Proposition for a methodological Monitoring Reporting & Verification framework and prototype of operational processing chain for monitoring cropland C stock change at high resolution over large regions

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Contributions:
CESBIO: Ahmad Al Bitar, Veronica Antonenko, Andrea Geraud, Rémy Fieuzal,
INRAE: Taeken Wijmer, Ludovic Arnaud, Ainhoa Ihasusta, Suzanne Reynders
ISRIC: Gerard B.M. Heuvelink, Niels H. Batjes, Fenny van Egmond

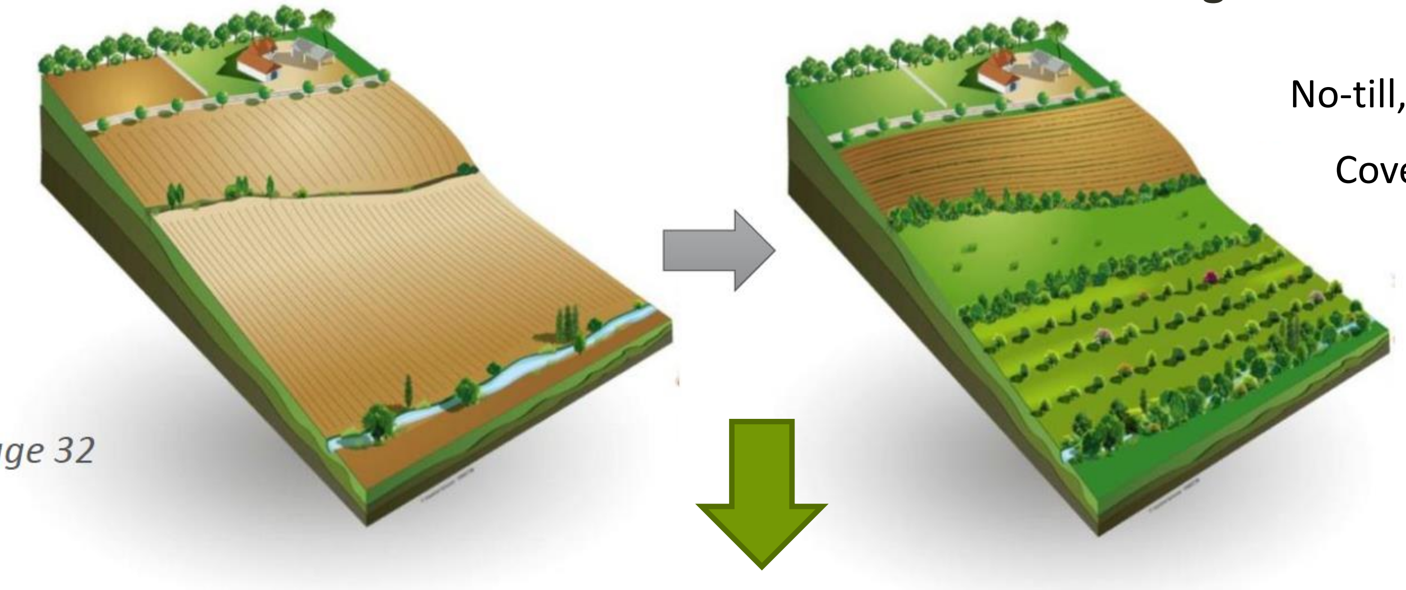
SoilCET International Symposium, 24-26 January 2024, Rueil-Malmaison, France

Context/societal challenges

- Climate mitigation ➔ remain below 1.5°C of temperature increase by 2100 (COP21, initiative 4 per 1000),
- Soil quality ➔ more resilience to extreme climatic events, improved soil fertility…

Conventional agriculture

Agro-ecological practices



Illustrations:
Arbre et Paysage 32

No-till, crop diversification

Cover crops

Agroforestry

C storage ?

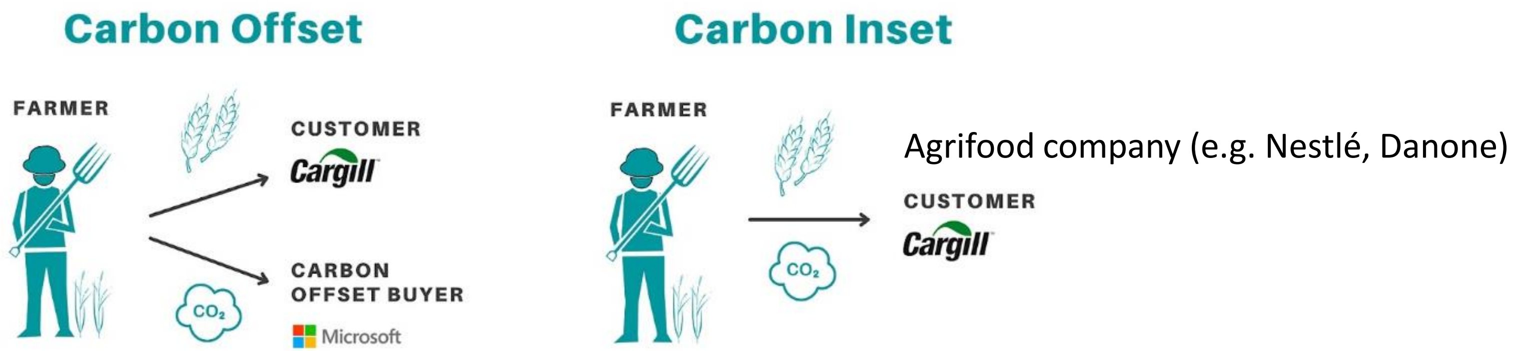
How to assess the impacts of those practices in terms of CO_2 emissions/soil organic carbon storage at the plot scale but over large areas?

➔ **Need for a new generation of tools providing an exhaustive/objective vision of the effect of management on SOC stock changes adapted to different contexts of application**

Different context of MRV the SOC stock changes

MRV = Monitoring, Reporting and Verification

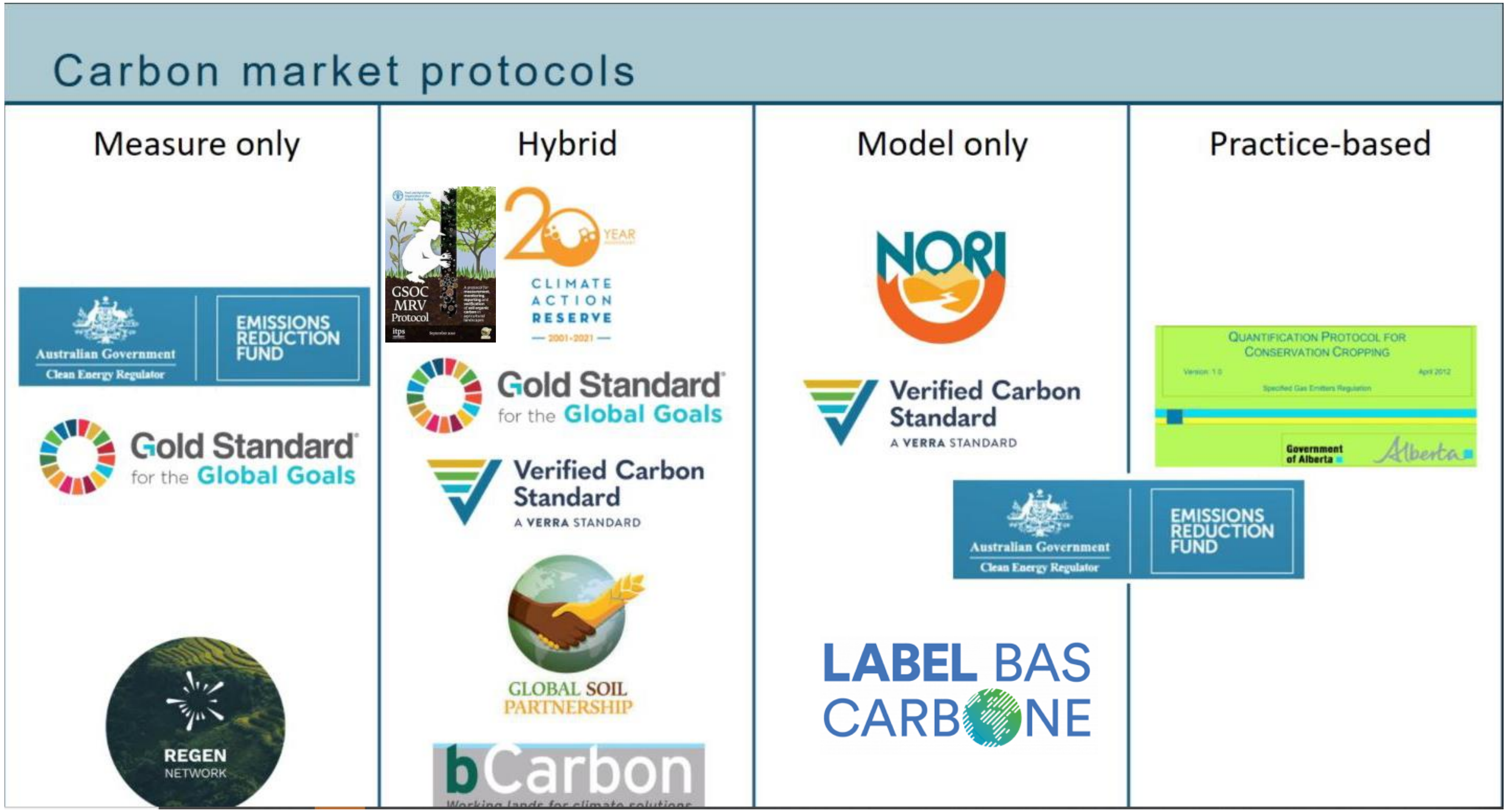
- National inventories; Nationally Determined Contributions (NDCs) under the Paris agreement,
- Common Agricultural Policy? but operational methods are still missing for the current one
- Carbon offset programs (voluntary Carbon market) mainly on forest up to now but emerging for cropland (e.g. LABEL BAS CARBONE), and recently insetting programs are developing also,



Each context of application has its specificities, requirements & rules

A « jungle » of methods, guidelines, frameworks, certification standards for MRV of SOC stock changes

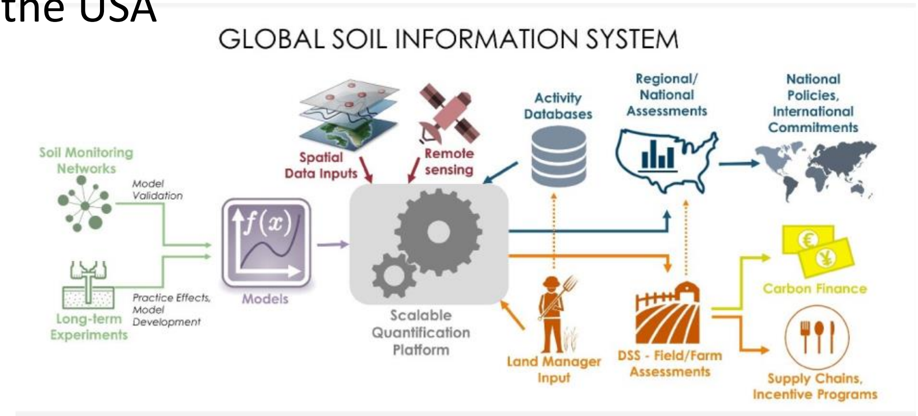
Demenois et al. (2021) Surviving the jungle of soil organic carbon certification standards: an analytic and critical review. Mitigation and Adaptation Strategies for Global Change 27, 1.



