Sentinel-2 Based Empirical Indicator of Cropland Annual CO_2 Fluxes

A. Ihasusta [a,*], L. Arnaud [a], A. Al Bitar [a], M. Fauvel [a], A. Favreau [b], R. Fieuzal [a], E. de Laroche [c], D. Laurent [d], G. Marchand [d], A. Tarko [c], V. Thierion [a], T. Wijmer [a], E. Ceschia [a]

[a] CESBIO, CNES/CNRS/INRAE/IRD/Université Toulouse III, Toulouse, France
[b] IPGP, IGN, Université de Paris - ENSG-Géomatique, IGN, France
[c] Agence de Services et de Paiement (ASP), Montreuil, France
[d] IGN, F-94165 Saint-Mandé, France

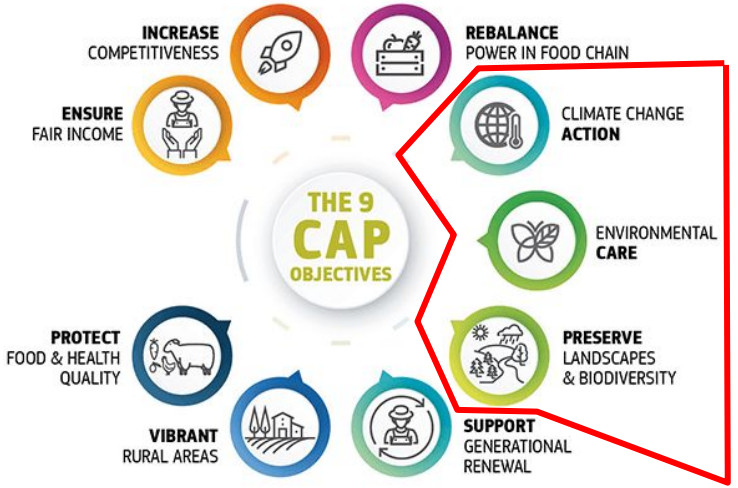
* *e-mail: ainhoa.ihasusta@univ-tlse3.fr*

Common Agricultural Policy & agri-environmental indicators

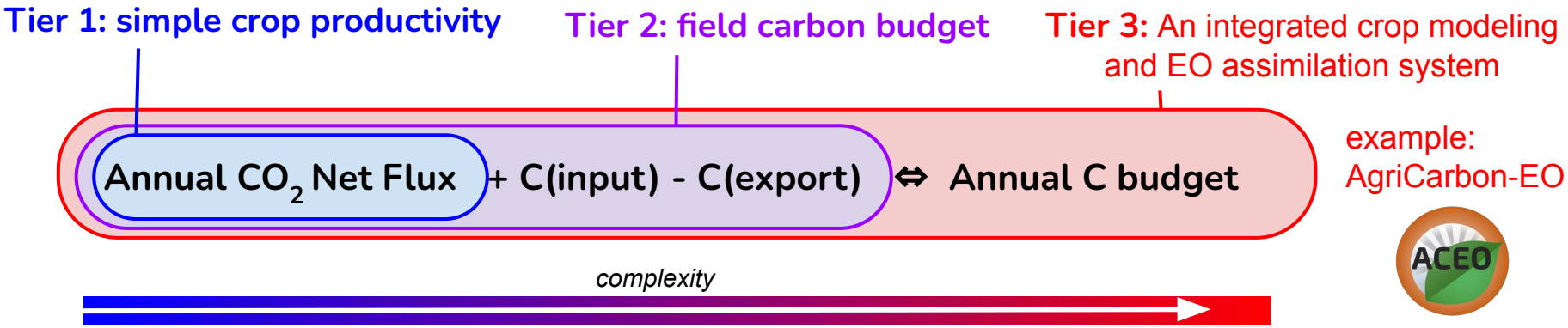
- Currently, modernizing the Integrated **A**dministration and Control System (**IACS**) and the payment of insurance premiums by the **C**ommon **A**gricultural Policy (**CAP**).

- Develop tools to map agri-environmental indicators:
  - biodiversity
  - leaching nitrates risks
  - **carbon budget**

- To be integrated in the next CAP, supported by the GreenDeal initiative and EC Climate Action (Carbon Farming, 2021)



Carbon budget indicator, the Tier complexity approach



In this study:

Carbon indicator TIER 1 (CT1) compute the annual **N**et **E**cosystem **P**roductivity (**NEP**)(tC/ha)

- **computed at intra-field** scale resolution (10m)
- **aggregated over the fields**
- **operationally** ready
- produced at **national scale**

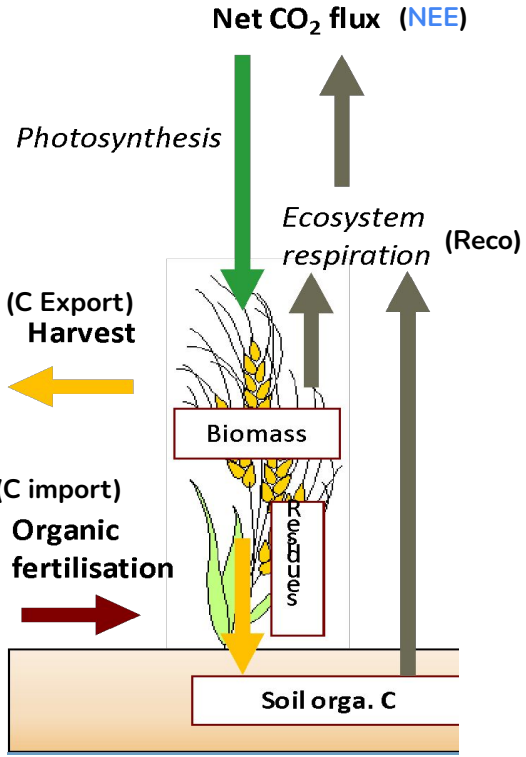
Carbon indicator Tier1

- We present the **methodology** applied to obtain the Carbon tier1 indicator for **crop fields** with its associated **uncertainty** over metropolitan **France for 2019**.

- We present **analysis of the spatial variability** of the indicator in terms of vegetation cover duration with respect to:
  - **the crop type**
  - **the cropping practices**
  - **the legislative frame**
    - Nitrates directive → mandatory to have covercrops for 2 months minimum.
    - Clay exemption → removes the Nitrates directive when soil clay percentage is high (defined per region).

