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

EO for MRV of Cropland SOC stock changes & Carbon budget components

Eric Ceschia

With contributions from Ahmad, Al Bitar, Taeken Wijmer, Ainhoa Ihasusta, Ludovic Arnaud, Rémy Fieuzal, Jean François Dejoux

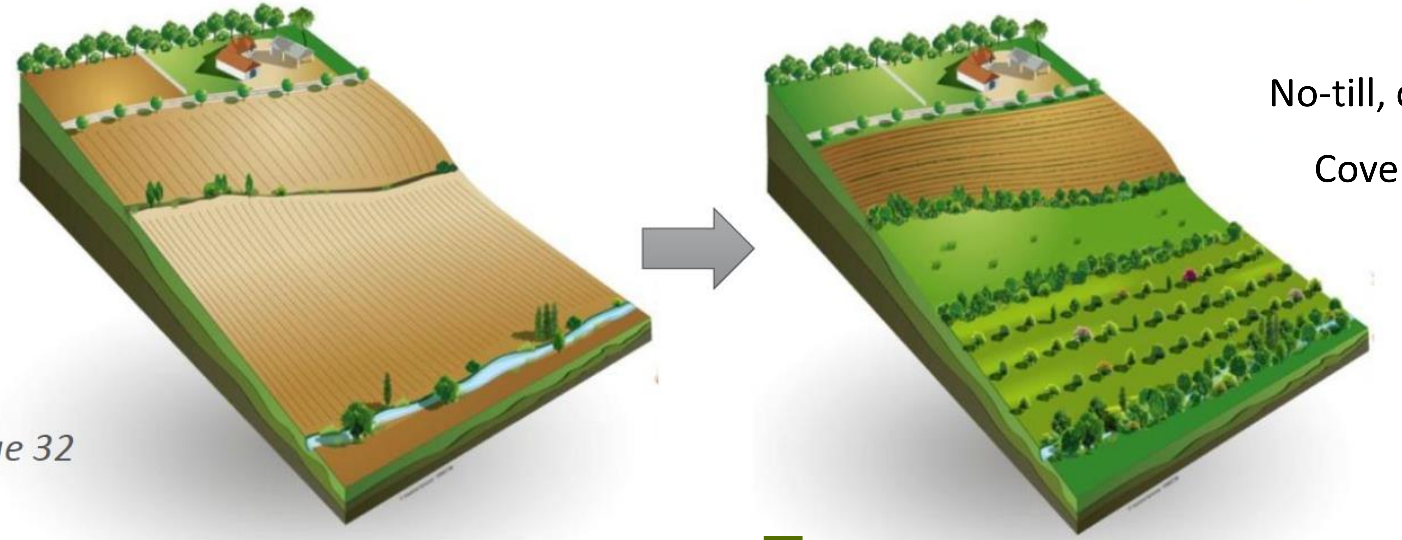
BOG1 Enhancing Earth Observation Monitoring Capabilities
Chairs: Nathalie Morin (Geoville) and Michelle Hermes (EARSC)

EO Conference on MRV of Carbon Removals, 8-11 October 2024, Copenhagen

Context and chalenges

Conventional agriculture

Agro-ecological practices



Illustrations:
Arbre et Paysage 32

No-till, crop diversification

Cover crops

Straw management

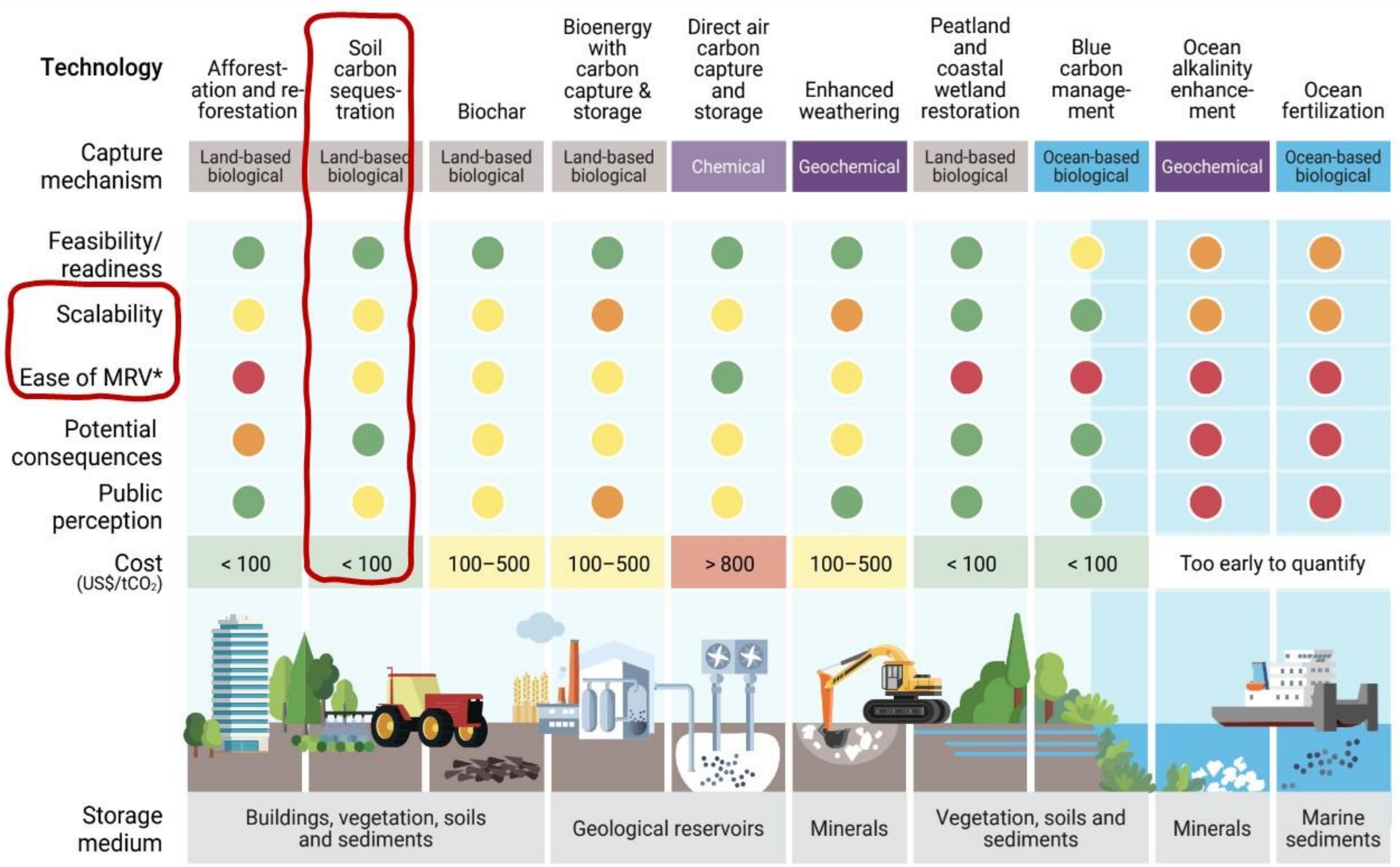
C storage ?

How to assess the impacts of those practices in terms of CO_2 emissions/soil organic carbon (SOC) stock changes 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**

Key message

One of the main challenge for promoting SOC storage and to assess the impacts of Carbon Farming on SOC stocks of cropland concerns Monitoring



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 SOC storage and to assess the impacts of Carbon Farming on SOC stocks of cropland concerns Monitoring ➔ need for scalable, multi-context (NDC, CAP, VCM, insetting), automatized, cheep, reliable, transparent method

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

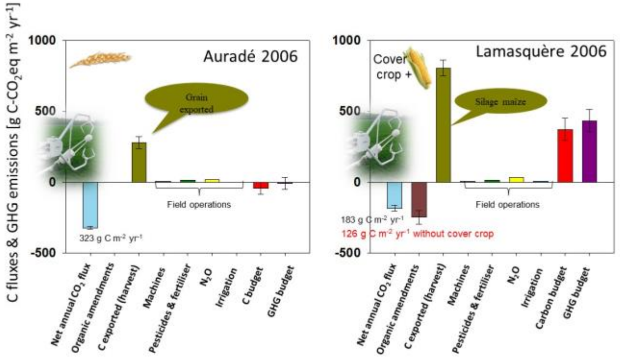
- Modular & transparent approach with uncertainty assessment on SOC stocks,
- Several soil models instead of one ➔ allowing ensemble approach,
- Assessment of the different components of the C budget in the development/verification process (see next slide),
- Relying on strong data infrastructures following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

An compliant with the EU Carbon Removal Certification Framework in terms of baselines, assessment at plot scale, practices accounted for, uncertainty assessment…)

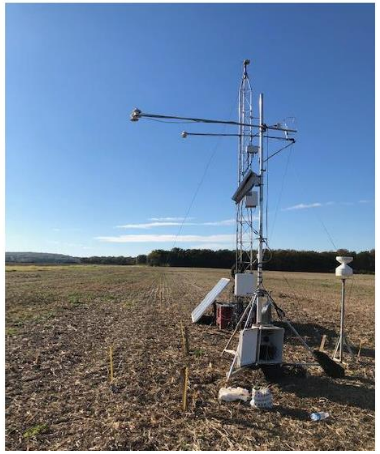
A carbon budget approach to estimate SOC stocks changes

Béziat et al. (2009) in AFM
Ceschia et al. (2010) in AGEE
Smith et al. (2010) in AGEE

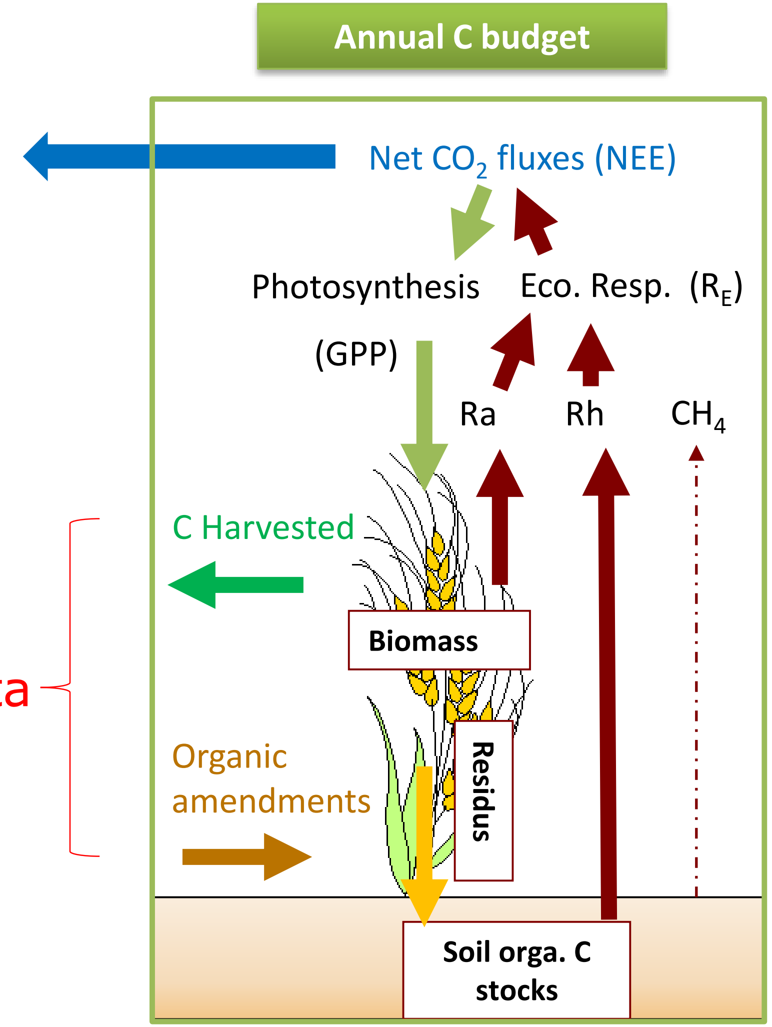
Yearly ΔSOC stock = Net CO_2 flux + C_{import} - C_{export}



Models or



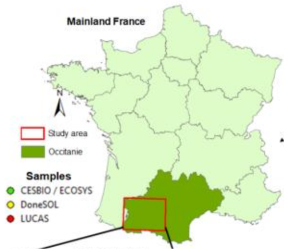
Flux tower

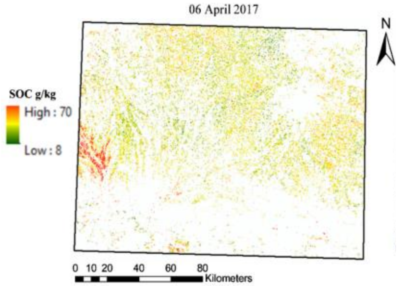


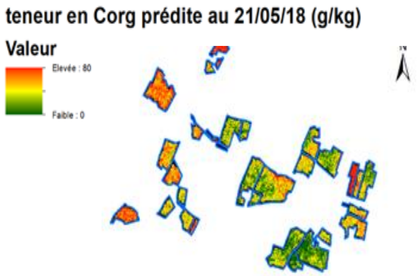
EO for MRV of SOC stock changes

- **Monitoring SOC from EO ➔ EO allows to monitor superficial SOC content, not SOC stocks nor SOC stock changes**
  - See review by Vaudour et al 2022 (https://doi.org/10.3390/rs14122917) for superficial SOC mapping
  - Example of SOC mapping

Urbina-Salazar et al. (2021)
https://doi.org/10.3390/rs13245115

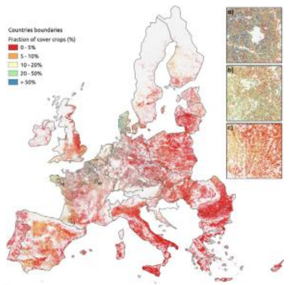




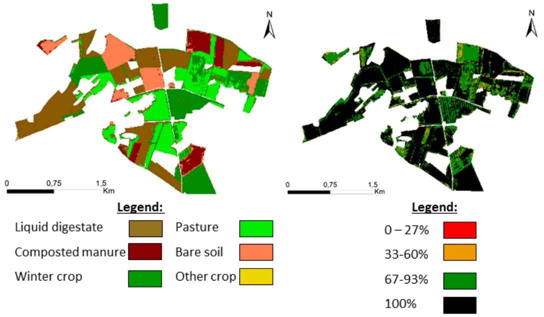


Representative of which soil depth?
How to use this information as input for soil models ?