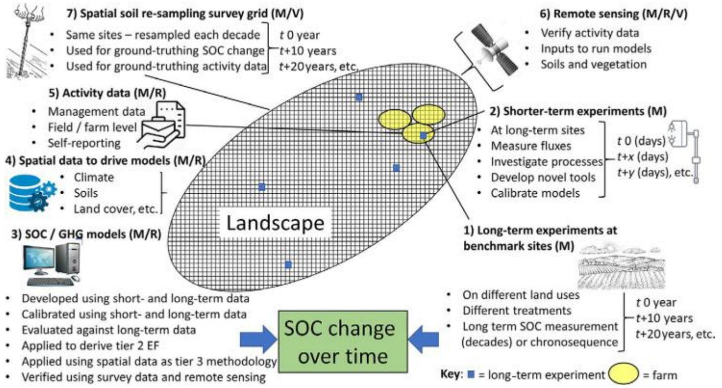
Propositions of MRV frameworks for cropland

Conceptual

Paustian et al. (2019): NDC, C market in the USA



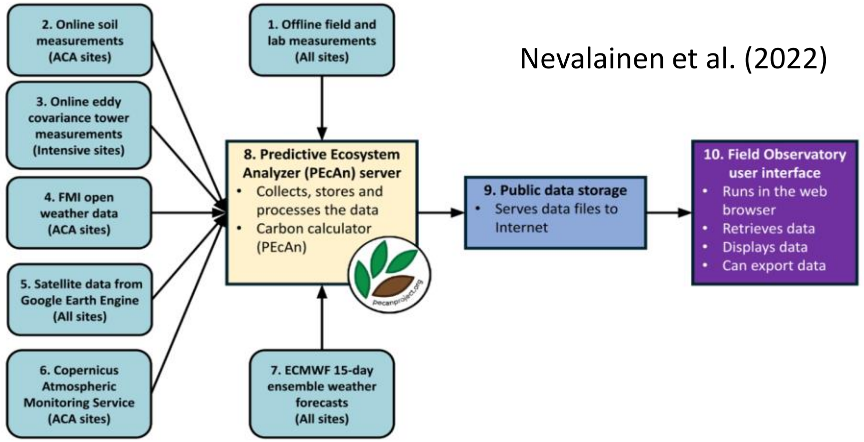
Smith et al. (2020) CIRCASA



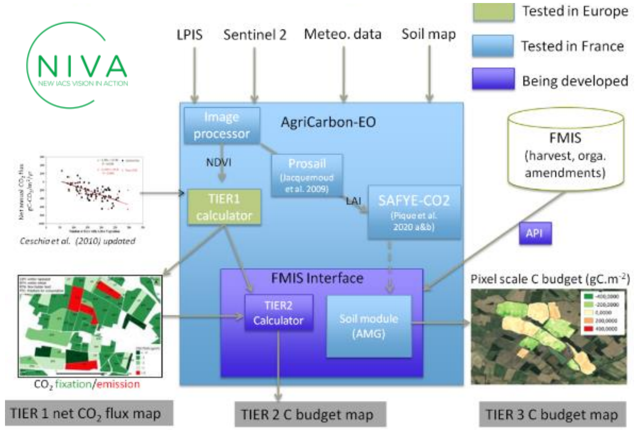
Operational

Field observatory network

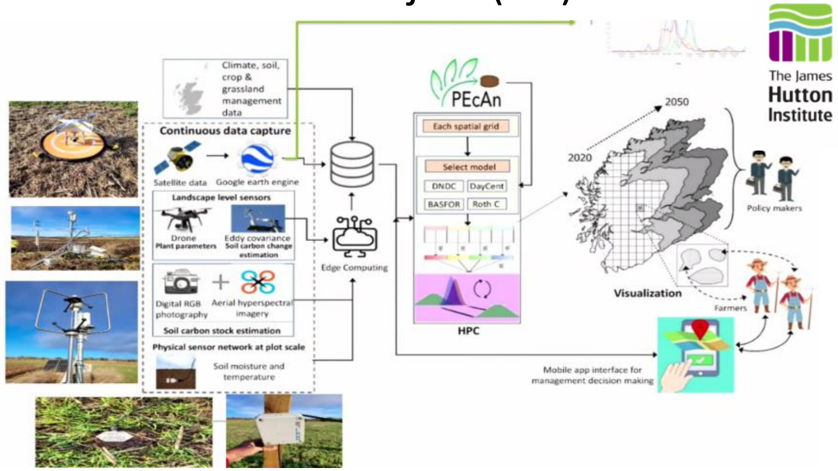
Nevalainen et al. (2022)



Bockstaller et al. (2020) for CAP

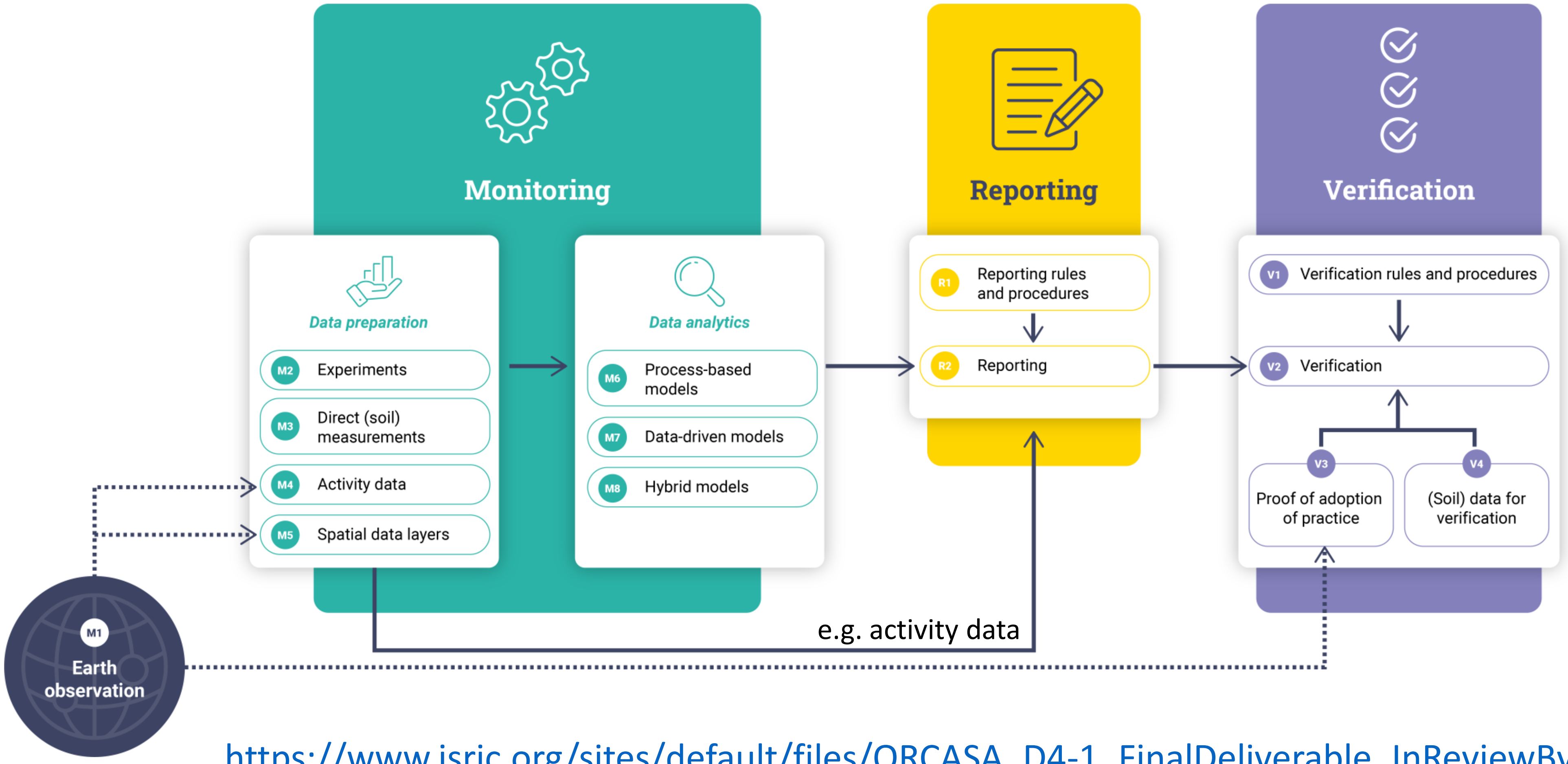


RETINA Project (UK): C market



ORCaSa's propositions for an harmonized MRV framework

Schematic representation of the components/building blocks and information flow for a generic MRV framework following several workshops with stakeholders and the analysis of existing MRV guidelines/methodologies



https://www.isric.org/sites/default/files/ORCASA_D4-1_FinalDeliverable_InReviewByEU_0.pdf

ORCaSa
Because soil carbon matters

Challenges of methods for CO_2 removal

Soil Carbon in the Ecological Transition 2024
INRAE

Technology	Afforestation and reforestation	Soil carbon sequestration	Biochar	Bioenergy with carbon capture & storage	Direct air carbon capture and storage	Enhanced weathering	Peatland and coastal wetland restoration	Blue carbon management	Ocean alkalinity enhancement	Ocean fertilization
Capture mechanism	Land-based biological	Land-based biological	Land-based biological	Land-based biological	Chemical	Geochemical	Land-based biological	Ocean-based biological	Geochemical	Ocean-based biological
Feasibility/ readiness	green	green	green	green	green	green	green	yellow	orange	orange
Scalability	yellow	yellow	yellow	orange	yellow	orange	green	green	orange	orange
Ease of MRV*	red	yellow	yellow	yellow	green	yellow	red	red	red	red
Potential consequences	orange	green	yellow	yellow	yellow	yellow	green	green	red	red
Public perception	green	yellow	yellow	orange	yellow	green	green	green	red	red
Cost (US$/$tCO_2$)	< 100	< 100	100–500	100–500	> 800	100–500	< 100	< 100	Too early to quantify	
Storage medium	Buildings, vegetation, soils and sediments			Geological reservoirs		Minerals	Vegetation, soils and sediments		Minerals	Marine sediments

Sources: UNEP - Emissions Gap Report (2023), Adapted from Geden et al. (2022) and Pisciotta, Davids and Wilcox (2022).