Net Ecosystem Exchange & Net Ecosystem Productivity

Main components of carbon budget



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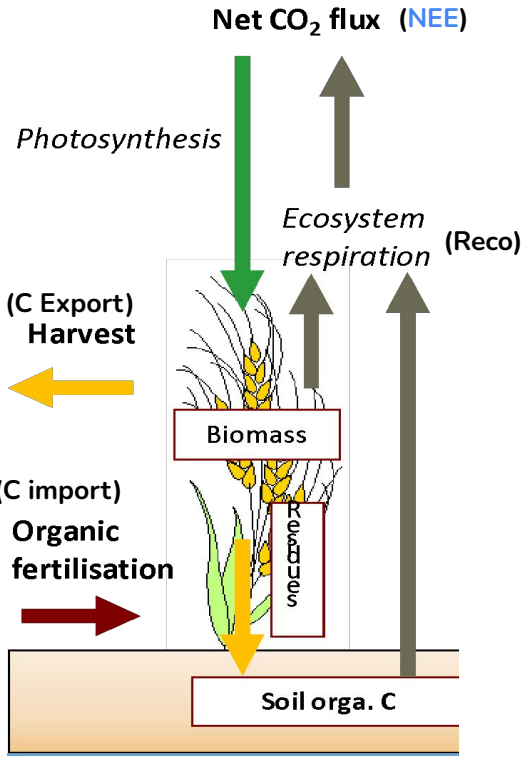
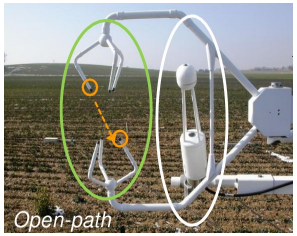


Eddy covariance method



Sonic anemometer and gas analyzer in open path. Source : T.Tallec

Net Ecosystem Exchange :

$NEE = cov(w', [CO_2]')$

$$NEP = \sum_{1\ year} NEE$$

Net Ecosystem Exchange & Net Ecosystem Productivity

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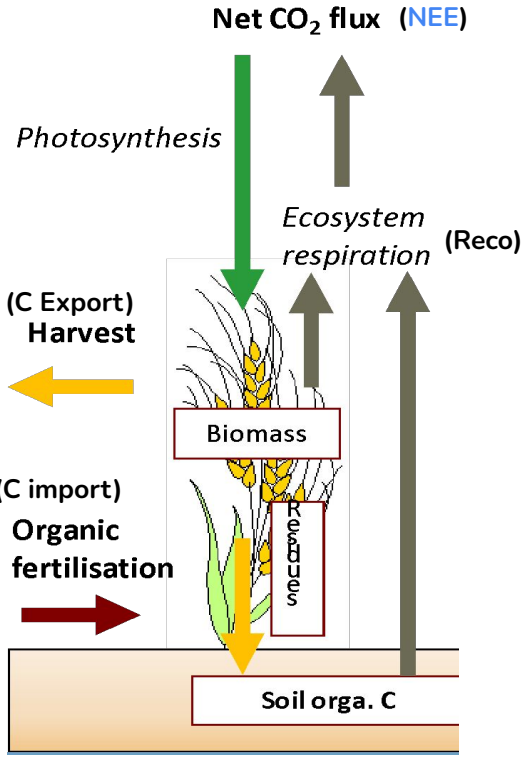

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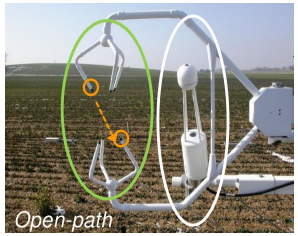

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Net **E**cosystem **E**xchange :

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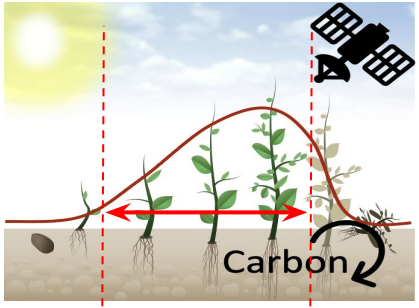
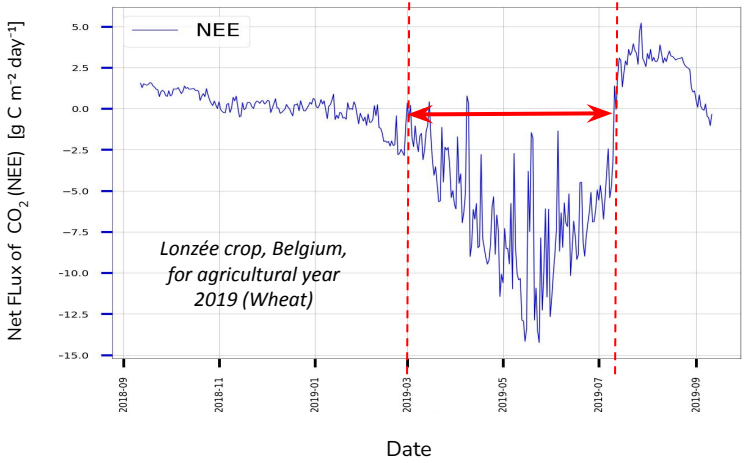
Number of **D**ays of **A**ctive **V**egetation

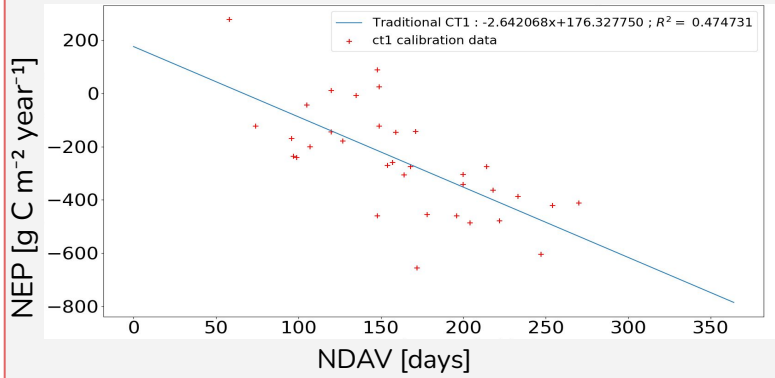




$NEP_{2019,\ Lonzée}$ = - 6.65 tC of CO_2 ha^{-1}

Mapping Cropland Annual CO_2 Fluxes using S2

Relation between NDAV and NEP
(Ceschia et al.,2010)



> Eddy Covariance based fluxes.
> 15 European sites (climate variability).
> Main crops (wheat, maize... ~ 15 cultures but not rice).

