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

AgriCarbon-EO: an innovative approach for mapping cropland carbon budget components at large scale and high resolution

Eric Ceschia (INRAE) & Ahmad Al Bitar (CNRS)

With contribution of Taeken Wijmer, Rémy Fieuzal, Ludovic Arnaud, Jean François Dejoux, Gaétan Pique

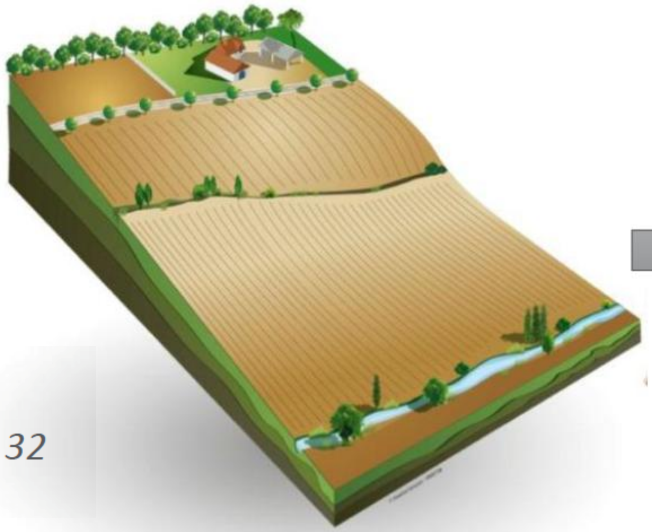
Joint Seminar of the IHSS-NOM and IRC-Soil Carbon

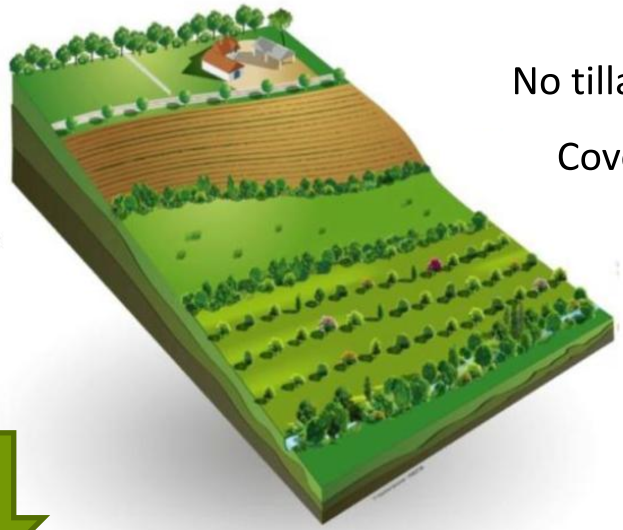
August 4, 2023

Context/Societal challenges

- Fight against global warming ➔ remain below 1.5°C of temperature increase (COP21 initiative 4 per 1000),
- More sustainable agriculture ➔ better resilience to extreme climatic events, soil fertility…

Questioning of conventional agriculture





Agro-ecological practices

No tillage, diversification

Cover crops

Agroforestry

C storage

Illustrations: Arbre et Paysage 32

- What are the impacts of those practices in terms of CO_2 emissions/soil carbon storage?
- How to quantify these effects at the plot but over very large territories?

➔ **Need for a new generation of tools providing an exhaustive/objective vision adapted to different contexts of Monitoring Reporting & Verification (NDC, C market, CAP) and meeting the highest scientific standards (CIRCASA's requirements)**

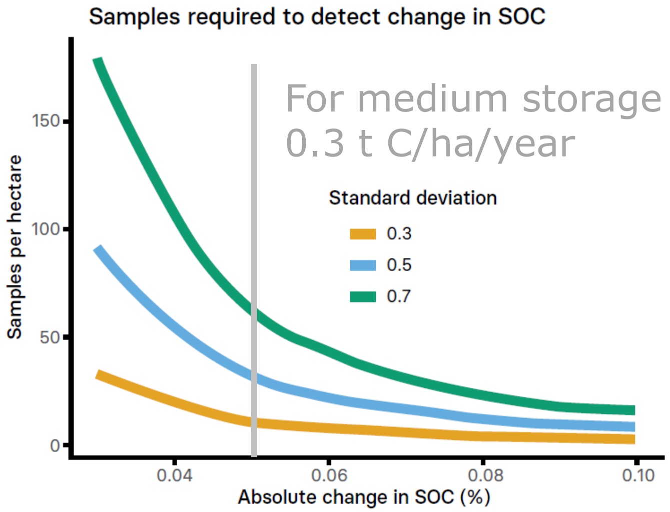
What is the C budget of an agricultural plot?
And how to quantify it?

- The C budget represents a carbon gain or loss of a soil, mainly in the form of organic matter, between two dates (crop year, rotation, etc.)

2 approaches

Direct measurement of changes in soil organic C stocks

- Requires a large number of samples between 2 dates ➔ very expensive, risk of unrepresentative sampling (can be reduced by mapping soil properties ➔ stratified sampling)



➔ Need to collect between 25 and 75 samples per hectare!!!

D'après EDF.ORG/SOILCARBON

What is the C budget of an agricultural plot?
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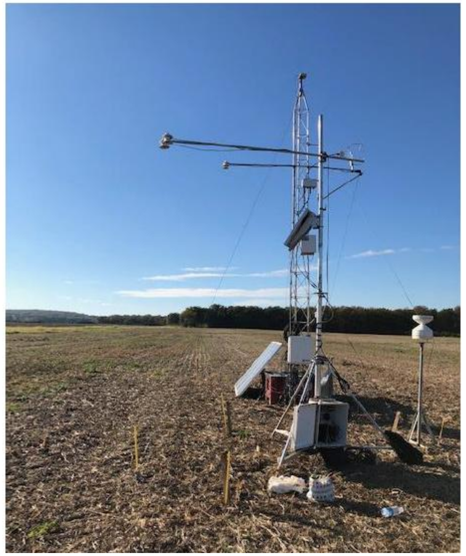
C budget approach = accounting for inputs & outputs of C

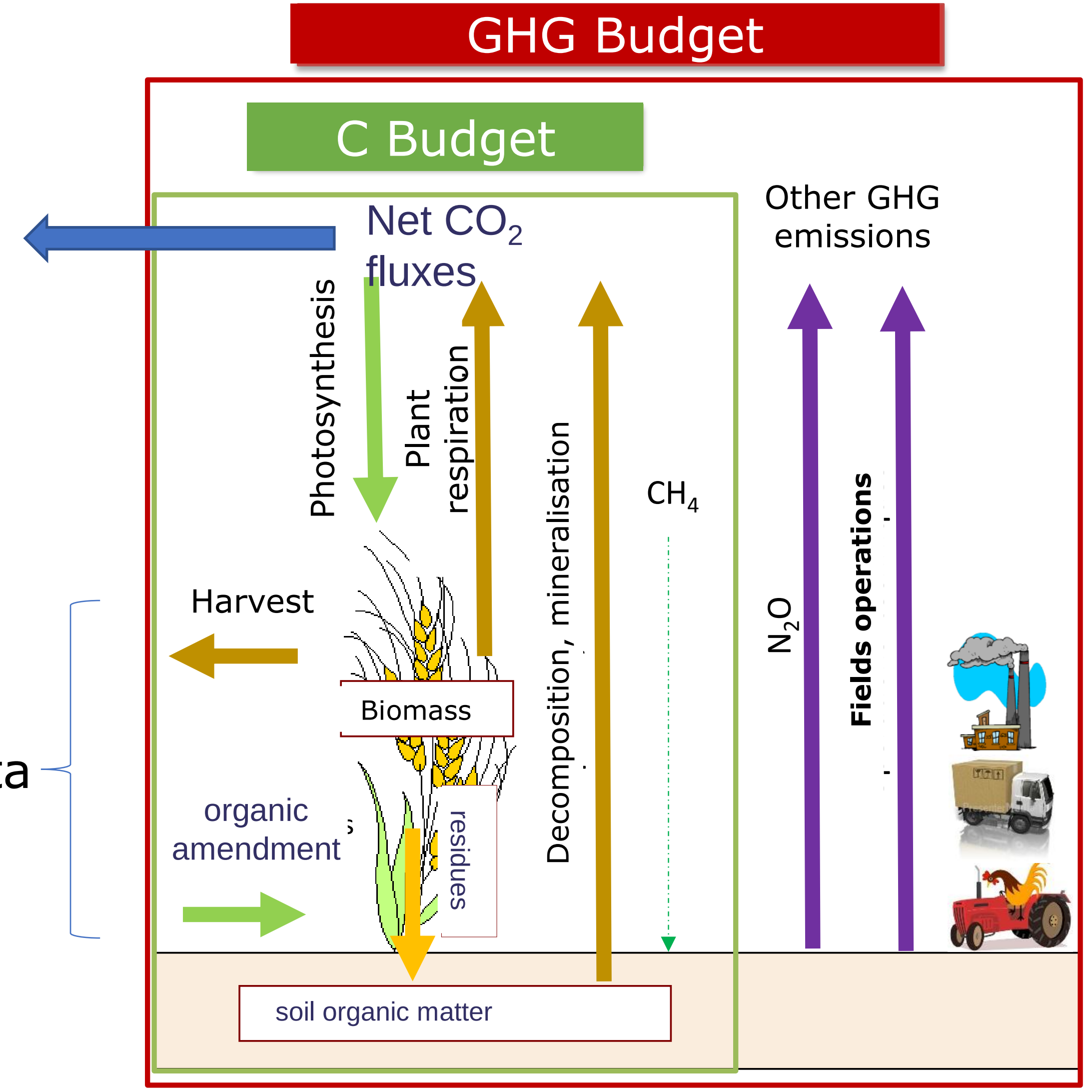
- More dynamic approach but quantification of all fluxes (vertical/lateral) of C between the parcel and its environment (by measurements or via modelling) ➔ see Smith et al 2010

Accounting of Inputs-Outputs and difference between C budget and GHG budget

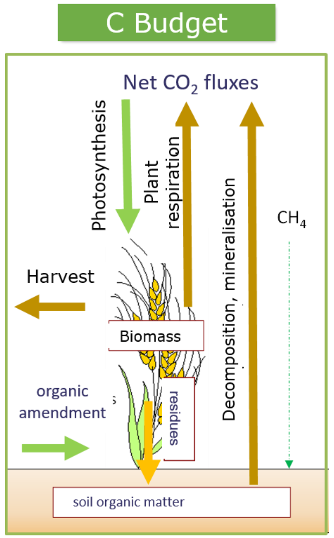


Flux tour (Pibrac, 32)