Key message

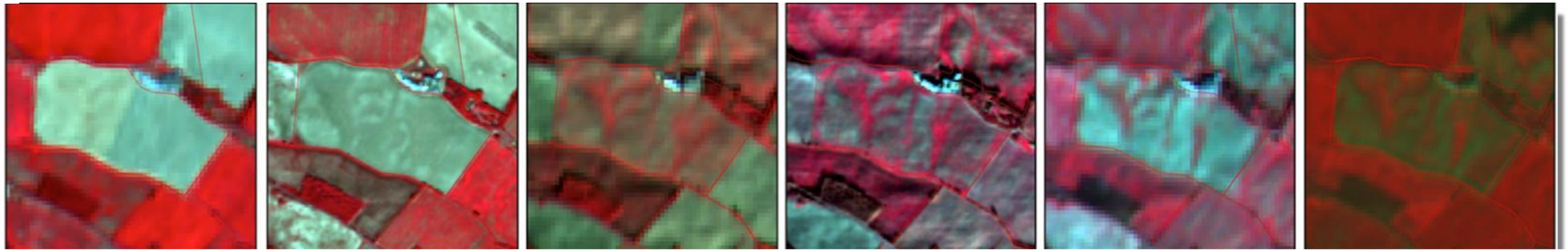
One of the main challenge for promoting C storage in the agricultural soils is about Monitoring ➔ need for scalable, multi-context, automatized, cheep, reliable, transparent methods for monitoring SOC stock changes in agricultural soils,

Following as much as possible CIRCASA's recommendations (see Deliverable 3.1):

- Modular & transparent approach with uncertainty assessment on SOC stocks,
- Several soil models instead of one ➔ allowing ensemble approach,
- Assessment of the different components of the C budget in the development/verification process,
- Relying on strong data infrastructures following the FAIR principles: e.g. Copernicus, ICOS…
- High resolution, relying on remote sensing (e.g. Sentinel 2) to quantify biomass production & restitution to the soil,
- …

18/07/2012 06/09/2012 15/11/2012 29/12/2012 03/03/2013 12/04/2013

Data SPOT4/5



Cover crop in red/pink, bare soil in blue/gree

Key message

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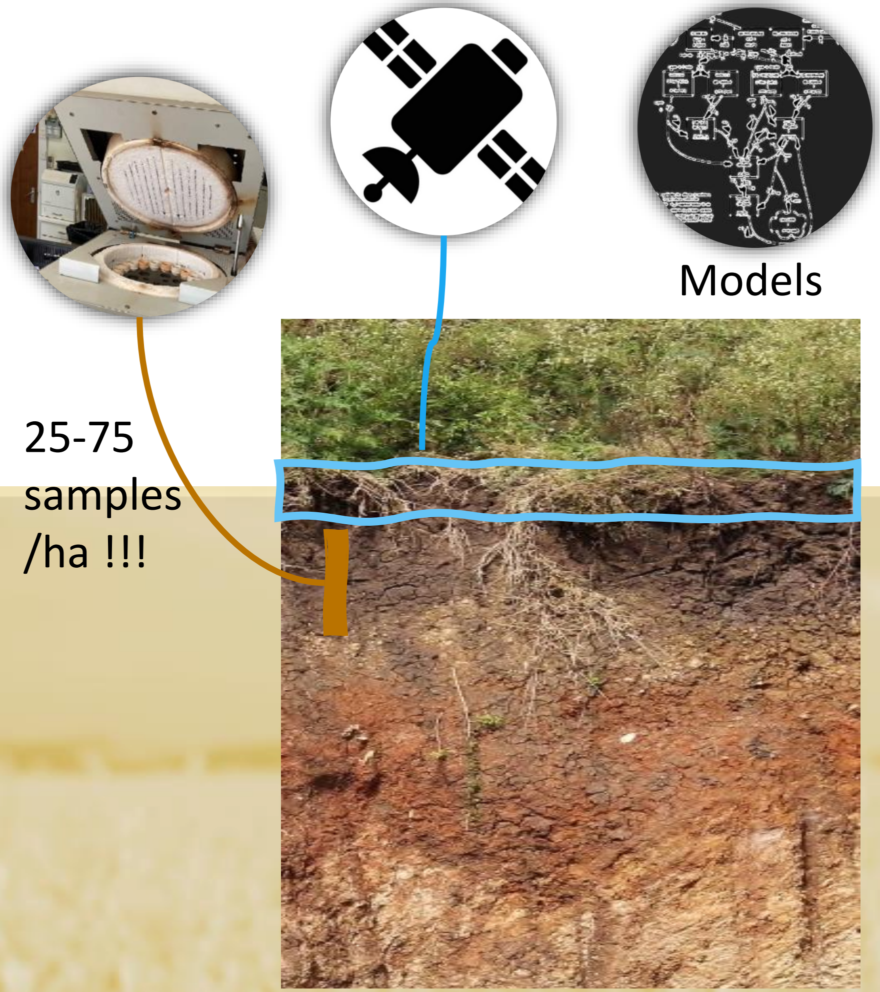
- …

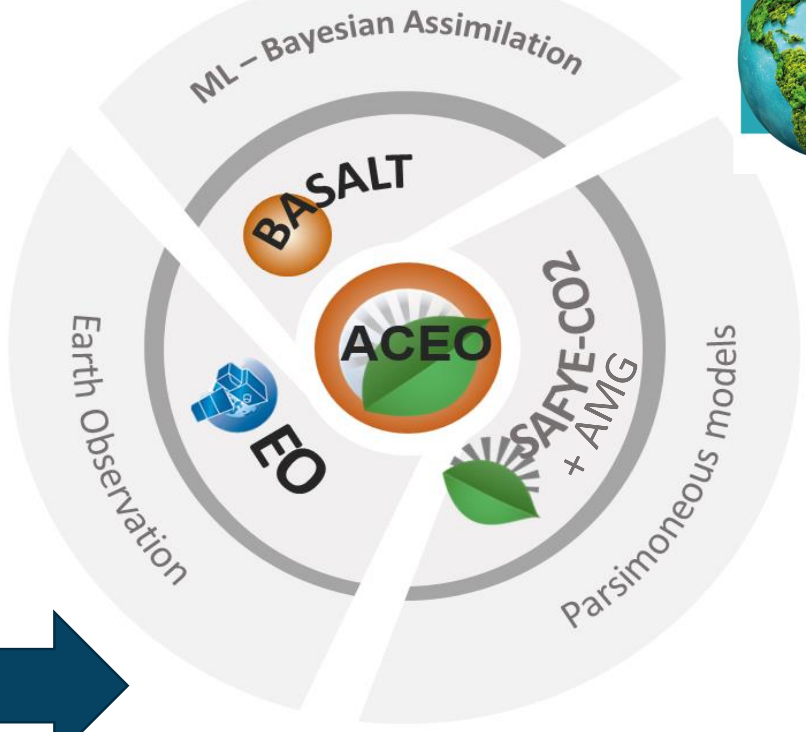
An compliant with the Carbon sequestration certification framework under development in Europe

ORCaSa
Because soil carbon matters

Limits of current methods for monitoring soil carbon



4 PER 1000
CIRCASA
NIVA
ClieNFarms
Climate Neutral Farms
ORCaSa
MARVIC
MRV for carbon farming
MyEasy Biomass
esa



Soil Carbon in the Ecological Transition 2024
INRAE

AgriCarbon-EO

A hybrid method combining parcimonious process based modelling, remote sensing data assimilation and Machin Learning + In-situ data for cal/val

➔ Strong focus on assessing the effect of biomass input to the soil on SOC stock changes

https://www.cesbio.cnrs.fr/agricarboneo/agricarbon-eo/

The AgriCarbon-EO processing chain

A pre-operational multi-context end-to-end processing chain.