NDAV2NEP

Analytic derivation of the fitting uncertainty :

$$\sigma_{NEP} = \sqrt{\sigma_a^{\,2}\, NDAV^2 \; + \sigma_b^{\,2} \; + a^2 \sigma_{NDAV}^{\;\;2}}$$

Hypothesis :

- Gaussian error model for the flux of CO_2 **&** NDAV~ $N(\mu_{NDAV} = x, \sigma_{NDAV})$
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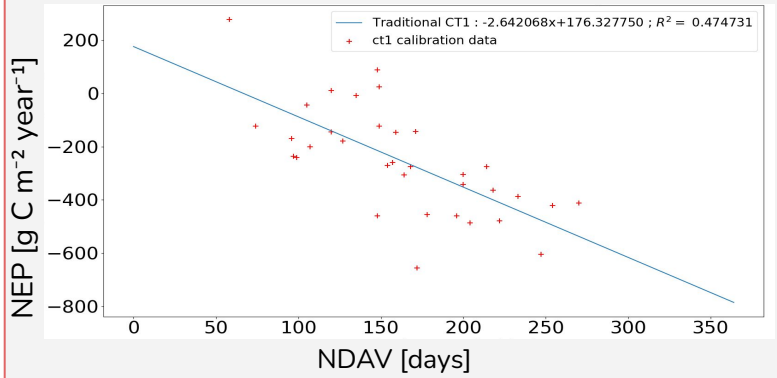

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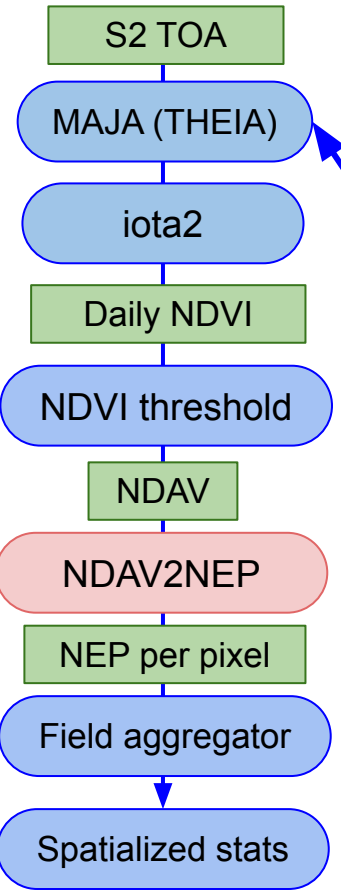

Sentinel 2A&B :
Optical satellites (13 bands)
High spatial resolution (10m) and temporal (5 days)

- **MAJA** : atcor for Atmospheric correction and MACCS for cloud mask,
- Distributed through THEIA

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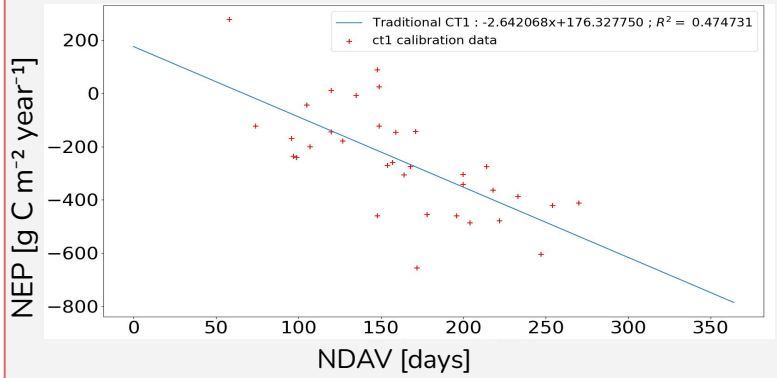

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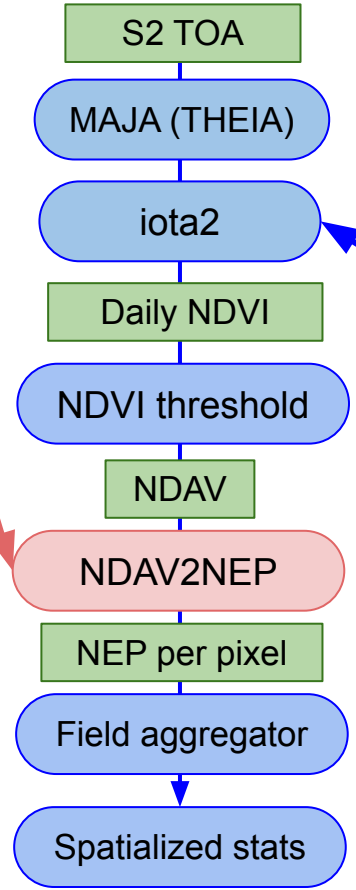

iota2

A framework for landcover production based on Orfeo toolbox.

It generates intermediate product for daily smoothed reflectances.

https://framagit.org/iota2-project/iota2/

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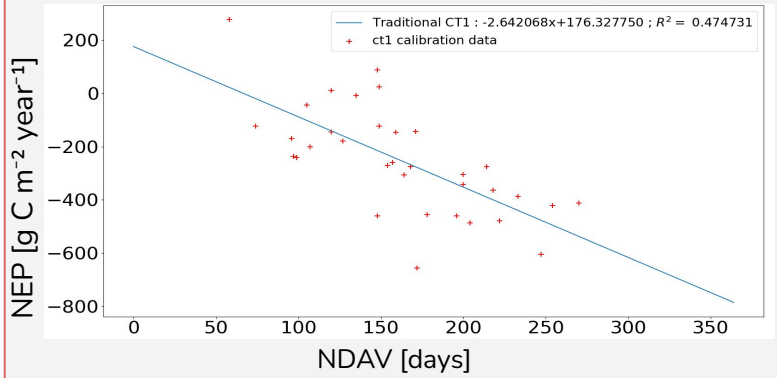

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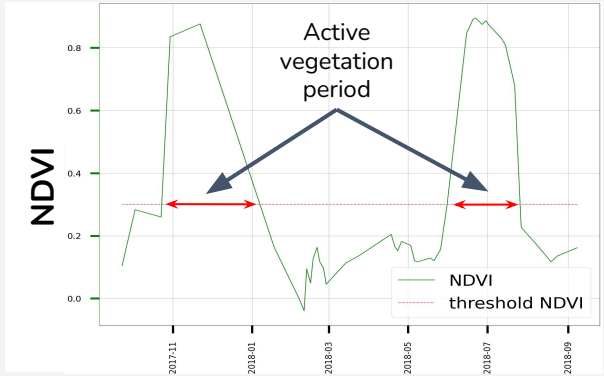
S2 TOA
MAJA (THEIA)
iota2
Daily NDVI
NDVI threshold
NDAV
NDAV2NEP
NEP per pixel
Field aggregator
Spatialized stats

NDAV Estimation



Lonzée parcel, Belgium, for agricultural year 2018 (Mustard + potatoes)

