# Analysis of the biogeochemical and biogeophysical effects of cropland management changes to prioritize actions in a perspective of climate change mitigation

Eric Ceschia, Dominique Carrer, Morgan Ferlicoq, Gaétan Pique, Rémy Fieuzal, Raphaël Garisoain, Elias Azzi

# Analysis of the biogeochemical and biogeophysical effects of cropland management changes to prioritize actions in a perspective of climate change mitigation

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And

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# Introduction

- First studies comparing biogeochemical and biogeophysical effects were on forest ecosystems (e.g. *Betts et al. 2000 ; Rottenberg & Yakir 2010 ; O'Halloran et al. 2011*)

- For cropland, during many decades, studies were either focussed on :
  - 1) Soil C storage and reduction of Green House Gases (GHG) emissions for climate mitigation,
  - 2) Or the effects of management practices on biogeophysical effects (e.g. RFα) caused by changes in cropland management (e.g. *Genesio et al., 2012 ; Davin et al. 2014 ; Luyssaert et al., 2014*).

- To compare biogeochemical effects with the $RF_\alpha$ caused by cropland management changes, the latter had to be converted in $CO_2$-eq but stabilised methodologies to do so were missing,

- In recent years, though, methodological advances allowing to convert albedo effects in $CO_2$-eq raised awareness of the potential significative effects of $RF_\alpha$ on climate mitigation (see *Bright et al. 2015*).

- As a consequence, recent studies showed that for some management changes $RF_\alpha$ had impacts of the same order of magnitude than biogeochemical effects.

# Introduction

In this presentation we will :

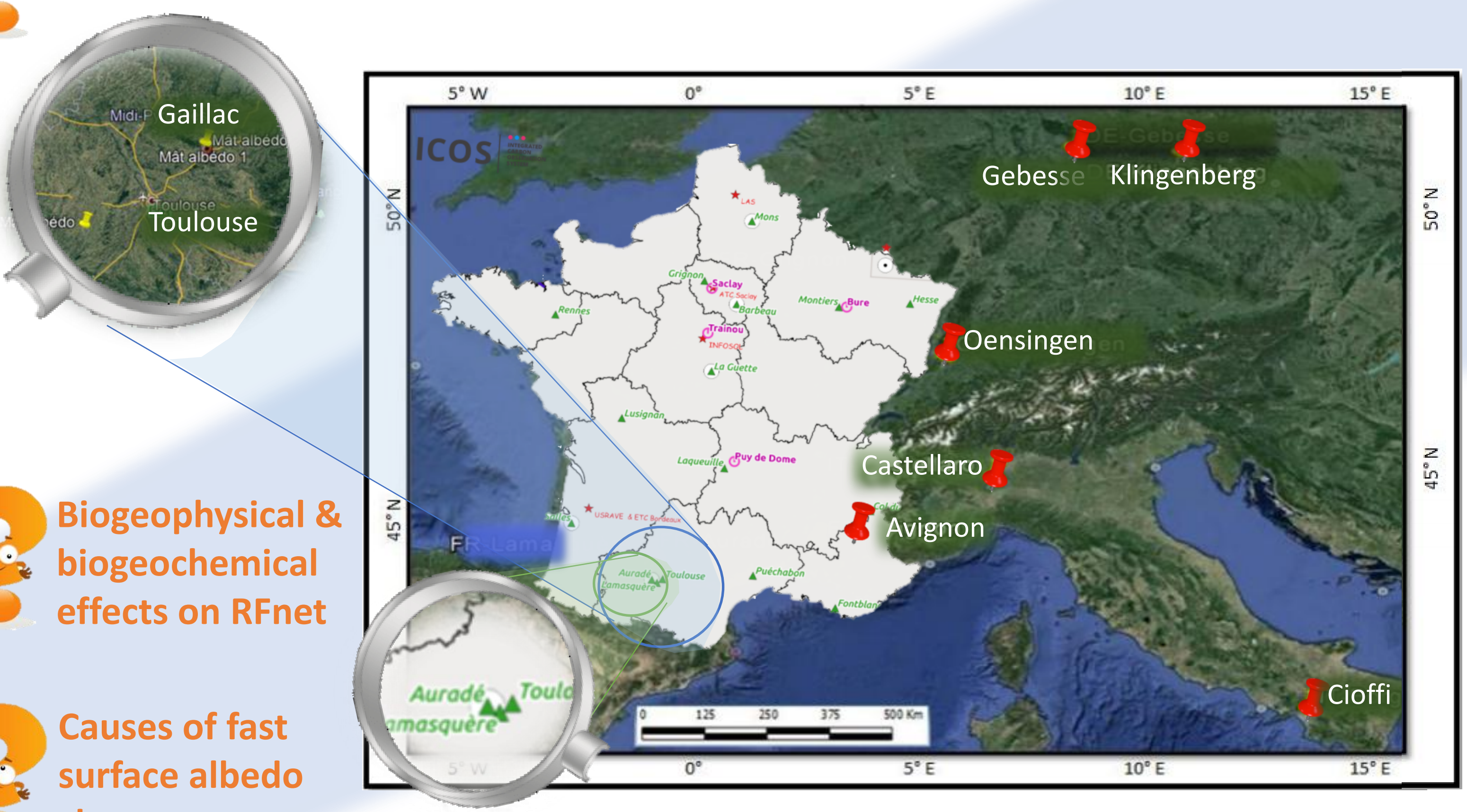
- First analyse the causes of surface albedo dynamics on croplands in order to identify land management changes that could contribute to climate change mitigation through both CDR and SRM approaches,

- Then we will compare short term and long terms biogeophysical and biogeochemical effects of some management changes at larger scale to analyse their direct and undirect effects on the net radiative forcing.

# Various spatial and temporal scales of study

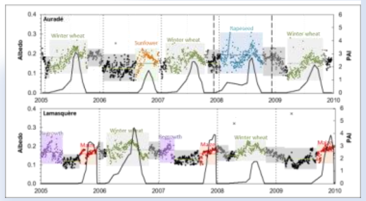
**Gaillac (81)**

**Biogeophysical effects of cropping sytems**




**Lamasquère (31)**

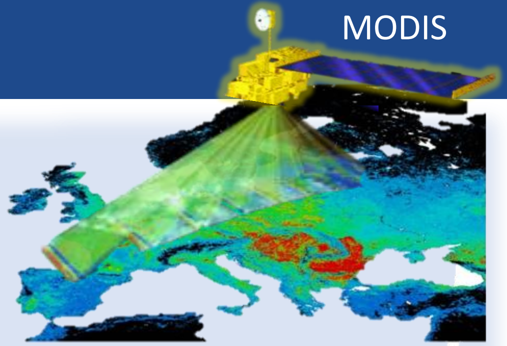

**Biogeophysical & biogeochemical effects on RFnet**



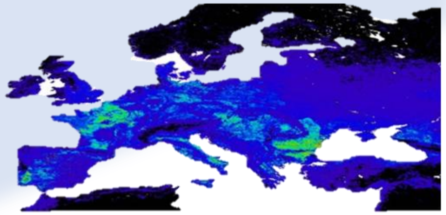

**Causes of fast surface albedo changes**

In situ measurements/Southwest France

European ICOS sites




Surface albedo dynamics



RFα

**Consequences of cropland management changes on biogeochemical & biogeophysicial (mainly RFα) components of RFnet**

Satelite data and /or modelling at European scale

# What do local scale studies teach us ?

# Methodology for in situ measurements


**Dynamics of surface albedo :**

① **Daily weighted average albedo**

**Half-hourly measured albedo** (CNR1) and weighted by incident solar radiation

② **Radiative forcing equation. We choose a bare soil albedo (measured on each site) as a reference for croplands.**

$$RF\alpha\ (W.m^{-2}) = -SWin \times TA \times \Delta albedo$$

$$T_A = \frac{SW_{IN}}{R_{TOA}}$$

$$\alpha_{daily} - \alpha_{bare\ soil}$$

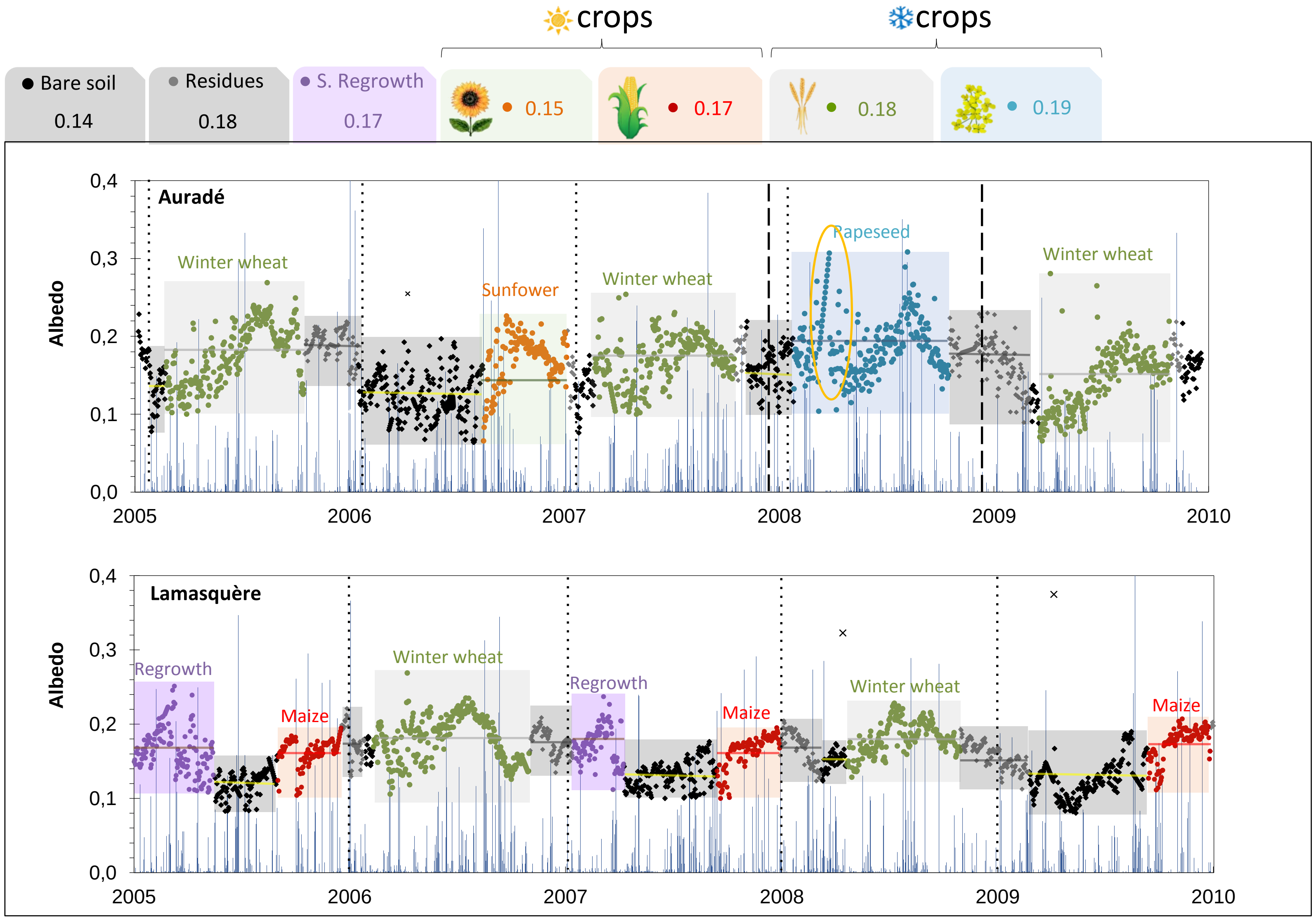
③ **Annual radiative forcing was calculated over a cropping year by using the dynamics of each terms of the previous equation.**

if α increase, $FR_\alpha < 0$ (Eq. C sink)

if α decrease, $FR_\alpha > 0$ (Eq. C source)

④ **Conversion in $CO_2$-eq based on AF method (*Betts et al. 2000*)**

# Albedo vs. cropland status (land cover)




The rapeseed suffered from November **drought and frost** that increased surface albedo because of leaf damage + snow.