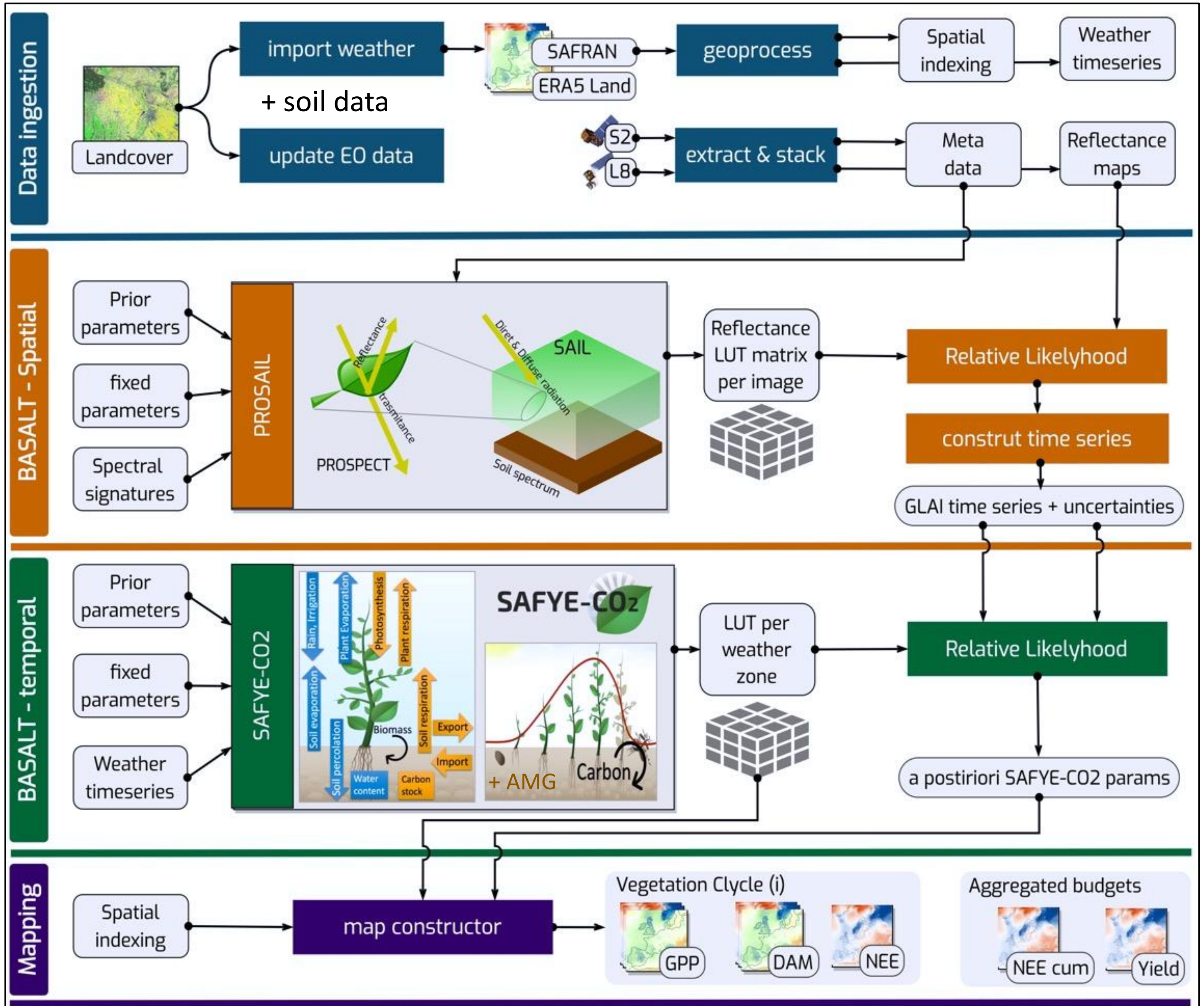
Wijmer et al. (2024)

Geoscientific Model Development

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, Ahmad Al Bitar, Ludovic Arnaud, Rémy Fieuzal, and Eric Ceschia

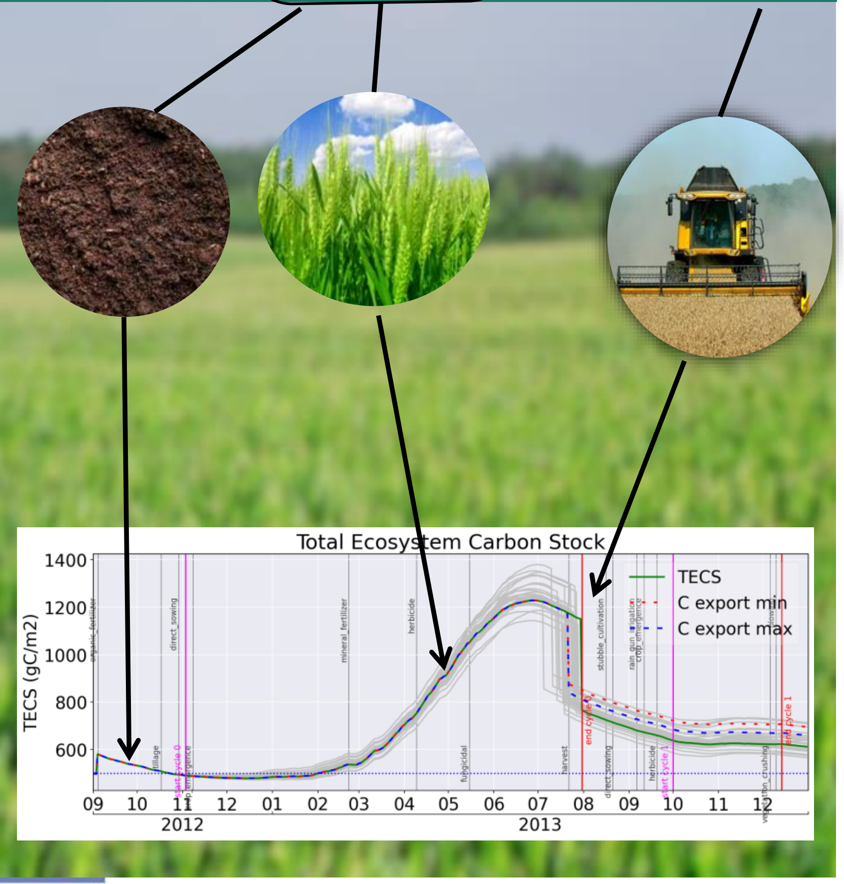
Agri sector:



Straw cereals near Toulouse in 2019:
scenario with straw restitution and no organic amendment

Annual carbon budget components

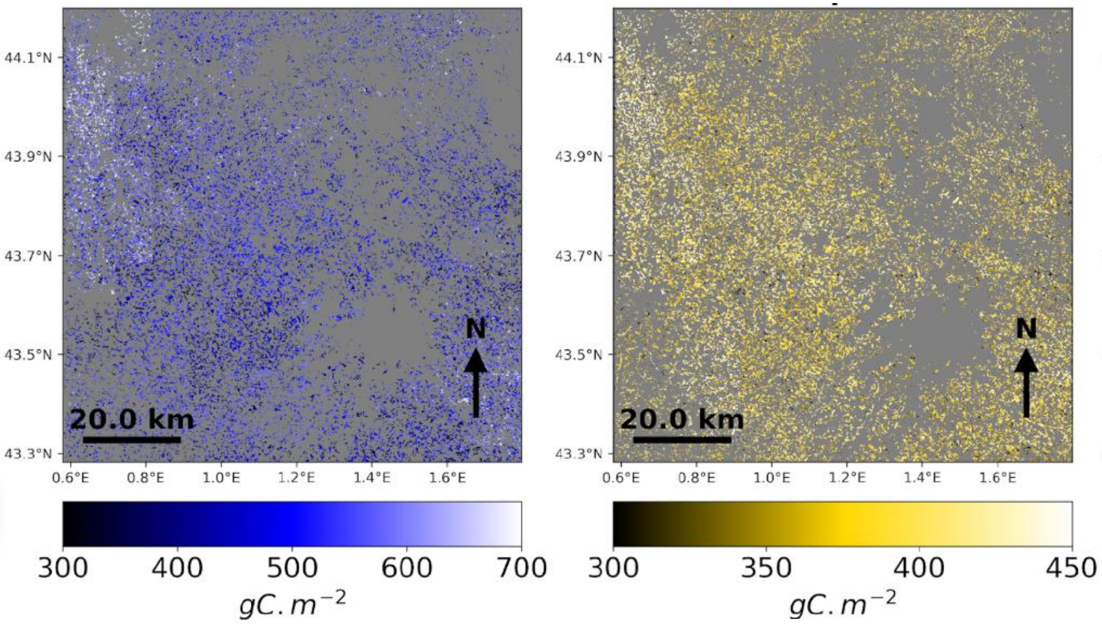
ΔSOCstock = Net CO_2 flux + C_{import} - C_{export}



Net annual CO_2 flux (NEP)

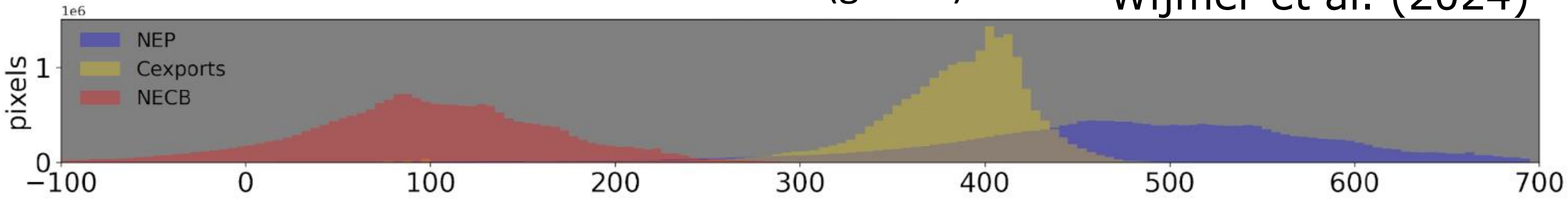
C exported at harvest

Annual C budget (NECB)

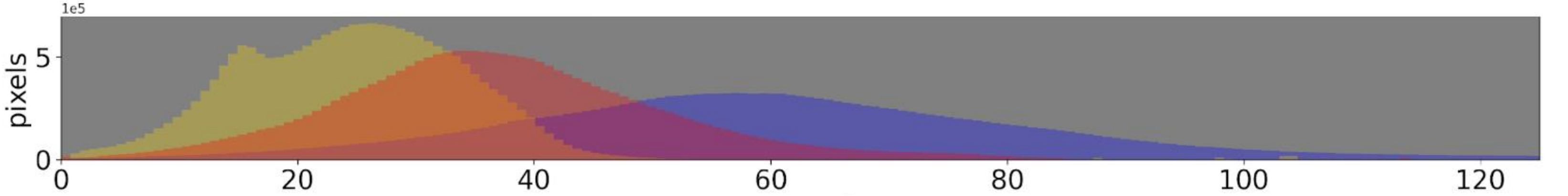


Mean value (gC.m[-2])

Wijmer et al. (2024)