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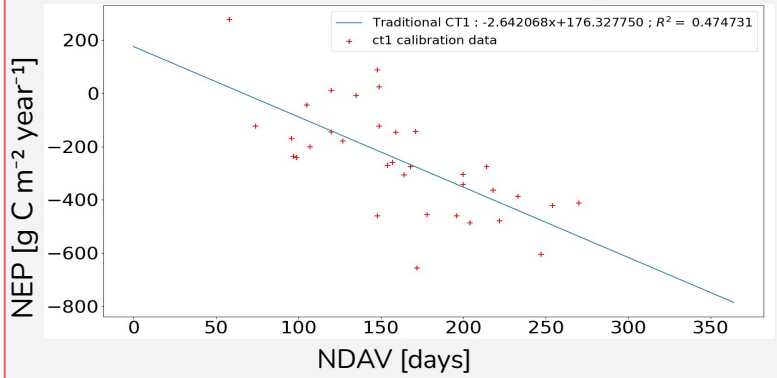

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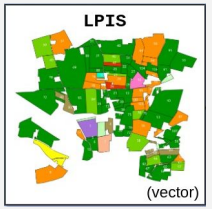
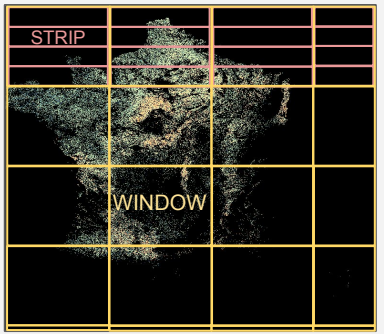
Field aggregation

➢ Crop boundary



*LPIS : Land Parcel Identification System

➢ NEP (14 billion pixel rasters)



Parallel computation

Mapping Cropland Annual CO_2 Fluxes using S2

Relation between NDAV and NEP
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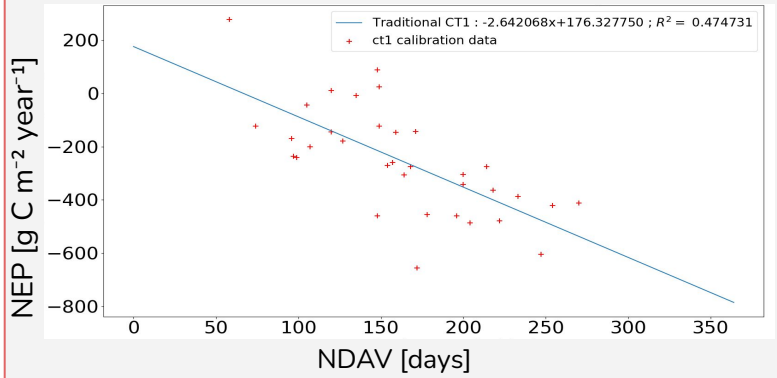

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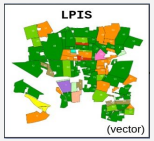
Spatialized data



Crop type from LPIS : Land Parcel Identification System

DIRECTIVE NITRATE

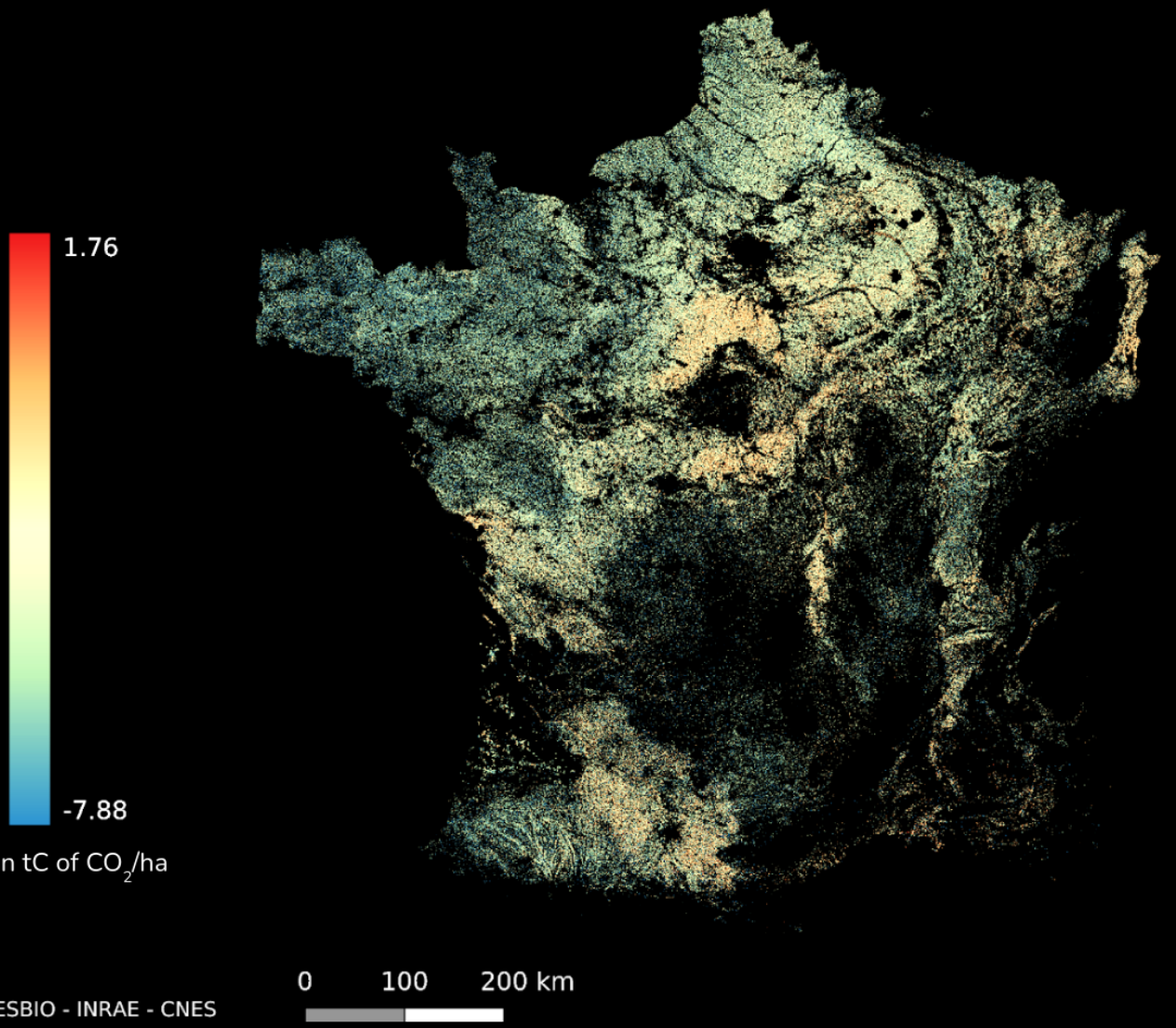
Vulnerable Nitrate Zones from Nitrate Directive