- **Monitoring management practices having an effect on SOC ➔ EO allows to monitor some practices impacting SOC stocks (mapping crop rotations & cover crop, soil work) but not two key ones;**
  - Straw management (exported/left) as EO only provides info on the % of soil coverage (no quantification of straw residues)
  - Type and amount of organic amendments, yet mapping yes/no possible see Dodin et al. (2021) https://doi.org/10.1080/10106049.2023.2245371



Mapping cover crop with Sentinel-1
(Fendrich et al 2023)



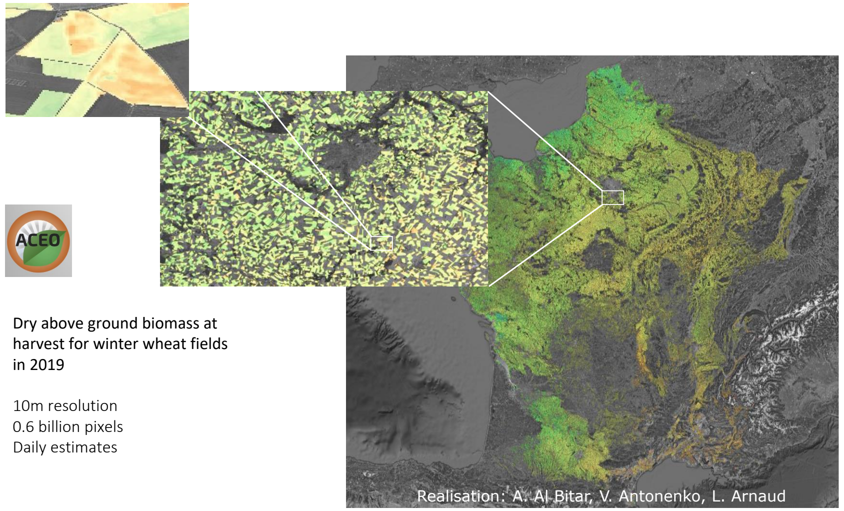
Mapping organic amendment application yes/no
Dodin et al. in preparation

- **EO for quantifying C inputs to the soil as biomass (crop residues, cover crops, spontaneous regrowth, weeds)**

Spatial variability in aboveground biomass, yield and C inputs

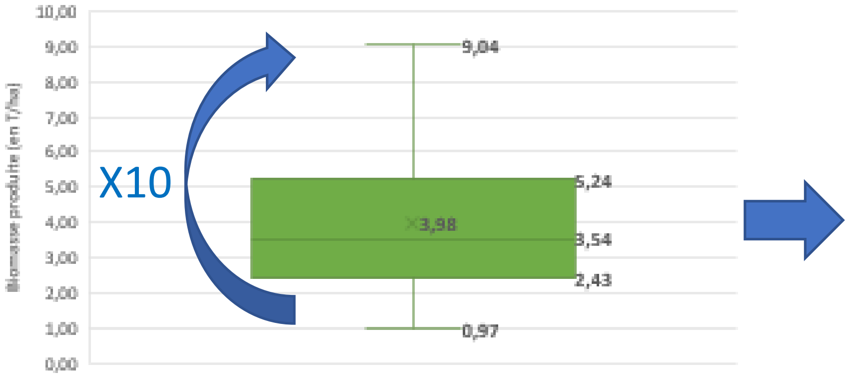
CROPS

Intra and inter plot spatial variability in straw cereal ABG biomass in France (2019)



COVER CROPS

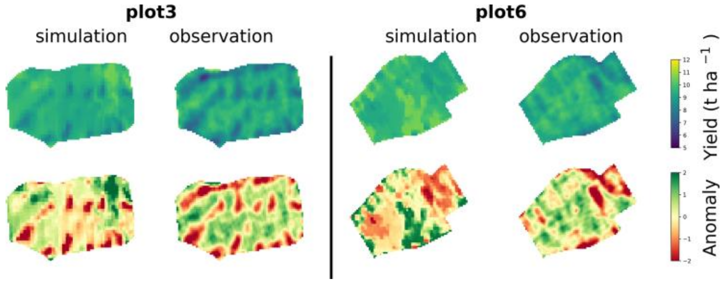
Variability in fava bean cover crop biomass at the Nataïs producer network in 2019



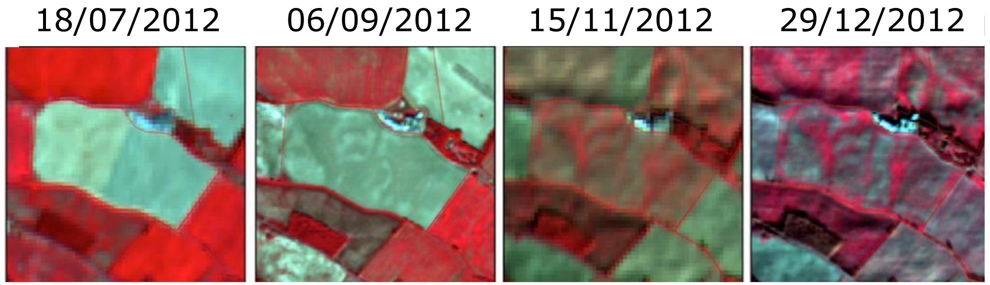
Field workers were asked to collect 2m^2 of biomass samples that they considered to be representative of the plot (source: Agrod'OC)

- Strong inter & intra plot spatial variability of biomass inputs to the soil not currently accounted for by most MRV approaches
- EO based approach are needed to better account for those effects !!!

Spatial variability in wheat yield in France (2019)



Data SPOT4/5



Harvest index (Yield/aboveground biomass) varies from 0.3 to 0.6 for wheat

(Dai et al 2016 : https://doi.org/10.1016/j.biombioe.2015.12.023)

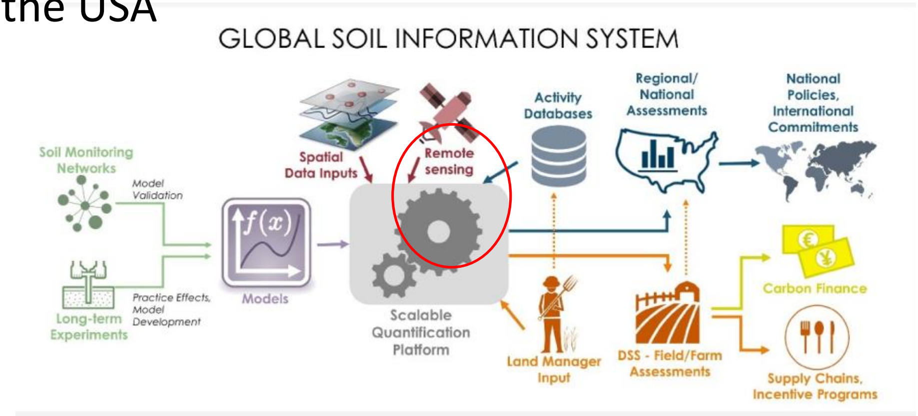
➔ **not an accurate approach to estimate ABG biomass and crop C input to the soil based on farmer's yield data !!!**

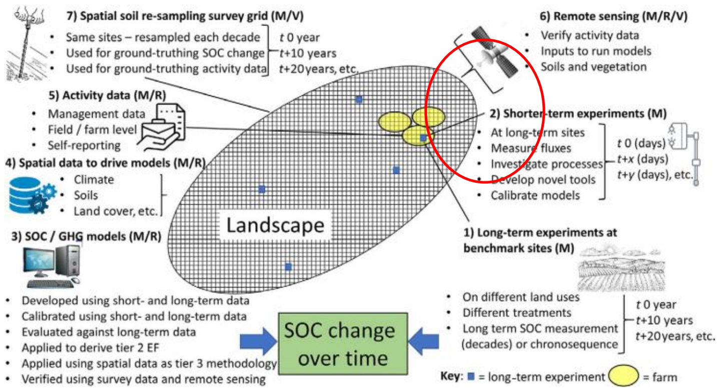
MRV frameworks for cropland

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

Conceptual

Smith et al. (2020)

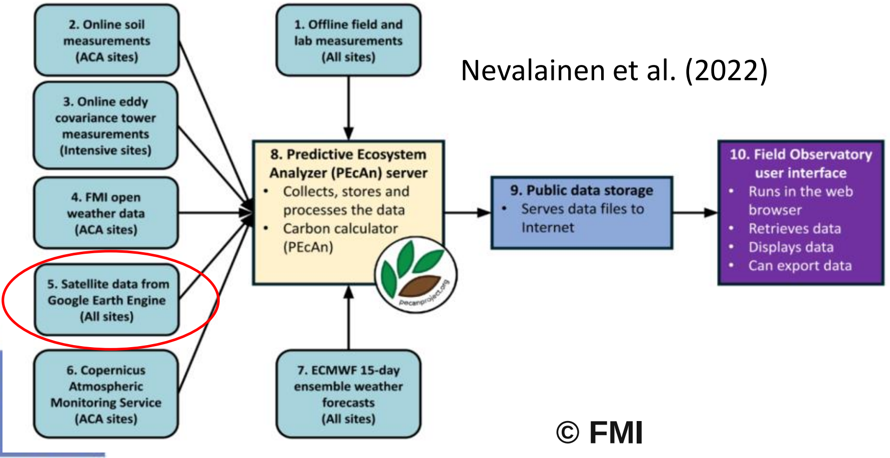




Prototypes of Operational Processing Chains

Field observatory network

Nevalainen et al. (2022)



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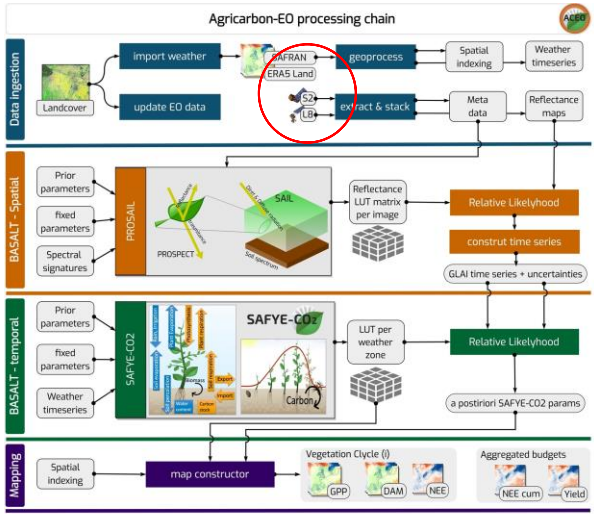
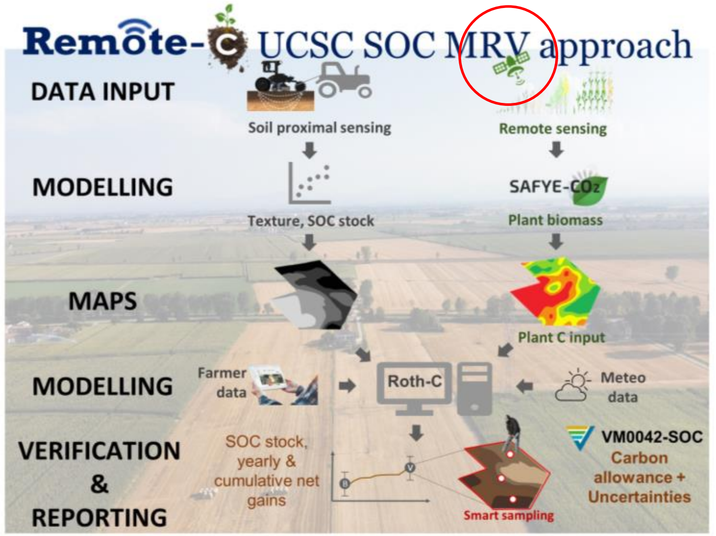