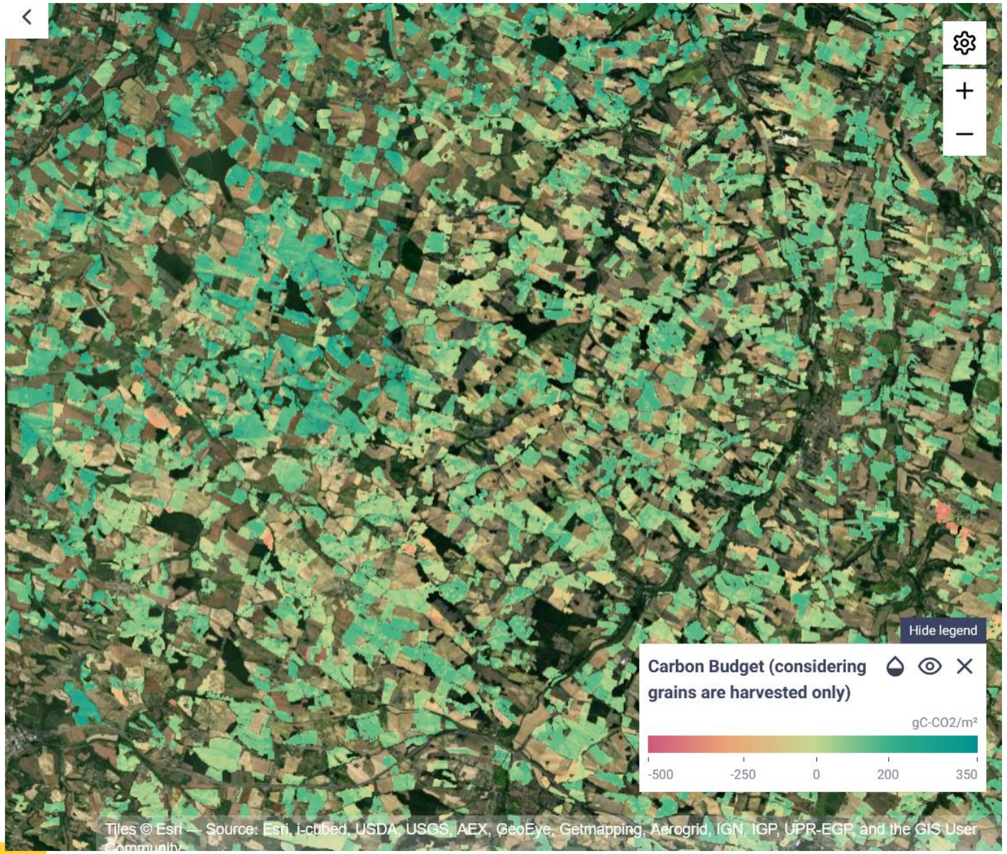


Uncertainty estimates

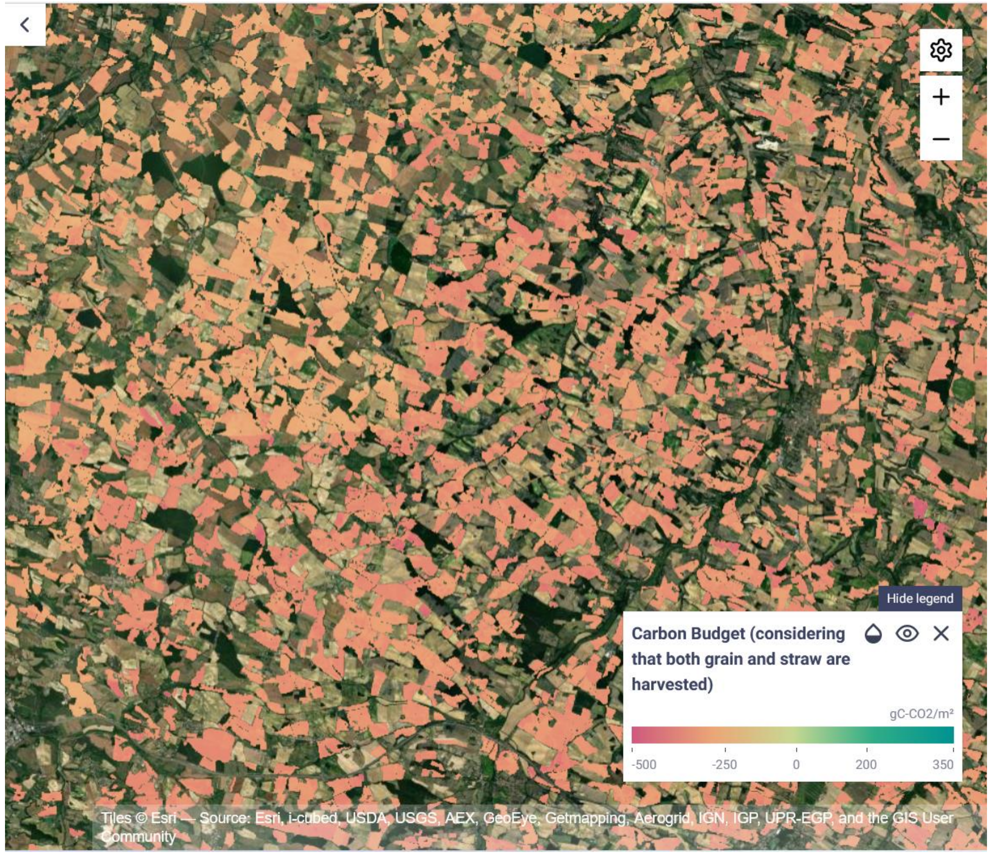


Effect of straw management on the annual SOC stock changes for straw cereals

Scenario 1: only grains are harvested and no organic amendment applied



Scenario 2: grains + straw are harvested and no organic amendment applied



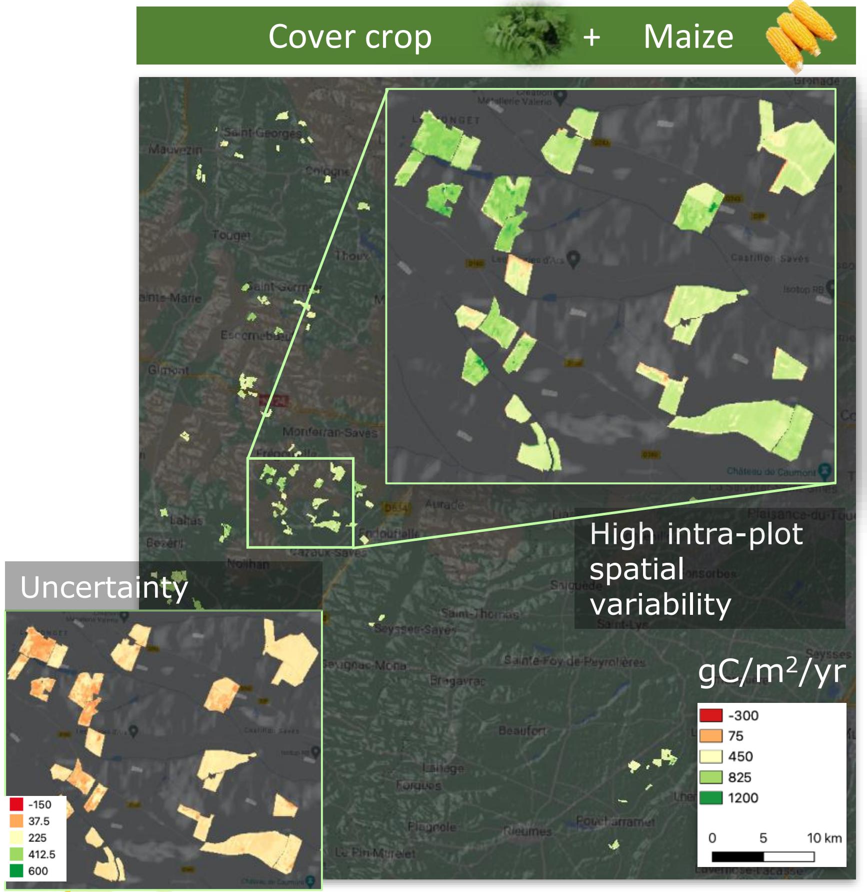
Realisation A. Al Bitar

More results at https://www.impact4soil.com/

Effect of cover crops on the net annual CO_2 fluxes

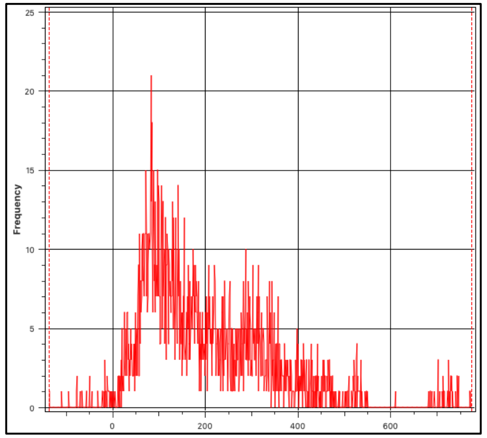
Over the double simulation exercice

Reality



Distribution of the differences between the 2 simulations

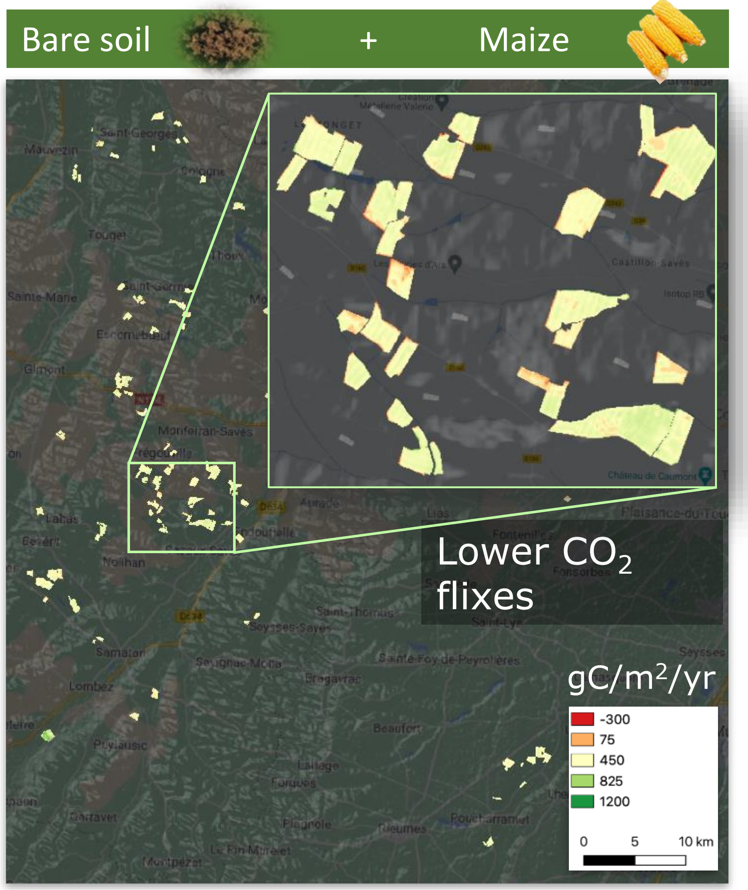
Number of pixels



Difference between simulations

On average 200gC of Dry Mass/ha/yr or approx 0,3 t C/ha stored/yr thanks to the cover crops