ISRIC World Soil Information

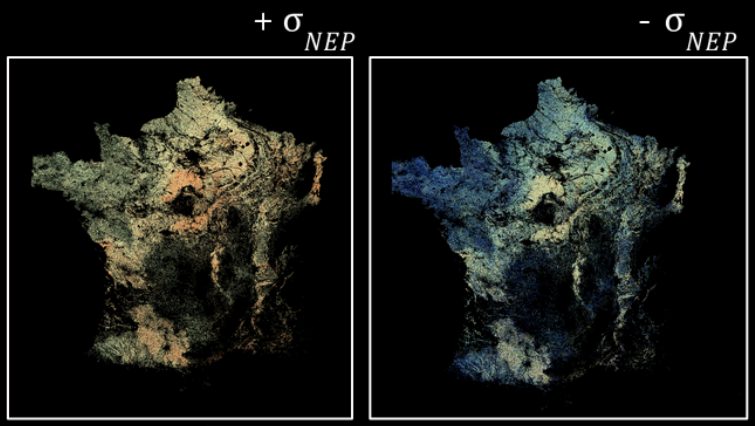
Soil Clay percentage from Soilgrids (International Soil Reference and Information Centre)

Net annual flux of CO_2 map for 2019

All cultures



- Blue/green areas: high CO_2 uptake ⇒ high probability of carbon sink.
- Yellow/orange zones: certainty of destocking carbon.
- Climate gradient can't explain spatial variability alone.



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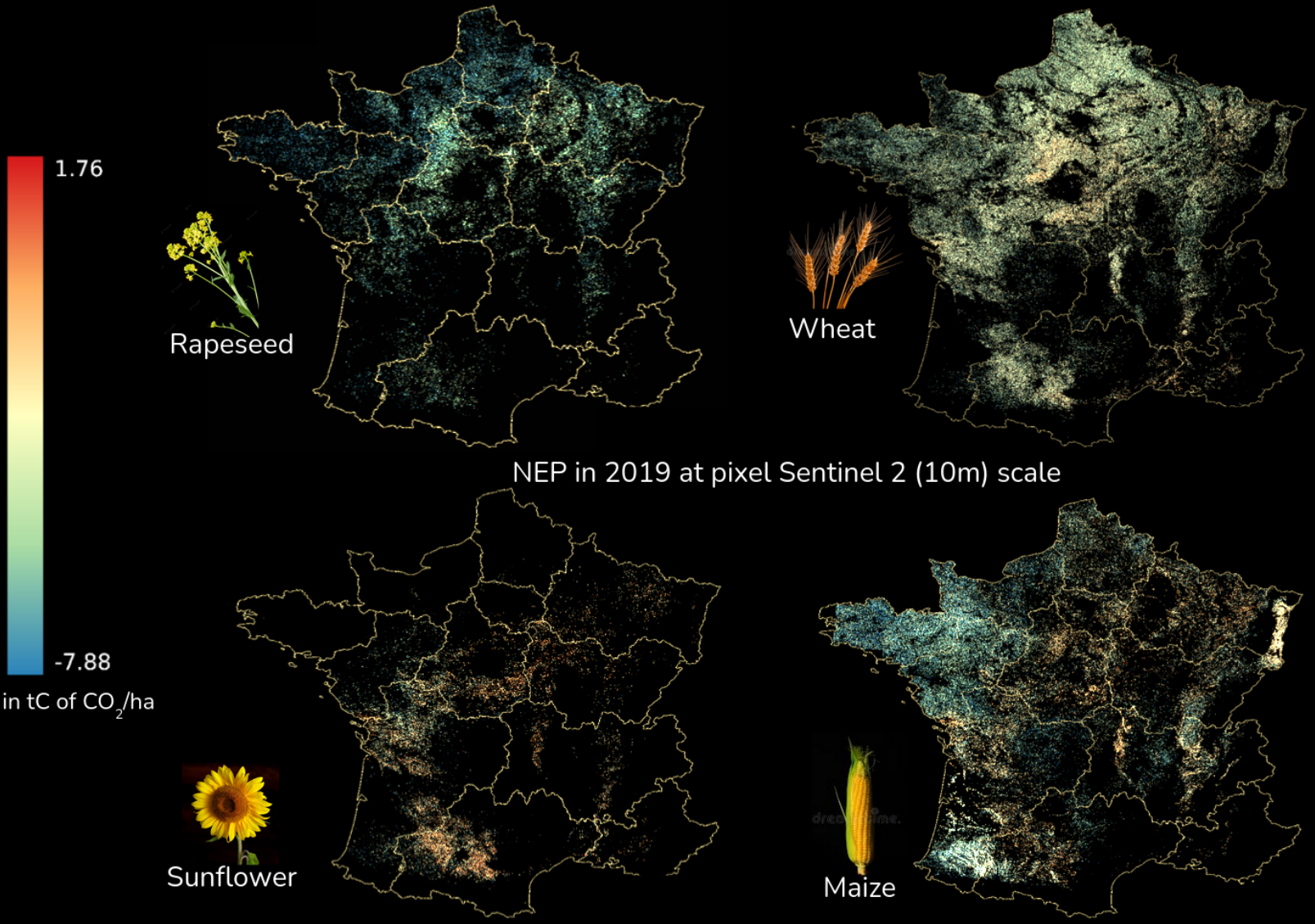
Intercrop comparison



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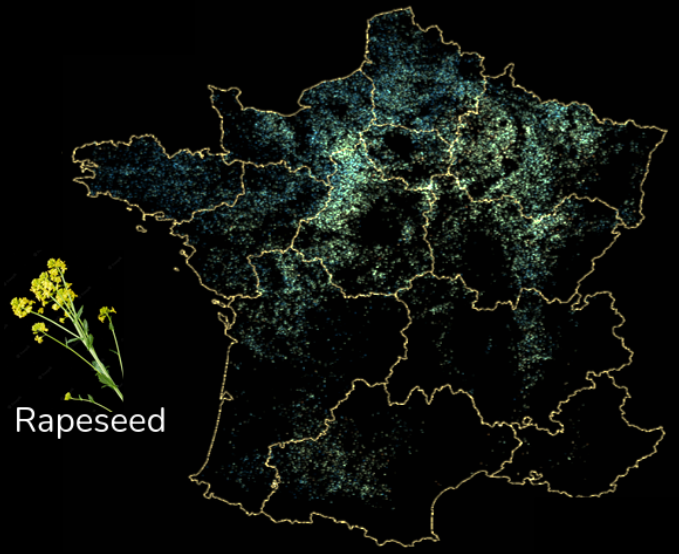
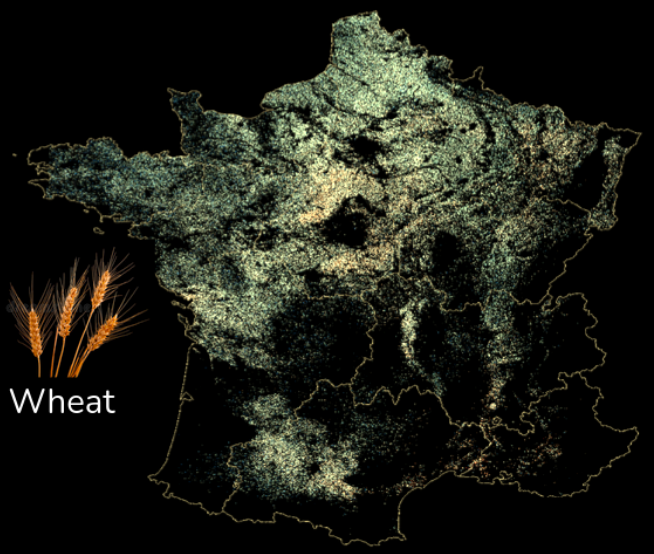