Wijmer et al. (2024) © INRAE/CESBIO



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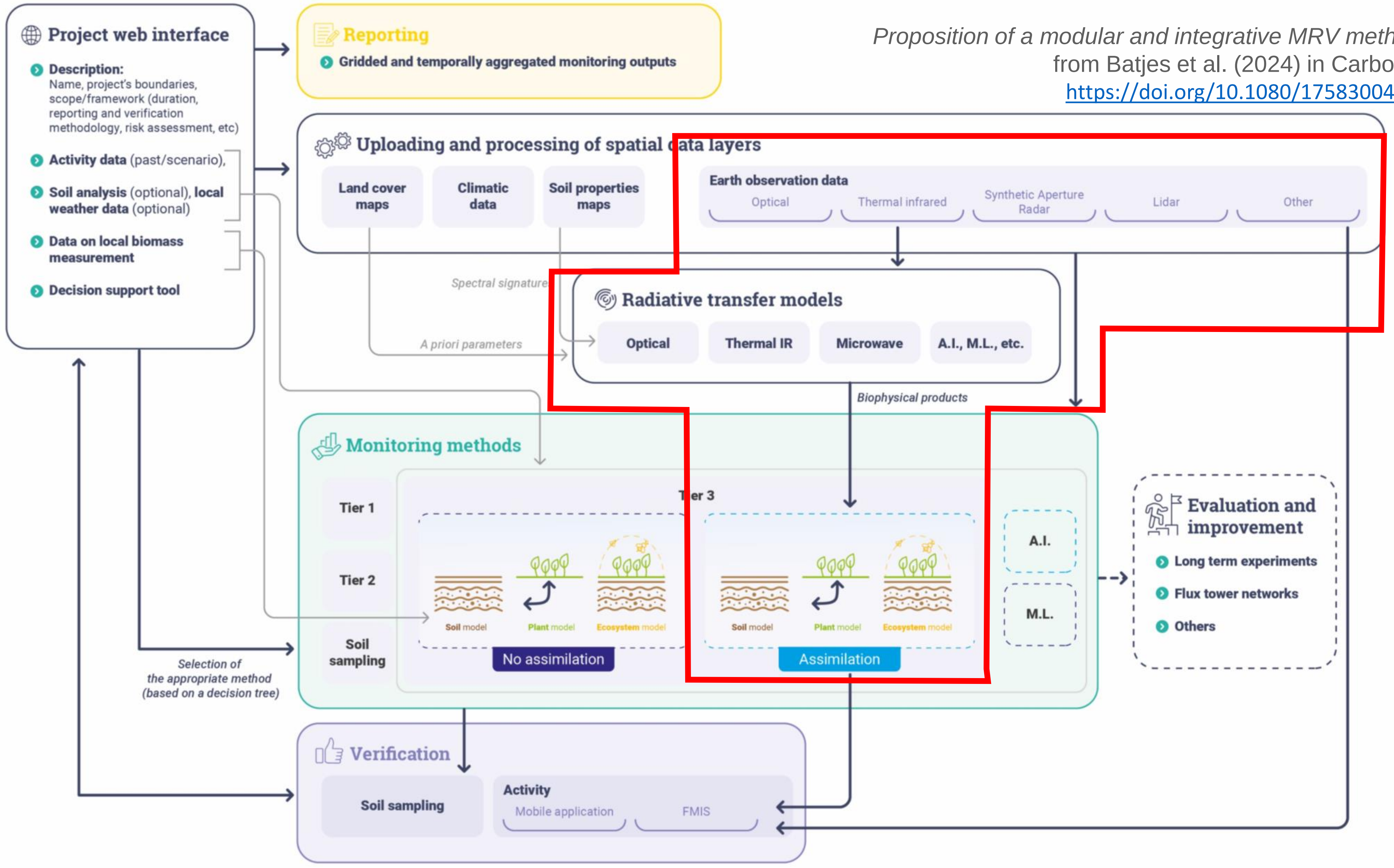
Modular MRV framework for cropland: focusing on the Monitoring component

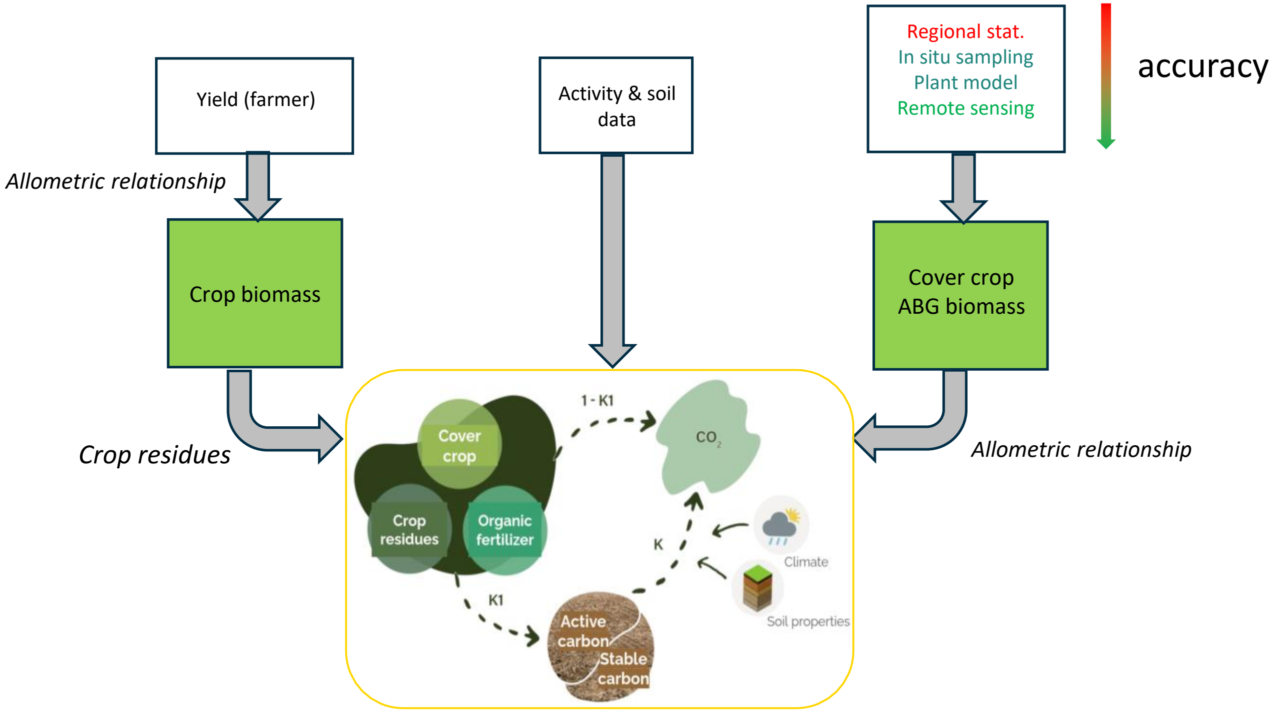


Proposition of a modular and integrative MRV methodology for SOC stock changes
from Batjes et al. (2024) in Carbon management
https://doi.org/10.1080/17583004.2024.2410812.

ORCaSa
Because soil carbon matters

Soil centered approaches for SOC monitoring

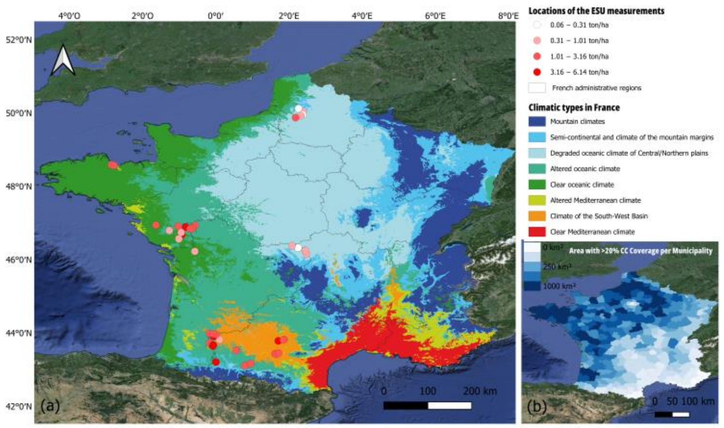
e.g. AMG ➔ LABEL BAS CARBONE



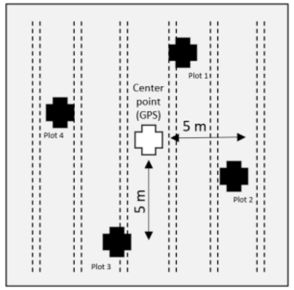
AMG soil model (Clivot et al 2019)

- **You can do MRV with only a soil model (simple approach…)**
- **Most crops & carbon farming practices**
- **Cropping systems of the farm (not plot level)**
- **Cost varies if initial soil sampling needed and access to activity data through FMIS**
- **Uncertainty assessment**
- **Scalability**
- **Accuracy (because of the biomass input data for the soil model)**

Remote sensing + ML to estimate cover crop biomass spatial variability and C inputs

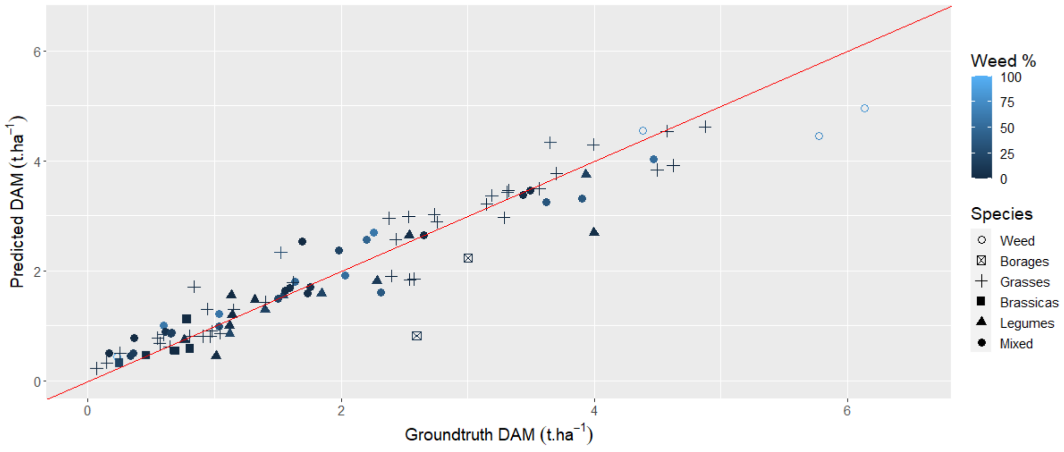


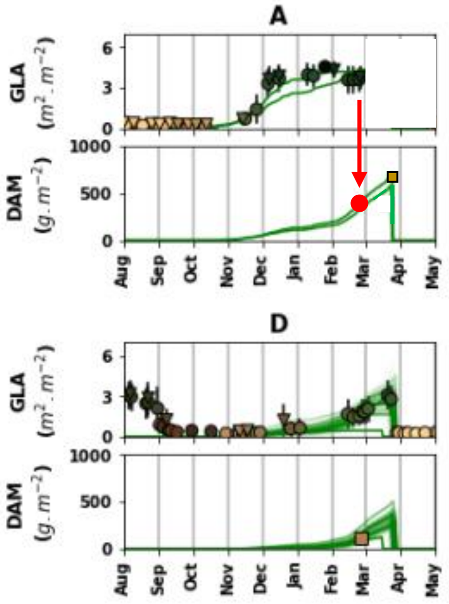
do Nascimento Bendini et al. (2014)



Example of ESU protocol

See T2.3 !!!



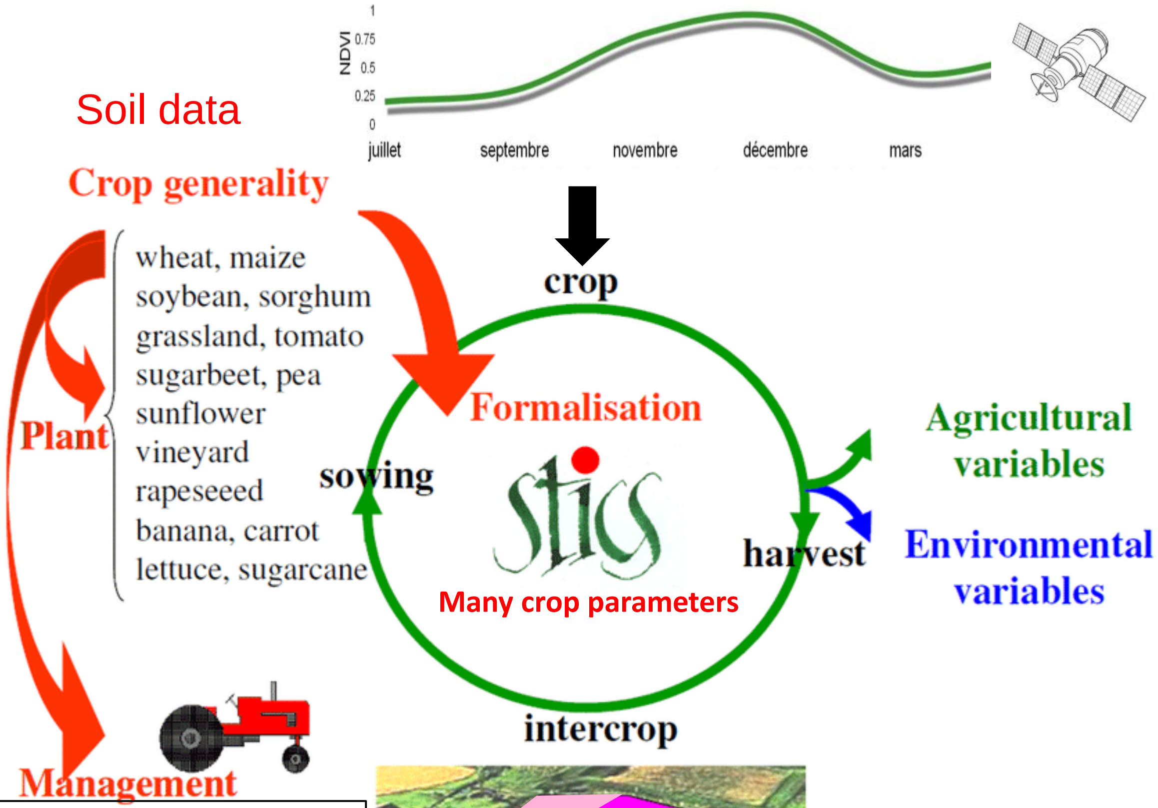


Good performance with ML but:

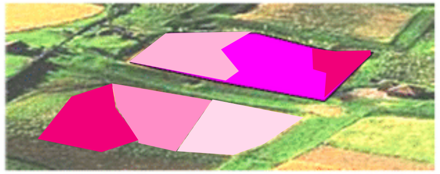
- little year to year transposability ➔ requires multi-year training dataset
- **Good estimates at the date of acquisition** but what happens if 2-3 weeks of clouds ? (cover crop biomass can double every week in spring !!!) ➔ need to combine this approach with crop modelling to interpolate/extrapolate biomass estimates