Farmer’s data



Limitations of classical input-output modelling approaches for upscalling

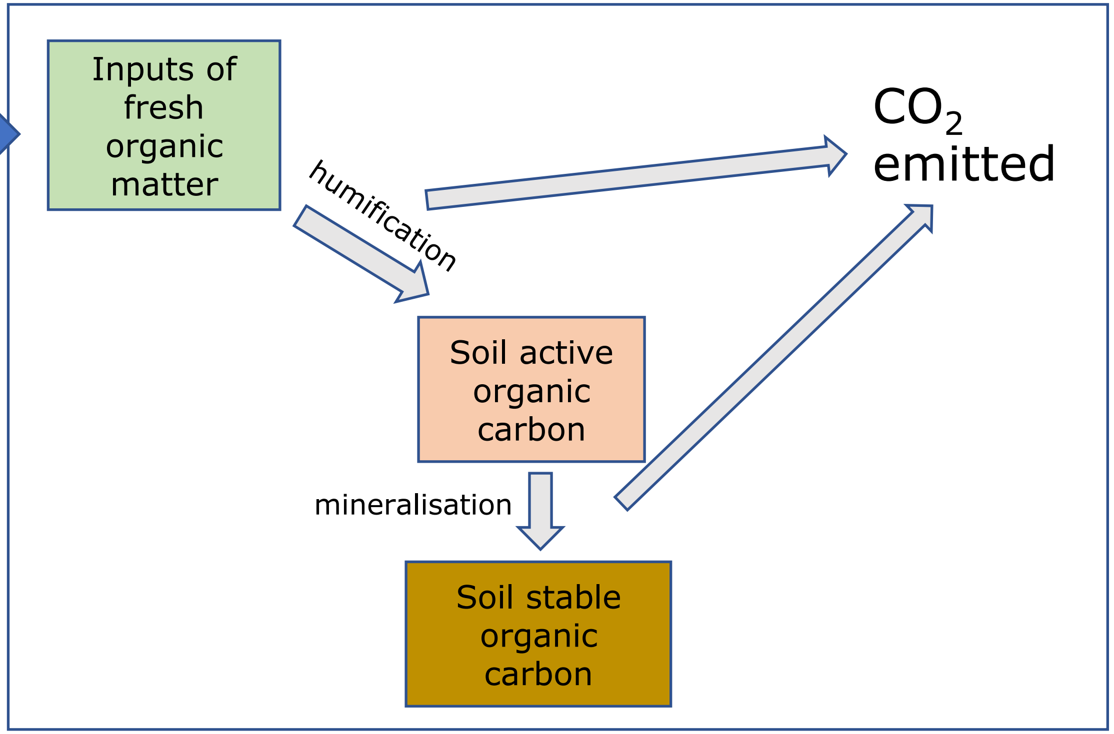


- Often (too) focused on soil modelling

Input data

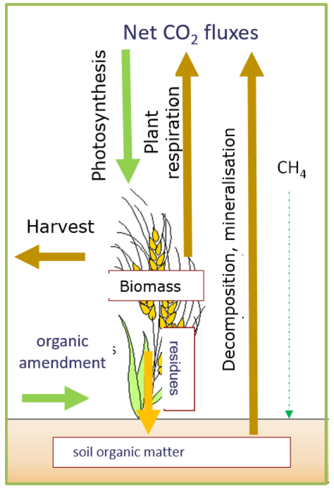
- Practices:
  - ploughing,
  - organic amendments,
- Estimated average biomass:
  - Crop fraction returned to the soil,
  - Cover crops,
- Climatic data
- Soil properties (texture, MO content, etc.)

Soil model example



Limitations of classical input-output modelling approaches for upscalling

C Budget



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Strong spatial heterogeneity!!

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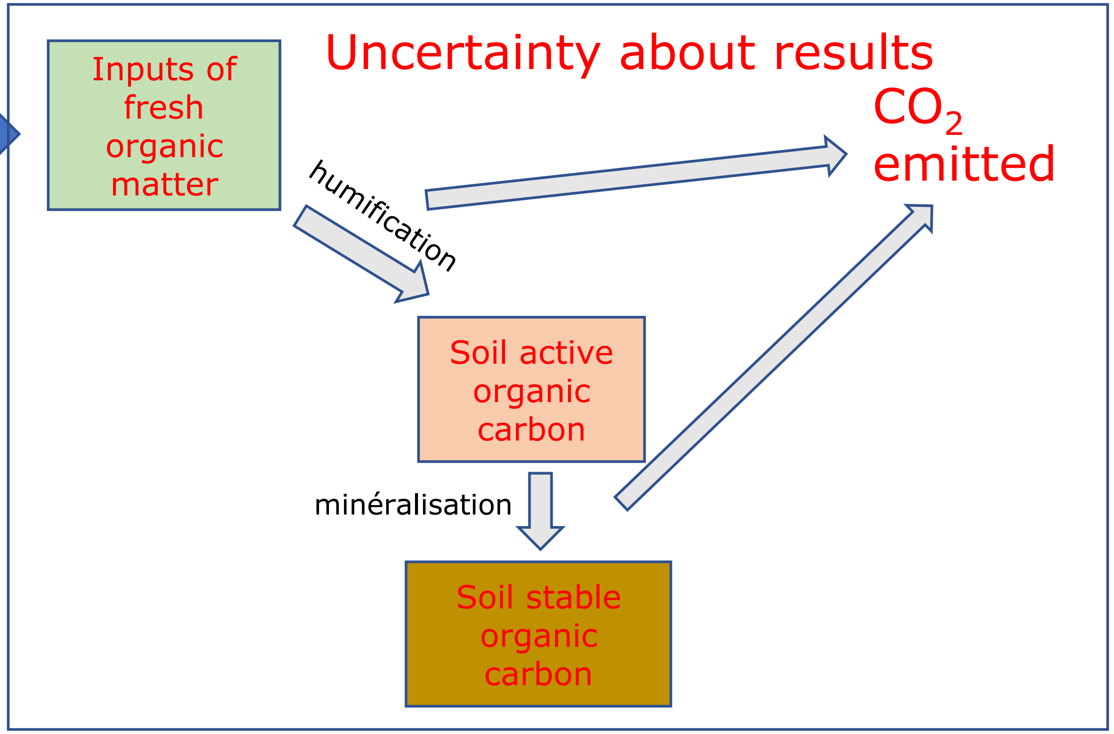

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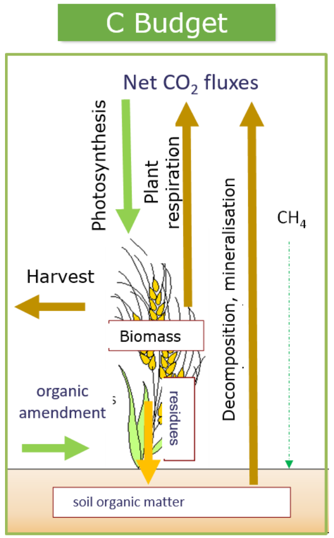

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LABEL BAS CARBONE

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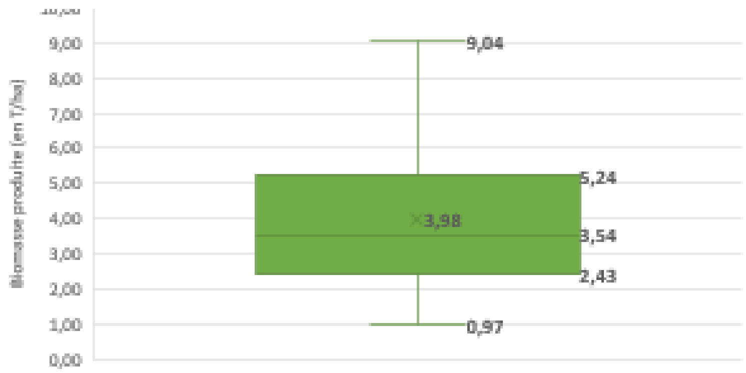
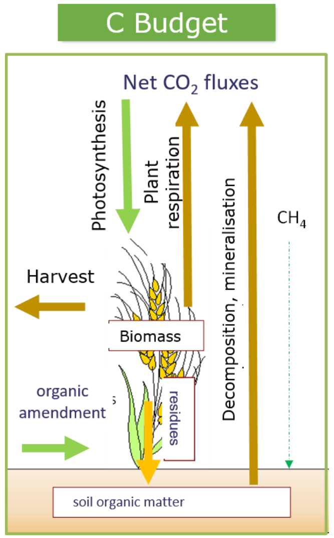
Strong spatial heterogeneity!!

Variability of cover crop biomass in the Nataïs producer network in 2019



Source Nataïs

Limitations of classical input-output modelling approaches for upscalling



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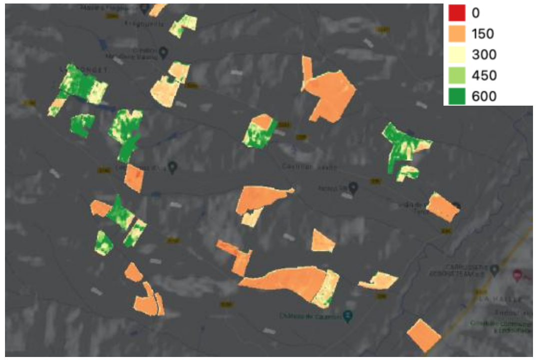
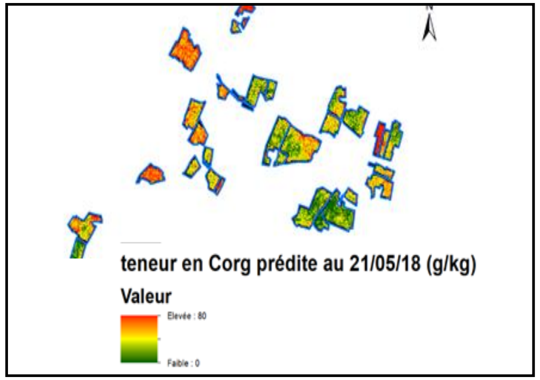
Strong spatial heterogeneity!!

