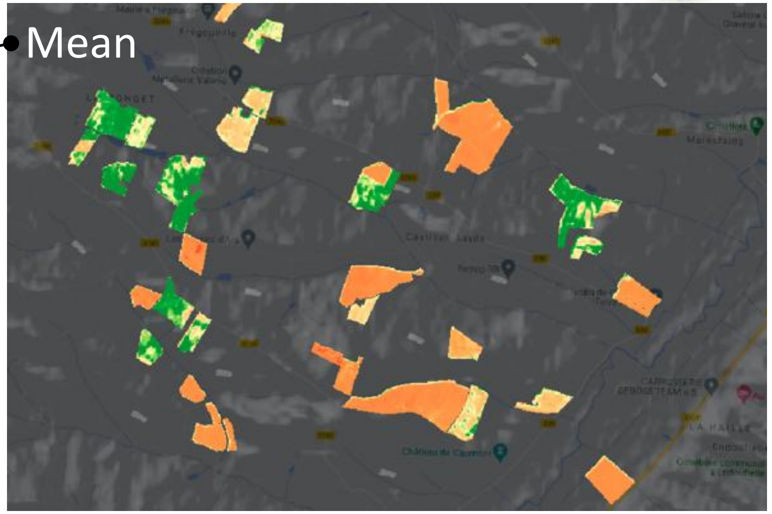


Exemple 1: NEE (T31TCJ, Sudouest, France)

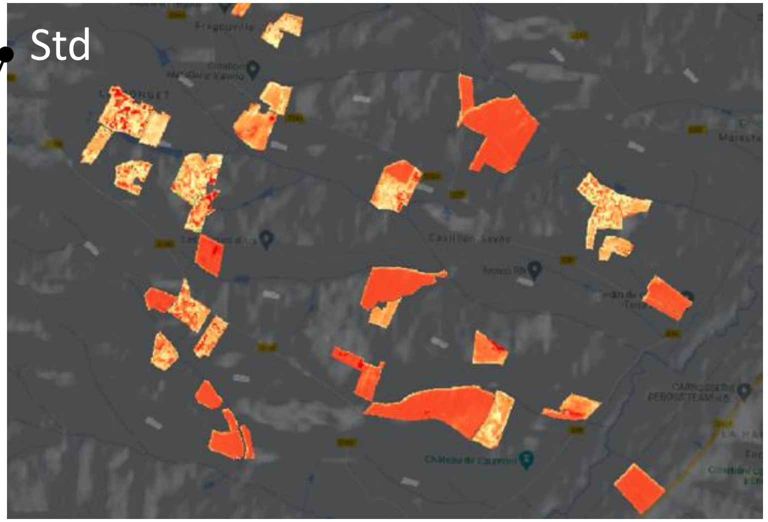


Dry Above Ground Biomass – with cover crops

DAM - Crop cover

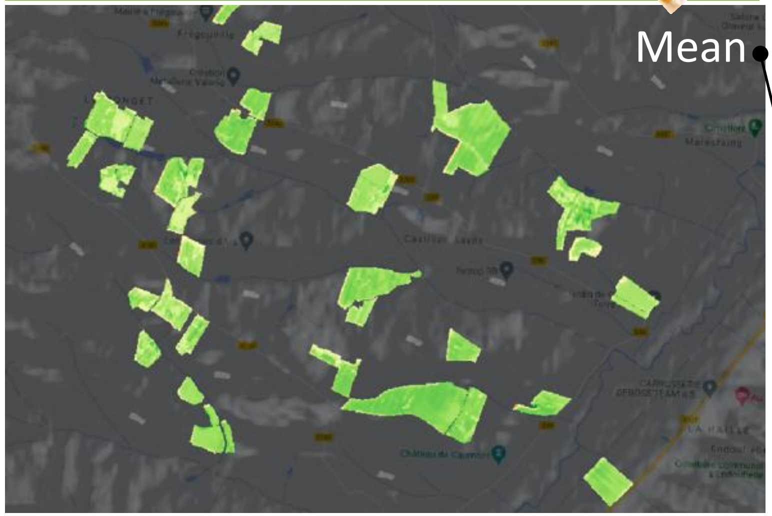


Not a negligeable biomass production, but very heterogeneous

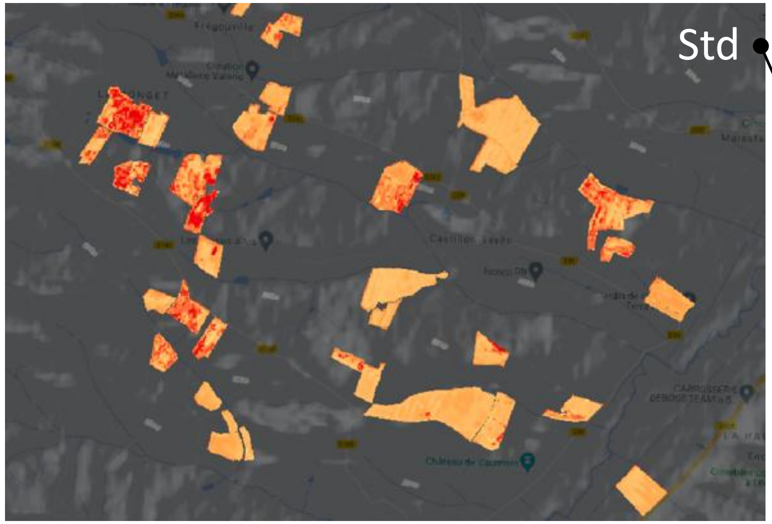


Lower because lower DAM, but relatively high uncertainty (30-50 %)