Neglecting the cover crop



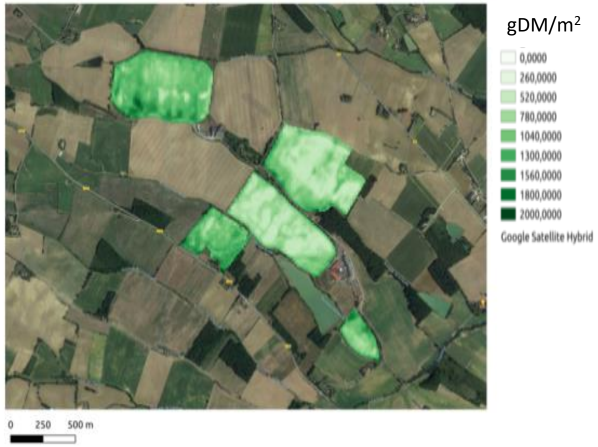
Realisation A. Al Bitar

High resolution C budget maps with ACEO

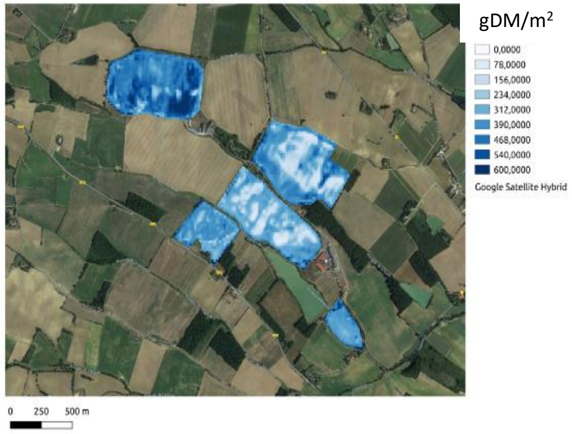
Naturellement popcorn project (insetting) ➔ farmers can receive a premium from the natais company depending on the amount of C they store in the soil thanks to cover crops biomass inputs

Realisation
T. Wijmer

Crop biomass + Uncertainties



Cover crop biomass + Uncertainties

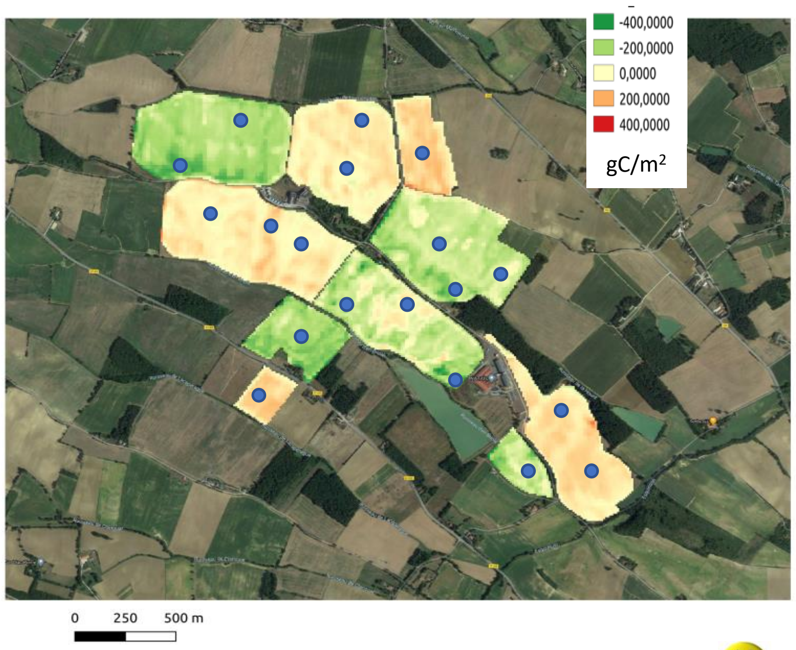


+ farmers data and the AMG soil model

10m resolution maps make it possible:

- to define an optimal soil sampling plan (high precision/low cost) for validation of delta SOC stocks at plot/farm level
- to detect faster SOC stock changes by sampling areas with contrasted dynamics

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

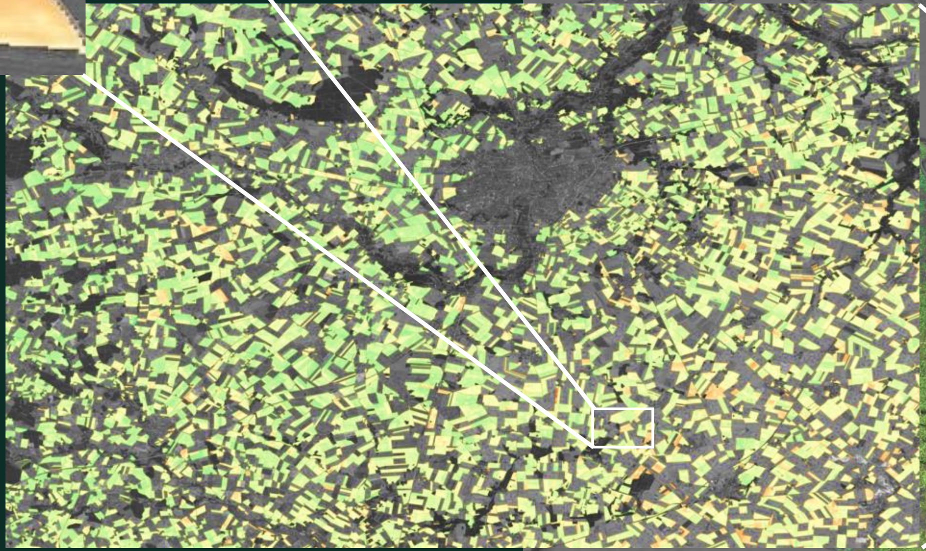


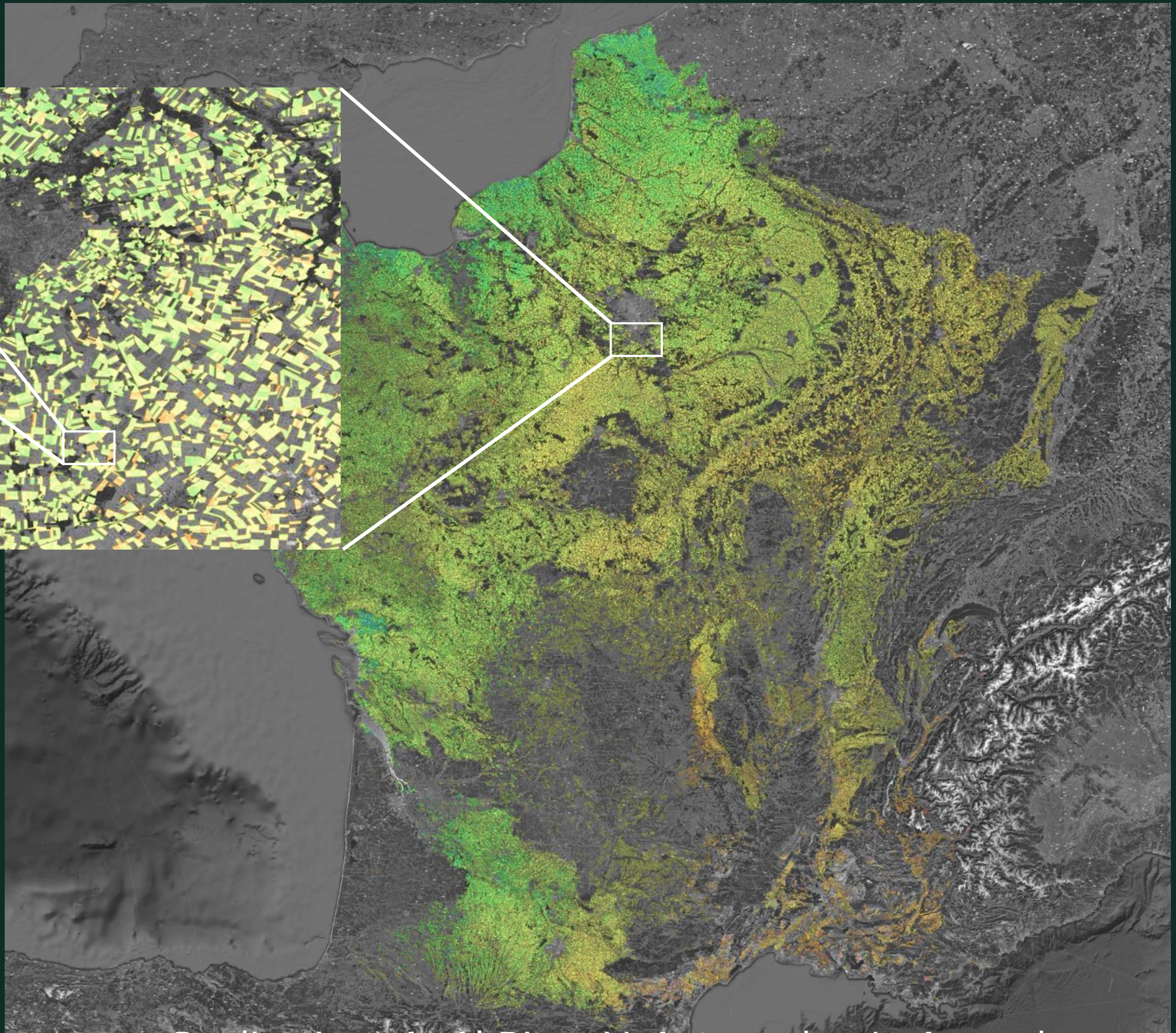
C storage by the soil

C losses by the soil

Scaling-up

Capturing intra-field to national scale spatial variability





Realisation: A. Al Bitar, V. Antonenko, L. Arnaud

Dry above ground biomass at harvest for winter wheat fields in 2019

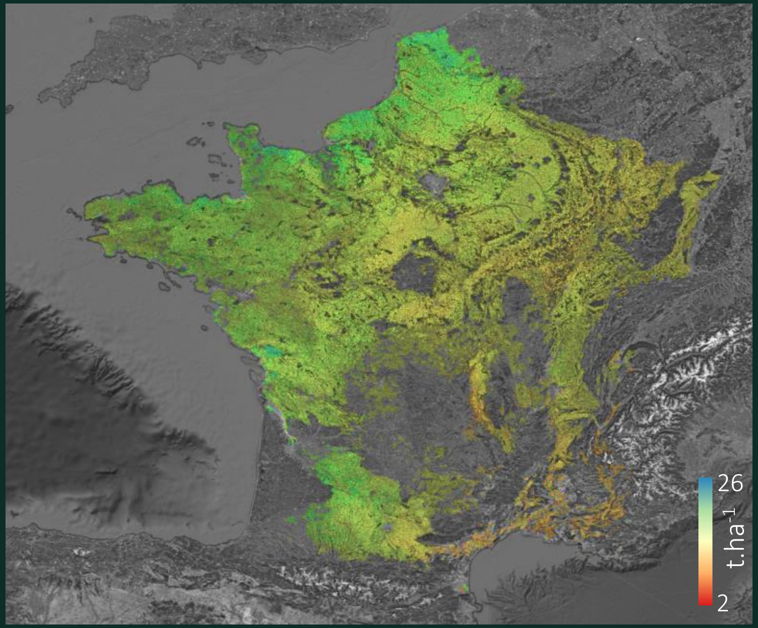
10m resolution
0.6 billion pixels
Daily estimates