Contribution of remote sensing for mapping:



- Crop biomass and plant cover

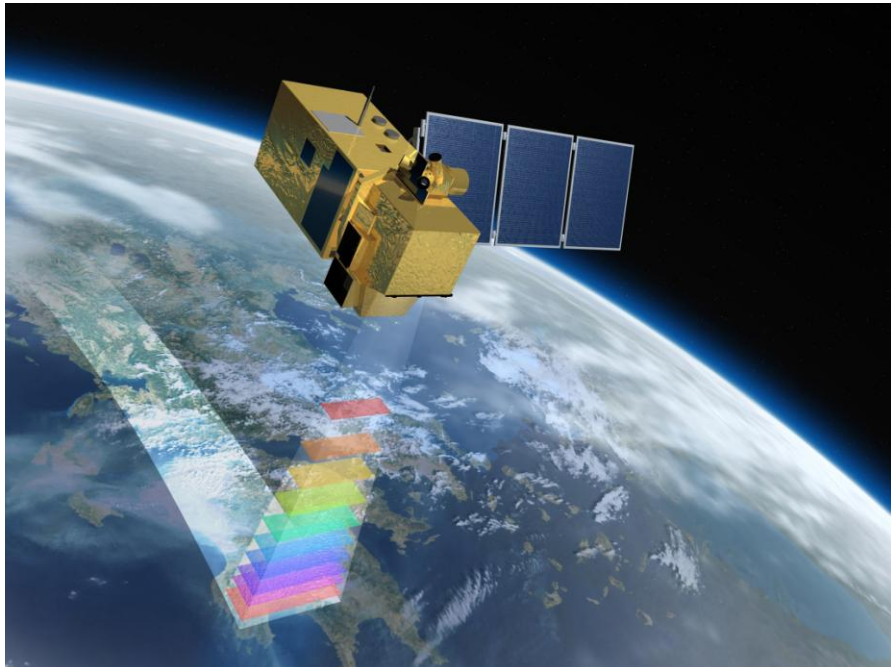


- soil properties

New satellites for agriculture

- Example of the European Space Agency's Sentinel-2 constellation

- 2 satellites in orbit since 2017,
- 13 observation wavelengths,
- 10 m resolution,
- A new image acquired every 5 days (in clear weather),
- All over the globe!
- Free data, accessible to all, easily downloadable and usable by non-experts.

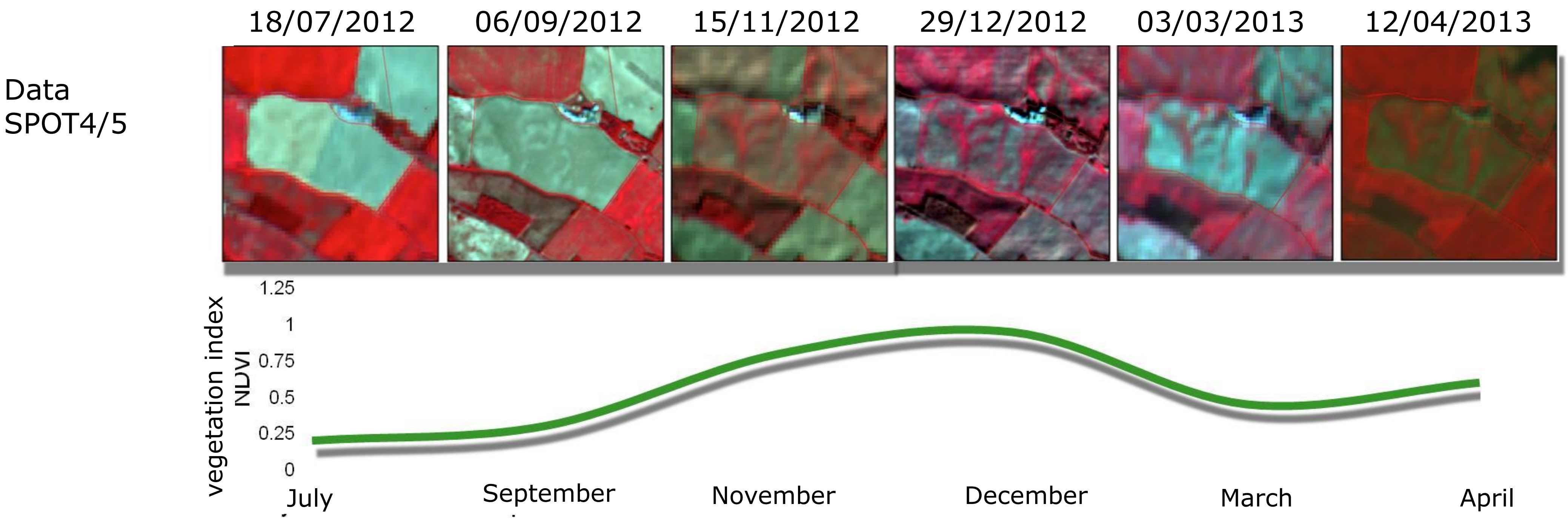


Crédits image : CLS

→ Possibility of developing operational services for agriculture

New satellites for agriculture

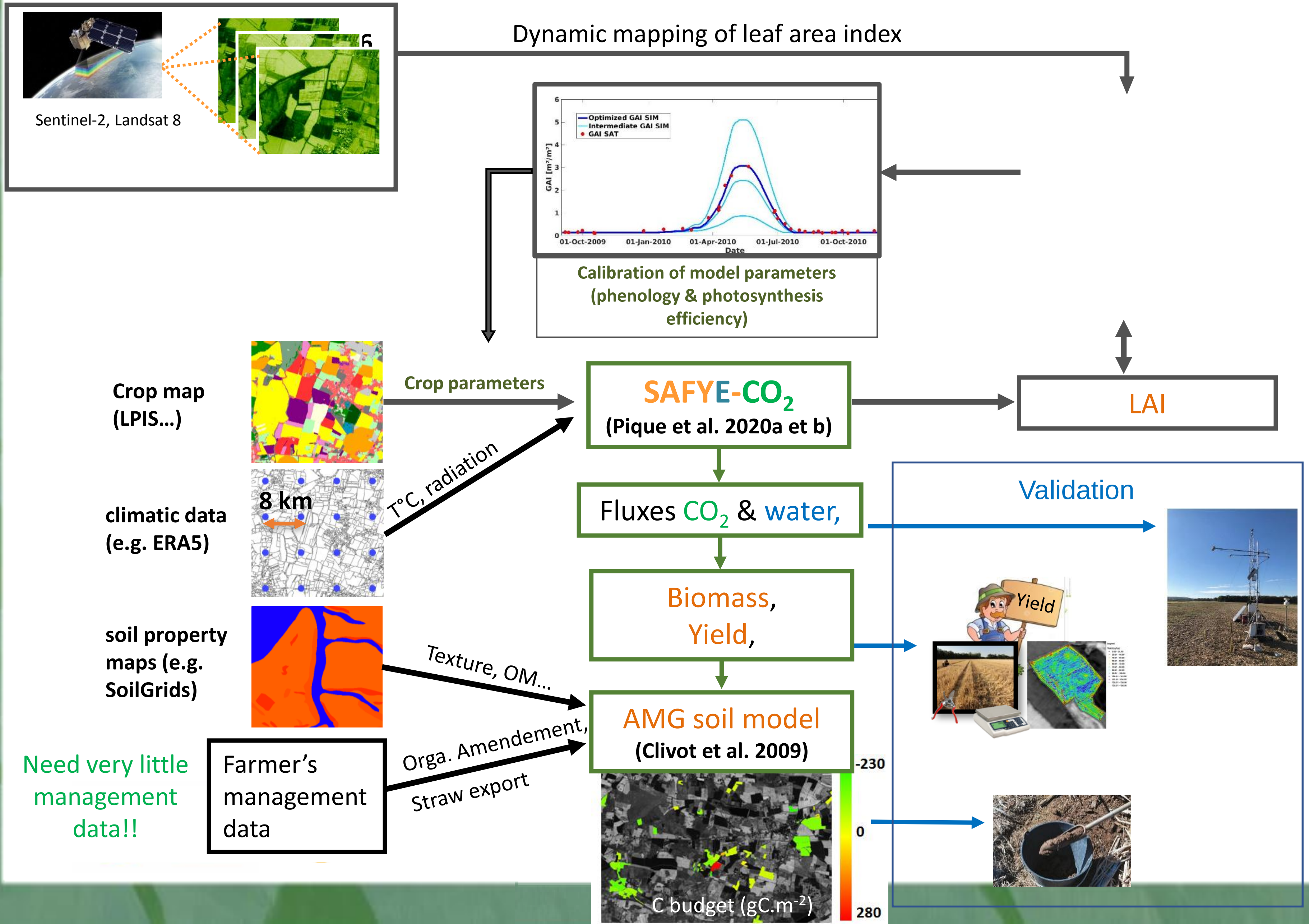
- Heterogeneous cover crop dynamic of development



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

SAFYE-CO2 model

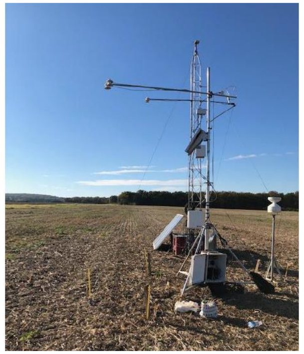


Started 10 years ago

Objective : To force the crop model (SAFYE-CO2) to reproduce at plot level the dynamics and development intensity of the crop/cover crops as seen by satellite ➔ more precise and objective biomass estimates, implicit consideration of stress (N, water, etc.) and of some practices,