DAM - Maize



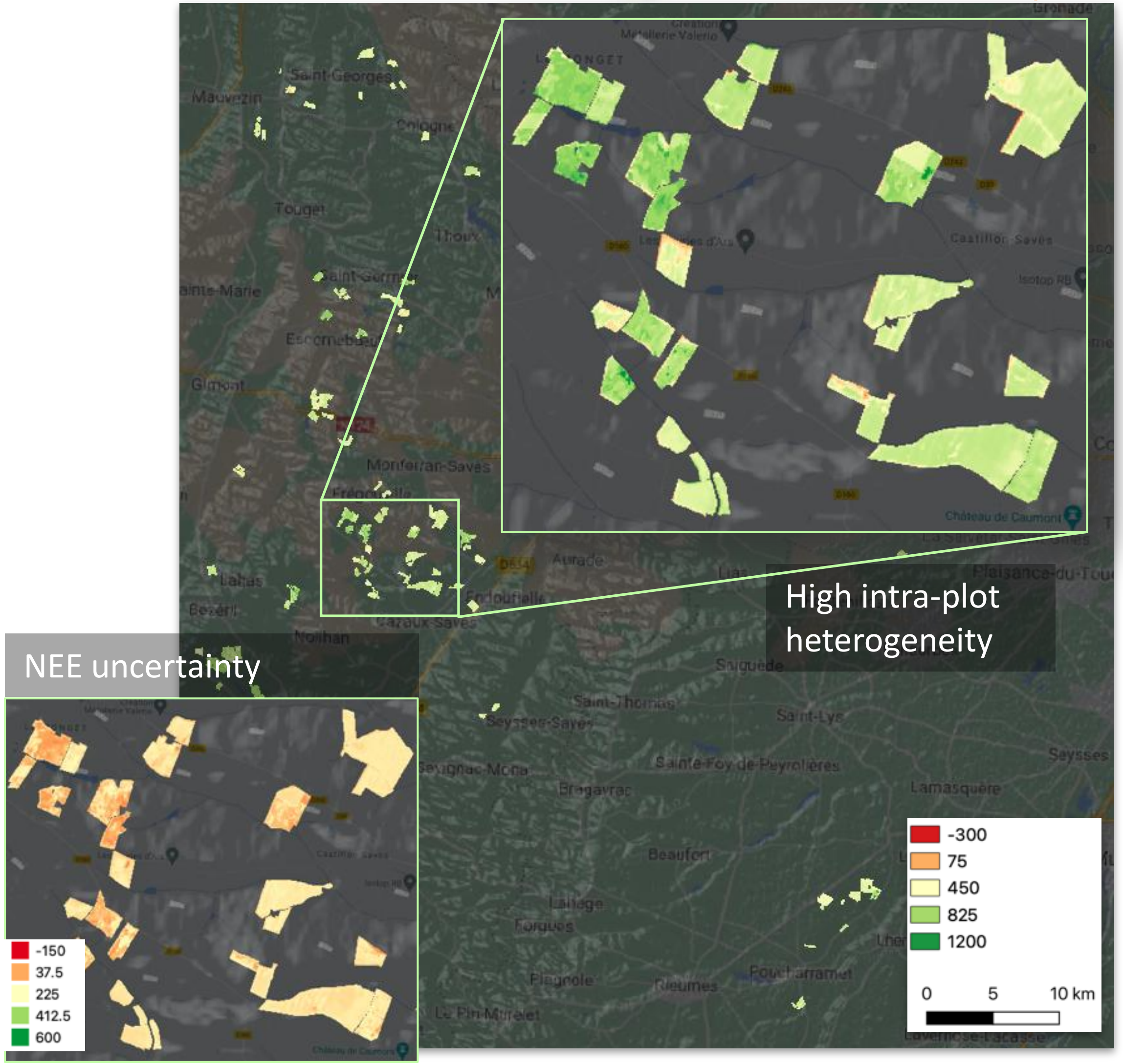
Standard values, and much more homogeneous. (Inputs, Agri. practices).



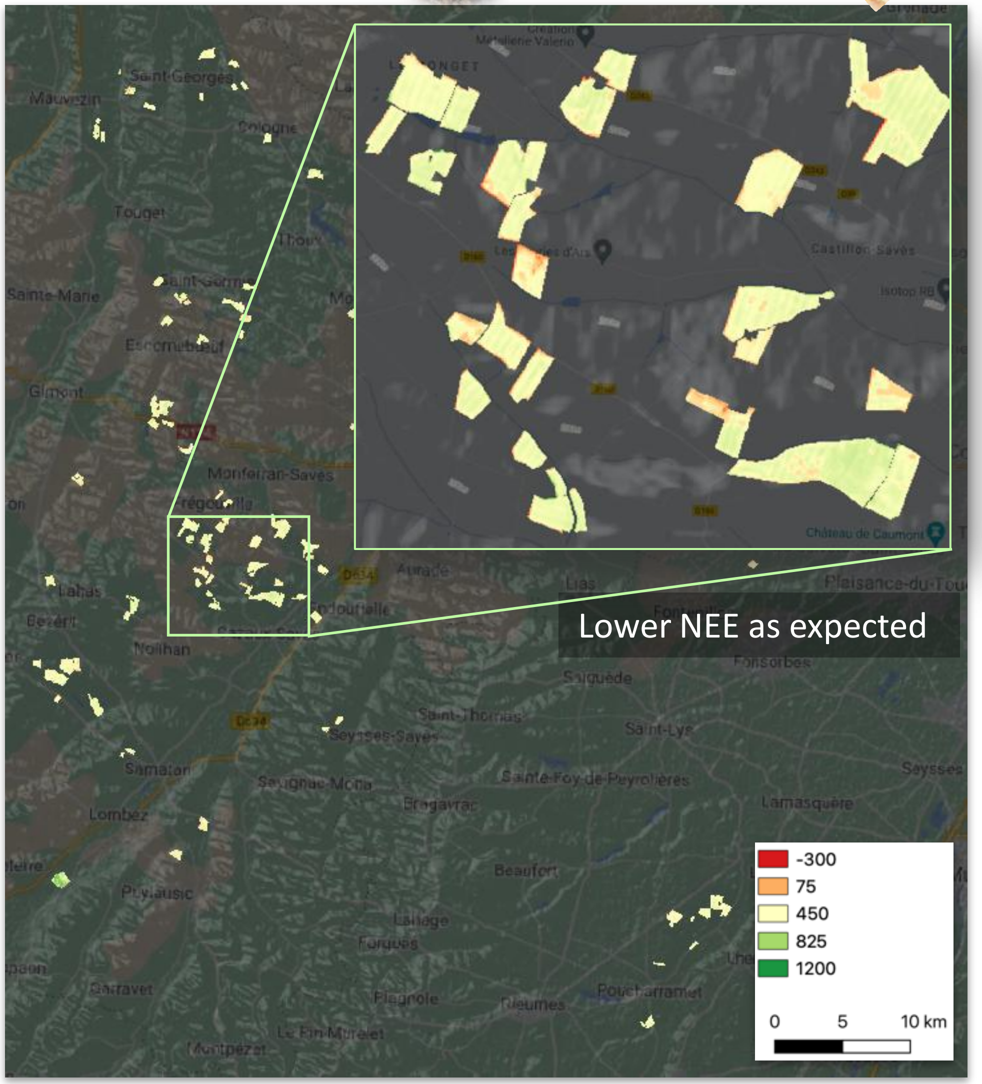
Uncertainty varies at intra-field but less than cover crops.