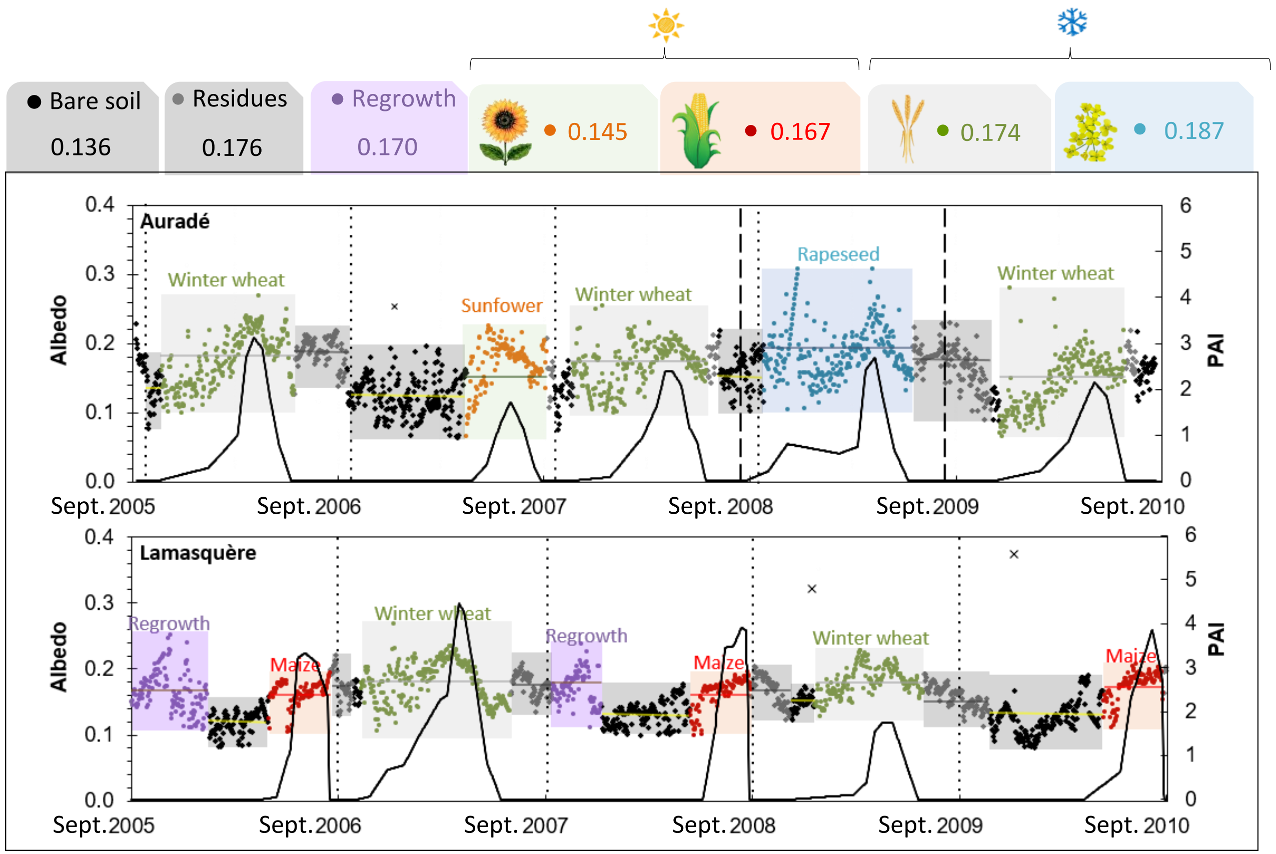
LC : $\alpha_{residues} \approx \alpha_{crop} \approx \alpha_{S.regrowth} > \alpha_{bare\ soil}$

$\alpha_{bare\ soil} = f(soil\ humidity)$

➔ Dry soil albedo > wet soil albedo

Crop type: $\alpha_{rapeseed} > \alpha_{WW} > \alpha_{maize} > \alpha_{sunflower}$

# How do crop development affects surface albedo ?

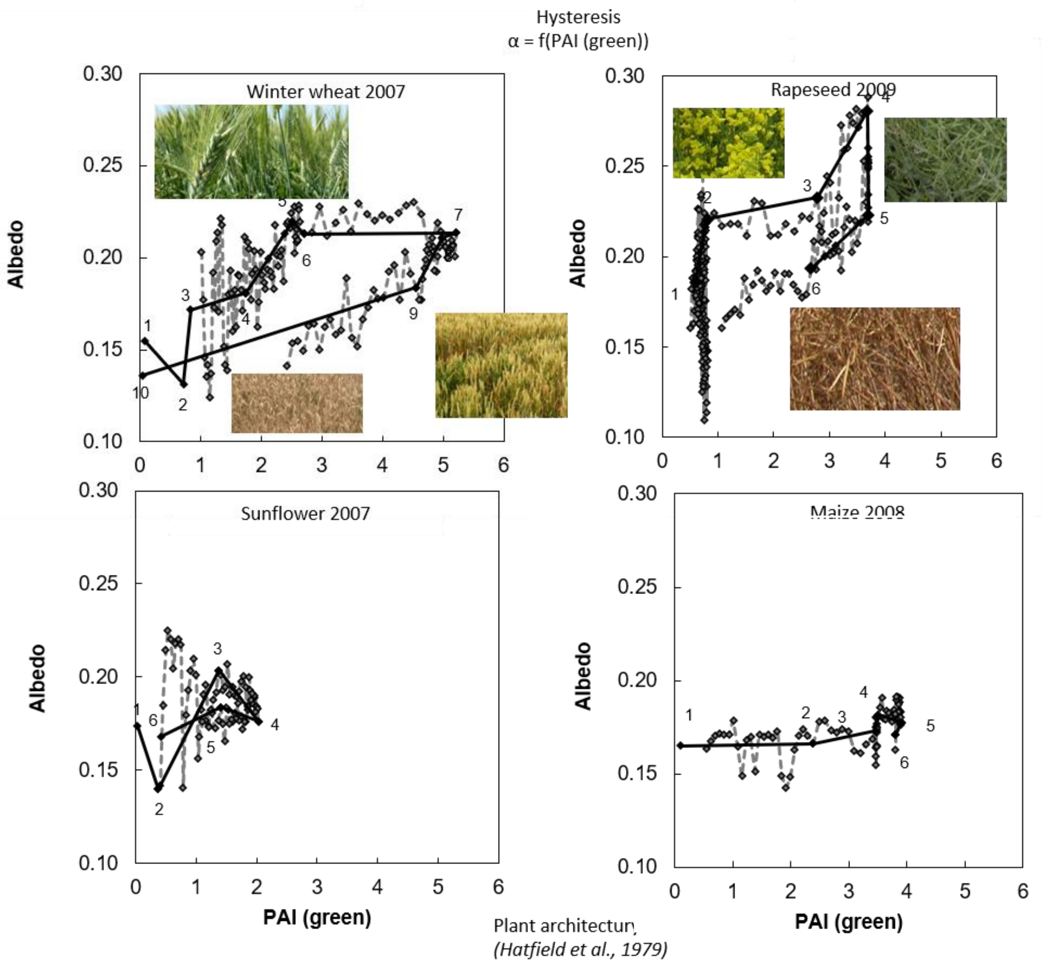



In general, surface albedo increases with the green plant area index (PAI) but the response is crop dependant;

- For winter wheat and rapeseed, PAI reaches its maximum at $PAI_{max}$,
- For maize, the albedo response to PAI is less pronounced,
- For sunflower maximum albedo occurred before $PAI_{max}$.

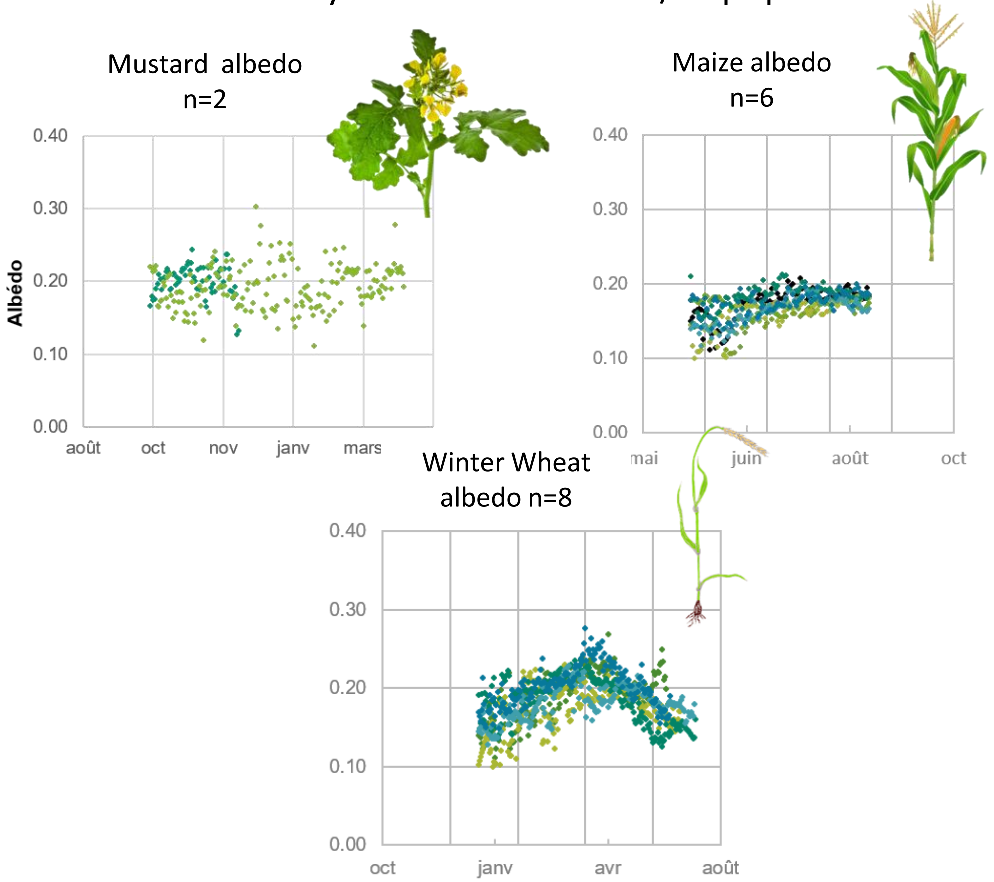
# How do crop development affects surface albedo ?