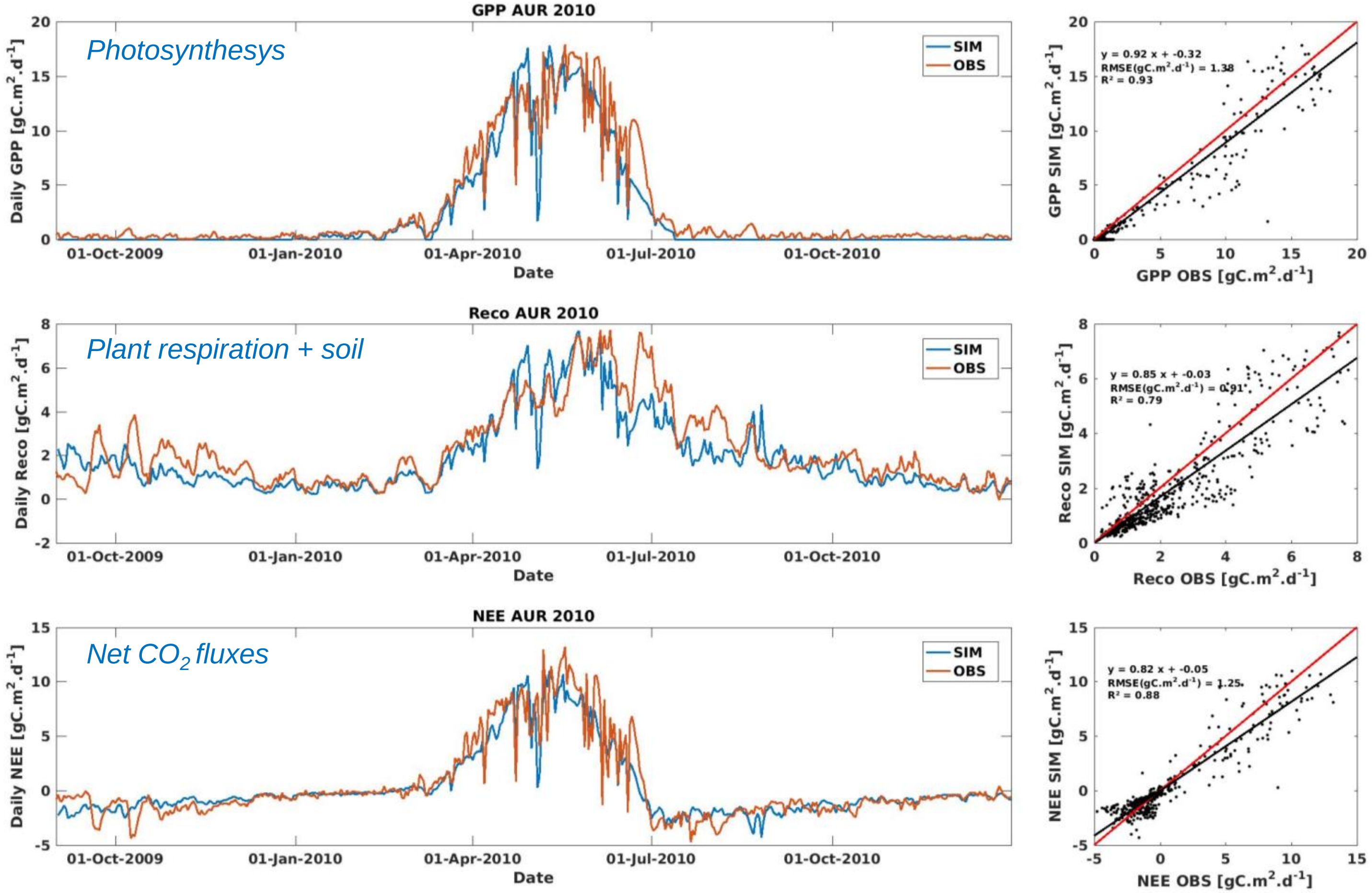
Accounting for soil processes: At first, a very simple modelling approach for simulating soil respiration was chosen (empirical function of T°C and SWC) because high uncertainty in soil properties of soil products (GSM, SoilGrids) for upscalling ➔ more recently coupling with the soil C models (e.g. AMG) activated when accurate soil data availlable

Example of results and precision of the approach



Comparison with flux tower measurements

CO_2 fluxes dynamics for wheat (Auradé site in 2010)



- Very good agreement in-situ data/model
- For net CO_2 fluxes over 8 years of measurements : **R^2 = 0,86** ; **RMSE = 1,29gC.m^{-2}.d^{-1}**

Pique et al. (2020a) in GEODERMA

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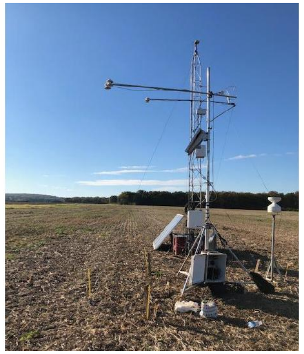

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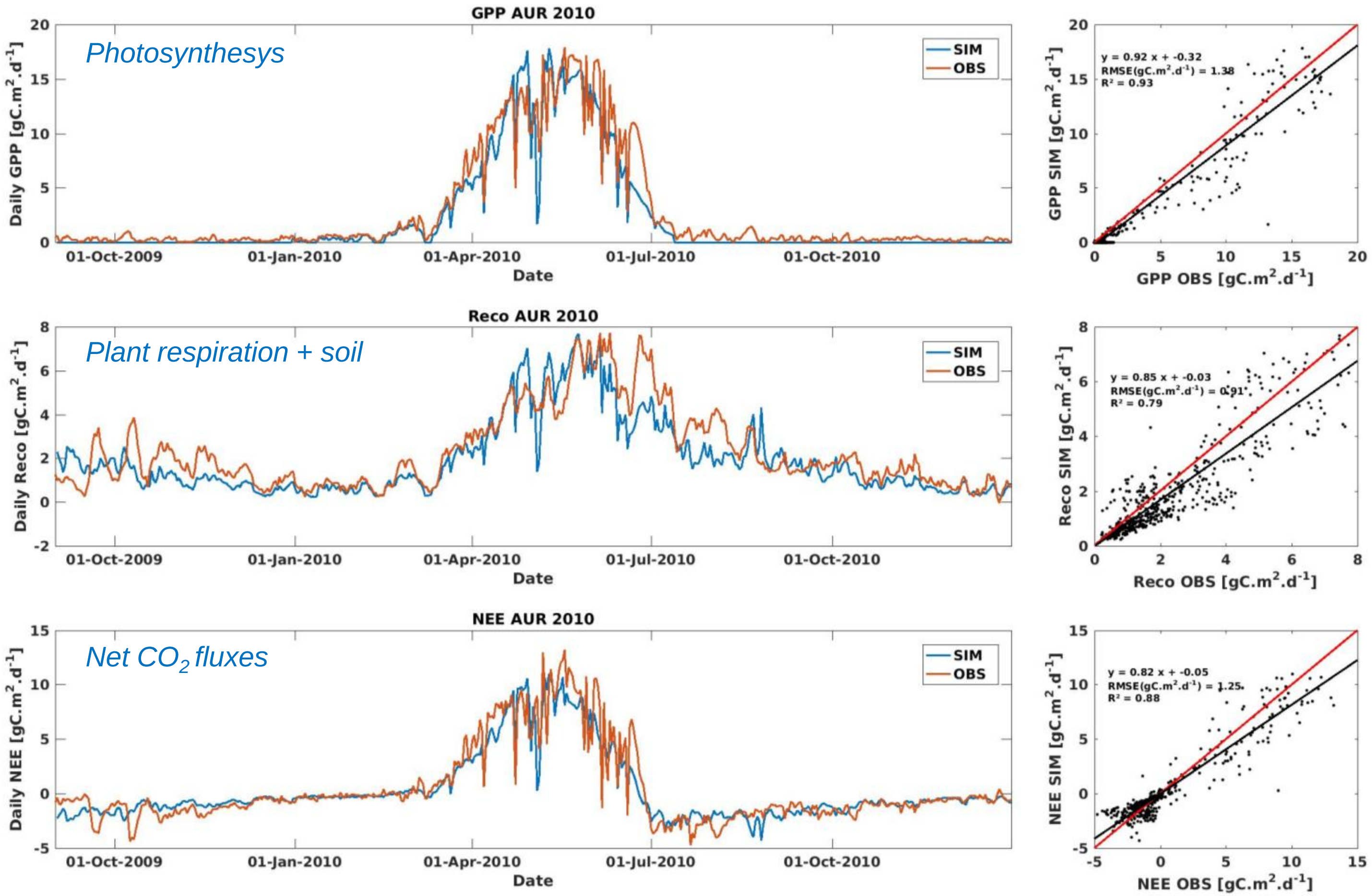
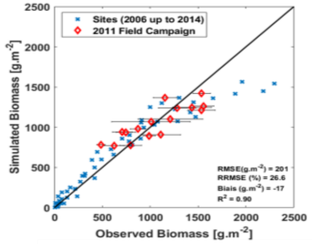
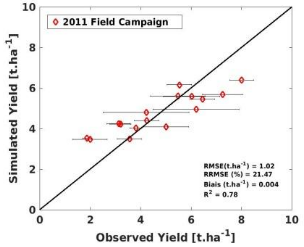


- Very good agreement in-situ data/model
- For net CO_2 fluxes over 8 years of measurements : **R^2 = 0,86 ; RMSE = 1,29gC.m^{-2}.d^{-1}**
- And for biomass & yield…



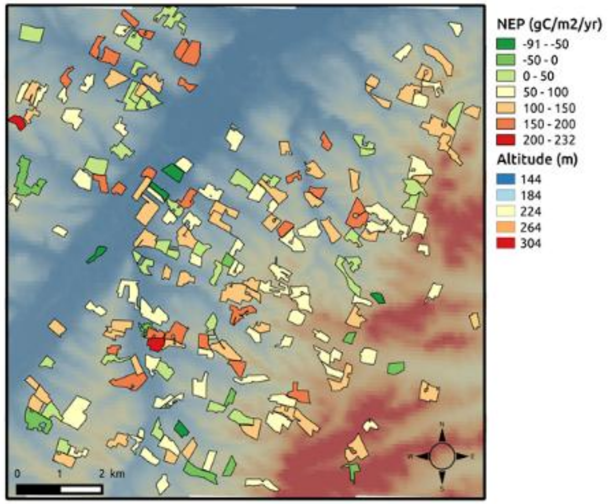


➔ Possibility to calculate carbon budgets over one or several cropping years

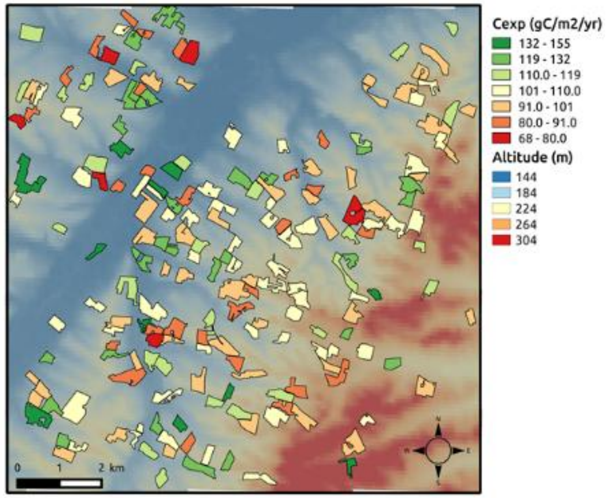
Pique et al. (2020a) in GEODERMA

Spatial variability of C budget components for sunflowers

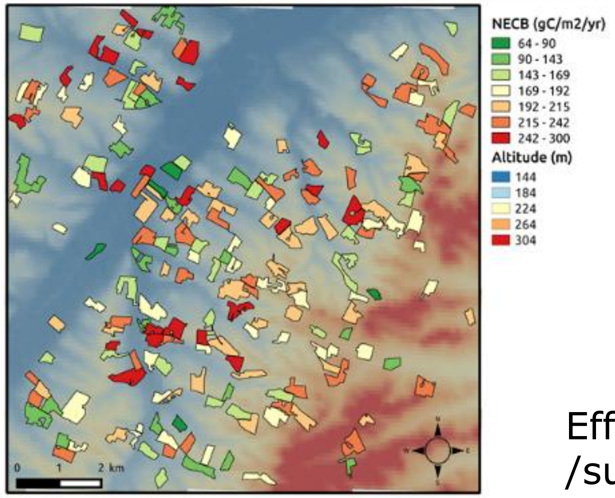
Pique et al (2020b) in Remote Sensing



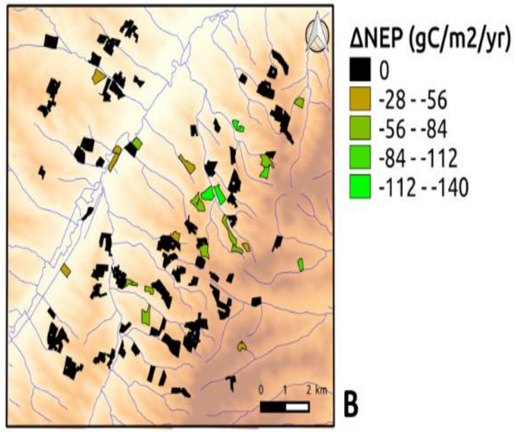
Net annual CO_2 flux



Harvested C



C budget



Effect of regrowth/weeds /summer cover crops on net annual CO_2 fluxes ➔ only a combined satellite/modelling based approach such as SAFYE-CO2 allows to quantify this

But strong limits to this approach:

- No simulation of the evolution of SOC pools, no accounting for priming effect… ➔ not eligible for most certifications systems (VERRA, Goldstandard, etc.)