NEE – over the double experiment

NEE : Cover crop + Maize

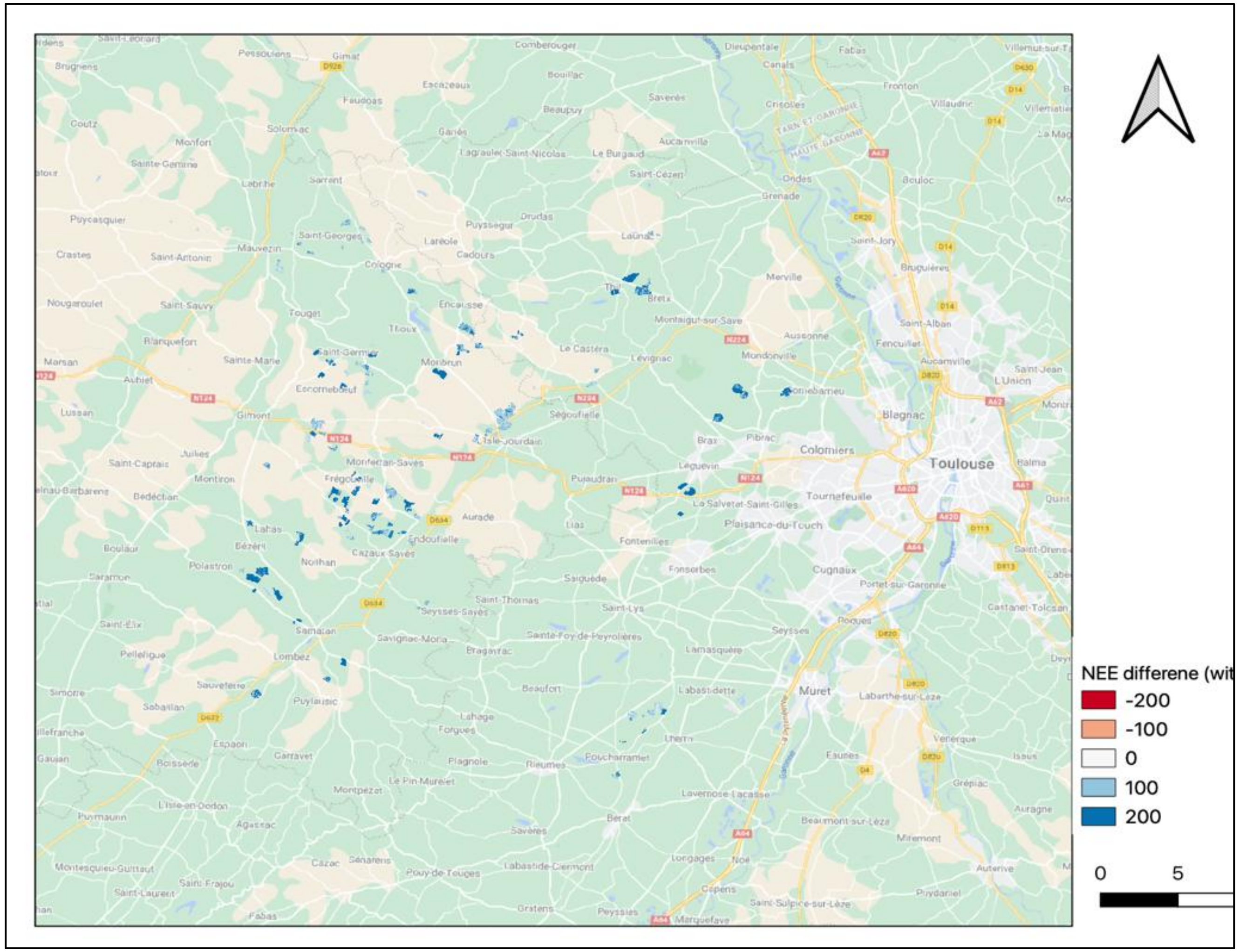


NEE : Bare soil + Maize

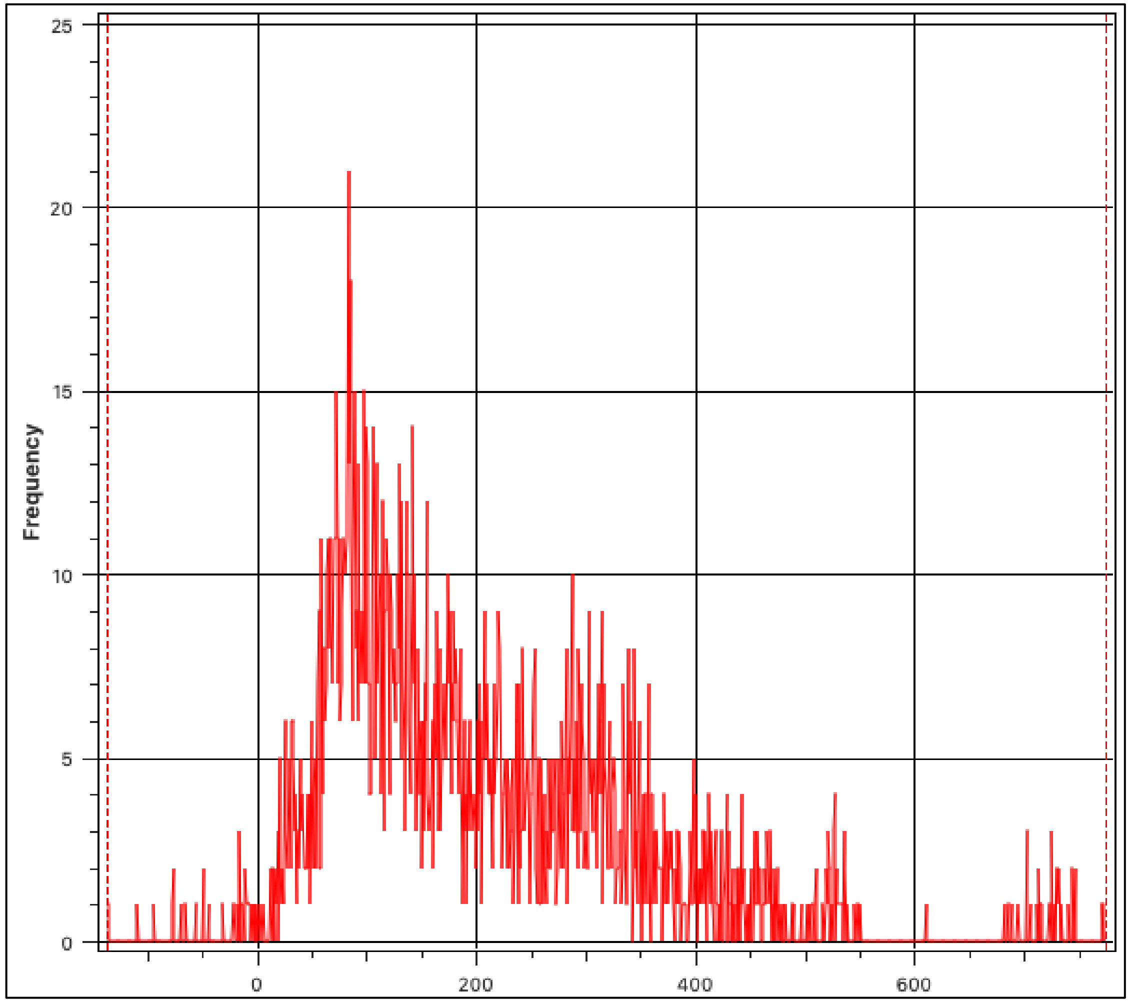


Net effect of cover crops on net annual CO_2 fluxes

Map of NEE (+) – NEE (+)



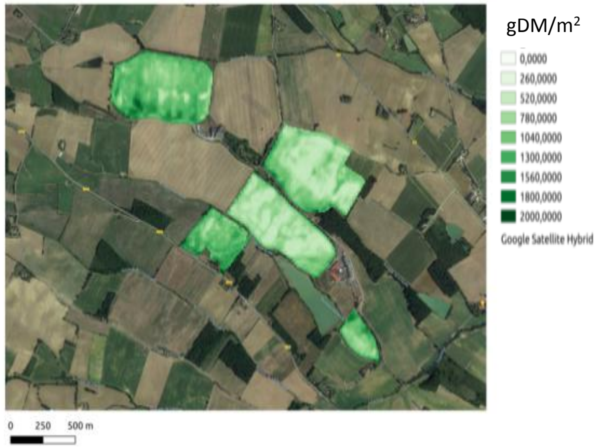
Histogramme NEE (+) – NEE (+)



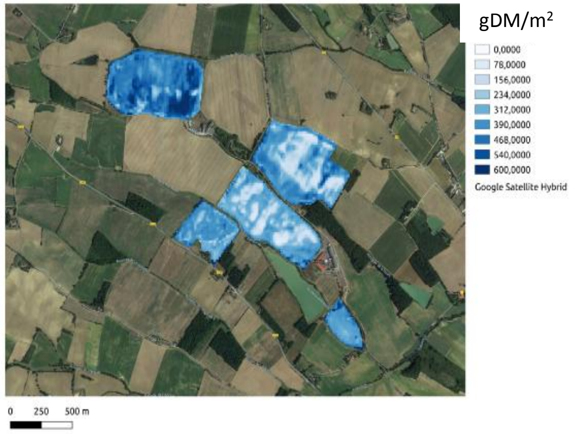
High resolution C budget estimates with ACEO

Project Naturellement popcorn ➔ farmers can receive a premium depending on the amount of C they store in the soil via intermediate crops

Crop biomass + Uncertainties

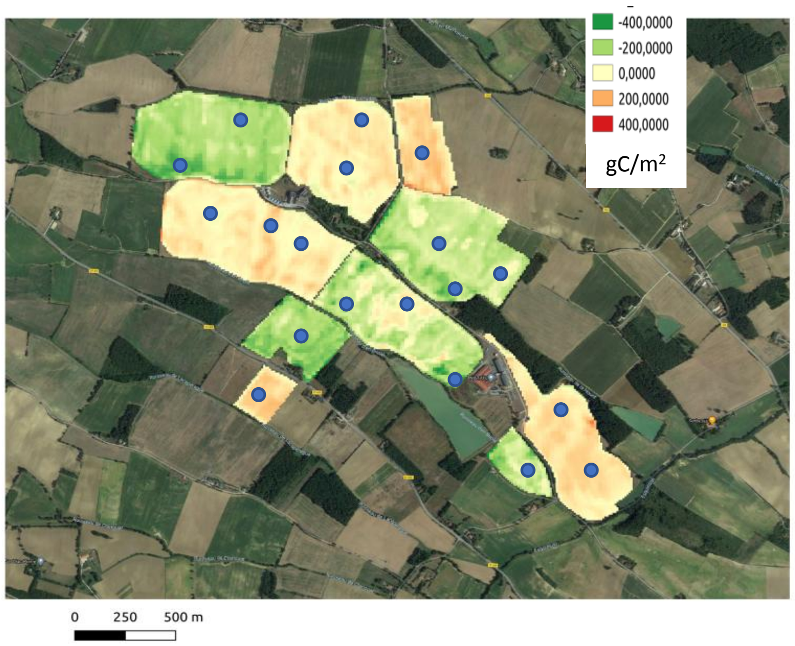


Cover crop biomass + Uncertainties



+ farmers data and the AMG soil model

First C budget map at 10m resolution in 2019, for rotation cover crop/corn/wheat (Ferme de Villeneuve, Bézéril, France)



C storage by the soil

C losses by the soil

Possibility to define an optimal soil sampling plan (precision/cost) for validation/analysis of delta stocks

Realisation T. Wijmer

Limits and perspectives for ACEO

- Diagnostic approach only but possibility to test the effect of some management scenarios (e.g. export of straws)

- Limited to a few crops and major cover crops types in Southwest France ➔ progressive acquisition of new in-situ datasets for CAL/VAL & transposability analysis in Europe

- Late coupling with the AMG soil model (simulates soil C pool dynamics) but an assumed choice because the current soil products (e.g. SoilGrids, etc.) do not have sufficient precision for simulations at the plot/intra plot level with soil models ➔ becomes relevant via increasing access to soil analysis data (e.g. Label Bas C) or upcoming more accurate/higher resolution soil products