In less than 1 day on the CNES supercomputer

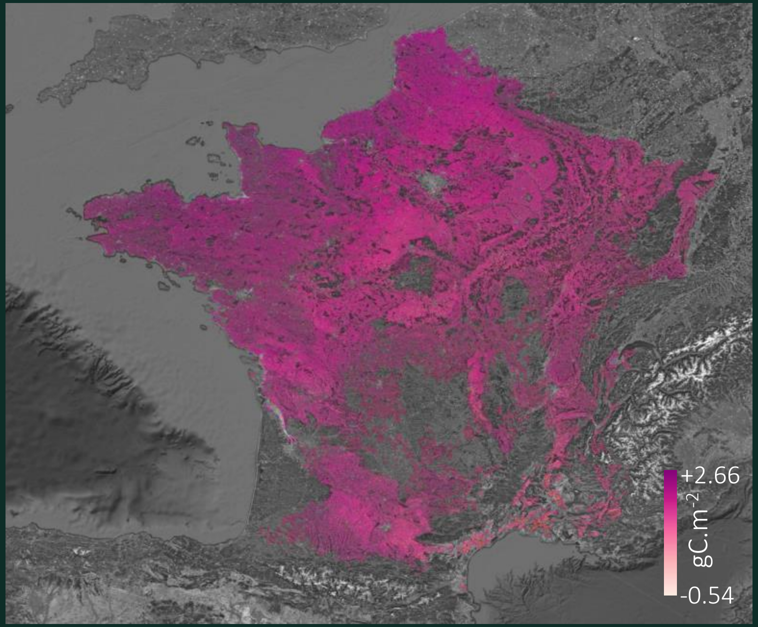
Coherent-set Of agri-environmental variables

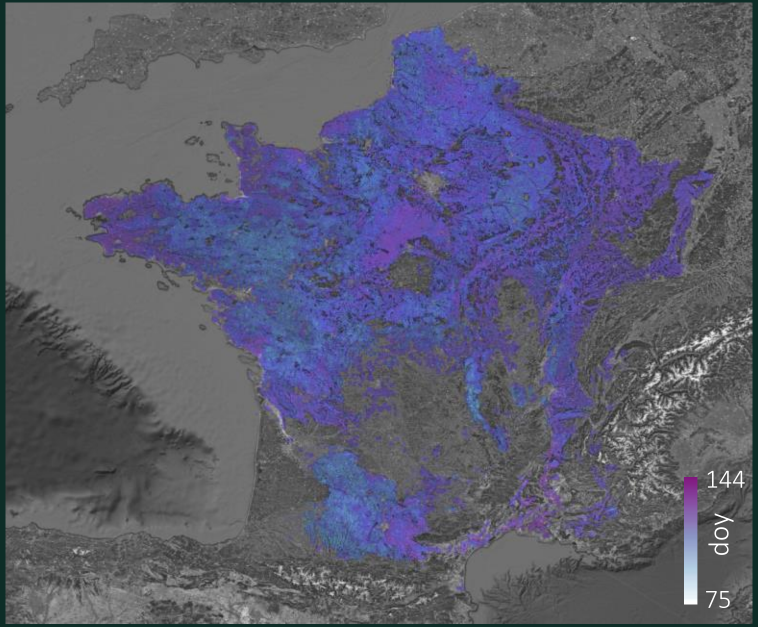
Realisation: A. Al Bitar, V. Antonenko, L. Arnaud

Dry Above ground biomass

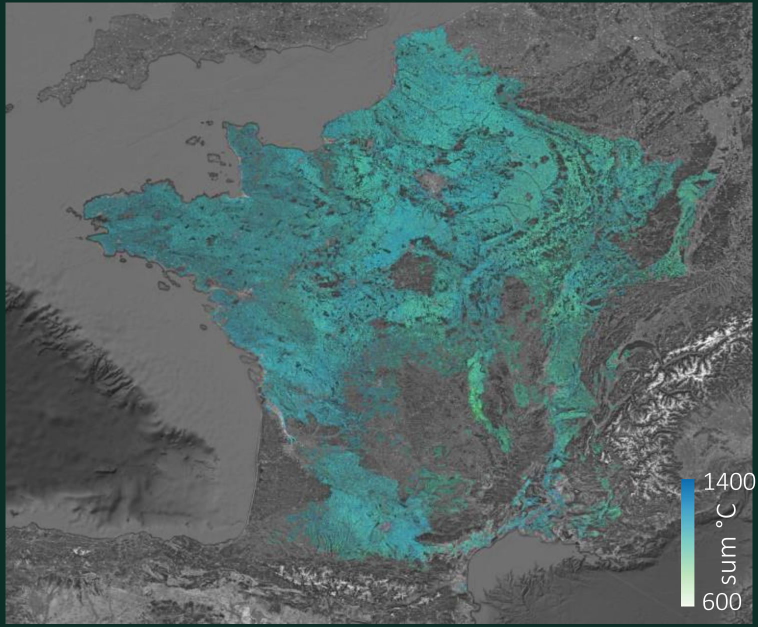


Net annual CO_2 flux

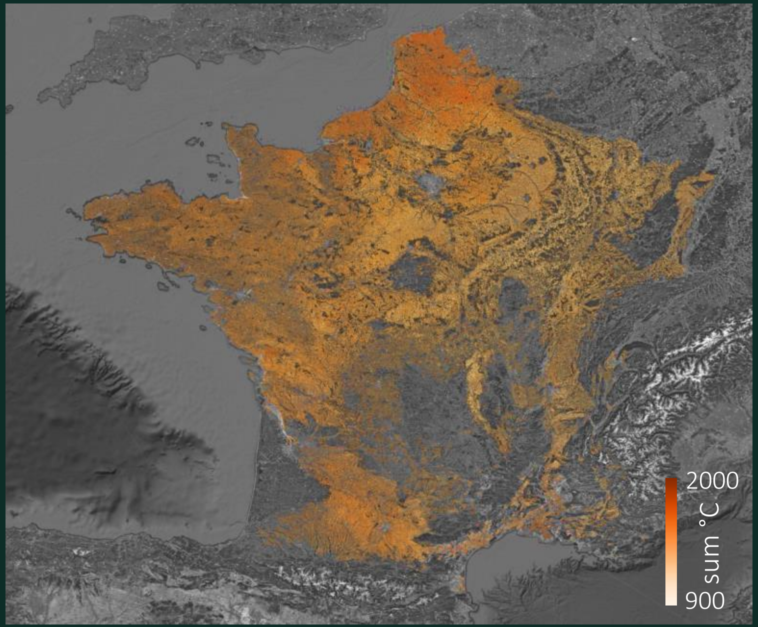




Day of emergence

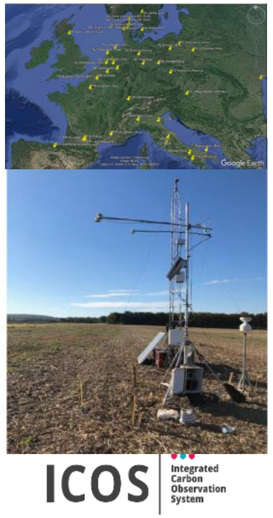


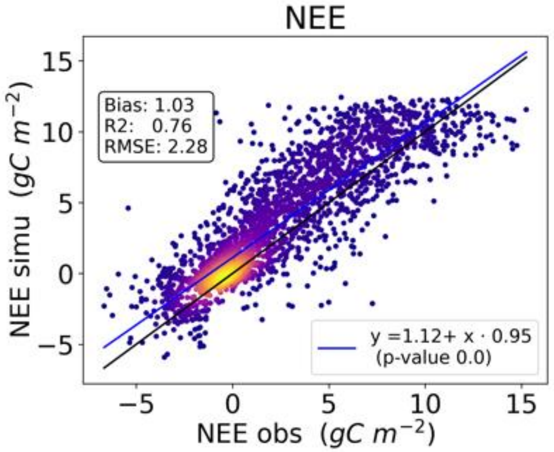
Maturation phase



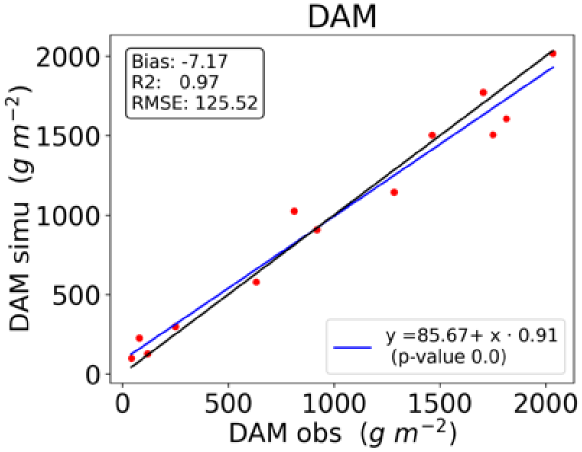
Senescent phase

Validation exercises for the C budget components

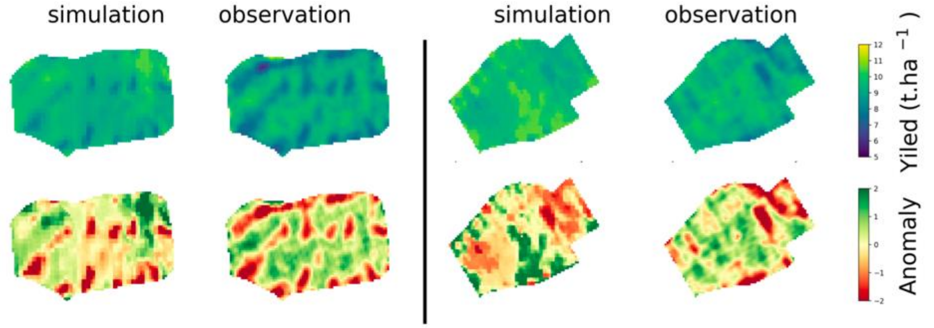




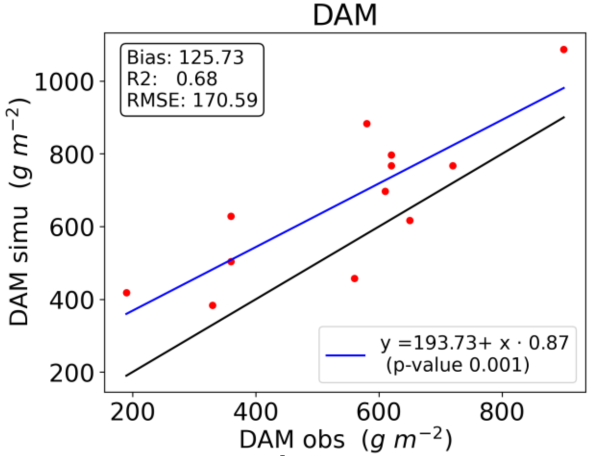
Net CO_2 flux for wheat in Europe at ICOS sites