- No uncertainty estimates & very slow calibration process ➔ analyses limited to a few thousand objects and plot average estimates: **not satisfactory given the fine spatial variability of vegetation developments.**

The AgriCarbon-EO processing chain

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

ACEO

BASALT

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

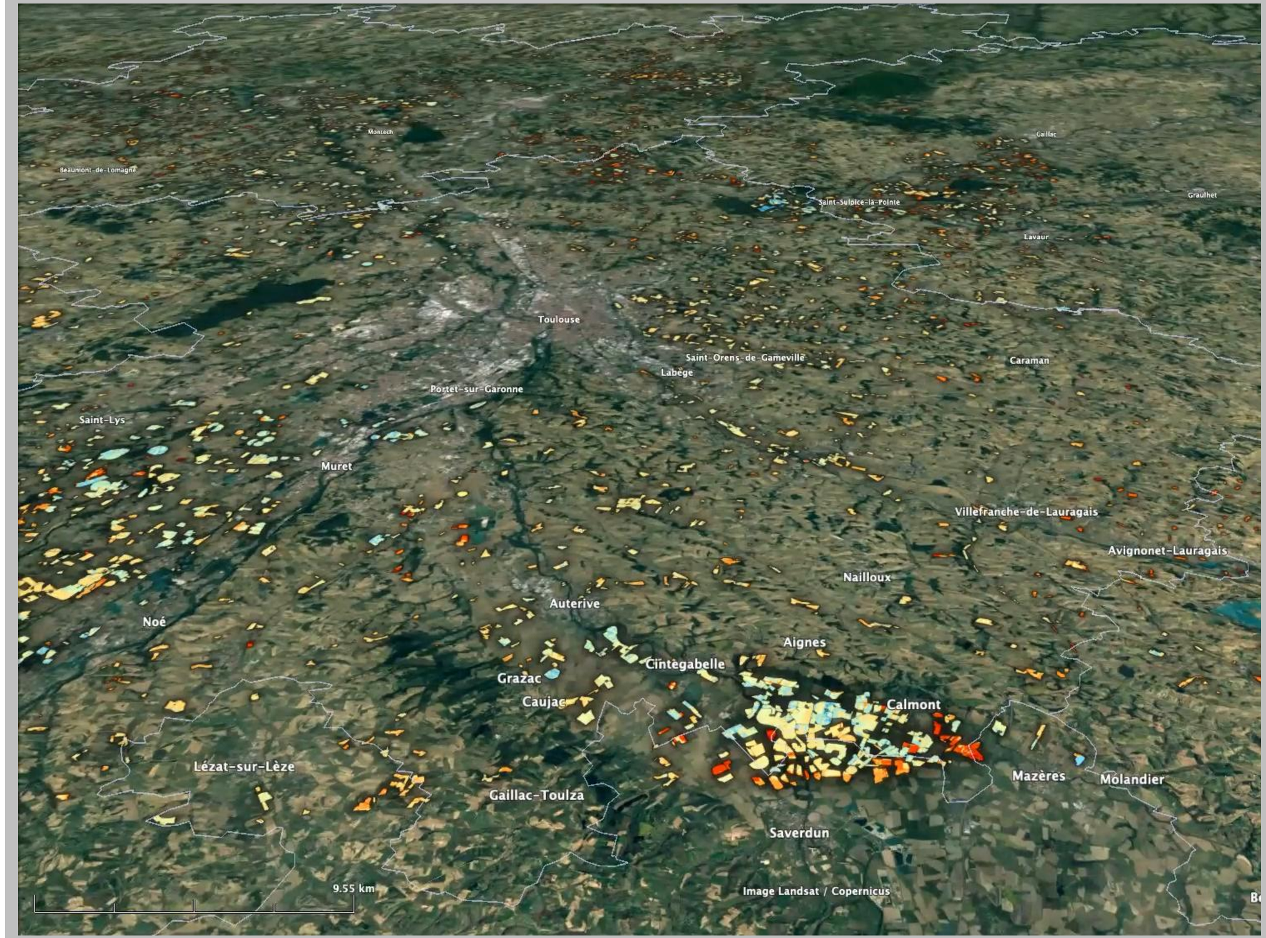
SAFYE-CO2

Parsimonious Agronomic model

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

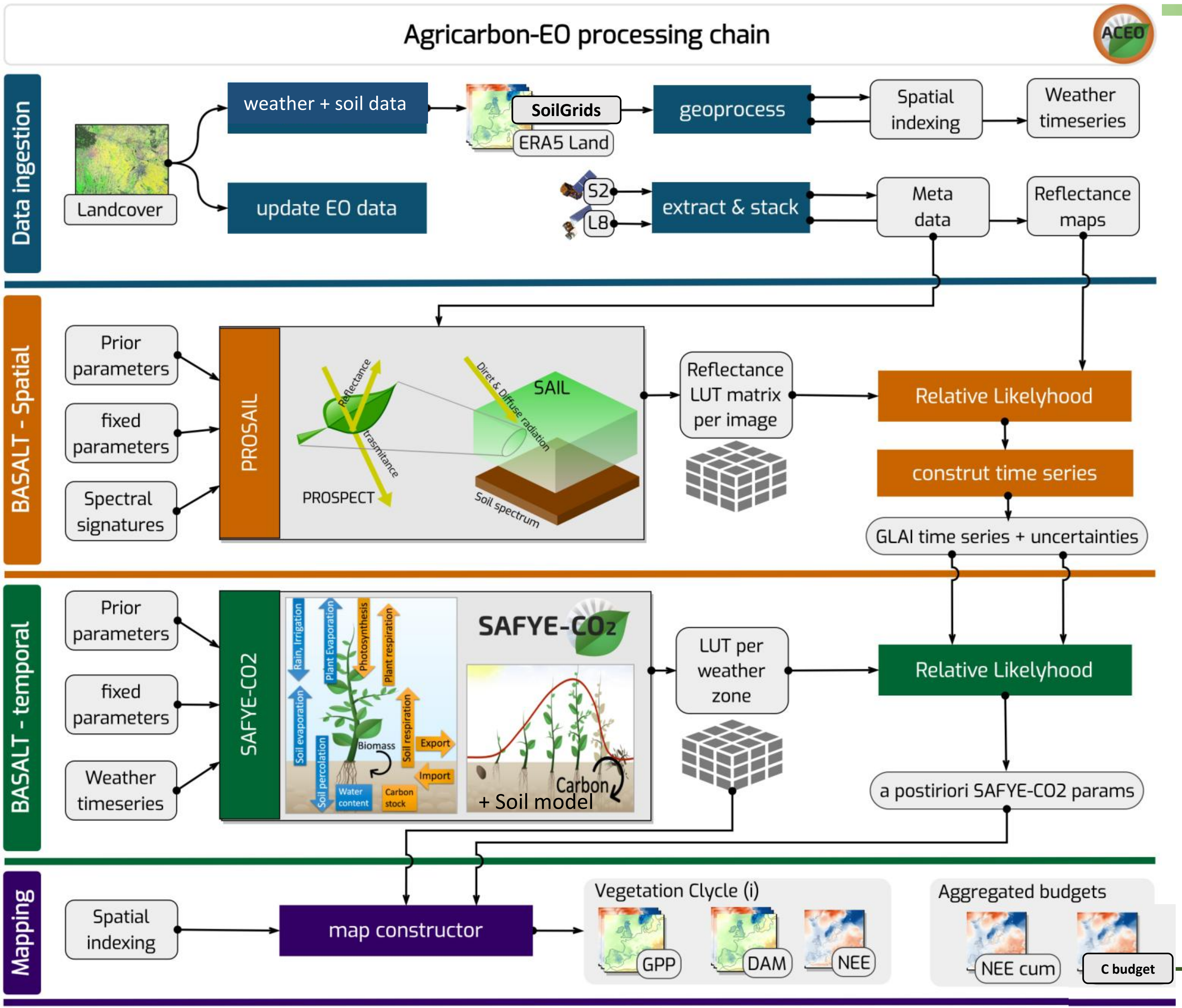
Taeken Wijmer[1,2,*], Ahmad Al Bitar[1,*], Ludovic Arnaud[1], Remy Fieuzal[1], and Eric Ceschia[1]
[1]CESBIO, Université de Toulouse, CNES/CNRS/INRAE/IRD/UPS, 18 Avenue Edouard Belin, bpi 2801, CEDEX 09, 31401 Toulouse, France

Net annual CO_2 fluxes for Wheat over 110x110 km at 10m resolution (in France)



https://egusphere.copernicus.org/preprints/2023/egusphere-2023-48/

AgriCarbon-EO – overview



- Generation of the simulation spatio-temporal grid
- Download (API) and formatting of input data:
  - Satellite images
  - Weather and soil properties data
  - And soon management data

- Calculation of green leaf area index (GLAI) with Prosail + uncertainties
  - Generation of look up prosail tables per image
  - Calculation of the relative likelihood of LUT inputs knowing satellite observations
  - Gaussian approximation of the posteriori distribution