## Crop phenology effect on surface albedo




## Albedo dynamics differ accroding to crop species

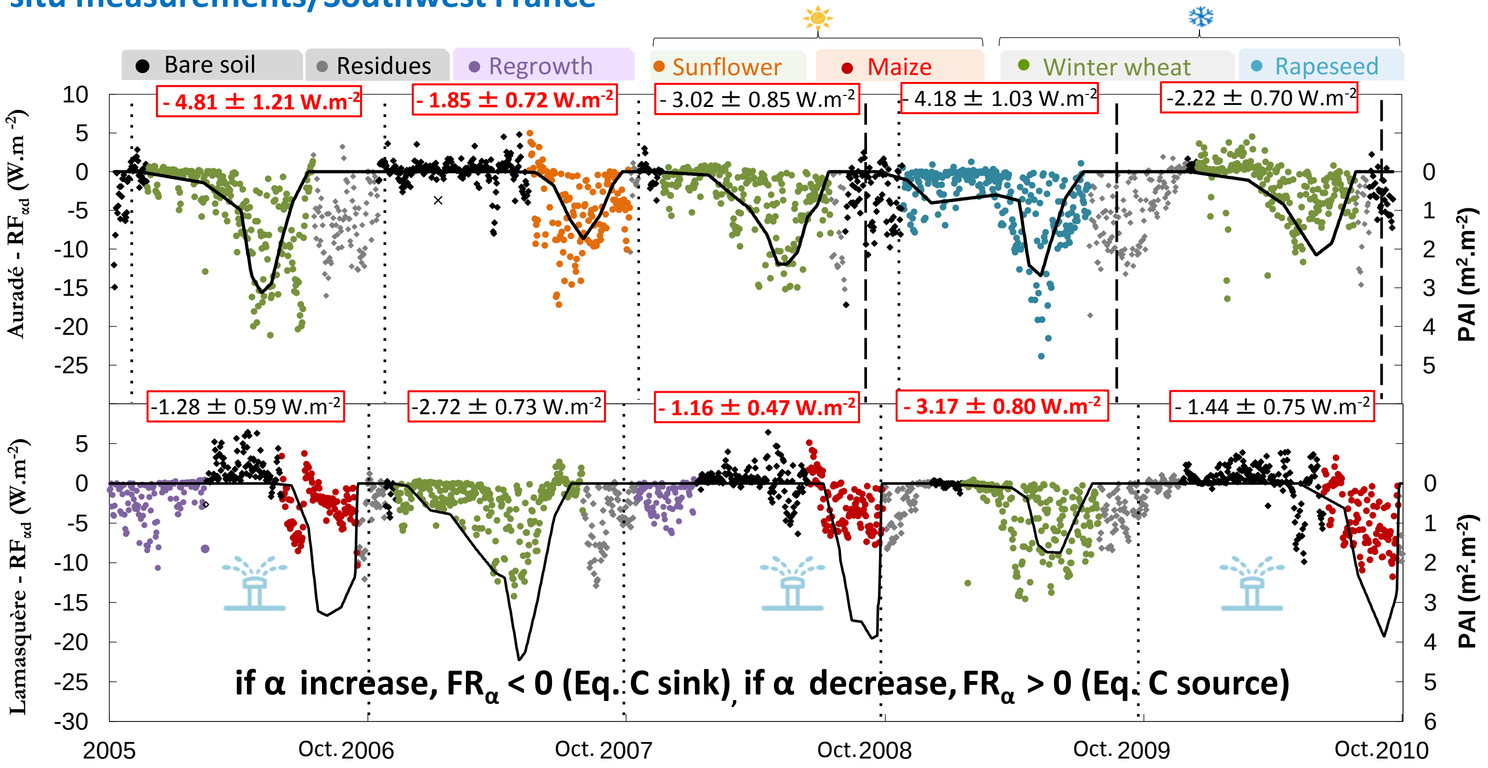
Several years of measuremets/crop specie



# RFα induced by cropland albedo dynamic in reference to bare soil

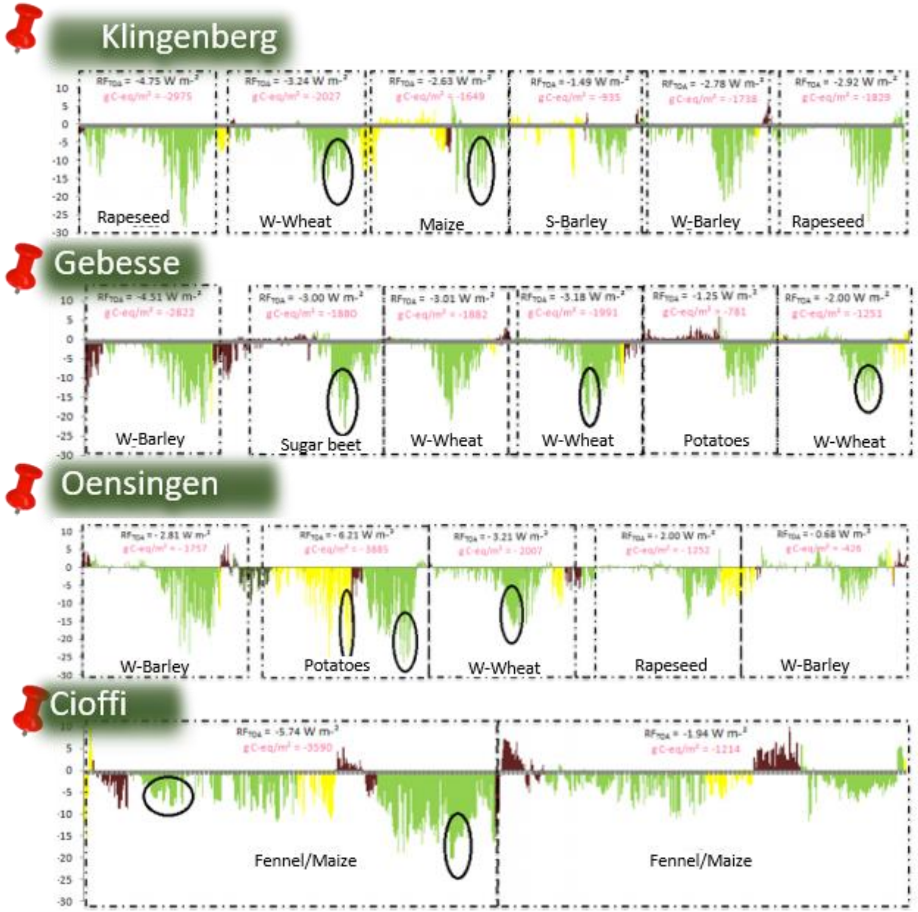
Illustrates the combined effect of albedo dynamics with those of Rg and TA

## In situ measurements/Southwest France



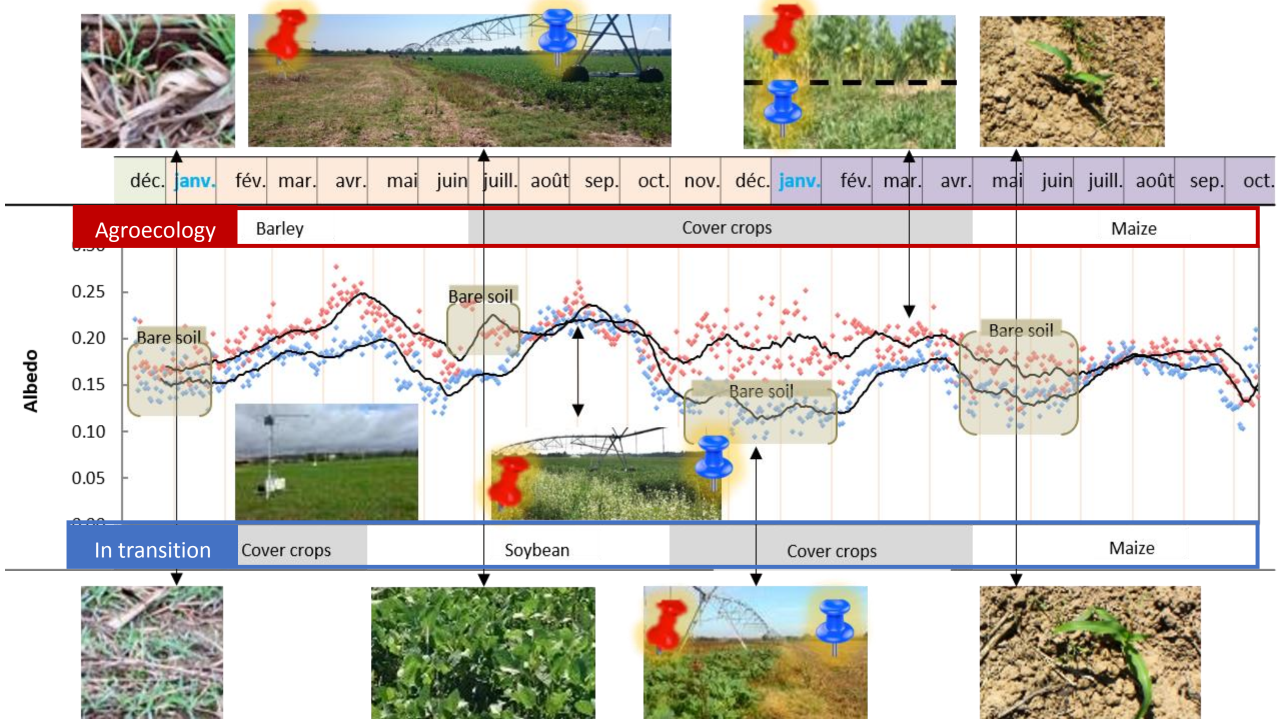

- Soil coverage may contribute to a “cooling” albedo effect,
- Same observations at other European flux sites

## European ICOS sites



# Comparison of biogeophysical effects between cropping systems

**Gaillac (France)**




- The two subplots are adjacents :
  - (Up) Agroecology practices since 5 years
  - (Down) in transition from conventional to agroecology practices

July 2016

| | Agroecology | | Transition | |
|---|---|---|---|---|
| Depth | Corg | OM | Corg | OM |
| 0 to 10 | **8.6 ± 0.4** | **14.9 ± 0.8** | **8.2 ± 1.0** | **14.3 ± 1.7** |
| 10 to 30 | 7.4 ± 0.4 | 12.8 ± 0.7 | 8.0 ± 0.9 | 13.9 ± 1.6 |
| 30 to 60 | 5.3 ± 0.4 | 9.1 ± 0.7 | 5.4 ± 0.5 | 9.4 ± 0.9 |
| 60 to 90 | 5.0 ± 0.3 | 8.7 ± 0.4 | 4.9 ± 0.3 | 8.4 ± 0.5 |

- Cover crop growing duration were about 6 to 9 months (common in our area).

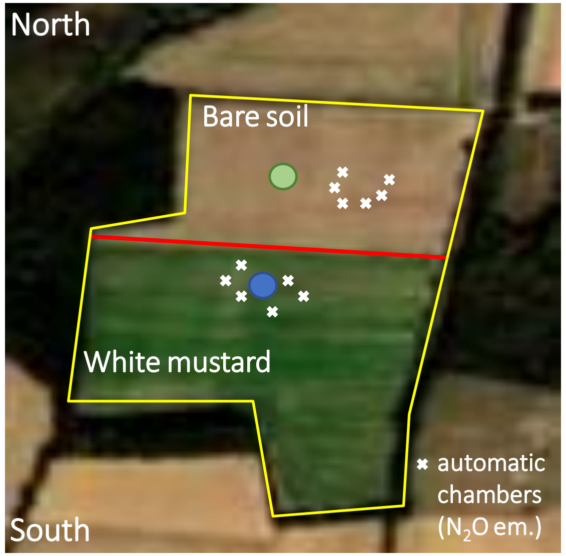
- At the "agroecology " site α were **always equal or higher** in spite of a higher top soil OM content because the soil was permanently covered by vegetation or crop residues.