Rapeseed



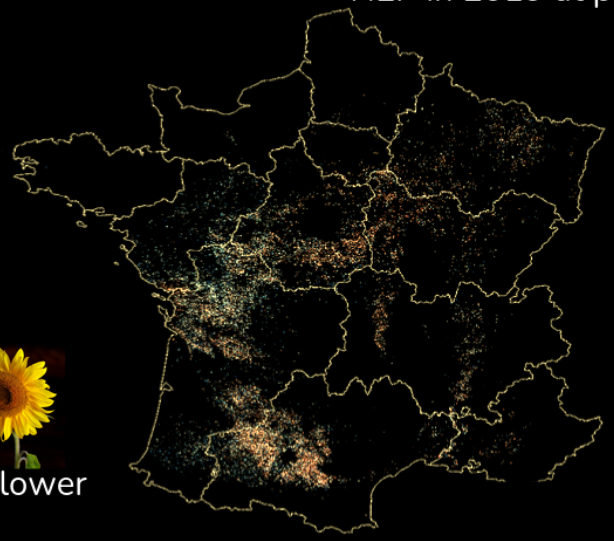
Wheat

NEP in 2019 at pixel Sentinel 2 (10m) scale

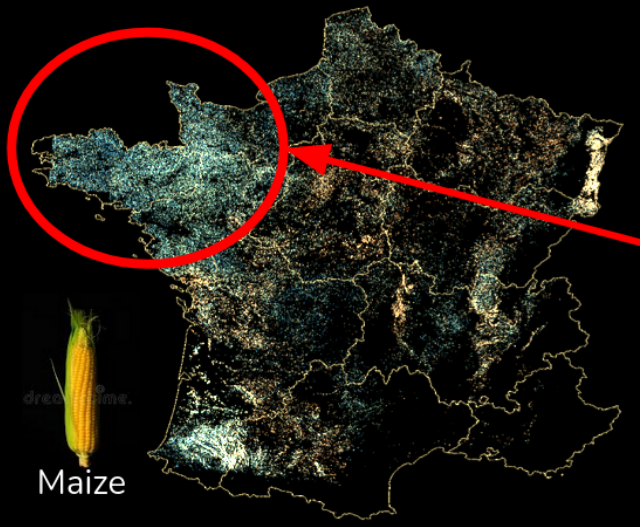
WINTER CROP

Winter crop fix more CO_2 → longer vegetation cycle for winter crop

BUT



Sunflower



Maize

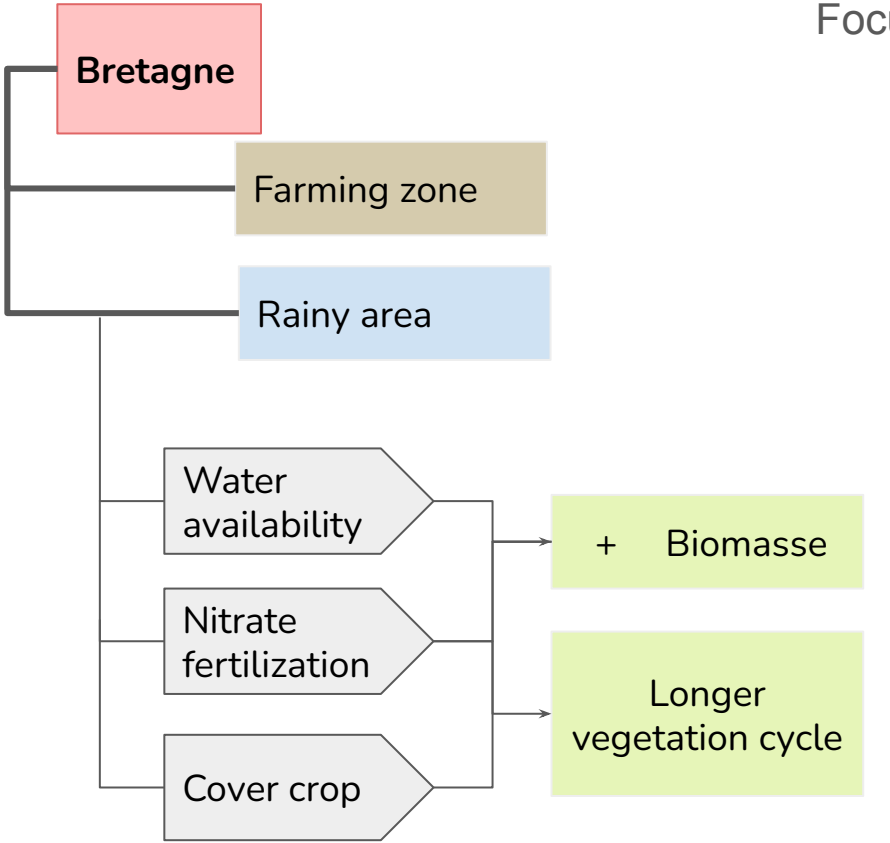
SUMMER CROP

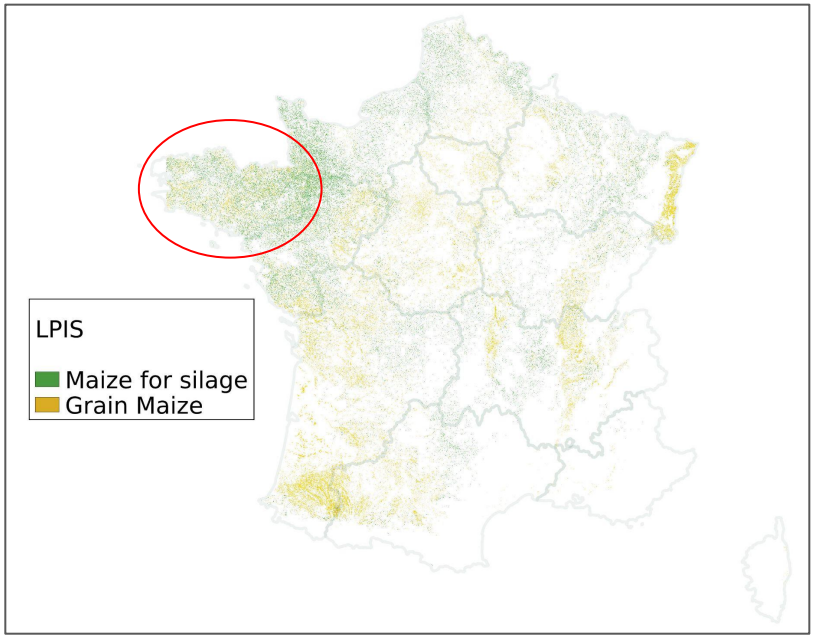
Exception for Maize, especially in Bretagne

0 100 200 km

Agricultural practices in Bretagne

Focus on Maize





Maize repartition from land cover information (LPIS)