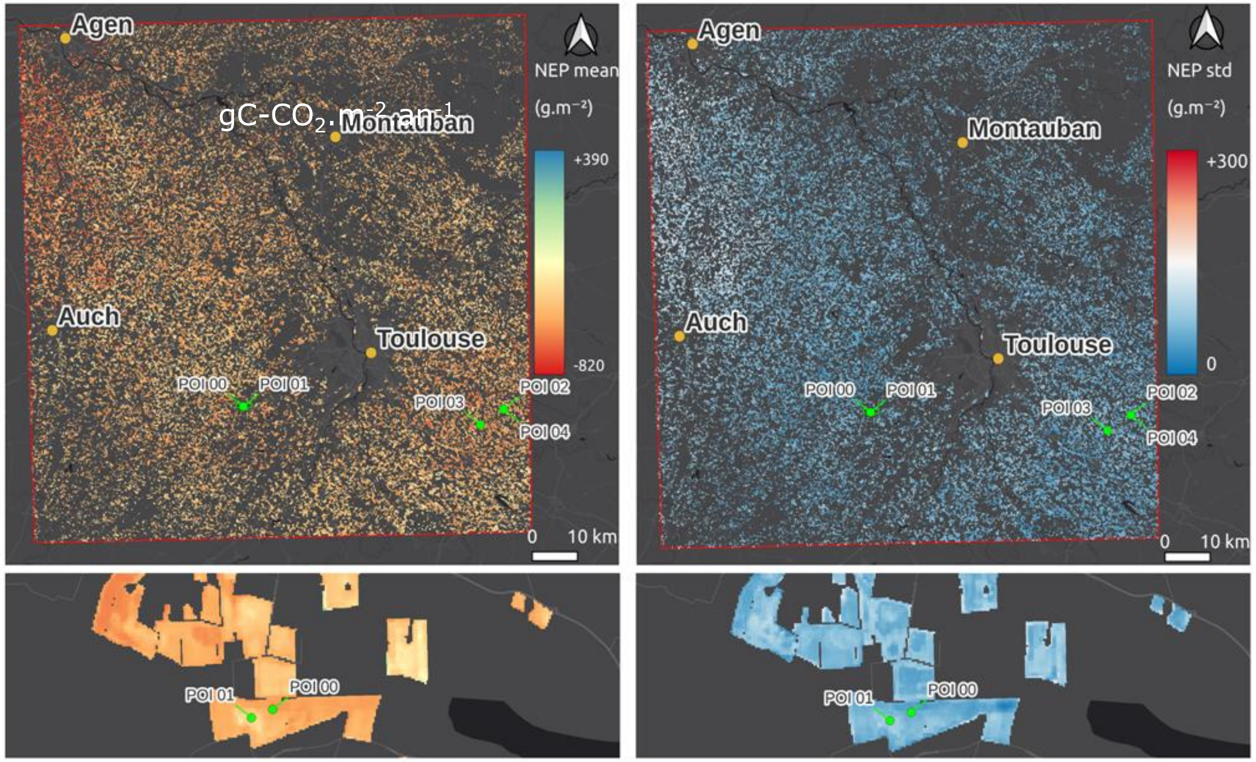
- Inversion of the SAFYE-CO2 model + uncertainties
  - Generation of SAFYE-CO2 tables by weather zone
  - Calculation of the relative likelihood of LUT inputs knowing the inverted GLAI
  - Estimates of biomass, yield, CO2 fluxes
  - Use of biomass outputs from SAFYE-CO2 as inputs in the soil models (AMG, COP…soon RothC) for the calculation of C budgets

- Postprocessing :
  - Construction of parameter or variable maps at time t or integrated variables
  - Calculation of precision statistics

High resolution net annual CO_2 fluxes and biomass

Taeken Wijmer's PhD co-funded by NIVA and Naturellement Popcorn projects

Annual net CO_2 fluxes at 10m resolution for straw cereals in 2017 (left average and right uncertainty)



Downloading remote sensing data takes close to 1 day but the run itself takes about 4h

(Al Bitar & Wijmer et al. Submitted to GMD)

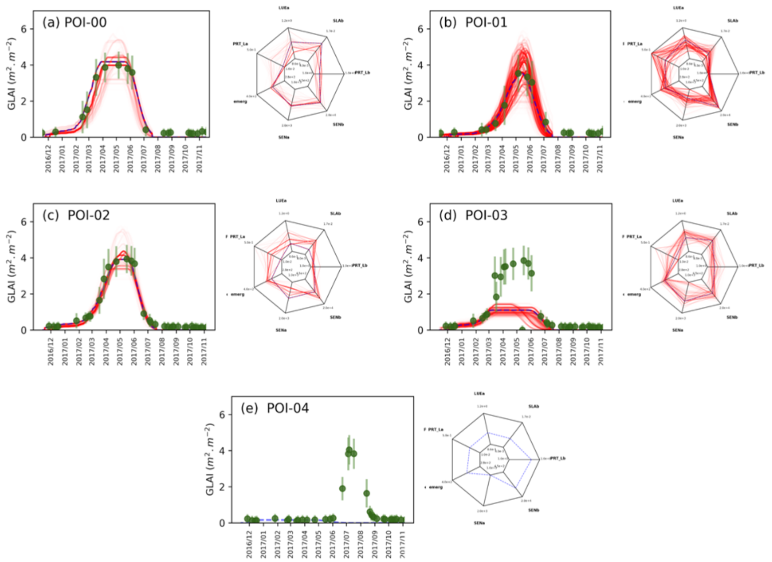
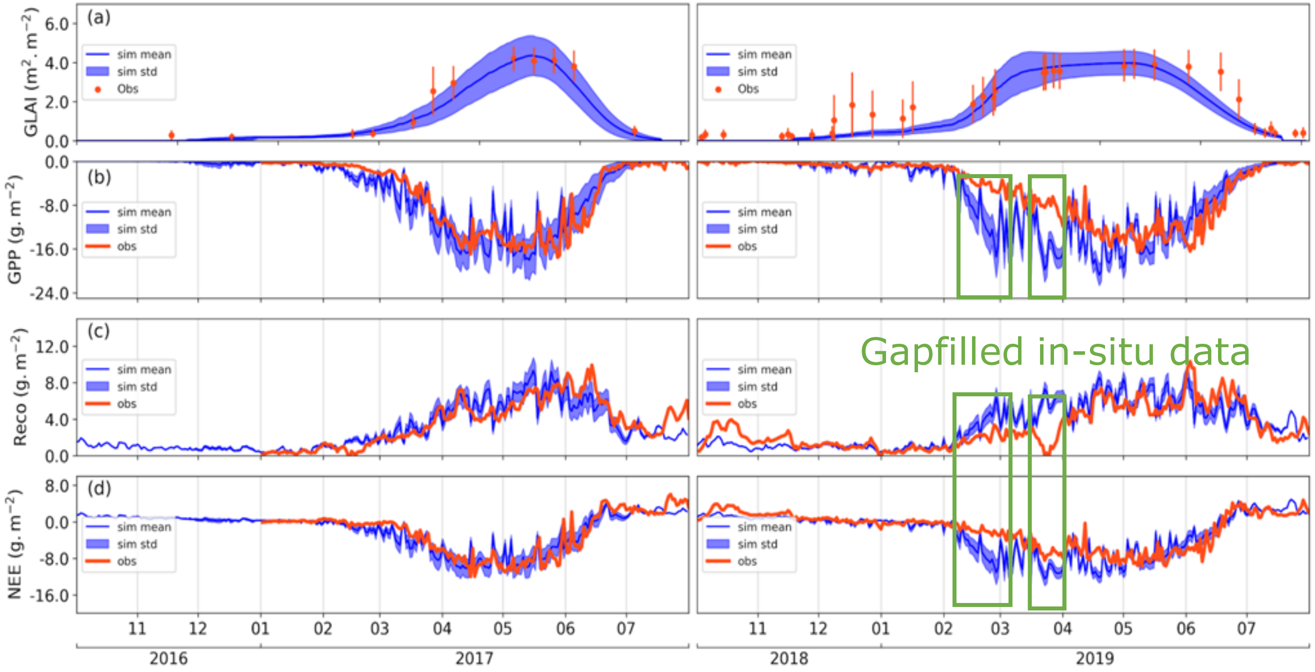


Illustration of simulations for 5 pixels of interest:

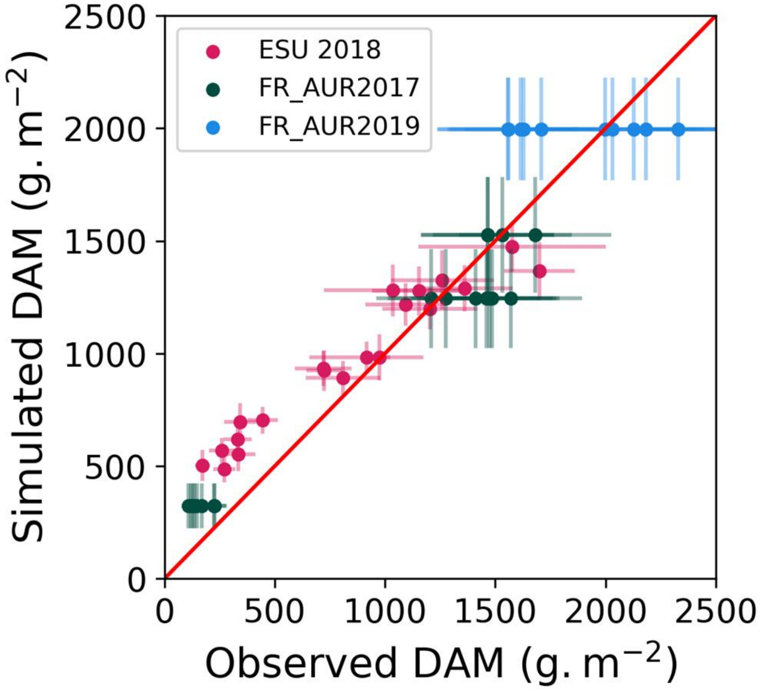
- **a and b - pixels in the same plot**
- **c and d - effect of an unfiltered cloud**
- **e - RPG error (incorrect declaration or crop accident)**

VALIDATION of the biomass & CO2 fluxes estimates

Simulation of GLAI & CO_2 fluxes at Auradé (FR_Aur) site in 2017 & 2019



Year:	stats	2017	2019
GLAI	Bias (m2.m-2)	0.26	0.35
	R2	0.93	0.88
	RMSE (g.m-2)	0.48	0.64
GPP	Bias (g.m-2)	0.36	1.23
	R2	0.91	0.76
	RMSE (g.m-2)	1.91	3.43
Reco	Bias (g.m-2)	0.03	-0.33
	R2	0.62	0.60
	RMSE (g.m-2)	1.91	1.59
NEE	Bias (g.m-2)	0.38	0.89
	R2	0.88	0.88
	RMSE (g.m-2)	1.69	2.40