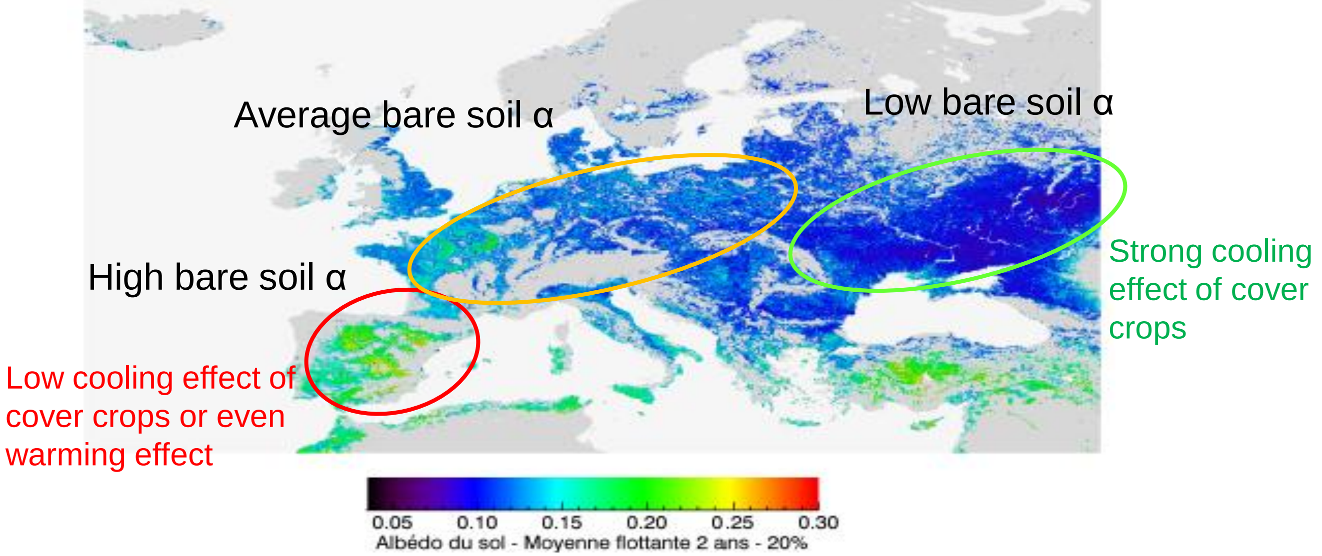
- Use of optical data alone may be limiting (long cloud periods) ➔ radar data to lift this constraint (Thesis A. Geraud in collaboration with NetCarbon)

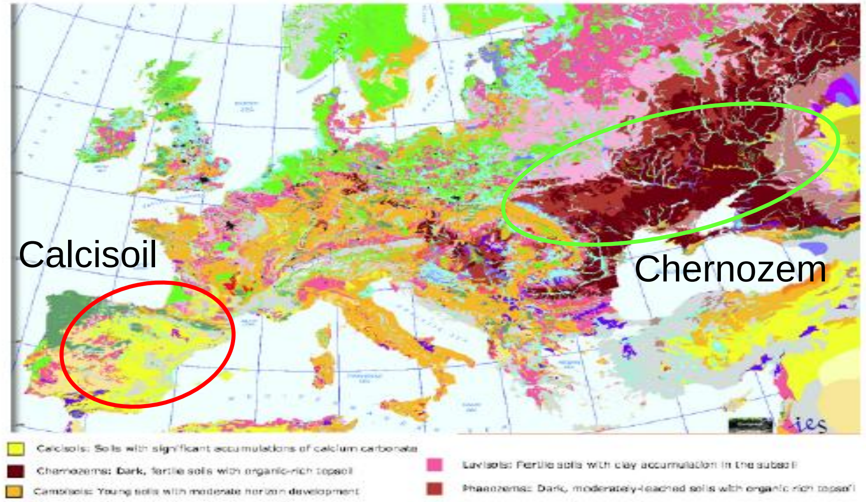
- Need to collect data on C inputs via manure and export of straws for calculation of C budget ➔ connection with current farm management information systems (ex. MesP@arcelles, projet SCO Quantica)

Effect of soil coverage by cover crops on albedo

- In general, the introduction of cover crops in the crop rotations increases the surface albedo relative to bare soil, but for some soil types (e.g. calcisoils) with high albedo, the introduction of high CI may be counterproductive (Carrer et al. 2018).

Winter bare soil albedo map for cultivated plots based on disaggregated MODIS satellite data (Carrer et al., 2012)



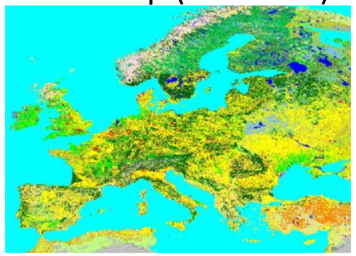


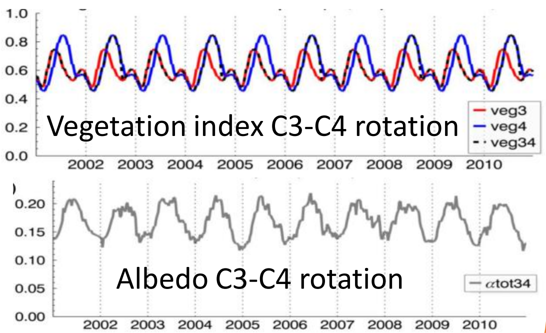
➔Remote sensing data are useful in determining where/when cover crops should be introduced (or not) to increase current surface albedo

Effect of soil coverage by cover crops on radiative forcing

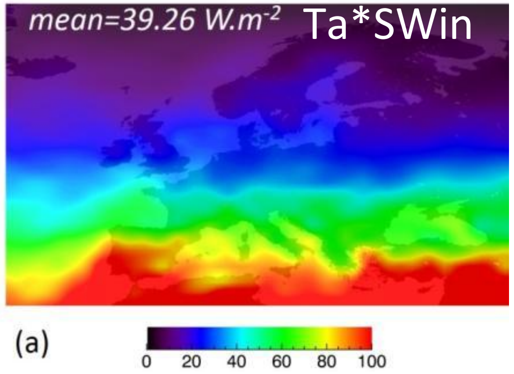
Carrer et al. (2018) in ERL

Ecoclimap (Land use)

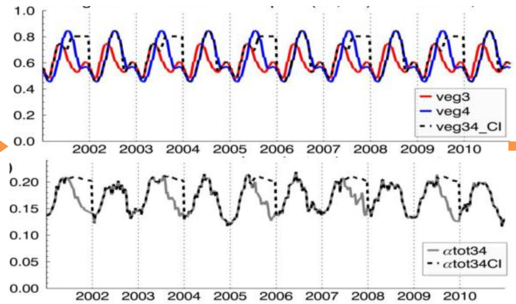




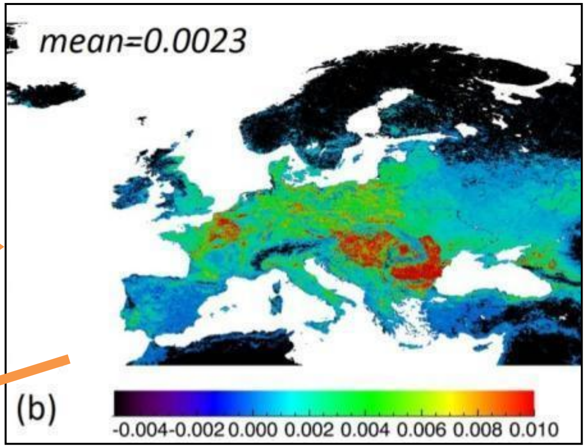
Desagregated vegetation index, bare soil albedo & vegetation albedo (snow free) derived from MODIS data at 5*5 km (Kalman filter ; *Carrer et al., 2014*) ➔ albedo of C3-C4 crop rotation