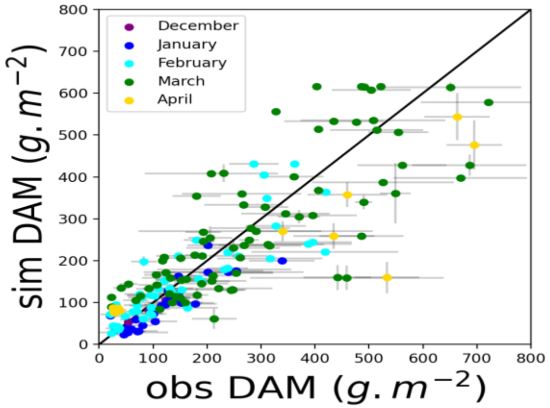
Biomass for wheat in Europe at ICOS sites



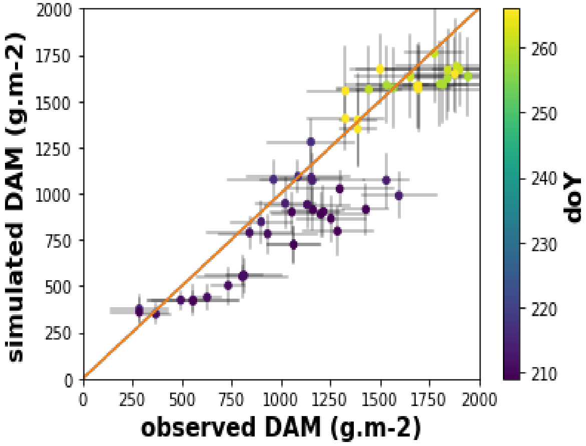
Winter wheat yield maps



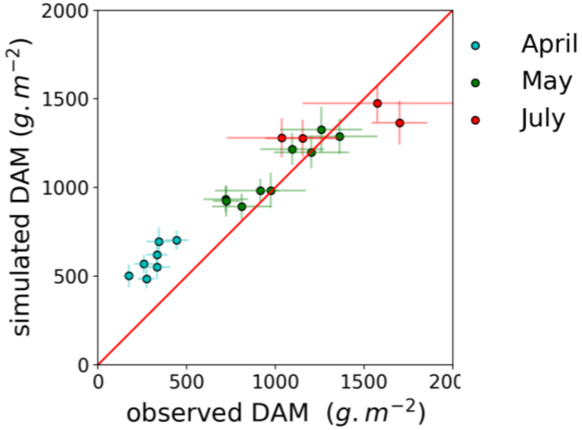
Mixed cover crops in France



Cover crops (Fava bean) in France



Biomass for Maize in France



Biomass for Wheat in France

More crops coming and no validation against soil measurements of SOC stock changes yet because data with measures and re-measures since Sentinel 2 data were launched are missing

Limits and perspectives for ACEO

- Diagnostic approach only although some scenarii can be tested (e.g. straws management, effect of cover crops) and good transposability to other pedoclimatic regions

- Limited to a few crops and cover crops ➔ progressive acquisition of new in-situ datasets for CAL/VAL in Europe (ICOS sites, collab with companies & cooperatives)

ICOS flux tower network

Limits and perspectives for ACEO

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- **Limited to a few crops and cover crops ➔ progressive acquisition of new in-situ datasets for CAL/VAL in Europe (ICOS sites, collab with companies & cooperatives)**

- **So far few soil models/formalisms have been tested in ACEO ➔ test the coupling to new models (e.g. RothC) in different context of applications (PhD A. Ihasusta)**

- **Use of optical remote sensing data only can be limiting for operational applications (long cloudy periods) ➔ combining optical satellite data with radar satellite data (Sentinel-1) will allow to overcome this issue (PhD A. Géraud in collab with Netcarbon)**

- **Access to reliable management data on straw management and organic amendments is currently a strong limitation ➔ use of API to access FMIS is not enough, management data must be verified first (agricultural advisor)**

- **Quality, accessibility and spatial resolution of the soil data/products (e.g. initial SOC stock, texture) ➔ use high resolution remote sensing data for digital soil mapping (collab with E. Vaudour) will partly solve this issue**

Conclusions

- As pointed out by CIRCASA/ORCaSa ➔ need to develop a consistent framework for MRV of SOC stock changes and methods to assess the components of the C budget (+ uncertainties) accounting for the spatial variability of biomass production/restitution and of soil properties.

Based on this **observation**:

- We proposed and harmonised MRV framework for SOC stock changes assessment,
- Development of an innovative hybrid Monitoring approach enabling dynamic and objective monitoring of the impact of biomass restitution to the soil on the SOC stock changes ➔ AgriCarbon-EO,
- Automated, large scale, high resolution, allowing uncertainty analysis at low cost but the lack of access to 1) reliable farm management data and 2) better spatialized soil properties products limits the systematic implementation of ACEO for the main crops,
- Adapted to different contexts of MRV (insetting, offsetting, CAP, NDCs) with the ambition of becoming a key component of the MRV service of the Soil Carbon IRC.

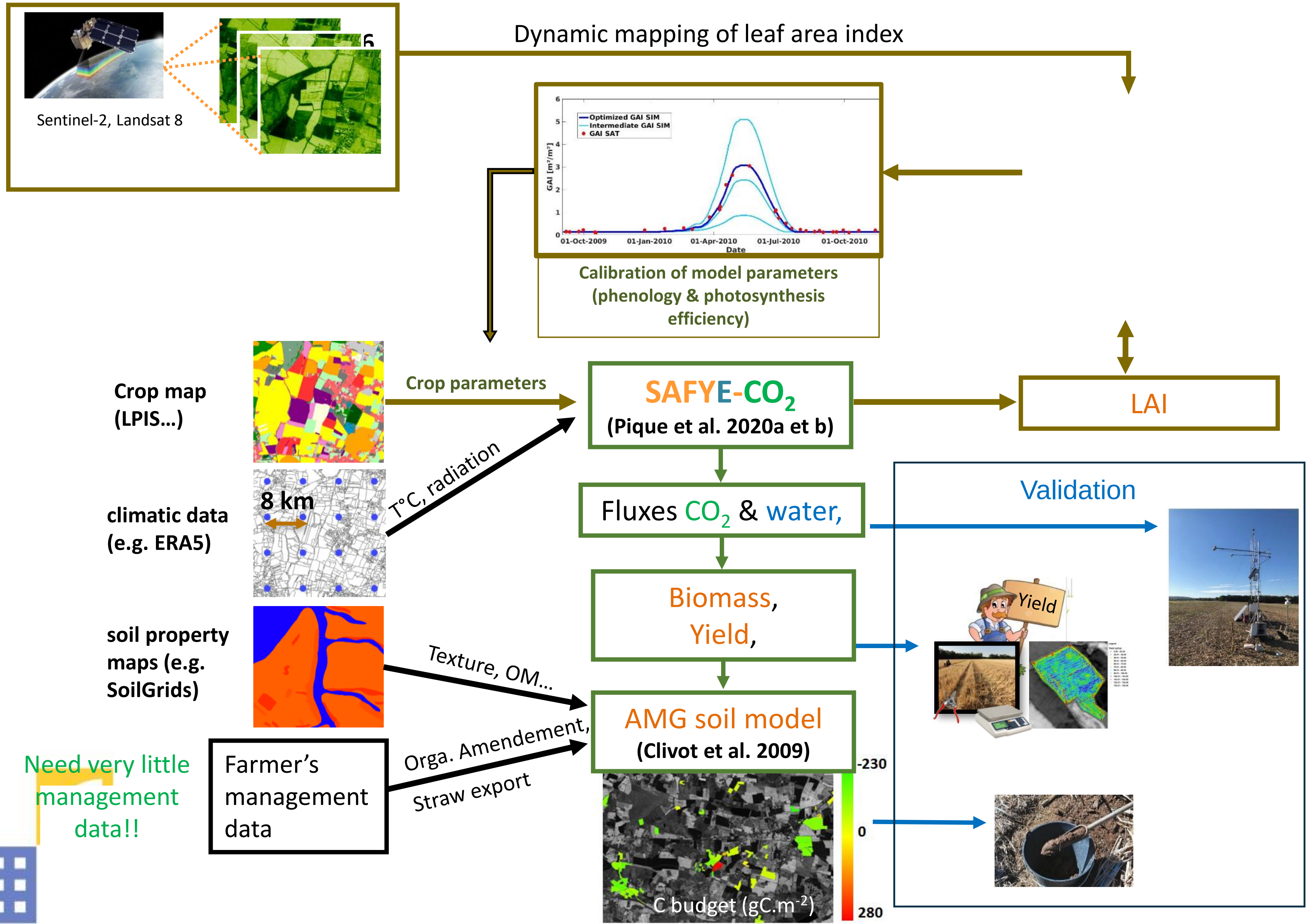
Thanks for your attention!!

Naturellement popcorn

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

Contact : eric.ceschia@inrae.fr and ahmad.albitar@gmx.com

The 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