Green curves are AgriCarbon-EO simulations (see next slides), dots are observations

Ecosystem modelling approach with EO assimilation for SOC monitoring



- Crop rotation,
- seeding data/density
- Mineral fertilisers
- organic amendments
- Irrigation
- …



Good expertise in agronomical modelling needed

Most crops & carbon farming practices

Cost varies if initial soil sampling needed and access to activity data through FMIS

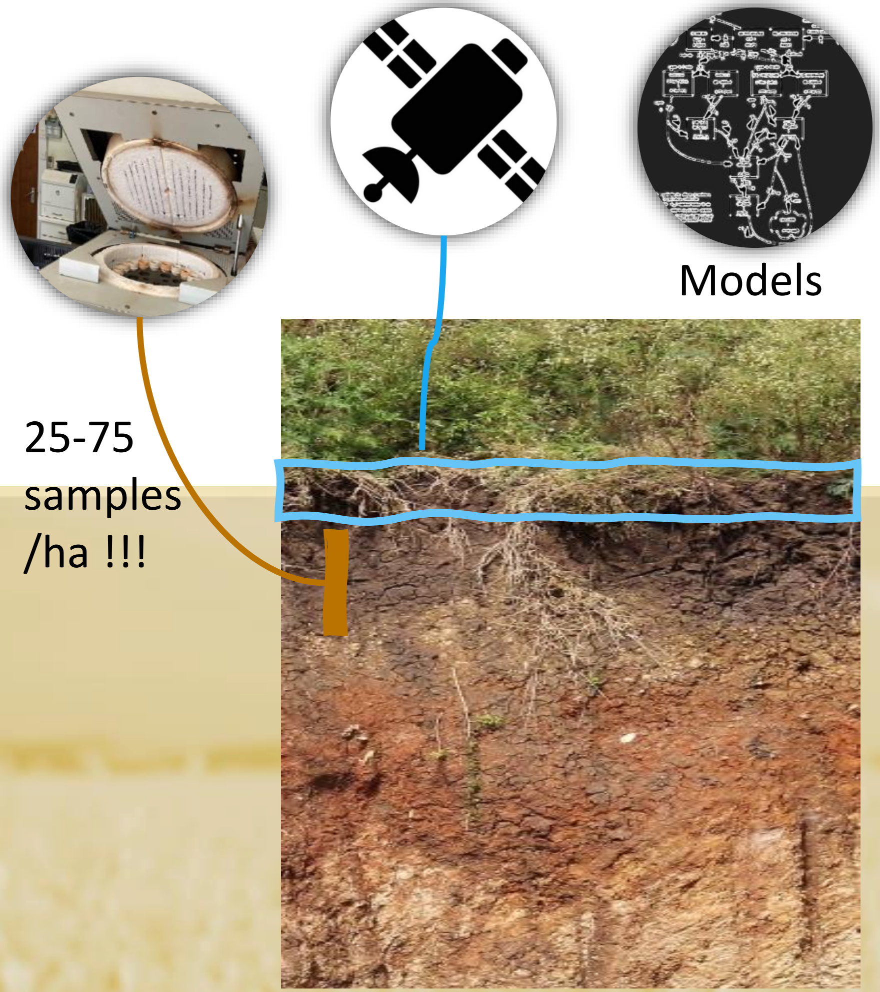
Uncertainty assessment

Scalability (many parameters…)

Better assessment of crop development

Accuracy depends on access or not to 1) local soil data, 2) accuracy on activity data and 3) access to operational EO obs.

Limits of current methods for monitoring soil carbon



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

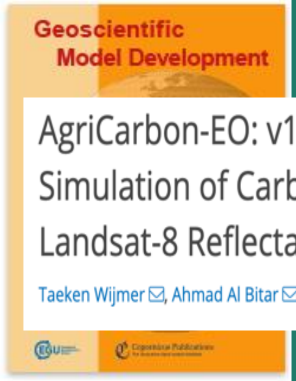
AgriCarbon-EO

A hybrid method combining **parcimonious process based ecosystem model**, 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

The AgriCarbon-EO processing chain

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



Wijmer et al. (2024)

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:

Toulouse Tech Transfer INNOVATIVE IMPACT

AIRBUS

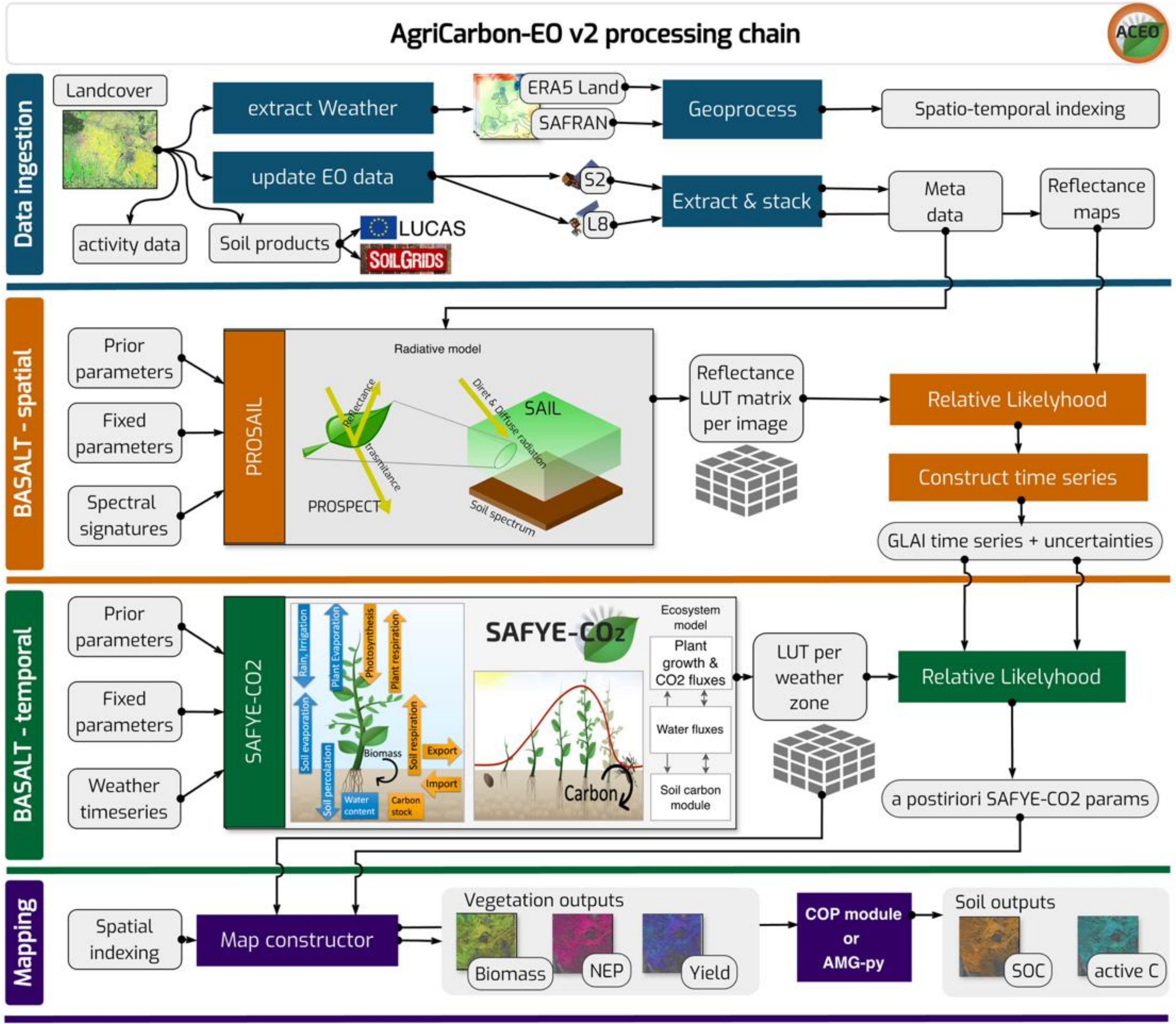
netcarbon

KERMAP

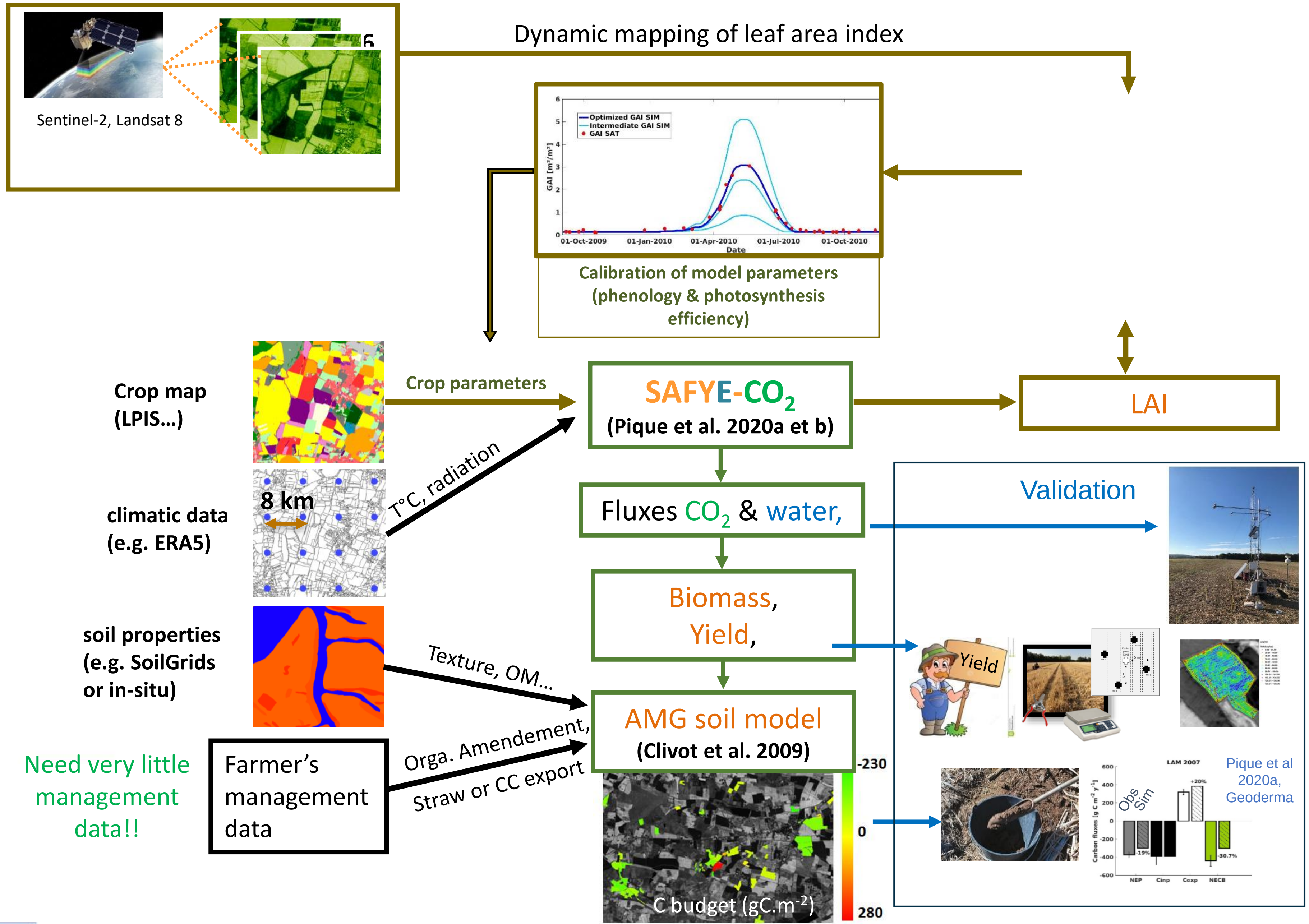
E2L Earth observation Living Labs

MyEasy Farm

natais



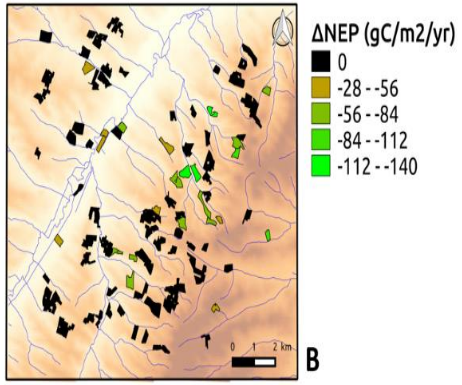
The SAFYE-CO2 model



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.