Analysis of where and when cover crops are introduced



Daily albedo increase with cover crops



Radiative forcing ($W.m^{-2}$)

Daily global radiation& atmospheric transmittance (ERA-INTERIM)

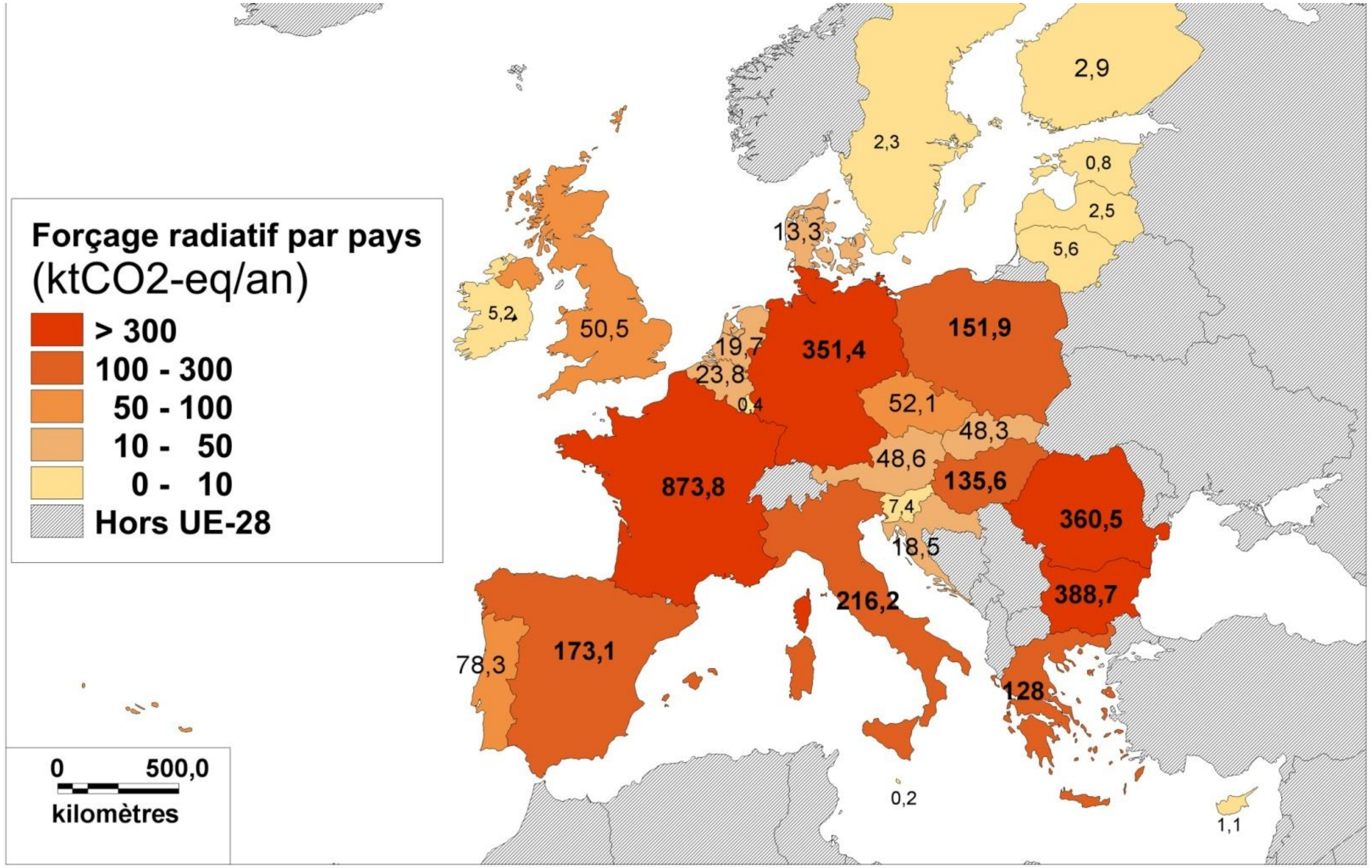
RFCC

Radiative Forcing of Cover Crop

$RF\alpha = - Rg \times TA \times \Delta\alpha$

Albedo effect of 3 month cover crop introduction in CO_2-eq

(Carrer et al. 2018)