- Punctually, we observed an increase in **LW radiation that overwhelmed the albedo effect** at the "agroecology " site during summer at the beginning of CC development (not showed here).

# Comparative in situ analysis of all RFnet components – bare soil vs cover crop



ICOS Lamasquère site




<u>Measured variables :</u>

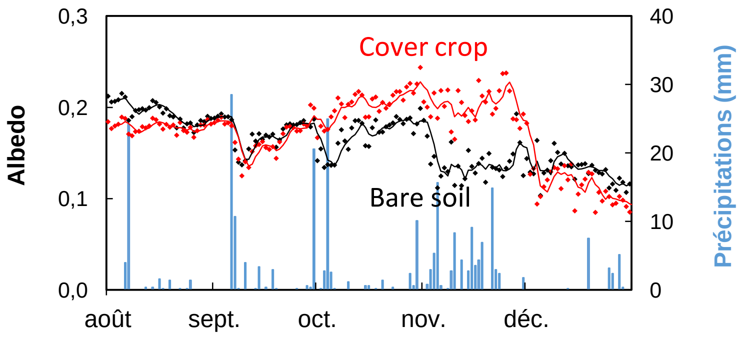
- $CO_2$, $N_2O$, water & energy fluxes
- Soil temperature & humidity at 0-5 cm
- Soil heat fluxes
- Solar incident/reflected radiation (short & longwave)

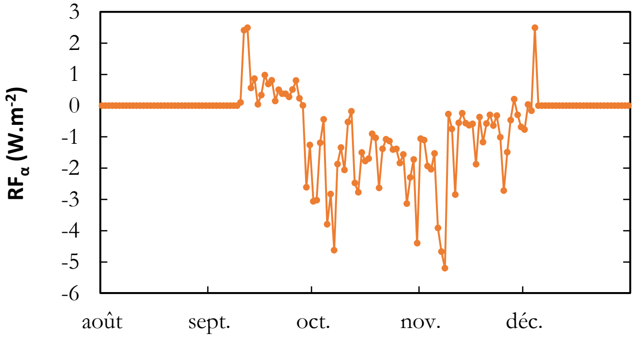
<u>Objectives :</u>

- Difference in surface albedo and RF induced by cover crop (CC)
- Effect of CC on :
    - Surface IR radiations & soil temperature
    - Sensible heat fluxes (hot eddys at the surface)
    - Latent heat fluxes (evapotranspiration)
    - C and GHG budgets

# Comparative in situ analysis – Radiative effects of cover crops

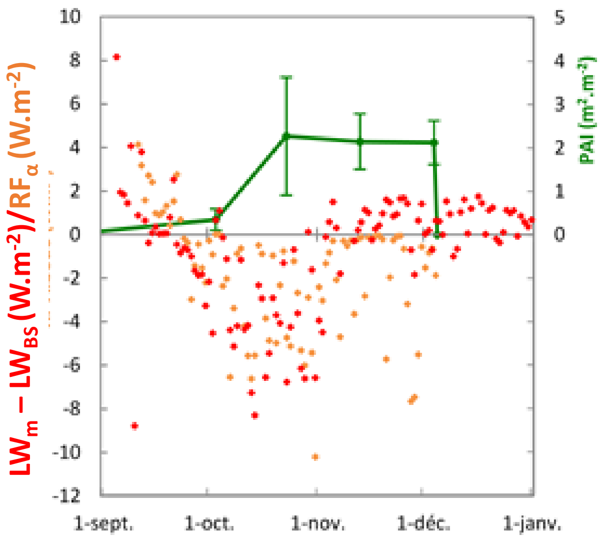
## 1. Shortwave (albedo) effect (RFα)



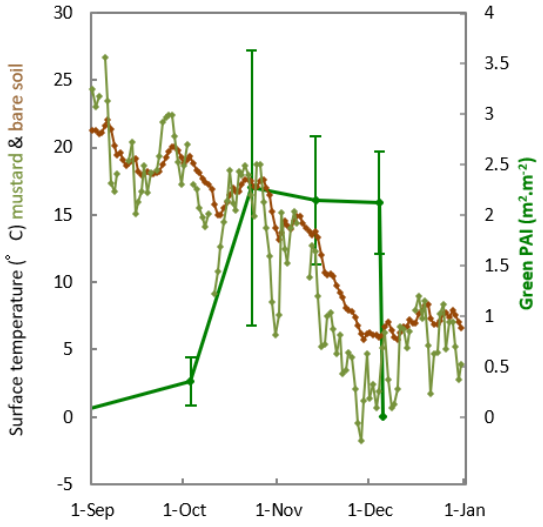

➔ Δα causes a cooling effect

## 2. Longwave effects




➔ Longwave effect ≈ RFα in term of intensity (not necessarily in term of cooling)

## 3. Soil temperature

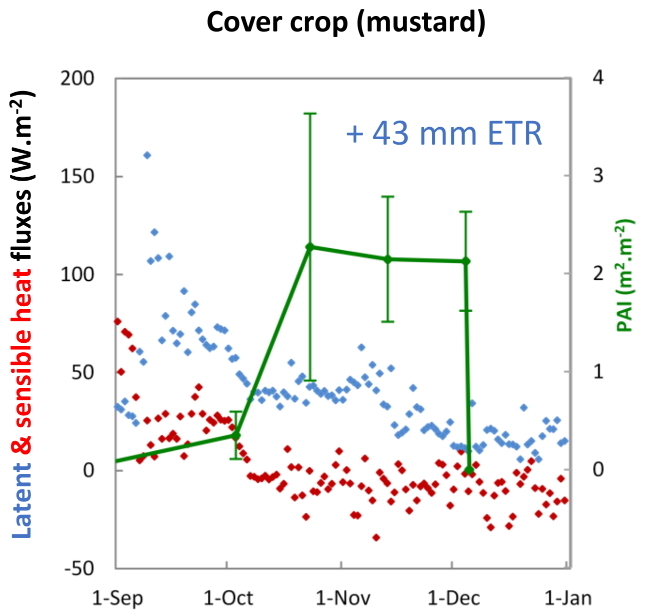


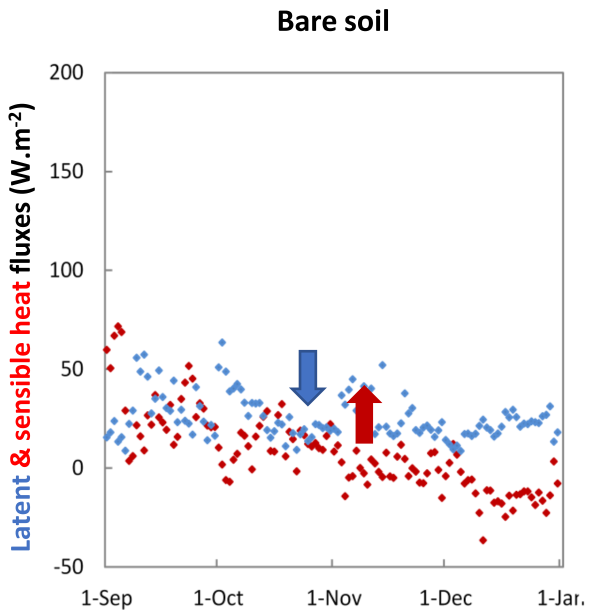

➔ Mean difference of 2.5°C

➔ Likely **slowdown** in OM mineralisation (and consequences on soil $CO_2$/$N_2O$ fluxes)

# Comparative in situ analysis – Non Radiative effects of cover crops

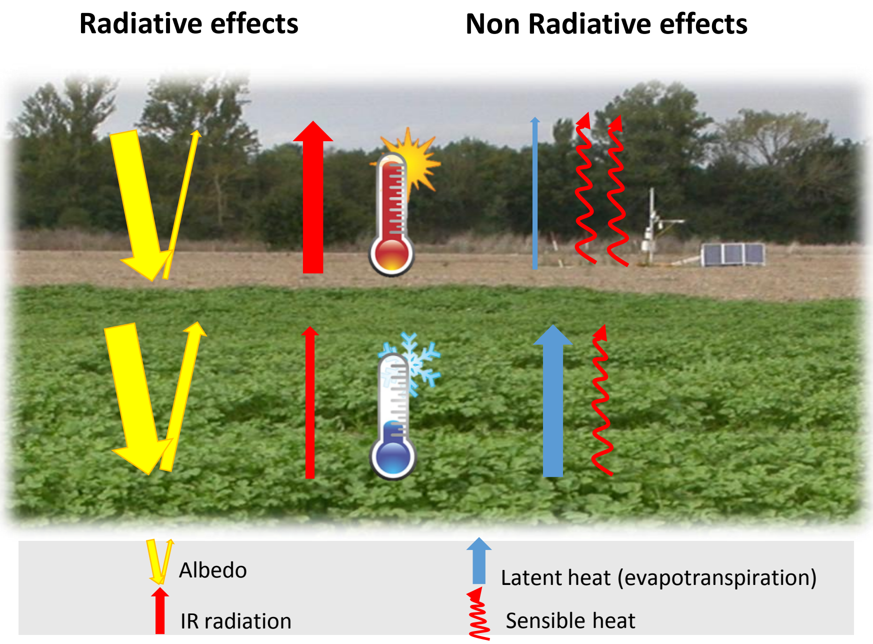
## Effects on latent and sensible heat fluxes