Automatic detection of cover crops, spontaneous regrowth /weeds and their impact on CO_2 fluxes/SOC ➔ only possible with EO



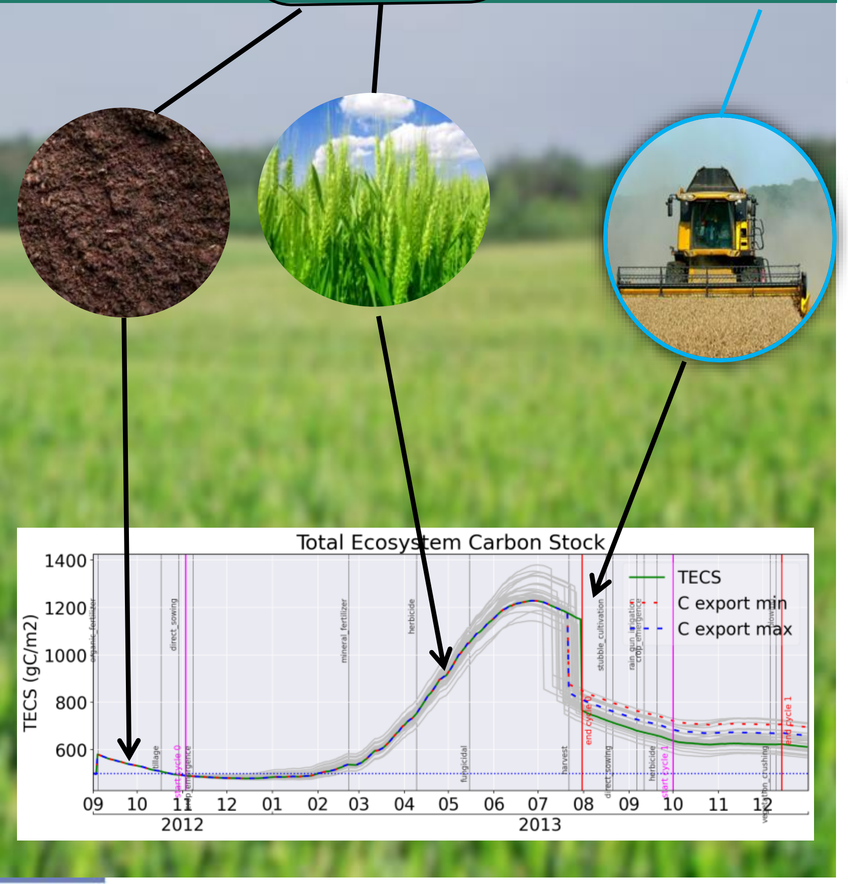
Pique et al (2020c) https://doi.org/10.3390/ecas2020-08141

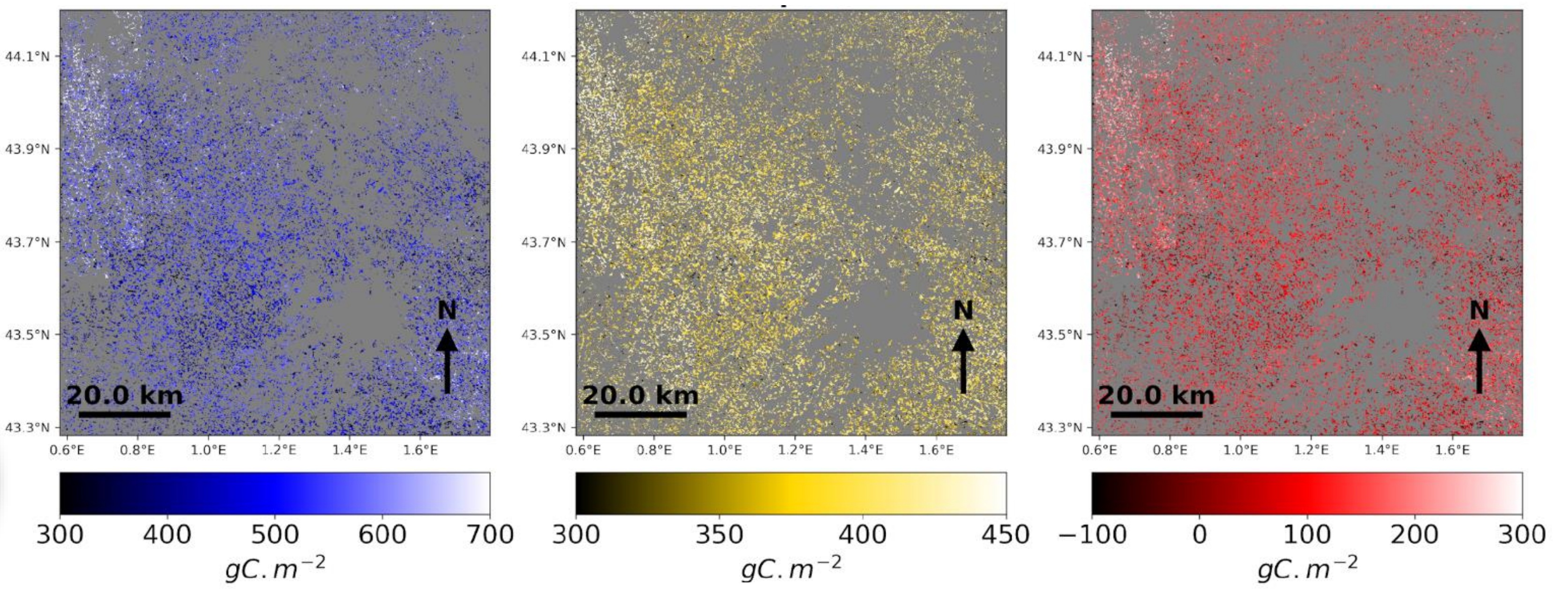
Activity data provided by the farmer

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

Annual carbon budget components

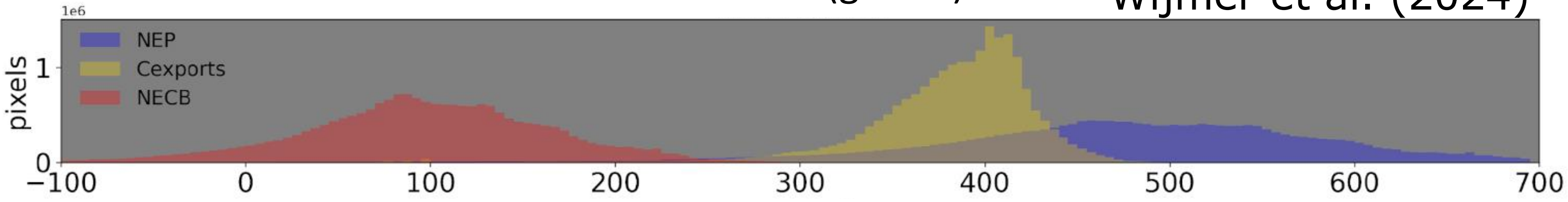
$$\Delta SOCstock = \text{Net } CO_2 \text{ flux} + C_{import} - C_{export}$$



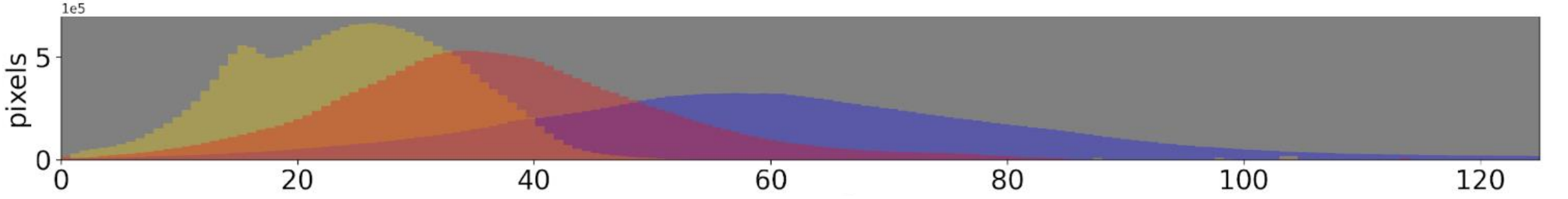


Mean value (gC.m^{-2})

Wijmer et al. (2024)



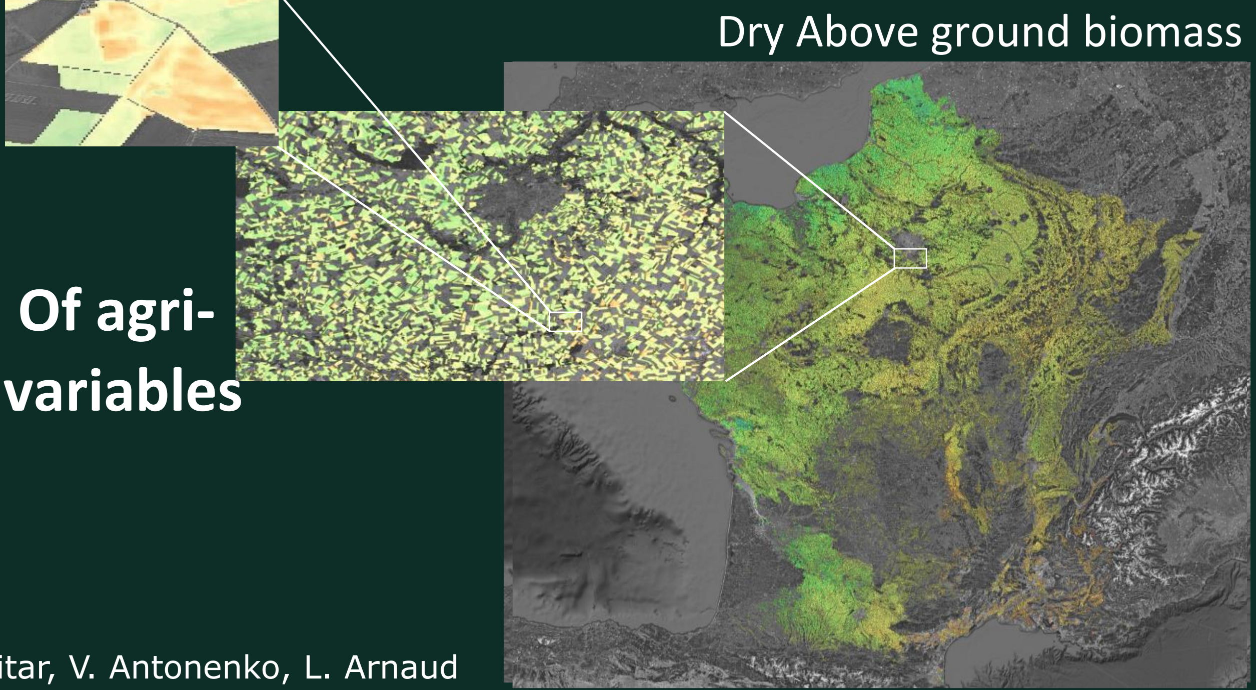
Uncertainty estimates



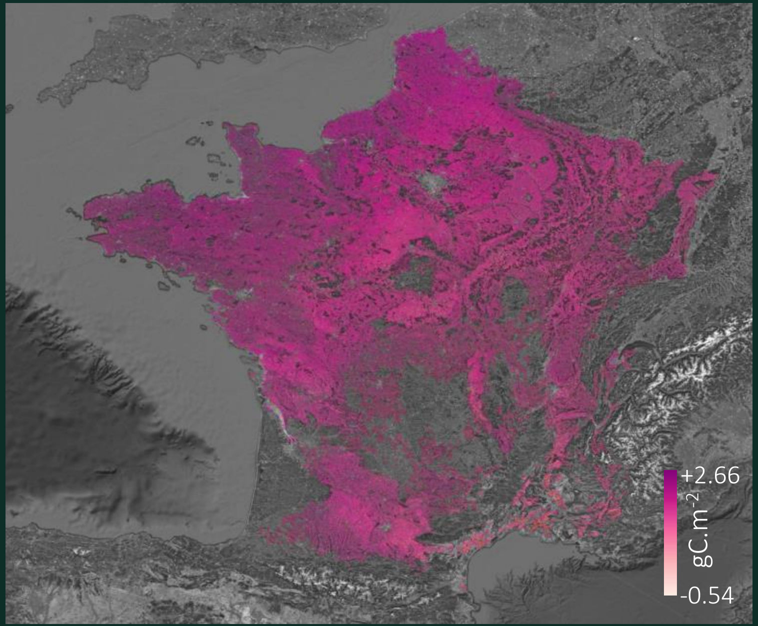
Coherent-set Of agri-environmental variables

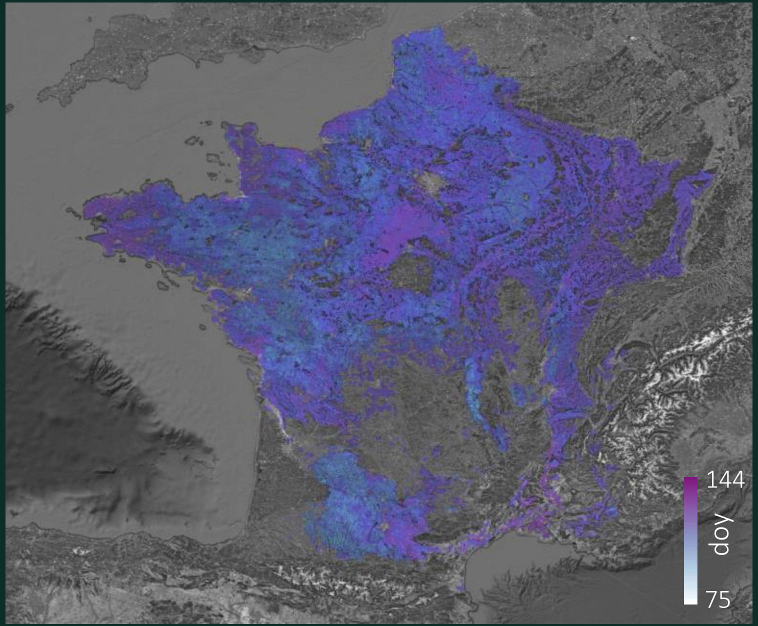
Realisation: A. Al Bitar, V. Antonenko, L. Arnaud