Agricultural practices in Britain

Focus on Maize

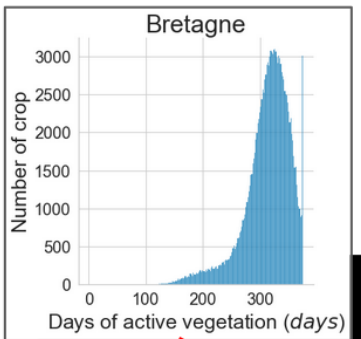
Bretagne

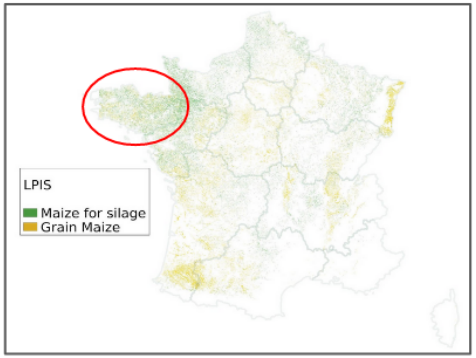
- Farming zone
- Rainy area

- Water availability
- Nitrate fertilization
- Cover crop

→ + Biomasse
→ Longer vegetation cycle

→ More CO_2 fixation





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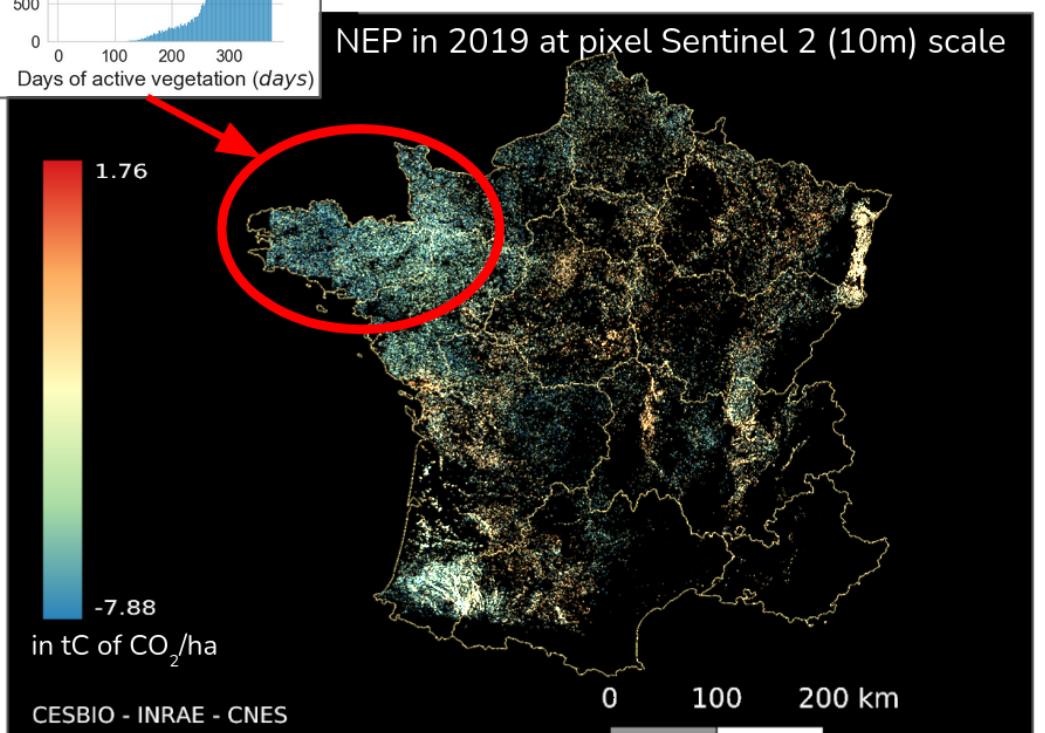
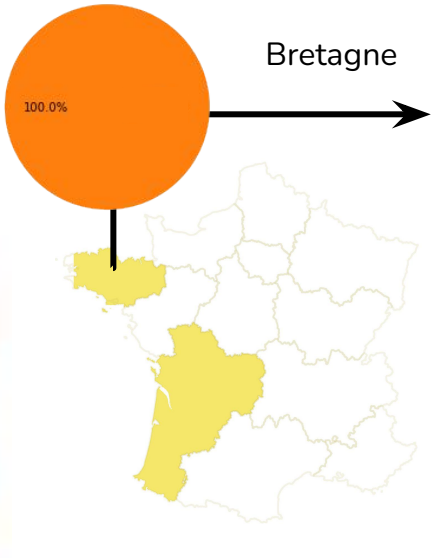
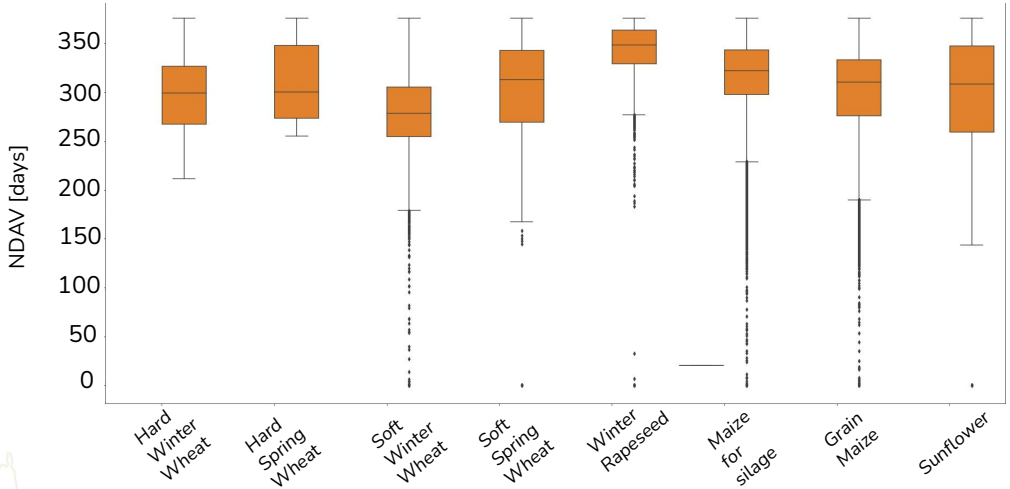


Practices or Reglementation influence ?