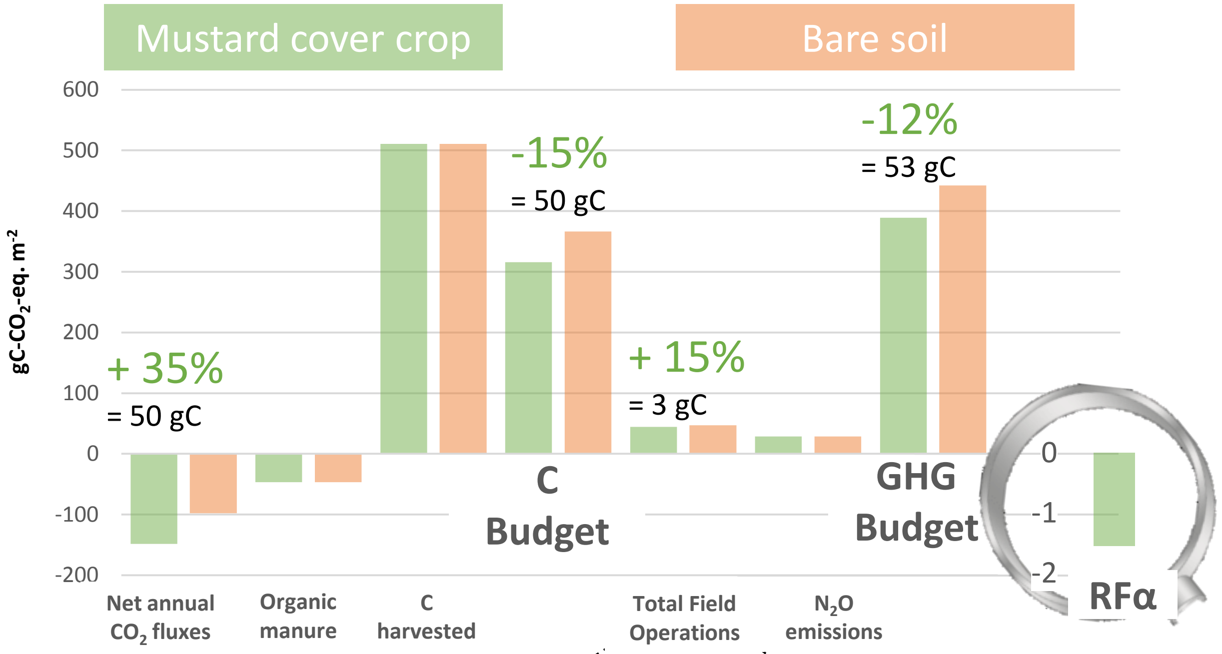

- ↑ evapotranspiration & ↓ sensible heat fluxes causes local surface climate cooling (*Boucher et al., 2004*) ➔ Natural air conditioner !! ;-)
- But this effect is difficult to express in term of radiative forcing (*Pielke et al., 2002), especially at local scale*

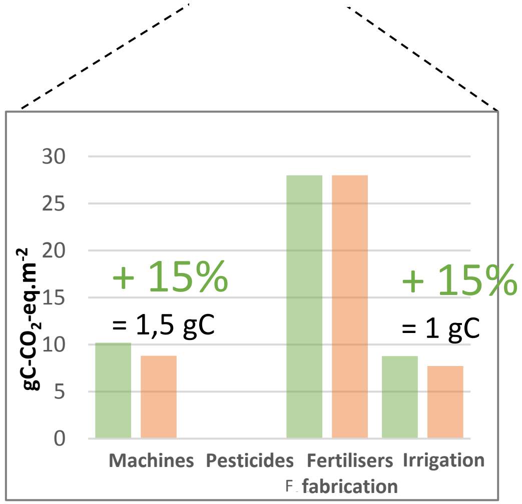
## Summarizing cover crop biophysical effects




**Global effect on climate of CC is difficult to estimate (requires coupled surface-atmosphere modelling exercises) but local/regional effect on perceived temperature at the surface could be significant (*Georgescu et al., 2011*).**

# Effect of cover crops on the components of the GHG Budget + RFα




*Calculations of GHG emissions from field operations are based on Ceschia et al. (2010)*

- The **differences in C & GHG budgets** were mainly **caused by the C storage effect** (but short term effect ➔ very depleted soil in OM) in spite of a low CC biomass production (2.2 t DM/ha) compared to mean regional figures (4 t DM/ha),

- Increase in $N_20$ emissions and GHG emissions from field operations were negligible,

-Albedo RF in $CO_2$-eq was calculated considering that CC would be maintained over the next 100 yrs

-Very low RFα because **CC was grown in late fall** with low TA and Rg (and destroyed in early December) ➔ this effect would have been close to 10 times larger if cover crop had been grown till spring (common in our area ; see Ferlicoq & Ceschia, 2015),

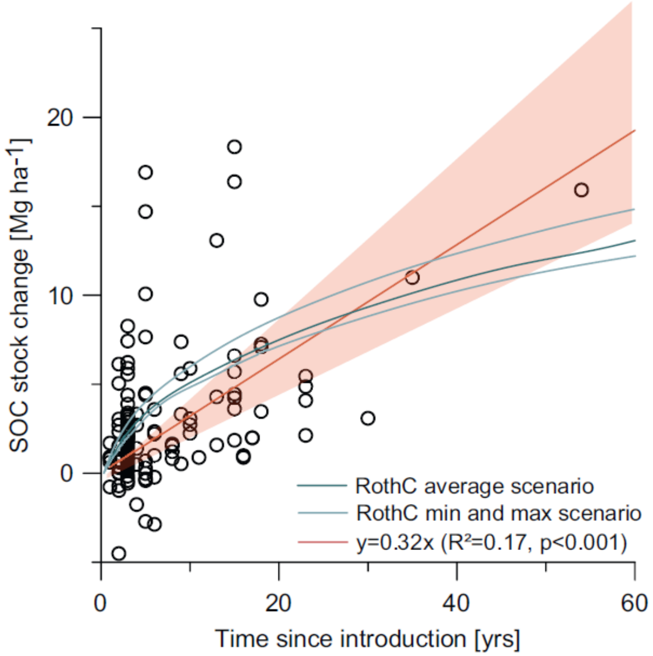
But is it appropriate to compare RFα in $CO_2$-eq with the C/GHG budget components? ➔ It will be discussed at the end of the presentation.

## What do studies at larger spatial and temporal scales teach us ?

# Carbon storage effect of cover crops (vs bare soil) in time

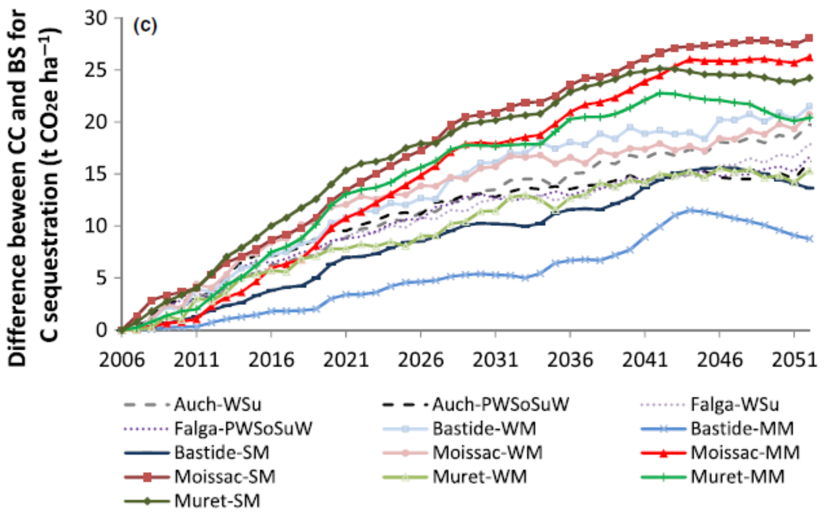
Several studies tend to show that :
- the carbon storage effect of the CC could be limited in time : new equilibrium reached after 45-50 year,

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

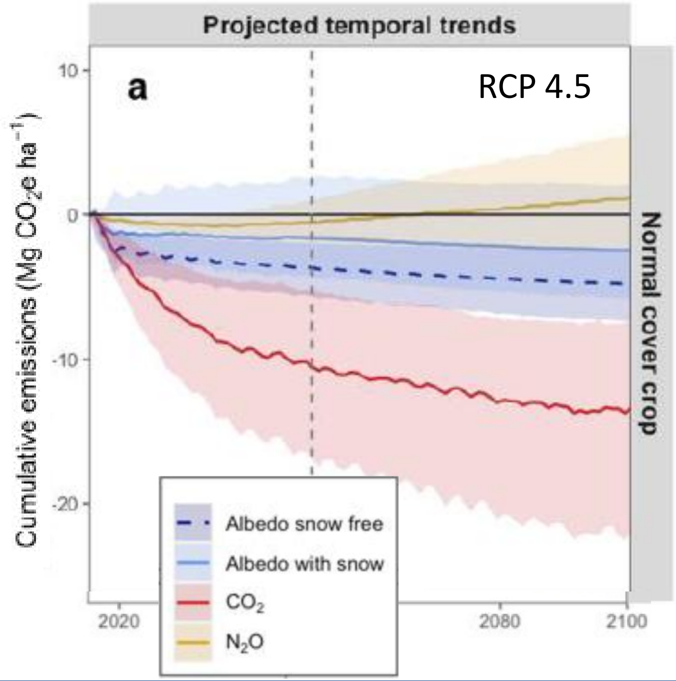



**STICS simulations in France (*Tribouillois et al., 2018*)**

RCP 4.5




**DayCent simulations over Europe (*Lugato et al., 2020*) : red line**



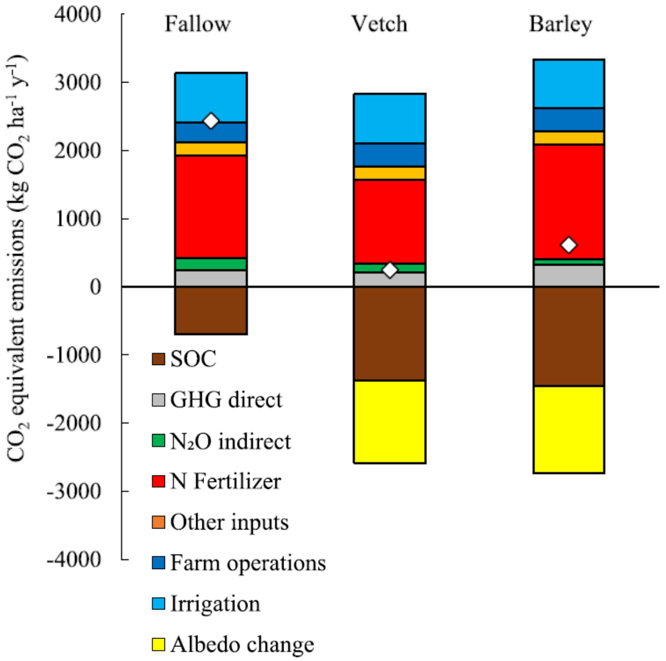

**Biophysical and biogeochemical effects of nature based solutions: toward an integrated evaluation of their climate mitigation potential,** *May 31, 2022 Workshop*

# GHG budget of cover crops (vs bare soil) in time

Several studies tend to show that :

- the carbon storage effect of the cover crops could be limited in time : new equilibrium reached after 45-50 year,
- $N_2O$ emissions may decrease on the short term but then increase 15-50 years after cover crop introduction ➔ Adapt N fertilisation after cover crop destruction ➔ integrated soil fertility management (Guardia et al. 2019 ; MERCI Meth.)