Dry Above ground biomass

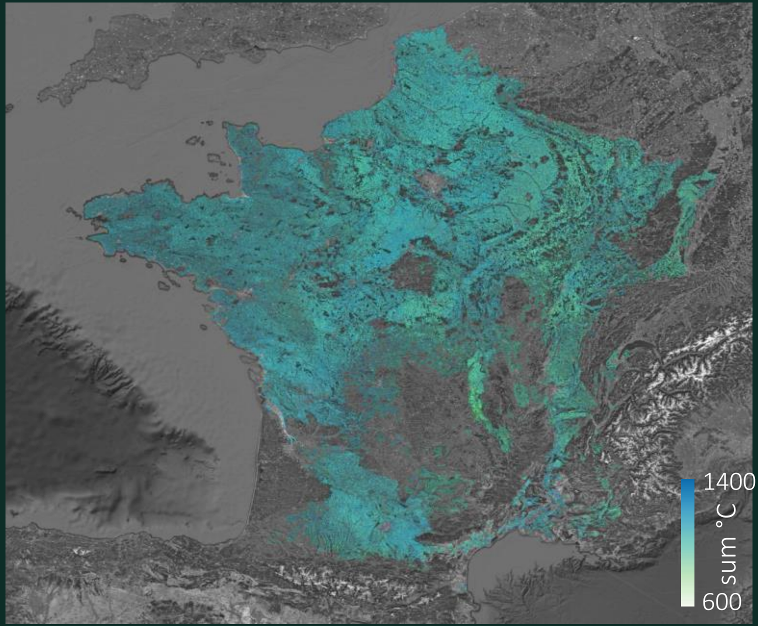


Net annual CO_2 flux

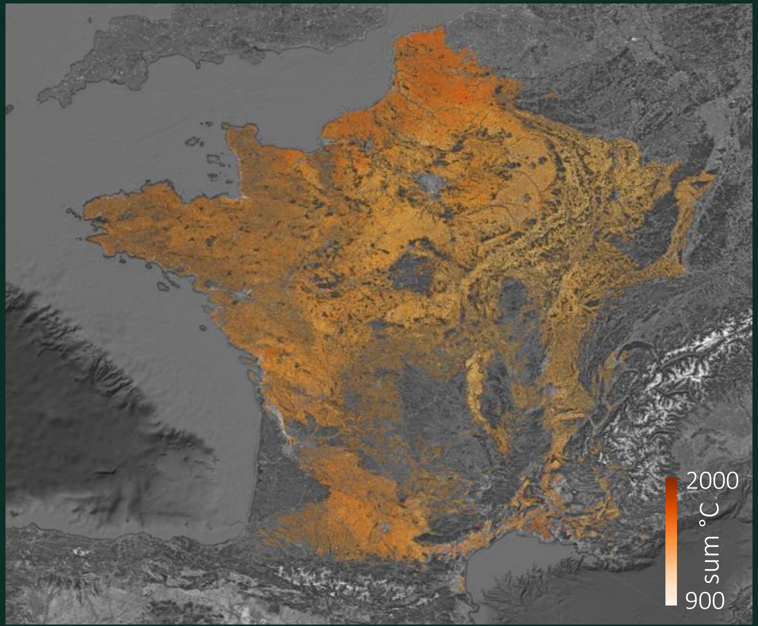




Day of emergence



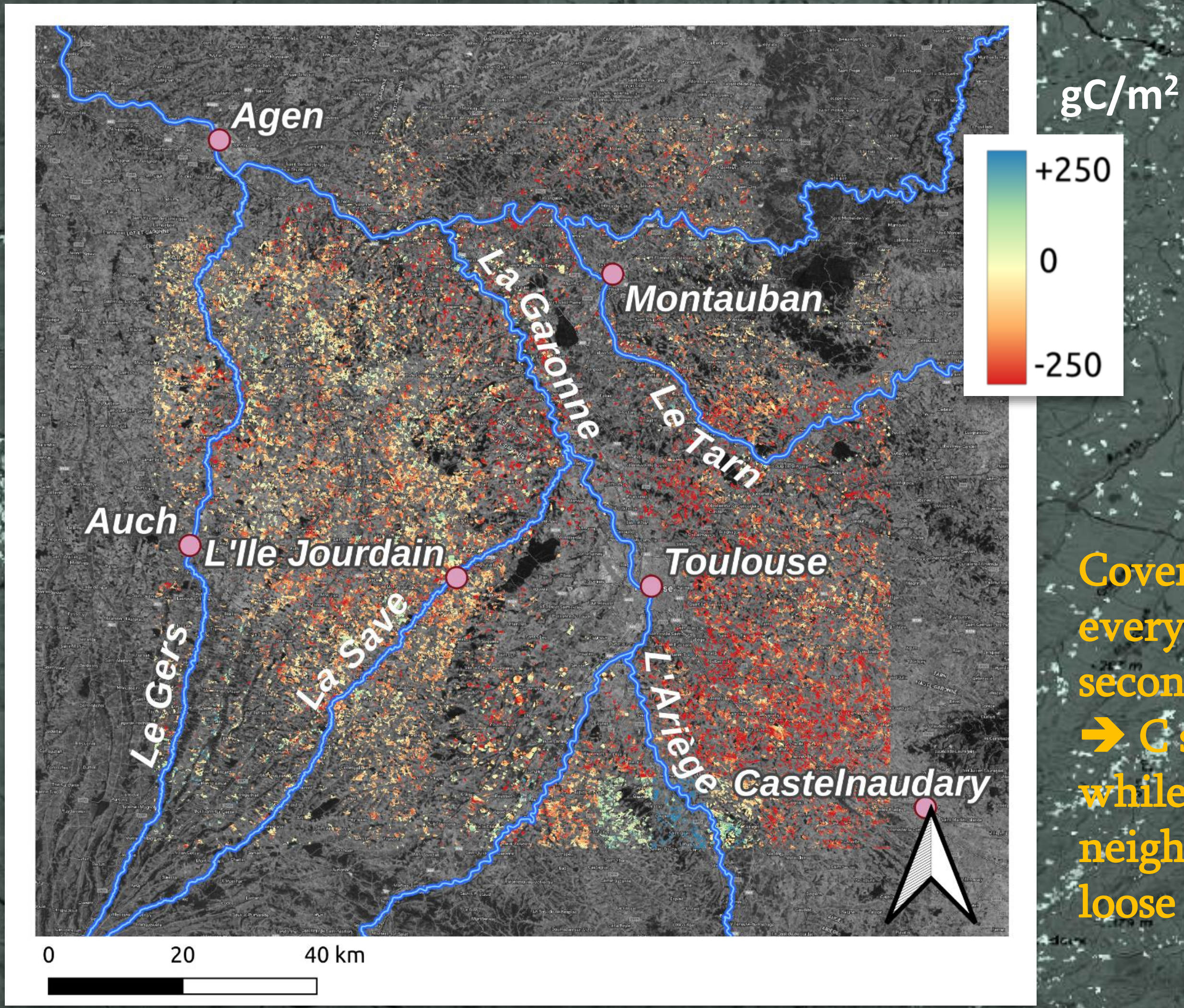
Maturation phase



Senescent phase

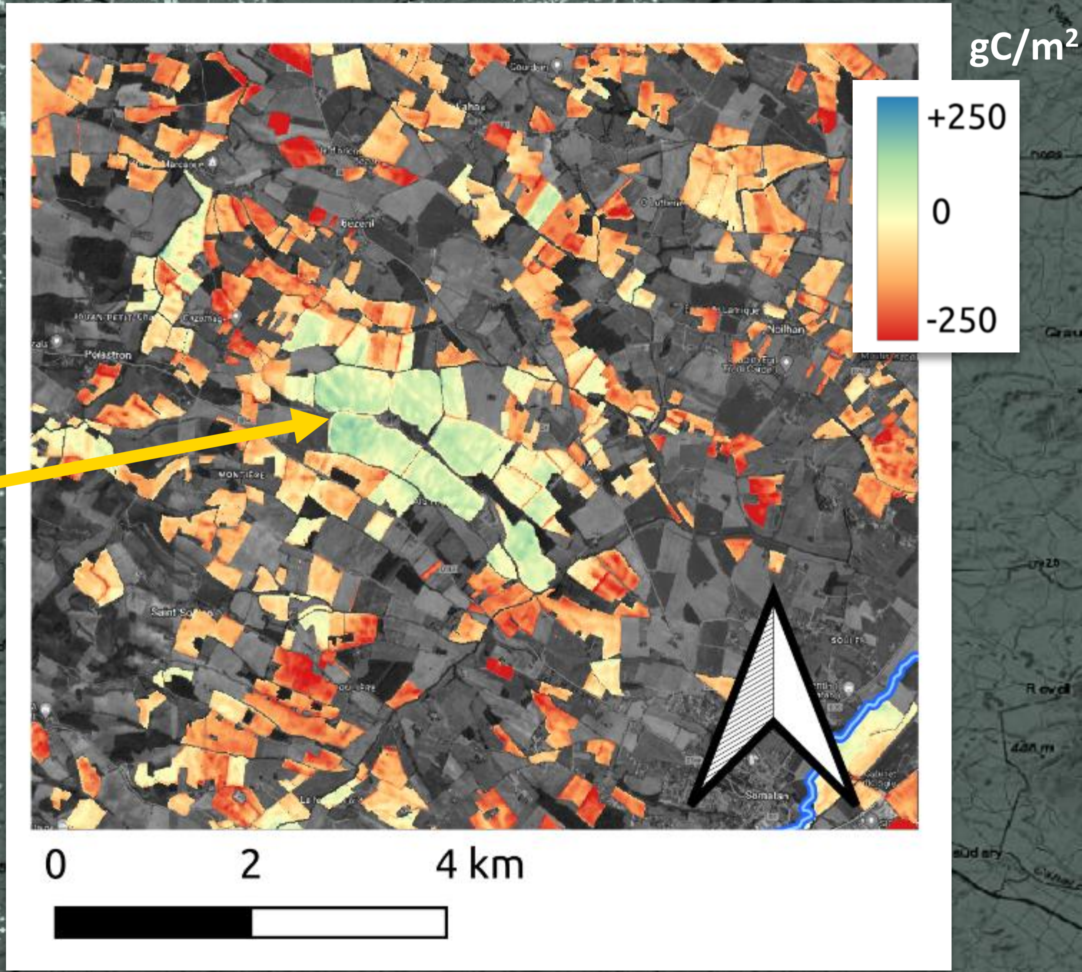
Soil Organic C Stock Changes over 5 years

Simulating crop rotations with straw cereal, maize, sunflower & cover crops considering no organic amendment and straw retention



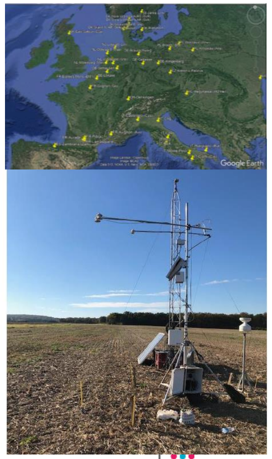
ACEO V2 integrating the AMG soil model

Villeneuve farm

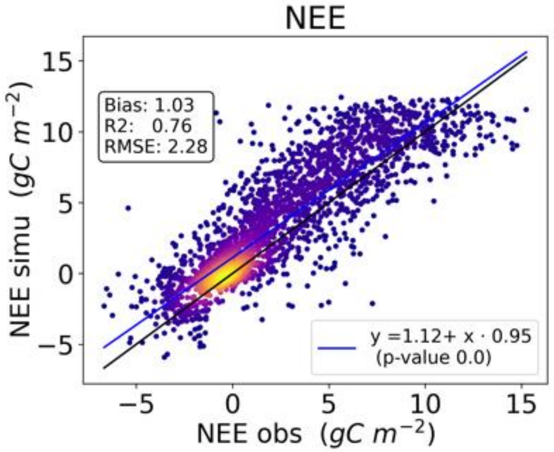


Cover crops every second year ➔ C storage while neighbors loose C

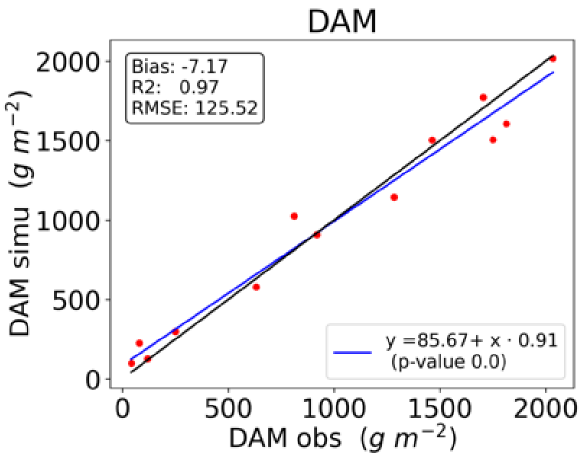
Validation exercises for the C budget components



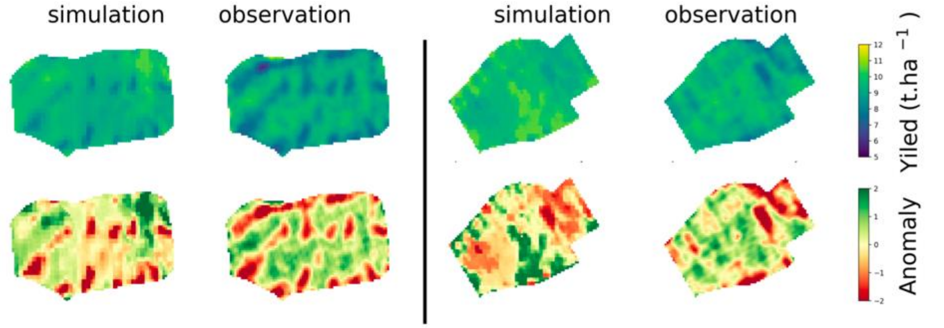
ICOS Integrated Carbon Observation System



Net CO_2 flux for wheat in Europe at ICOS sites

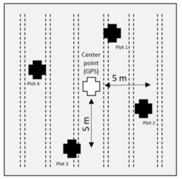


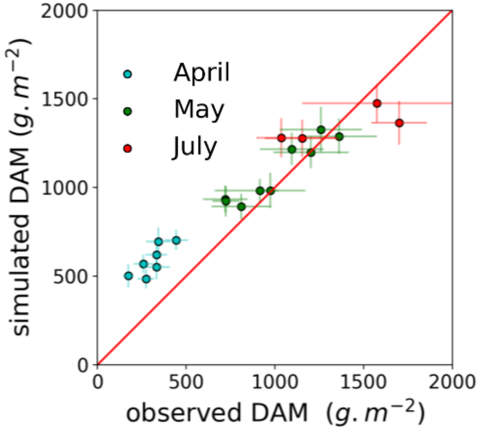
Biomass for wheat in Europe at ICOS sites