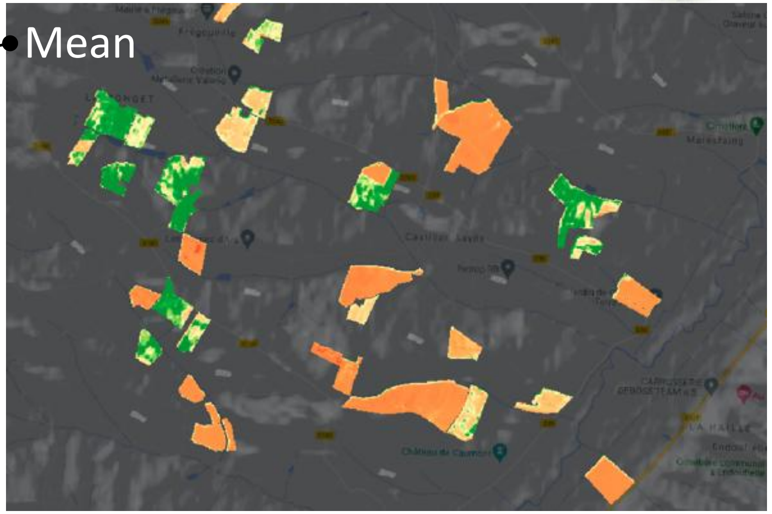
Validation against ESU measurements at regional scale

Realisation T. Wijmer

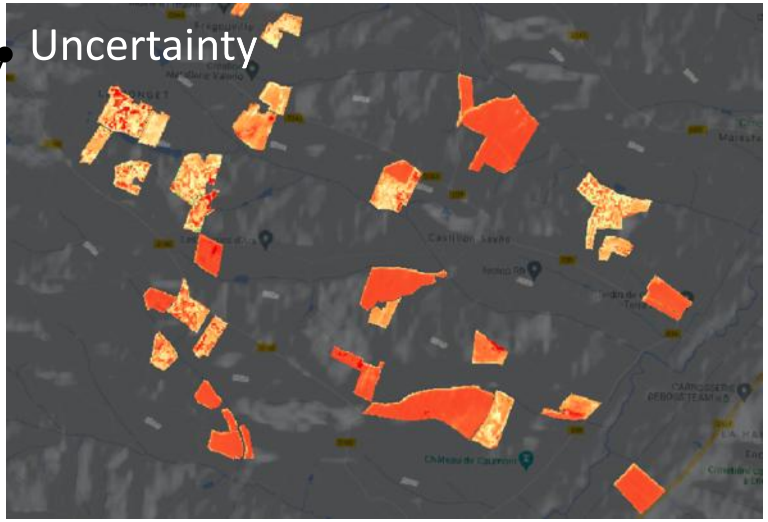
Dry Above Ground Biomass mapping

DAM - Crop cover

Not a negligeable biomass production, but very heterogeneous



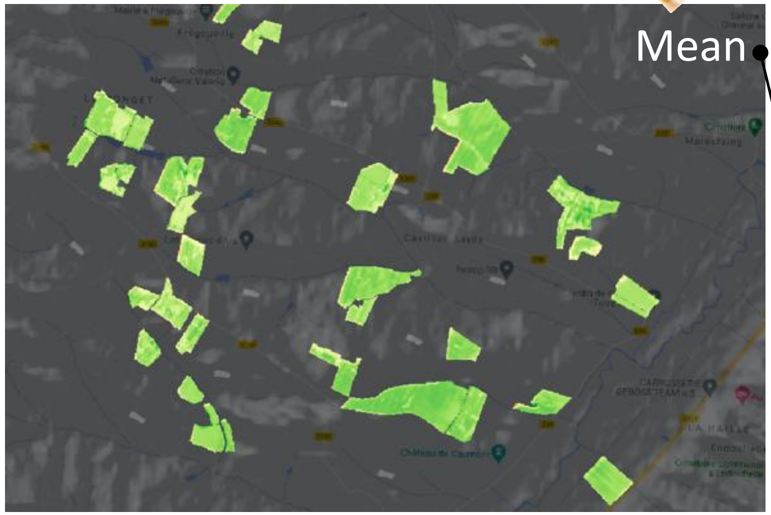
0
150
300
450
600



Higher relative uncertainty compared to maize (30-50 %): cloud cover…

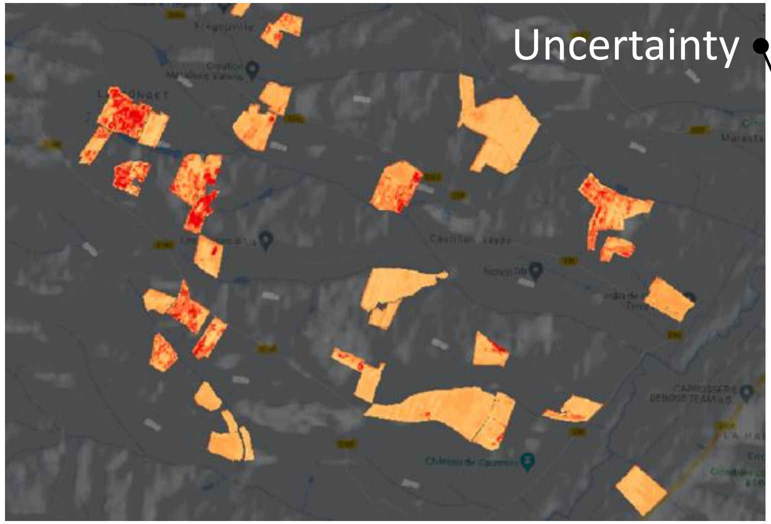
0
75
150
225

DAM - Maize



Standard values, and much more homogeneous. (irrigation, fertilisation).

0
625
1250
1875
2500



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

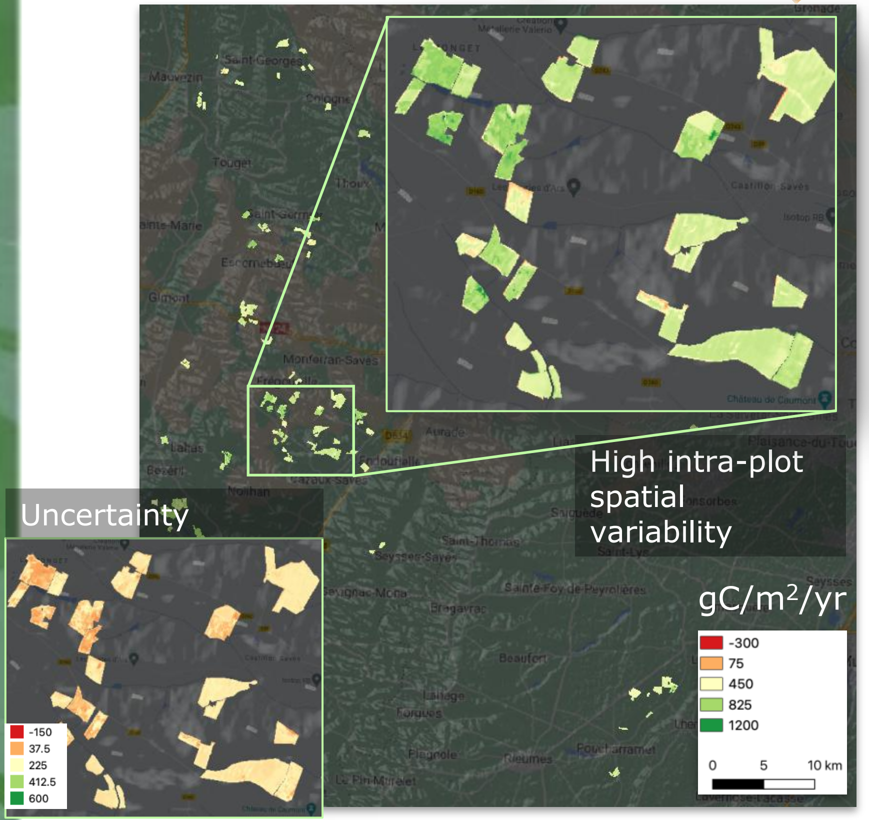
0
250
500
750
1000

Realisation A. Al Bitar

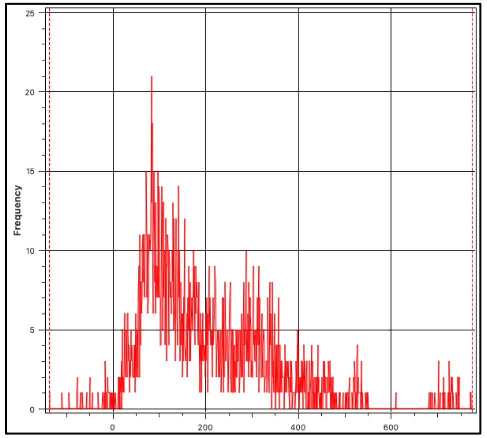
Effect of cover crops on the net CO_2 fluxes (NEE)

over the double experiment

Cover crop + Maize

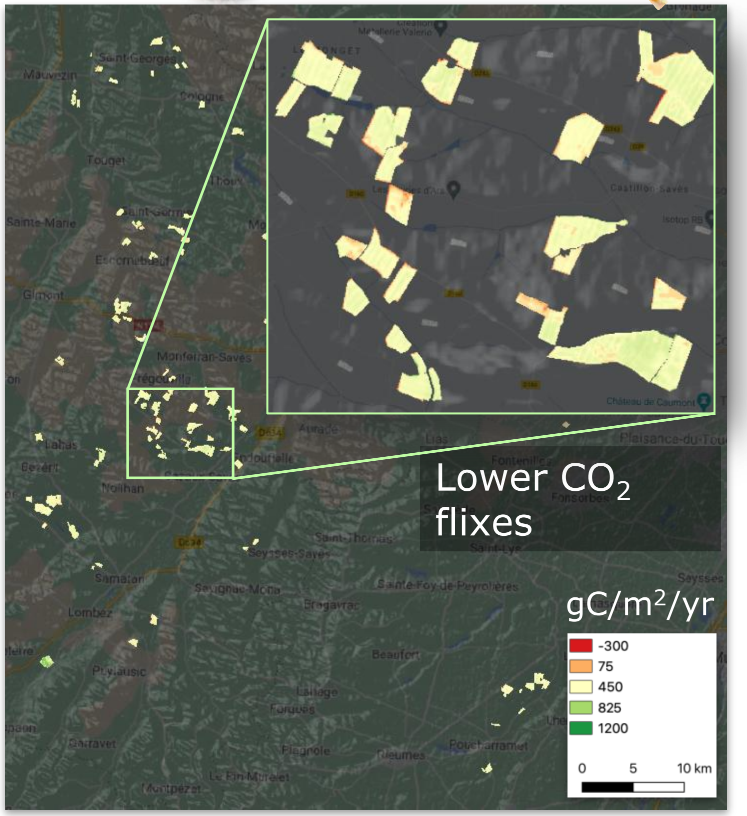


Distribution of the differences between the 2 simulations



On average 200gC of DM/ha/yr or approx 0,3 t C/ha stored/yr (or 1,1 t of CO_2-eq/ha/yr)