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

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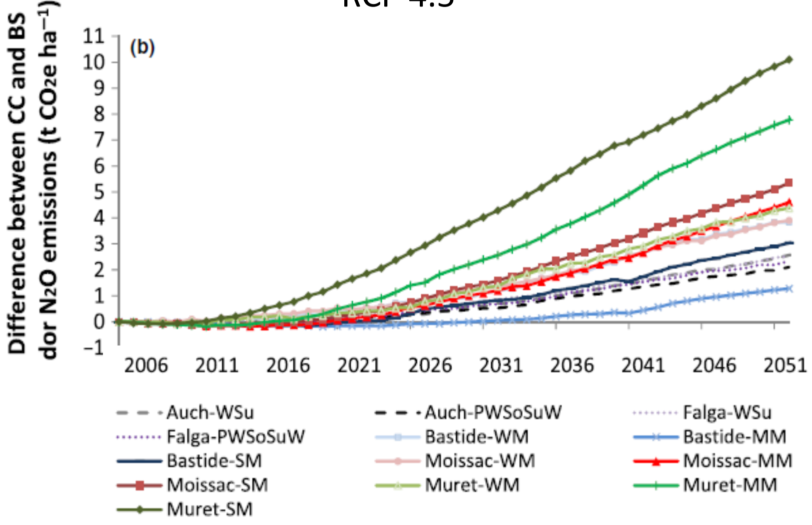
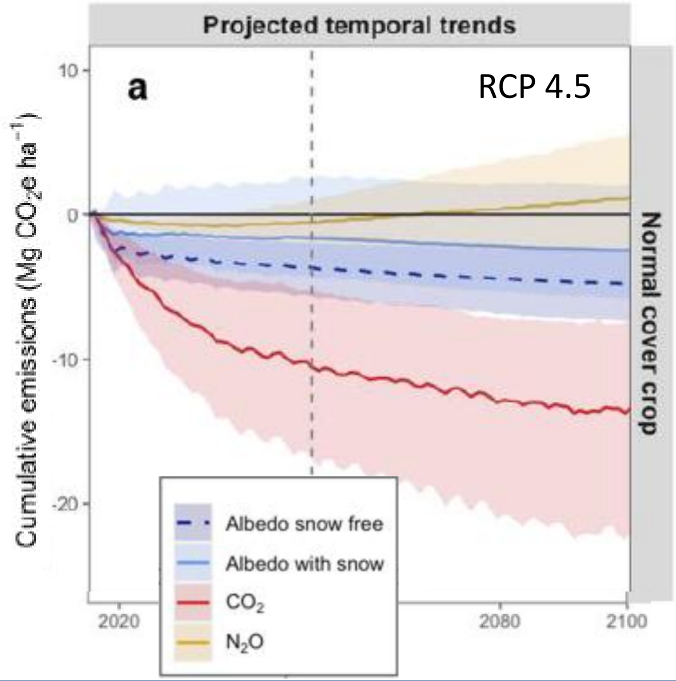



**DayCent simulations over Europe**
**(*Lugato et al., 2020*) : orange line**



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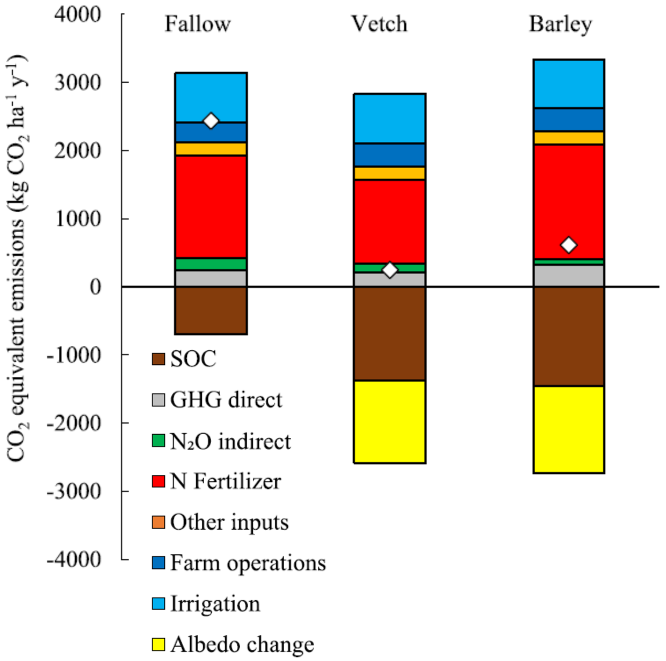
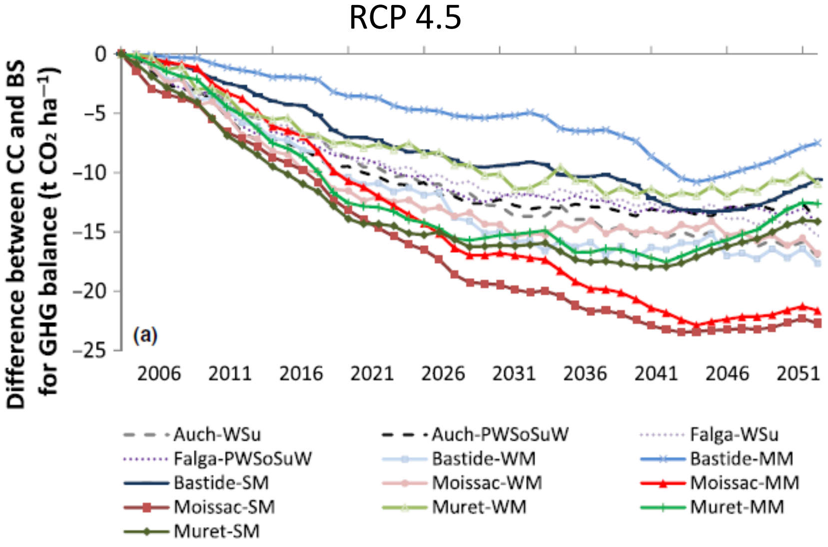
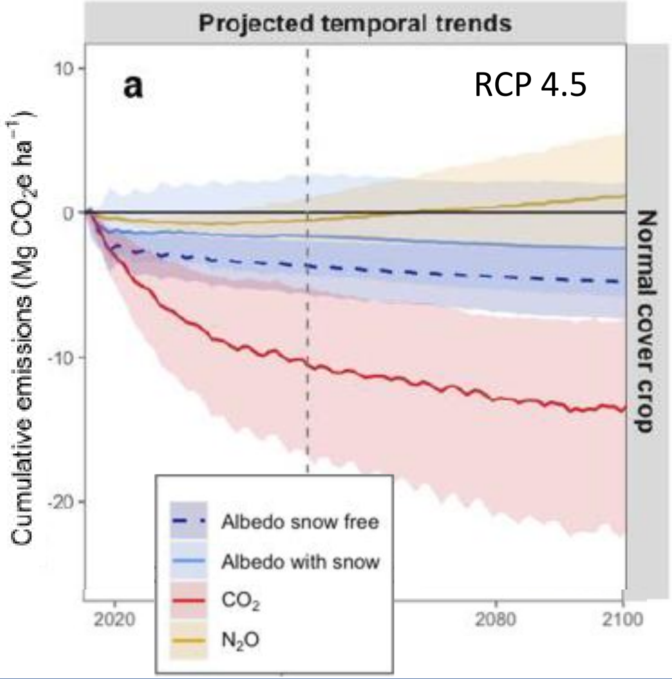



**STICS simulations in France (*Tribouillois et al., 2018*)**



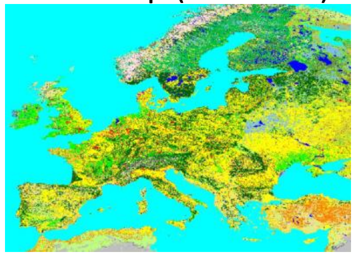

**DayCent simulations over Europe (*Lugato et al., 2020*) : red + orange**

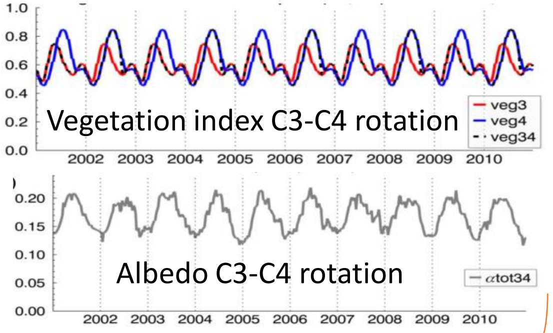


# Analysis of the cover crop albedo effect (vs bare soil) over Europe

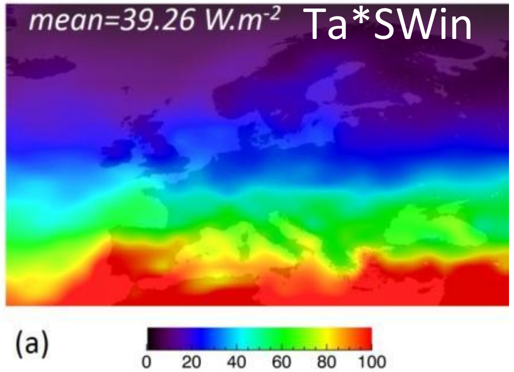
*Carrer et al. (2018) in ERL*

Ecoclimap (Land use)

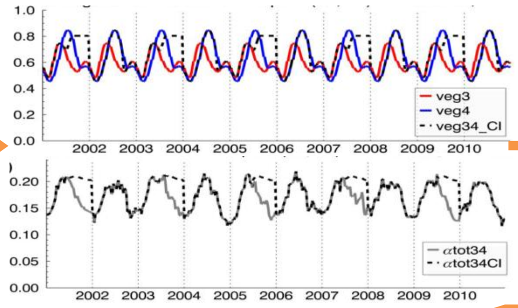




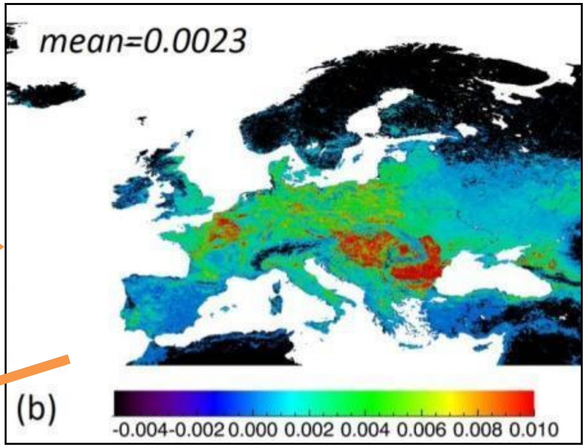

Desagregated vegetation index, bare soil albedo & vegetation albedo (snow free) derived from MODIS data at 5*5 km (Kalman filter ; *Carrer et al., 2014*) ➔ albedo of C3-C4 crop rotation




Analysis of where and when cover crops are introduced




Daily albedo increase with cover crops



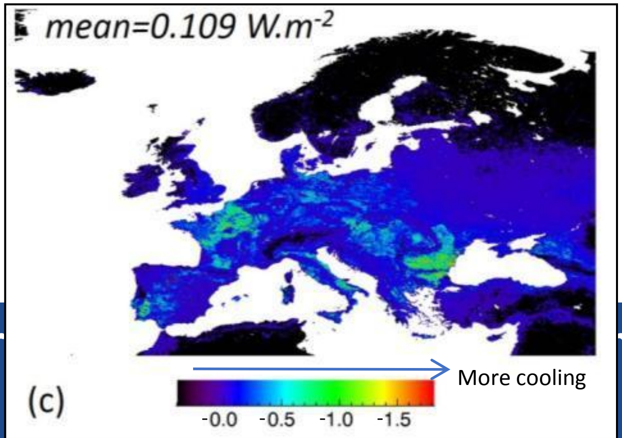

Daily global radiation& atmospheric transmittance (ERA-INTERIM)