4 categories of zones :

- No restriction
- Nitrates vulnerable
- Clay stress
- Nitrates vulnerable & Clay stress → Directive Nitrates exemption





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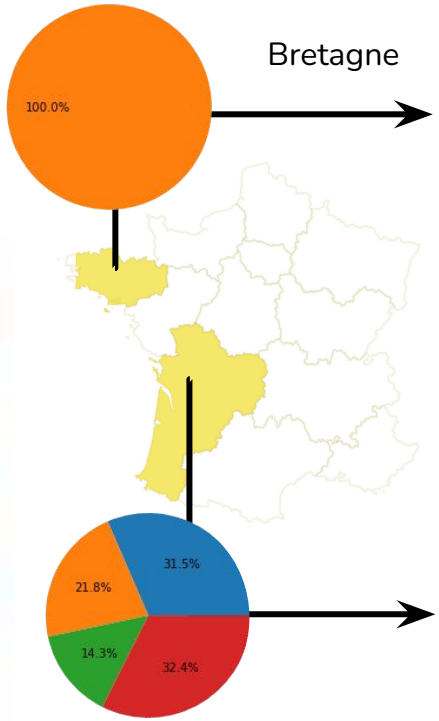

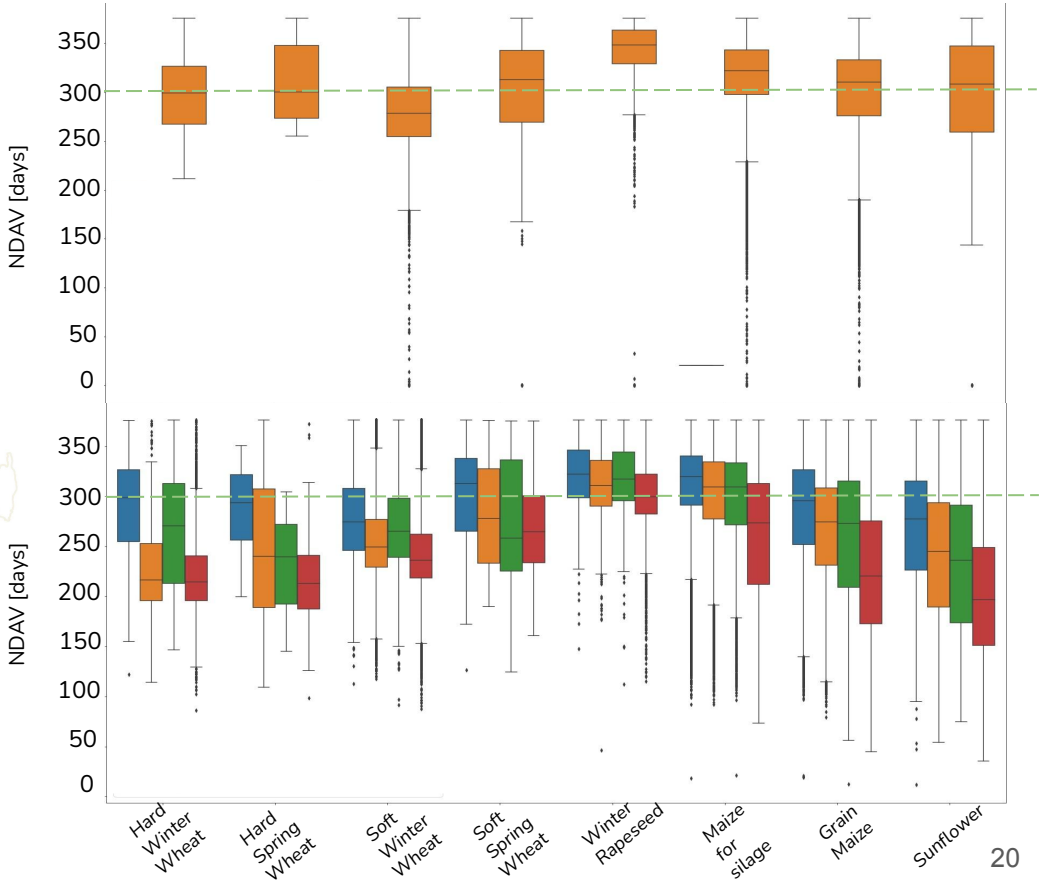

Conclusion

- **A Simple** model for Net Annual Flux of CO_2 estimation over the entire **metropolitan France**, for the **major cultures**, thanks to Earth Observation.
  → **Analytical** estimation of the fitting **uncertainty**.

- An **operationally ready** approach for estimating an indicator linked to the C budget of major crops with a view to **paying environmental premiums** (Ecoschemes) for the CAP.

- Regional multi-crop spatial analysis show that **agricultural practices and not restrictions (reglementation) is the main factor influencing the CO_2 flux.**
  Which may present an advantage in the context of incentives strategie for carbon ?

To go further :

- Improve uncertainty estimation with **NDAV uncertainty**

- Estimate the **total C budget** at parcel scale with the **Tier 2 approach** by adding the **agricultural data** on yield and fertilization ⇒ **To be preferred in the context of financing farmers** according the amount of carbon they store.

Thank you for your attention !

Questions ?

Ainhoa IHASUSTA

e-mail : ainhoa.ihasusta@univ-tlse3.fr

References

Carbon Farming (2021), European Commission, Directorate-General for Climate Action, Radley, G., Keenleyside, C., Frelih-Larsen, A., et al., *Setting up and implementing result-based carbon farming mechanisms in the EU : technical guidance handbook*, Publications Office of the European Union, 2021, **https://data.europa.eu/doi/10.2834/056153**

Ceschia, E., P. Beziat, J. F. Dejoux, M. Aubinet, Ch Bernhofer, B. Bodson, N. Buchmann, et al. 2010. *Management Effects on Net Ecosystem Carbon and GHG Budgets at European Crop Sites.* Agriculture Ecosystems & Environment 139 (3): 363-83. **doi.org/10.1016/j.agee.2010.09.020**.