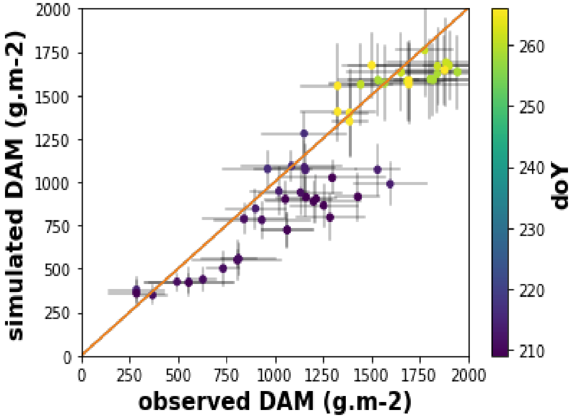
Winter wheat yield maps

Biomass with ESU protocol

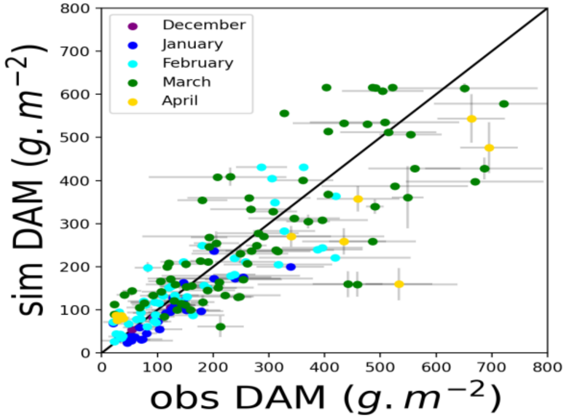




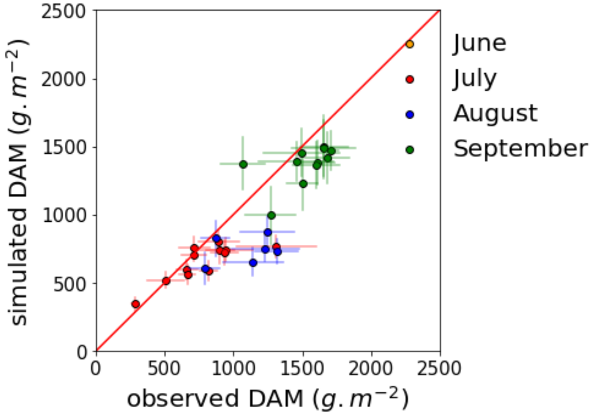
Biomass for Wheat in France



Biomass for Maize in France



Cover crops (Fava bean) in France



Tomato in Italy

More crops to come but no validation against ΔSOC stock changes yet because data with measures and re-measures since Sentinel 2 data were launched are not missing

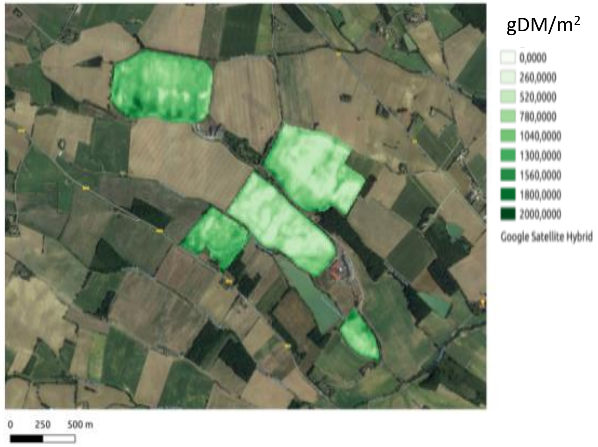
High resolution C budget maps with ACEO and verification strategy

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

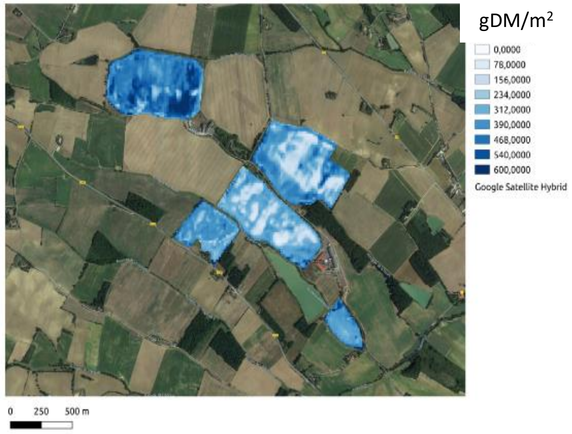
Realisation
T. Wijmer

ACEO

Crop biomass + Uncertainties



Cover crop biomass + Uncertainties

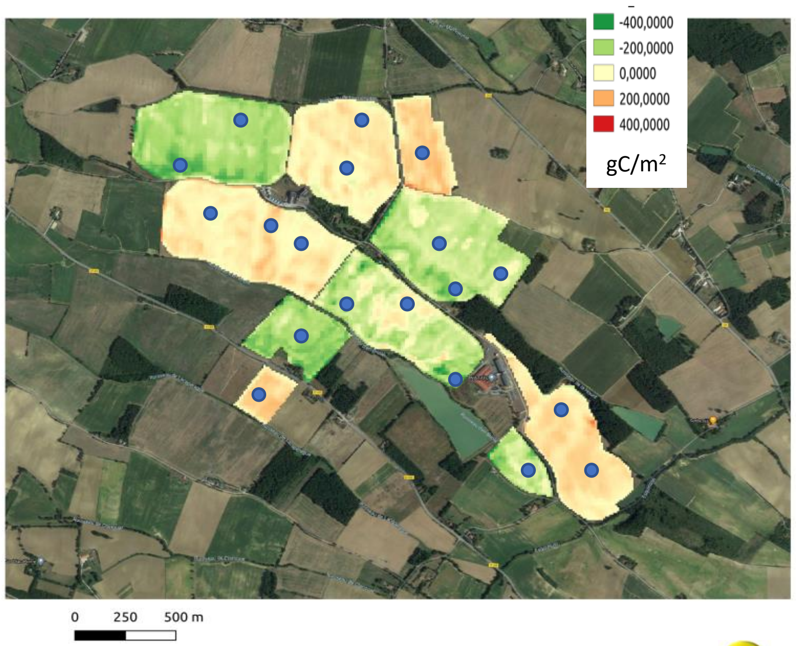


+ farmers data and the AMG soil model

10m resolution maps make it possible:

- to define an optimal cost/accuracy soil sampling scheme for verification of delta SOC stocks at plot/farm level
- to detect faster SOC stock changes by sampling areas with contrasted dynamics

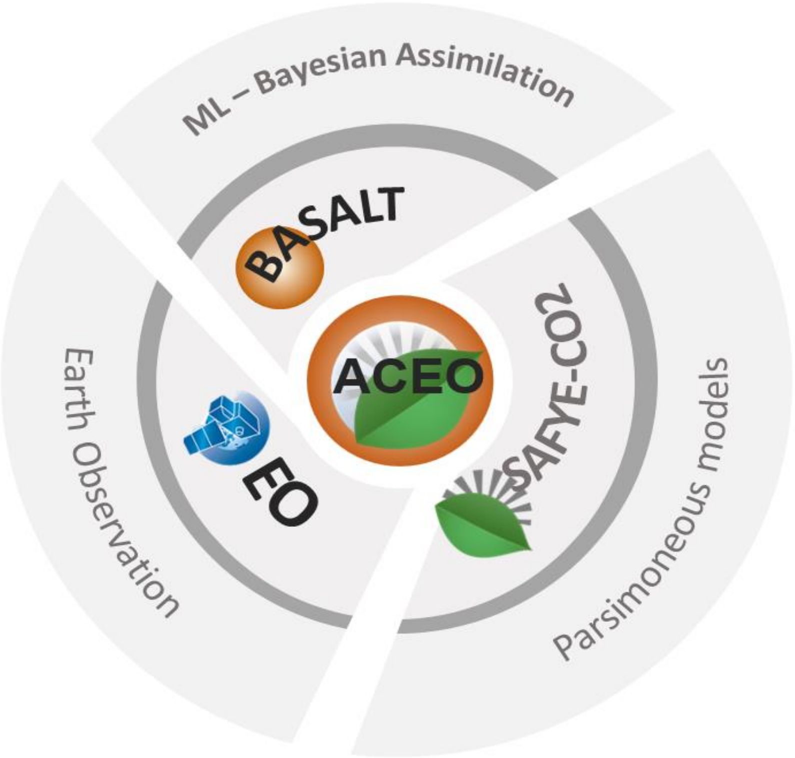
First C budget map at 10m resolution in 2019, for rotation cover crop/corn/wheat (Villeneuve farm, Bézéril, France)



C storage by the soil

C losses by the soil

Hybrid ecosystem modelling approach dedicated to upscalling



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

Not user friendly & good skills in programming

Main crops & some cover crops

Pixel level ➔ best for validation/verification

Cost depends on activity data collection method and soil sampling scheme for initialisation/verification

Scalability

Uncertainty assessment

Accuracy depends on access or not to local soil data, on accuracy of activity data (but less problematic than with classical crop models) and on operational EO obs.

Same tool whatever the context of application + baselines production (generic or specific)

Limits and perspectives for ACEO

- **Diagnostic approach only although some scenarii can be tested (e.g. straws management, effect of cover crops burial or export ➔ see BOS3) 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

- Diagnostic approach only although some scenarii can be tested (e.g. straws management, effect of cover crops burial or export ➔ see BOS3) and good transposability to other pedoclimatic regions
- Limited to a few crops and cover crops (straw cereals, maize, rapeseed, sunflower, fava bean, white mustard) ➔ progressive acquisition of new in-situ datasets for CAL/VAL in Europe (ICOS sites, collab with companies & cooperatives)
- So far only 2 soil models (AMG, COP) coupled to SAFYE-CO2 in ACEO ➔ coupling to new models (e.g. RothC) for ensemble approaches (PhD A. Ihasusta)
- Use of optical remote sensing data only can be limiting for operational applications (long cloudy periods) ➔ combining optical SAR (Sentinel 1) satellite data assimilation will allow to overcome this issue (PhD A. Géraud in collab with Netcarbon)
- Quality, accessibility and spatial resolution of the soil data/products (e.g. initial SOC stock, texture) ➔ 1) use high resolution remote sensing data for digital soil mapping (collab with E. Vaudour) for regional applications and 2) use local soil data (e.g. soil samples, plot level maps) when relevant (e.g. VCM)
- Access to reliable management data on straw management and organic amendments is currently the strongest limitation for all modelling & monitoring exercises (except in Spain, Netherlands?) ➔ use of API to access FMIS is not enough, management data must be verified first (agricultural advisor)

Conclusions

- **In the MRV context, EO data are mostly needed 1) for mapping some of the key Carbon farming practices (crop rotations, cover crop, management of weeds/spontaneous regrowth), 2) for quantifying C inputs to the soil as biomass.**

- **As pointed out by CIRCASA/ORCaSa ➔ need to develop a consistent framework for Monitoring of SOC stock changes (components of the C budget + uncertainties) for different context of application (NDC, VCM insetting, CAP) accounting for the spatial variability of biomass production, soil properties and C farming practices.**

Based on this observation and after analysing the pro & cons of current modelling approaches for monitoring SOC stock changes:

- **Development of an innovative Hybrid Monitoring approach enabling dynamic and objective/realistic monitoring of the impact of biomass restitution to the soil and C farming practices on the SOC stock changes ➔ AgriCarbon-EO**

- **Automated, large scale, high resolution, allowing uncertainty analysis at low cost adapted to different contexts of MRV (insetting, offsetting, CAP, NDCs) and compliant with common standards like VERRA, Label Bas Carbone and the CRCF ➔ e.g. able to produce both specific and regional pluriannual baselines see BOG3**

Thanks for your attention!!