**RFCC**

*Radiative Forcing of Cover Crop*

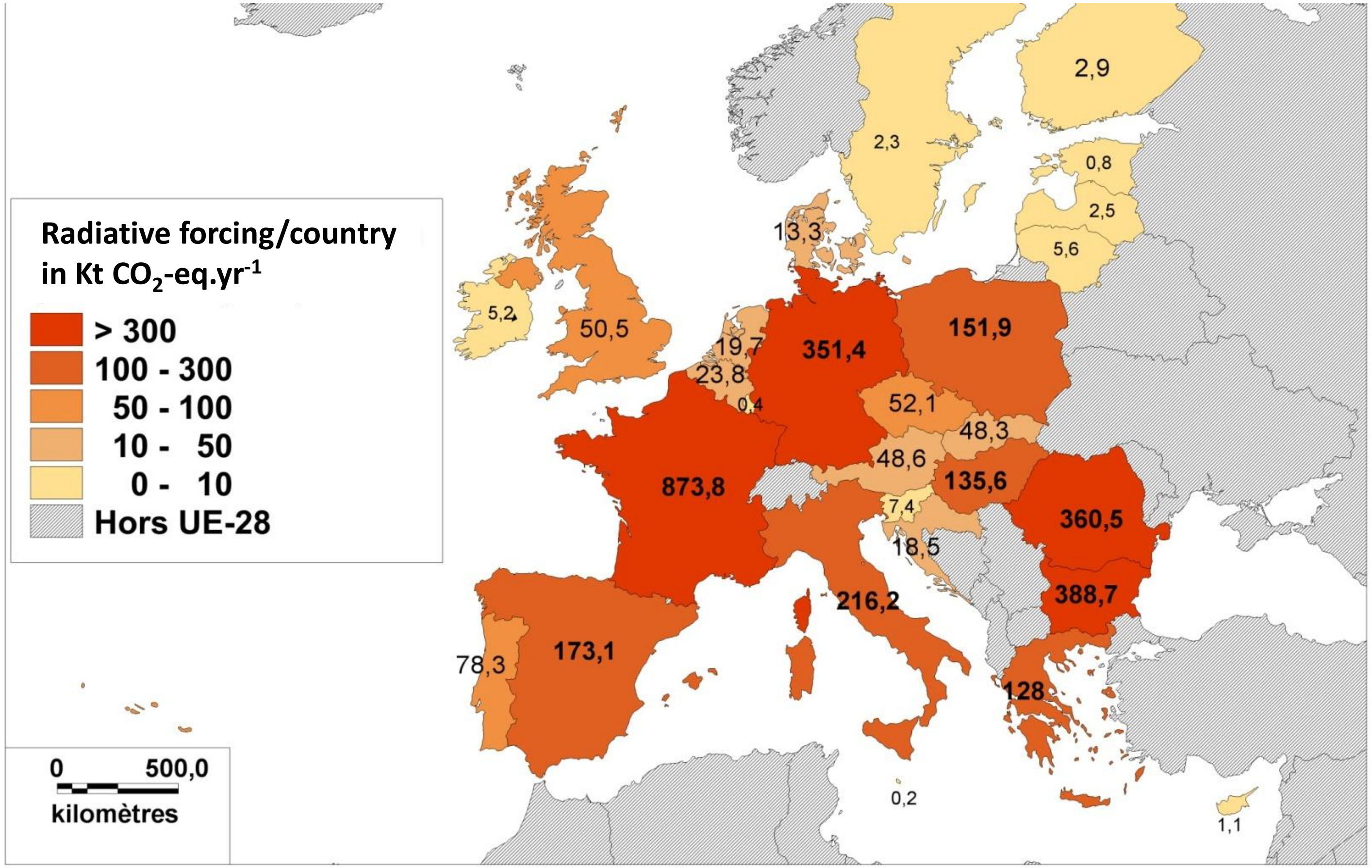
$$RF\alpha = - Rg \times TA \times \Delta\alpha$$

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



# Analysis of the cover crop albedo effect (vs bare soil) over Europe

(Carrer et al. 2018)




- Conversion in $CO_2$-eq with the constant airborne fraction method, e.g. see *Betts et al. (2000)* (and with GWP method by *Myhre et al. 2013*)

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

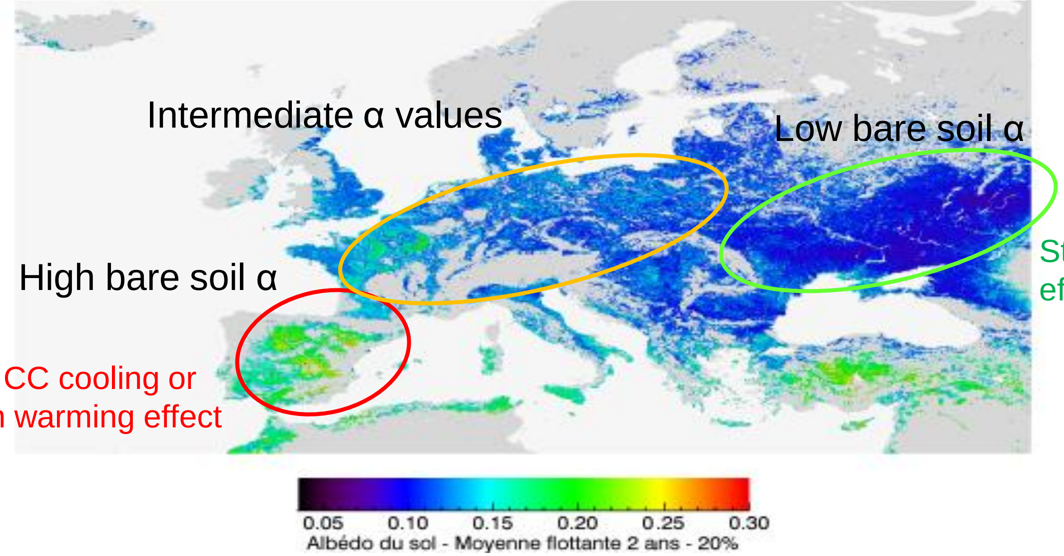
- Same but accounting for rain limitation ➔ the cumulative RFα over EU-28 was 2.3 (2.1) $MtCO_2$-eq.year$^{-1}$

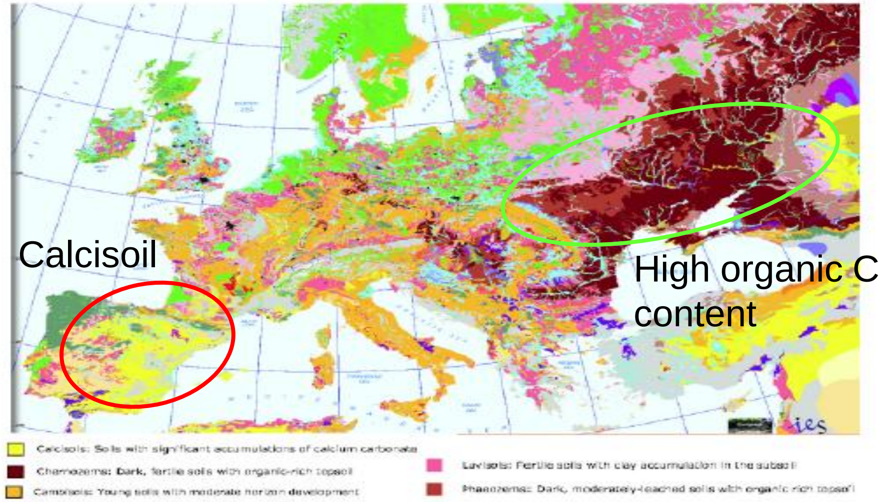
- 6 month duration cover crop scenario + rain limitation ➔ the cumulative RFα over EU-28 was 4.3 (4.0) $MtCO_2$-eq.year$^{-1}$ *i.e.* a compensation of up to 1.0 (0.9)% of the EU-28 agricultural GHG emissions.

# Analysis of the cover crop albedo effect (vs bare soil) over Europe

- In general the introduction of CC increase surface albedo compared to the bare soil (snow effect not accounted for) but for some soil types (e.g. calcisoils) with high albedo introducing CC could be counter productive.

Cropland bare soil albedo map in winter based on desagregated MODIS satellite data (Carrer et al., 2012)



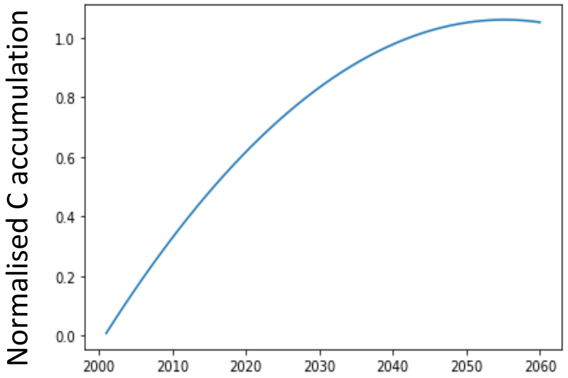




➔Remote sensing data are usefull to identify where/when cover crops should be introduced (or not) in order to increase the current surface albedo (even better when high resolution products available)

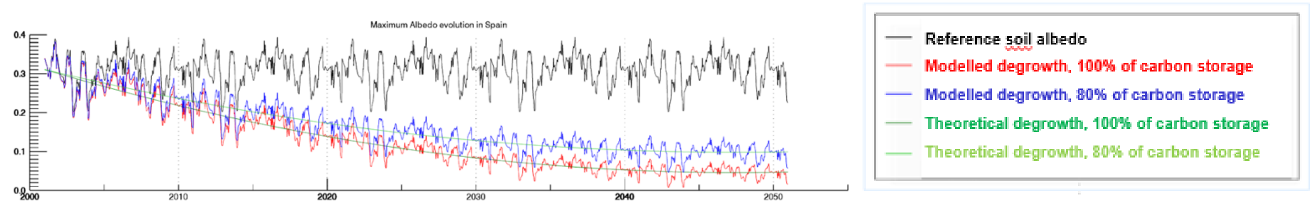
# Analysis of the cover crop albedo effect (vs bare soil) over Europe

However…

Pique et al.
(submitted to ERL)




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

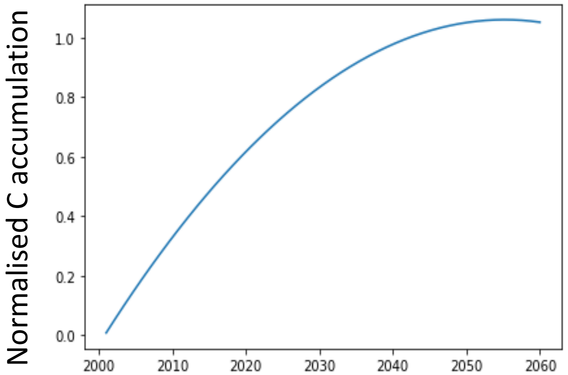



Modelled bare soil albedo decrease takes into account the progressive incorporation of organic matters in the soil (in the whole soil profile while in reality OM accumulates first in the top soil)

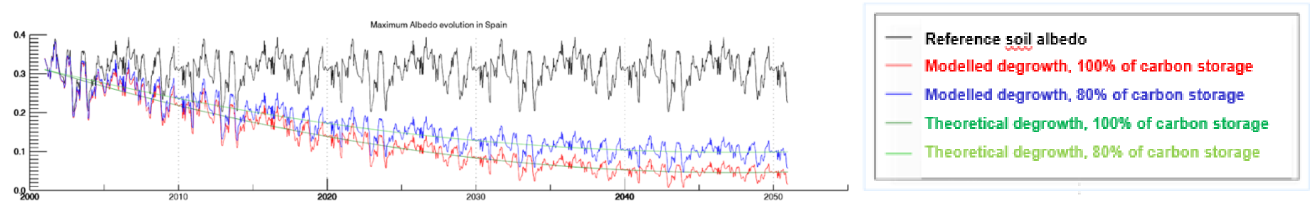
# Analysis of the cover crop albedo effect (vs bare soil) over Europe