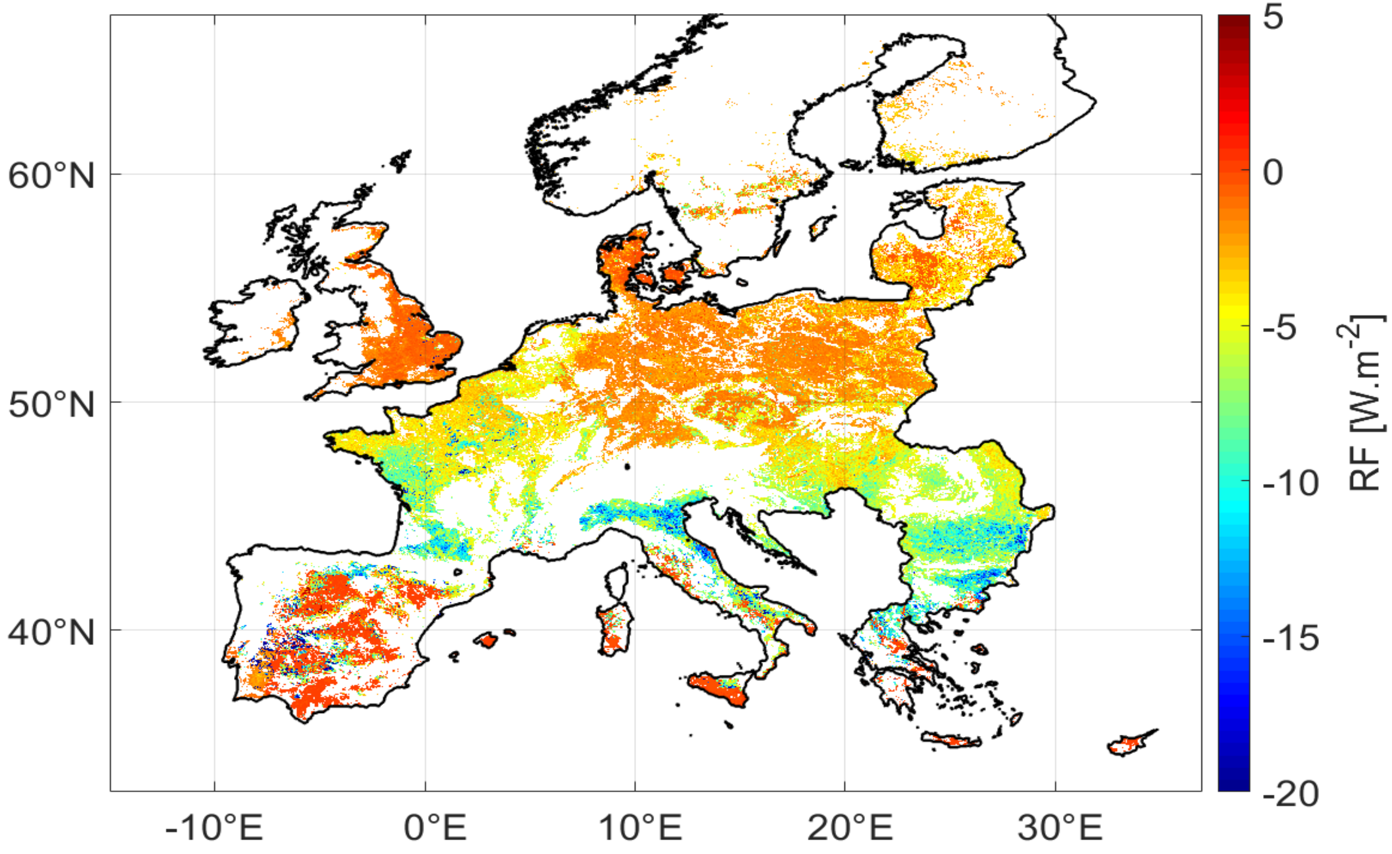
- 3 month duration cover crop scenario ➔ the cumulative RFα over EU-28 is 3.2 (2.9) $MtCO_2$-eq.year^{-1}.

- Same but accounting for rain limitation ➔ the cumulative RFα over EU-28 was 2.3 (2.1) $MtCO_2$-eq.year^{-1}

- 6 month duration cover crop scenario + rain limitation ➔ the cumulative RFα over EU-28 was 4.3 (4.0) $MtCO_2$-eq.year^{-1} *i.e.* a compensation of up to 1.0 (0.9)% of the EU-28 agricultural GHG emissions.

The countries with the greatest potential for albedo effect linked to the introduction of cover crops are France, Romania, Bulgaria and Germany,*

Albedo effect of cover crop: maximum duration of soil coverage

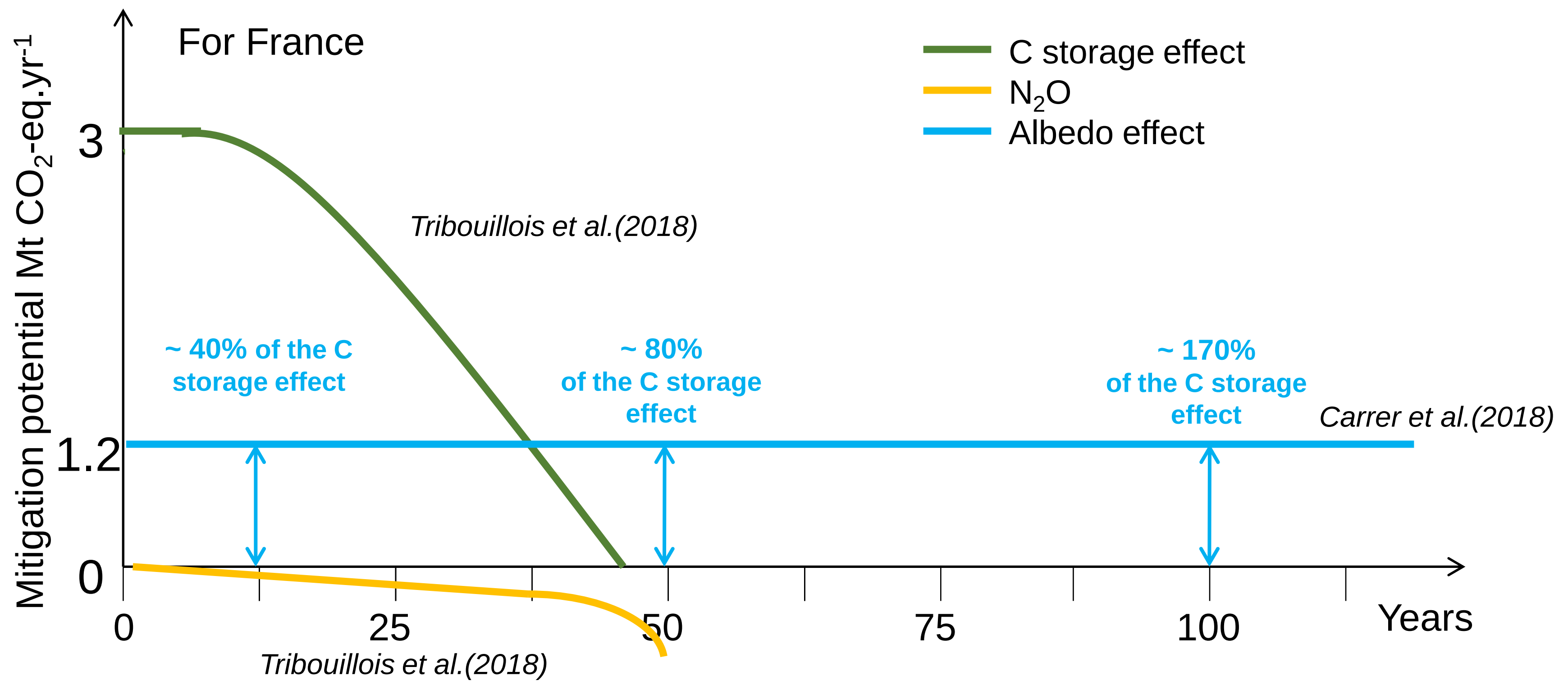


Pique et al. submitted

Equivalent to 6,7 Mt CO_2-eq/yr* on average over this area of study but in some areas like Spain, Sicilia and Greece cover crops increase surface albedo (anyway those areas are too dry to implement them…). Yet 3 times more thans with a 3 month cover crop scenario