Naturellement popcorn

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

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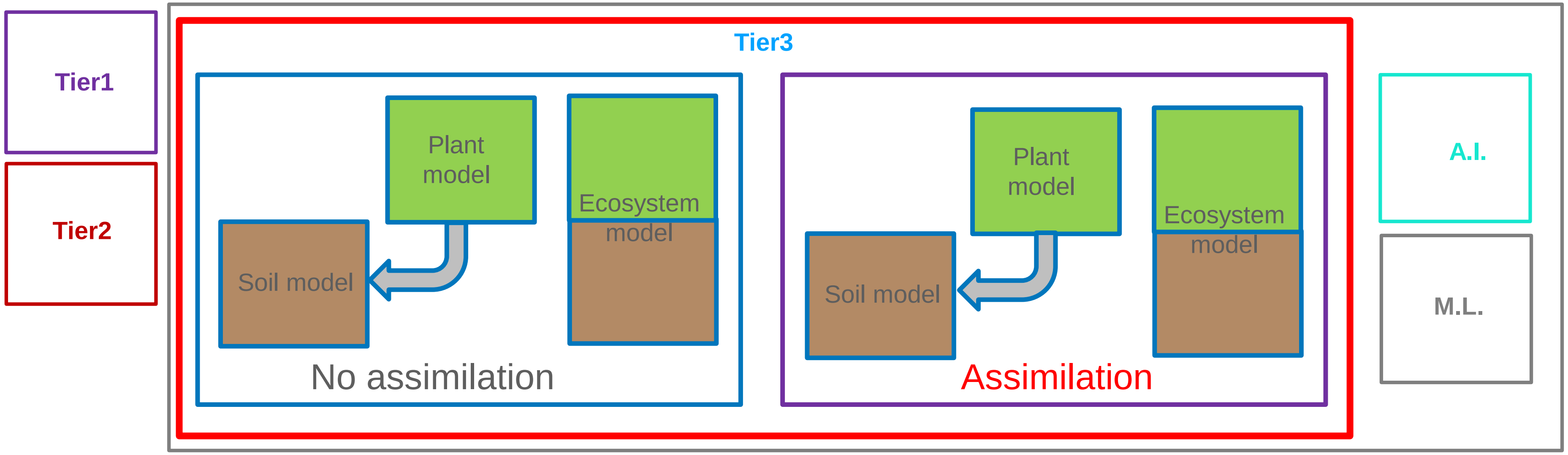
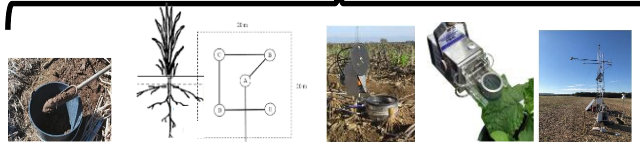
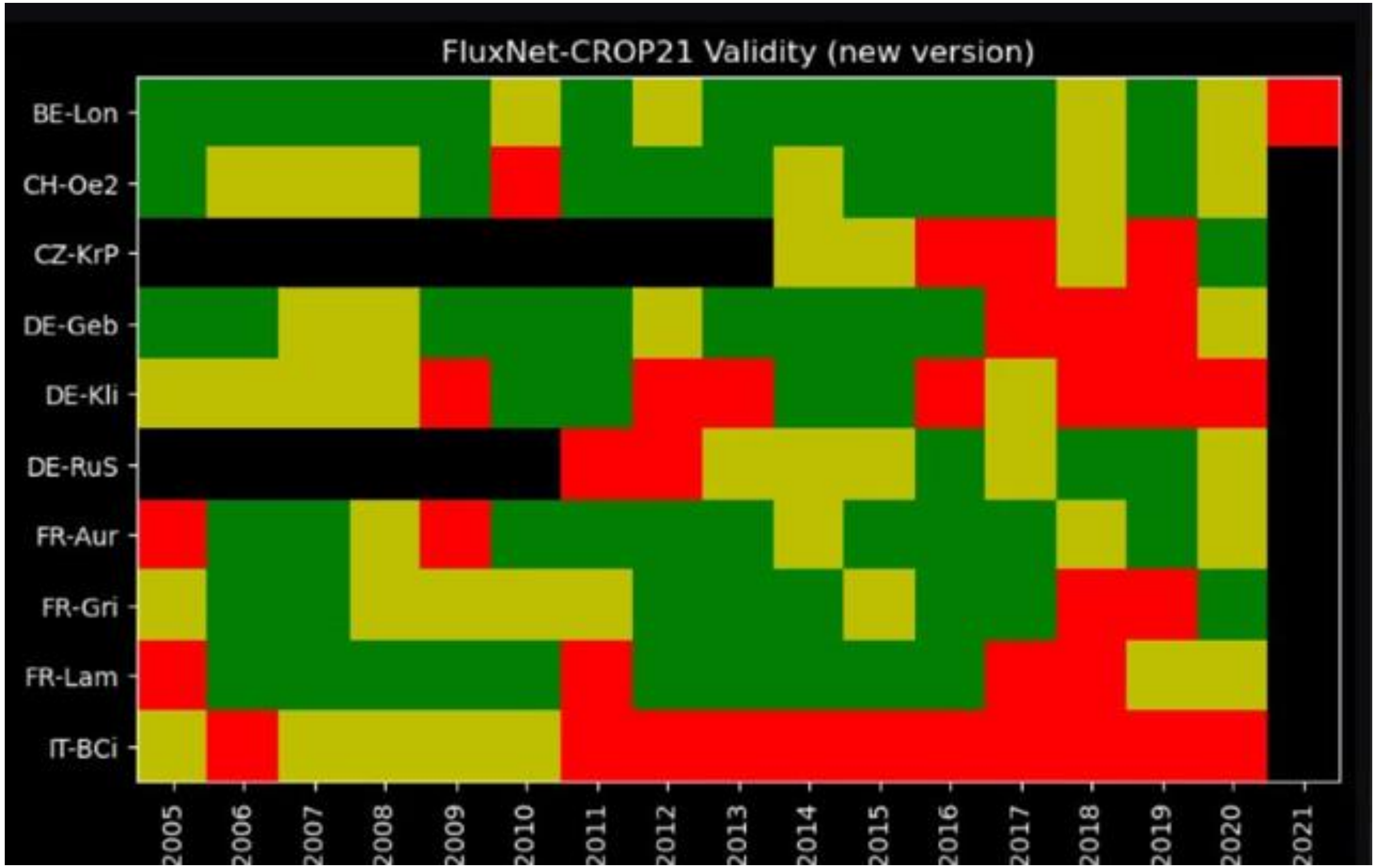
The soil and/or plant modelling approaches focussing on TIER3



Example of models	AMG RothC (Aarhus)	Process based or allometric models (e.g. Bollinder et al 2017)	STICS, CERES, EPIC, Daycent…	AMG + SAFYE-CO2 RothC + LUE model (RemoteC) ICBM + ML	FiON ACEO
Validation data Other data like SWC…may be usefull for evaluating the models	ΔSOC Soil respiration (Rh)	Biomass alloc *Fluxes (GPP, Ra)*	SOC Biomass alloc Fluxes (NEE, GPP, Ra, Rh)	SOC (ESU) Soil respiration (Rh) Biomass alloc (ESU) Fluxes	SOC (ESU) Biomass alloc (ESU)l Fluxes



Assessment of the data quality of the CROP21 dataset for our study

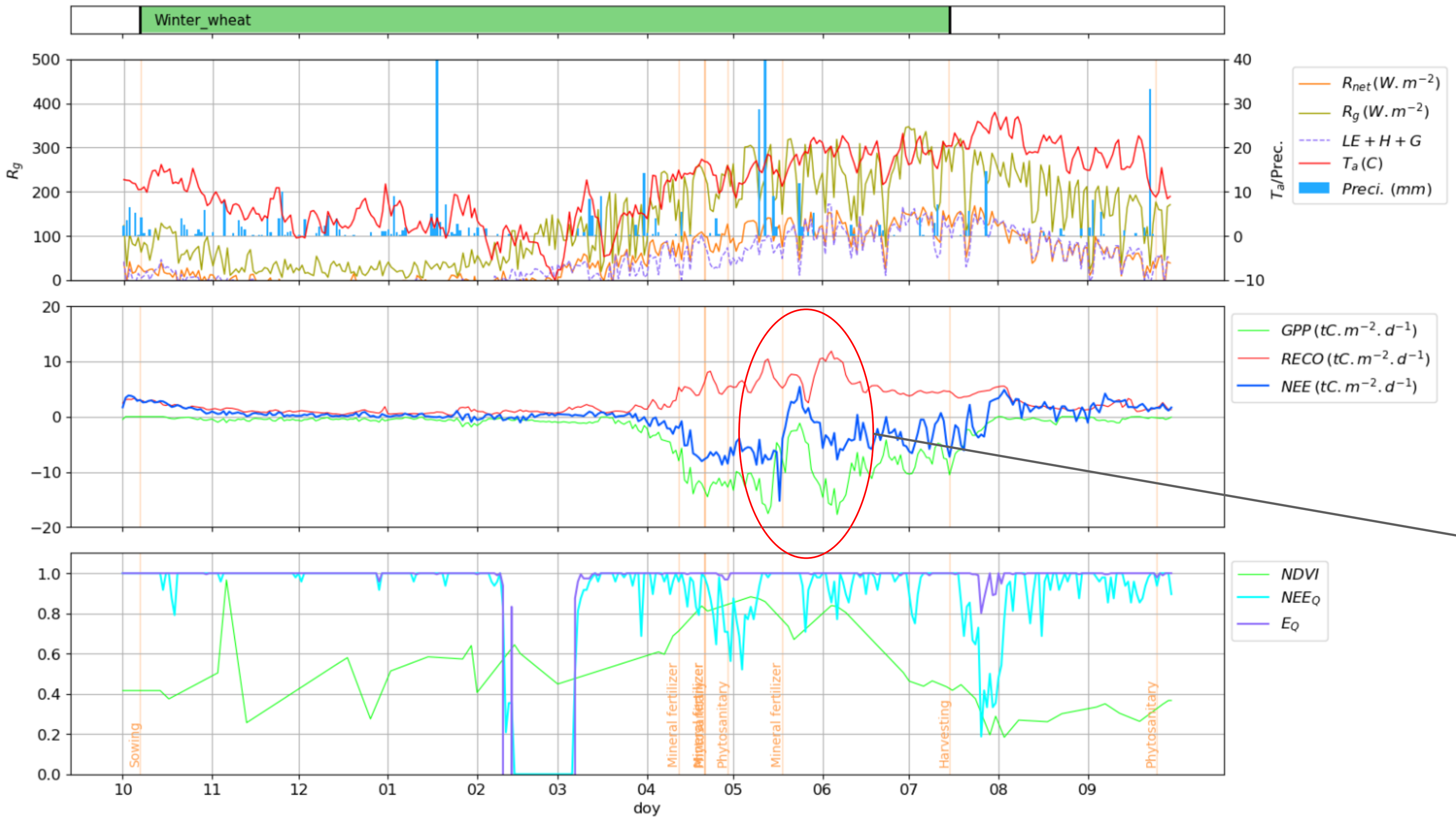


Unexploitable

OK

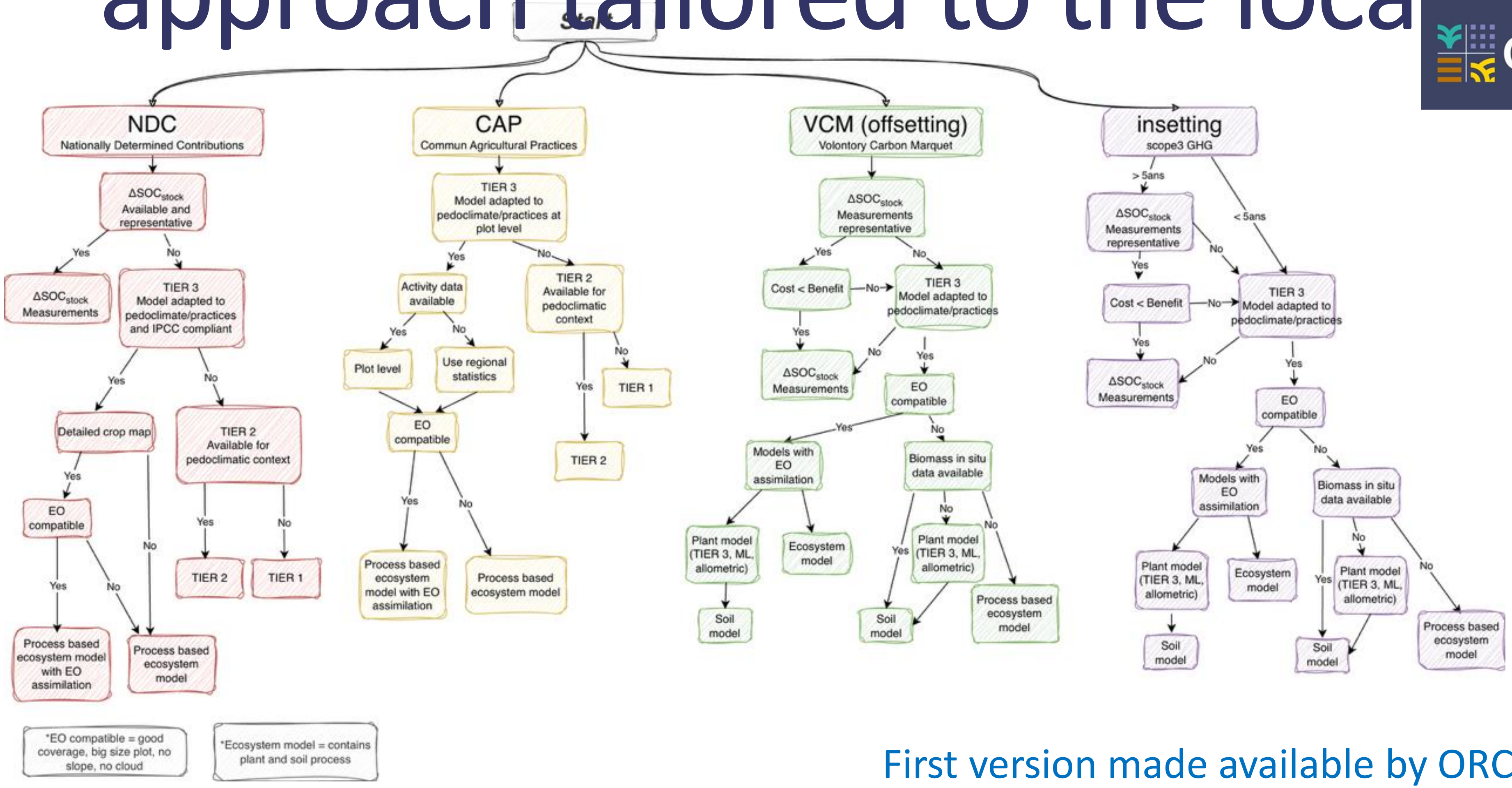
Good

DE-Geb in 2018 – Winter wheat



⇒ The drop in GPP is caused by the harvest on half of the parcel

Decision tree to choose the Monitoring approach tailored to the local context



ORCaSa MARVIC MRV for carbon farming

First version made available by ORCASA at the end of the year