However…

Gaétan Pique's PhD
(paper in prep)

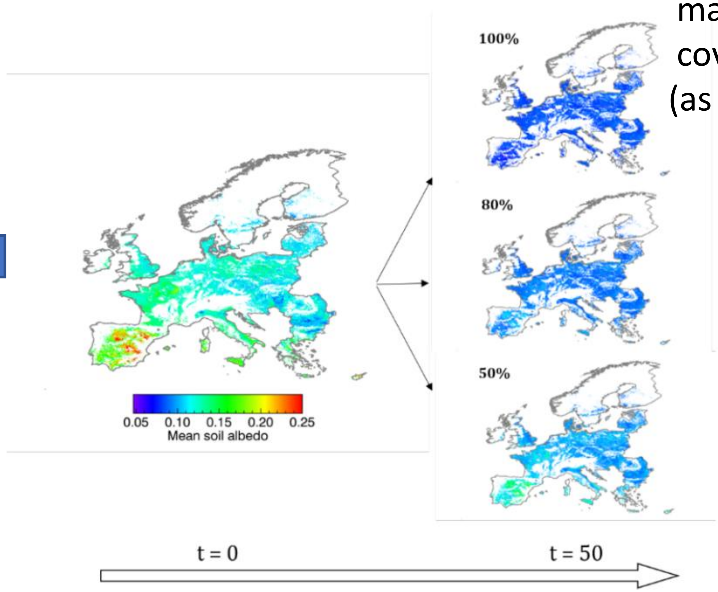



Adapted from Tribouillois et al (2018) and considering Corg max similar to Romanian soils

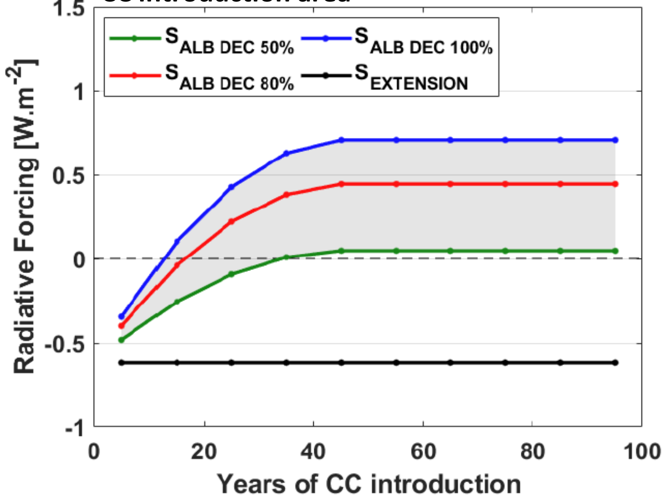



Modelled bare soil albedo decrease takes into account the progressive incorporation of organic matters in the soil (in the whole soil profile while in reality OM accumulates first in the top soil)

Same method as in Carrer et al. (2018) but over 50 years (current climate) + soil darkening (50, 80, 100% of C storage potential) + maximising soil coverage with CC (as in *Pellerin et al. 2019*)



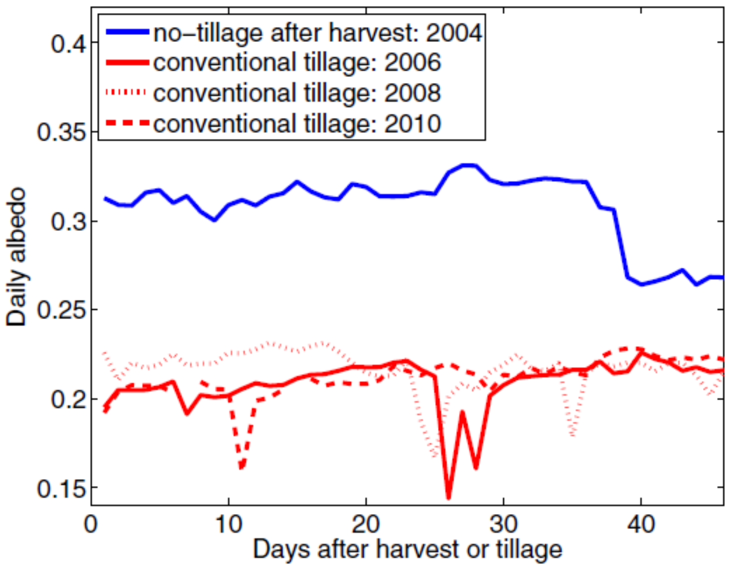

**Mean RFα for Europe expressed by unit of CC introduction area**




Once cover crop are adopted, soil should be covered permanently to avoid this drawback (as in Gaillac). This can be achieved by different means…

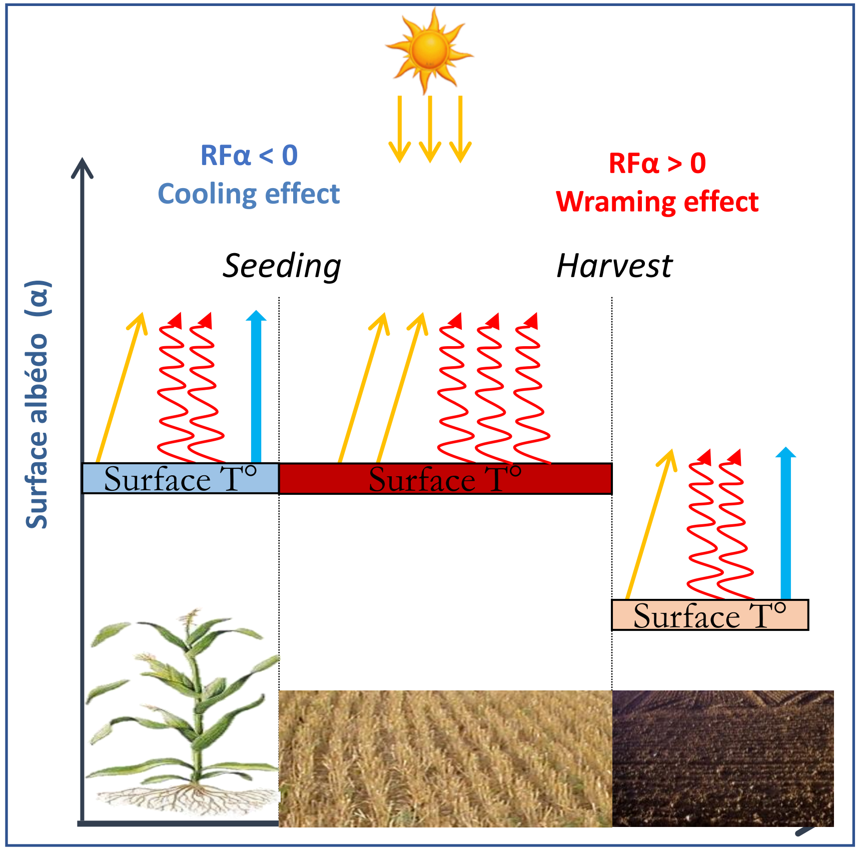
# RFα induced by soil coverage with crop residues vs ploughing

Davin et al. (2014)




- Generalising this practice to the whole Europe could decrease air temperature during summer heat waves by ≈2°C,
- However most of the albedo cooling effect is lost : why ?

- The mulch effect reduces evaporation ➔ higher surface temperature,
- This change in surface energy partitioning increases sensible heat flux and thermal IR radiations (interact strongly with GHGs in the atmosphere).




➔ Better cover the soil with CC. But in areas where CC cannot be grown during the fallow period (e.g. to dry, too cold), or in the interval between a crop and a cover crop, maintaining crop residues at the soil surface is to be encouraged (avoids soil darkening effect on albedo).

# Discussions

- Other ecosystem services, trade offs and drawbacks of CC…see *Justes et al. (2012), Kaye & Kemada (2017), Pellerin et al. (2019), Runk et al. (2020)*.

- They are still many things to investigate :

  - What is the potential increase in albedo cooling effect through the choice of CC species in the rotations and through varietal selection ?

  - Whats is the true effect of snow + CC ? More realistic approaches accounting for stand architecture/species, plant and snow heigt are needed ?

  - Whats are the CC effects on soil temperature/humidity ➔ consequences for soil mineralisation, $CO_2$ and $N_2O$ emissions ?

  - Consequences of CC on soil water retention & water ressources for the following cash crop ?

  - What is the durability of the C stored in the soil by CC (climate change) ?

- Appart from CC and no till, what are the biogeophysical effects of other cropland management changes ?

  - For biochar application, see *Genesio et al. (2012),*

  - What about agroforestry ?...

# Discussions

**What is/will be the net climatic effect of cover crops ?**

Difficult to answer now !!!

Because :

- Mitigations based on soil C storage or reduced GHGs emissions (CDR) have a global diffused effect on temperature, since GHGs are well mixed in the atmosphere. On the contrary, biogeophysical effects trigger predominantly local variation in temperature + difficult to predict non-local effects due to teleconnection in the climate system (e.g. mediated by clouds, advection of heat, etc.) ➔ the SRM effect caused by surface $\Delta\alpha$ (e.g. with cover crop), should not be considered as $CO_2$ accountable quotes equal to those generated by GHG reduction, but rather as an indication of the intensity and location of the albedo effect,

- Current Earth System Models do not have a sufficiently fine spatial resolution and detailed management schemes to represent local practices in a realistic way ➔ makes the overall biogeochemical + biogeophysical effects of CC difficult to quantify for now. Most (if not all) IPCC models only have 2 crop PFTs (C3 &C4) for cropland… and none of those models account for CC…

↳ Where the levers tested in the 2018 IPCC special report to define the pathways allowing to stay below 1.5 °C global warming by the end of the century the best ones ?

# Conclusions

- We have analysed the causes of fast albedo changes for cropland at a range of cropland sites over Europe and identified solutions for climate change mitigation through natured based SRM approaches,

- In several studies, cover crops appear as the perfect solution for climate change mitigation as synergies between C storage effects, radiative effects (short and longwave), changes in energy partitionning (e.g. sensible/latent) are observed + many other ecosystem services at an acceptable cost for the farmer (+ CAP subsidies and C market),

- Also additional $N_2O$ emissions caused by CC could be limited/neutralised through ISFM + GHG emissions associated to seeding/destruction are low compared to the C storage effect,

- However once C farming practices (e.g. Cover Crops) are introduced ➔ permanent soil cover to avoid the soil darkening effect,

- Yet, the net mitigation effect (+ retroaction) of CC is unknown ➔ must be addressed through coupled surface-atmosphere modelling exercices at global scale (including all biogeophysical and biogeochemical effects). At this point, it is not possible to do such exercices as Earth System models do not account for CC.

# Key messages

- So yes, we should consider biogeochemical and biogeophysical effects to prioritize changes in cropland management in order to implement more efficient climate change mitigation strategies but difficult to compare directly those effects,

- It is urgent to reduce the gap between agronomists/soil scientists… and Earth System modellers to obtain a more realistic quantification of the true climatic effect of cropland management changes.

- One starting point to achieve this could be to assimilate higher resolutions satelite products in the ES models.

# Many thanks for your attention !!!

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