* against 31 Mt CO_2eq/yr for the cover crop C storage effect in France only with the same scenario of introduction

Comparison of cover crop C and α effects on the long term vs short terms



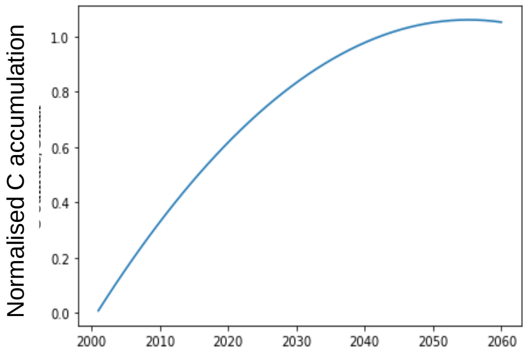
In the short term the albedo effect is lower than the storage effect of C intermediate crops but integrated over 100 years it is the reverse

Analysis of cover crop C and α effects on the long vs short terms

However…

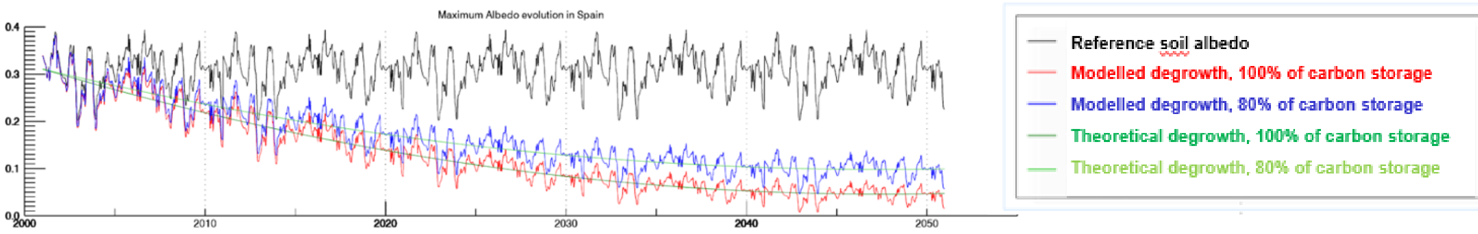
Pique et al submitted

More C in the soil…



Adapted from Tribouillois et al (2018) and considering Corg max similar to Romanian soils

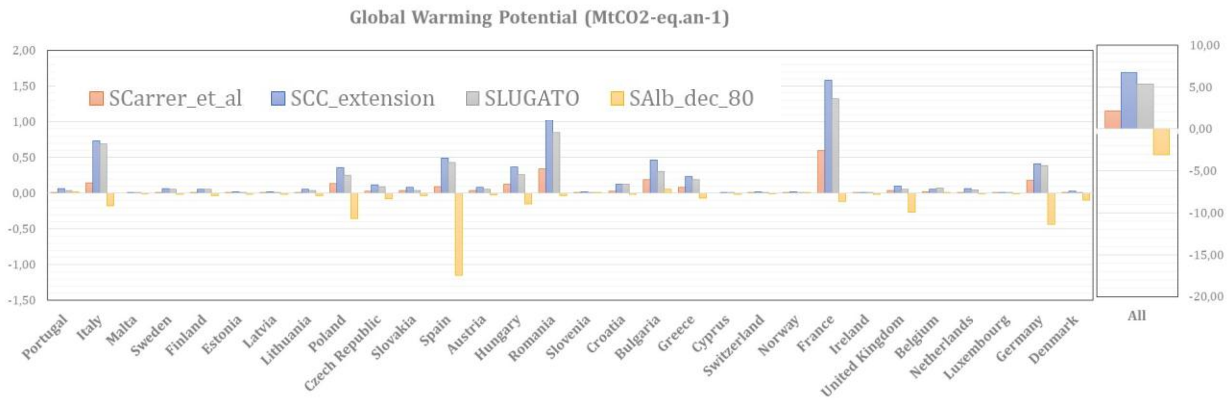
…means darker soil



Modelled bare soil albedo decrease takes into account the progressive incorporation of organic matters in the soil (in the whole soil profile while in reality OM accumulates first in the top soil)

Same method as in Carrer et al. (2018) but over 50 years (current climate) considering several scenarii:

- 3 month CC
- Extension cover crop (as in *Pellerin et al. 2019*)
- Extension CC + soil darkening with a realistic scenario (modelled with DayCent as in Lugato et al. 2020),
- Extension CC + soil darkening considering albedo decrease till 80% of the lowest soil albedo value in Europe



Once cover crop are adopted (or other practices increasing soil organic C content), soil should be covered permanently to avoid this drawback. This can be achieved by different means (e.g. crop residues)

Perspectives

- Extend these analyses to other scenarios: e.g. combining soil coverage by straw + cover crops,

- Analyze the effect of new cover crops cultivars with high albedo

Genesio et al., 2020

- Develop high resolution surface albedo products from Sentinel-2 and Landsat-8 (CES albedo of T of cover crops/crop rotations/fallow types (to better quantify these effects,

- Integrate other radiative effects (e.g. thermal infrared with the upcoming Thrishna and LST satellites) and changes in energy fluxes to calculate the net climate effect of cover crop ➔ 1 PhD in collab with the Institute of Convergence Cland.

Conclusions

- Cover crops have a strong climate change mitigation potential as the main mitigation lever for field crops and for storing C in French soils (Pellerin et al. 2019), but need remote sensing to quantify/objectify these effects,

- The cover crop biomass mapping work and its effects on C storage is only beginning:

  - Parameterization of a wide variety of crops, CC/CC mixtures in SAFYE-CO2/ACEO to evaluate their effects on C budget ➔ several ongoing projects/PhDs,

  - Still some methodological challenges to apply the ACEO approach at very large scale/high resolution modeling in an operational manner (e.g. clouds)…

  But a very promising tool that meets 1) the requirements of the scientific community (CIRCASA) and 2) the need of a multitude of players (CAP, C market, etc.) ➔ wishes to pool skills and mobilize different types of partners (research/private) to accelerate the development of these tools

- Until recently, the albedo lever of climate change mitigation was unknown in agriculture ➔ remote sensing revealed its importance (new avenues to explore),

- **Combined use of high resolution remote sensing products (e.g. albedo) and models would allow us to better guide the farmers in the transition toward more sustainable practices & quantify their environmental impacts ➔ define much more effective mitigation strategies for climate change: this is vital !!!**

Many thanks for your attention

and to our financers

ORCaSa

Naturellement popcorn

: https://www.cesbio.cnrs.fr/agricarboneo/

Contact : eric.ceschia@inrae.fr