Bare soil + Maize

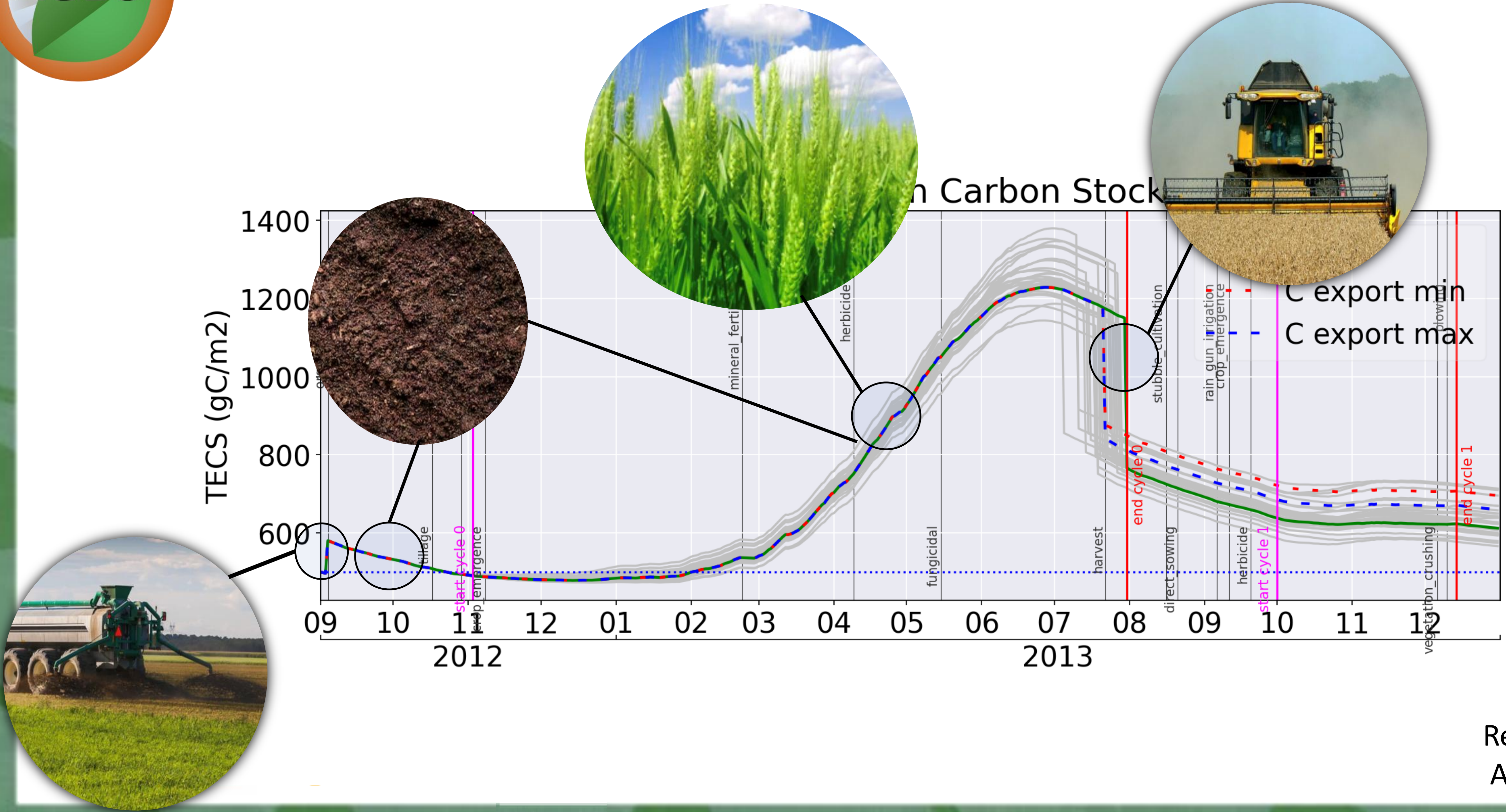


natais

CENTRE NATIONAL D'AGROÉCOLOGIE
Carbone Fertile

Realisation A. Al Bitar

Dynamics of the ecosystem's carbon stock at pixel/plot level

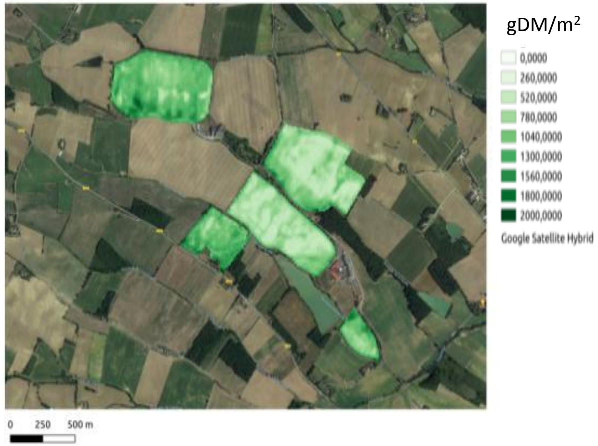


Realisation
A. Al Bitar

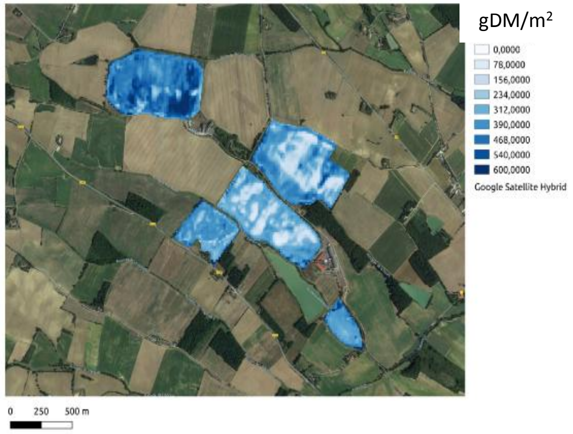
High resolution C budget estimates with ACEO

Project Naturellement popcorn ➔ farmers can receive a premium depending on the amount of C they store in the soil thanks to cover crops biomass inputs

Crop biomass + Uncertainties

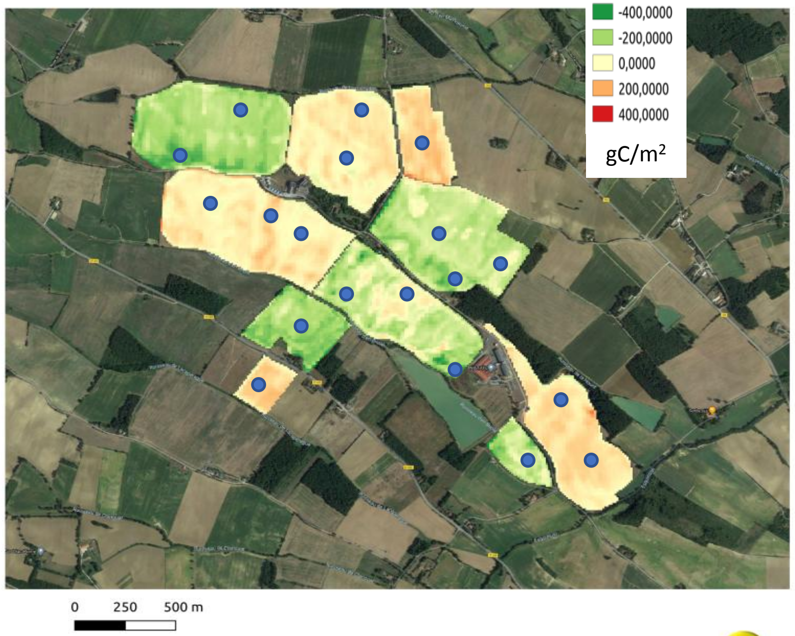


Cover crop biomass + Uncertainties



+ farmers data and the AMG soil model

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



10m resolution maps make it possible to define an optimal soil sampling plan (high precision/low cost) for validation/analysis of representative delta SOC stocks at plot/farm level

C storage by the soil

C losses by the soil

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, effect of cover crops)
- Limited to a few crops and cover crops ➔ progressive acquisition of new in-situ datasets for CAL/VAL & transposability analysis in Europe

European ICOS network flux stations

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

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

- Late coupling with soil models (to simulate 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 (e.g. Digital Soil Mapping based on Sentinel's data)

- Use of optical data alone may be limiting (long cloud periods) for operational applications ➔ radar satellite data (e.g. Sentinel 1) to lift this constraint (PhD A. Geraud in collaboration with NetCarbon)

- Need to collect management data on C inputs (e.g. manure) and straw management (C exported) for calculation of C budget ➔ connection with current farm management information systems (ex. MesP@arcelles, SCO Quantica project)

Conclusions

- As pointed out by Smith et al. 2020 and CIRCASA ➔ need to implement a consistent approach for simulation/validation of C budget and its components (+ uncertainties) taking into account the spatial variability of biomass production/restitution and of soil properties.

  Based on this observation:

  Development of an innovative MRV approach enabling dynamic (annual) and more objective monitoring of the impact of the practices on the C budgets ➔ better accounting of the effect of biomass restitution to the soil on the C budget,

- Automated, large scale, high resolution, uncertainty analysis and low cost,
- Adapted to different contexts of application: agri-food sectors (insetting), voluntary C market (offsetting), CAP, National Inventories ➔ development and test in the framework of several projects/initiatives in France (Naturellement popcorn, Solnovo, Quantica) and in Europe (e.g. ORCASA, MARVIC projects) with the ambition of defining an international methodological framework for SOC monitoring (e.g. for the future IRC on soil C)
- Partnerships with companies (Nataïs, MyEasyFarm, Airbus, Kermap, Netcarbon, Terranis, EarthDailyAgro) and cooperatives (Euralis, Agrod'Oc) that could operate a MRV service

Thanks for your attention!!

Naturellement popcorn

ORCaSa

More about our work: https://www.cesbio.cnrs.fr/agricarboneo/

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