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

Eric Ceschia, Morgan Ferlicoq, Rémy Fieuzal, Gaétan Pique, Pierre Mischler, Dominique Carrer

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

Eric Ceschia (INRAE/CESBIO)

And

Morgan Ferlicoq (CESBIO), Gaétan Pique (CESBIO), Dominique Carrer (CNRM), Remy Fieuzal (CESBIO), Pierre Mischler (IDELE)

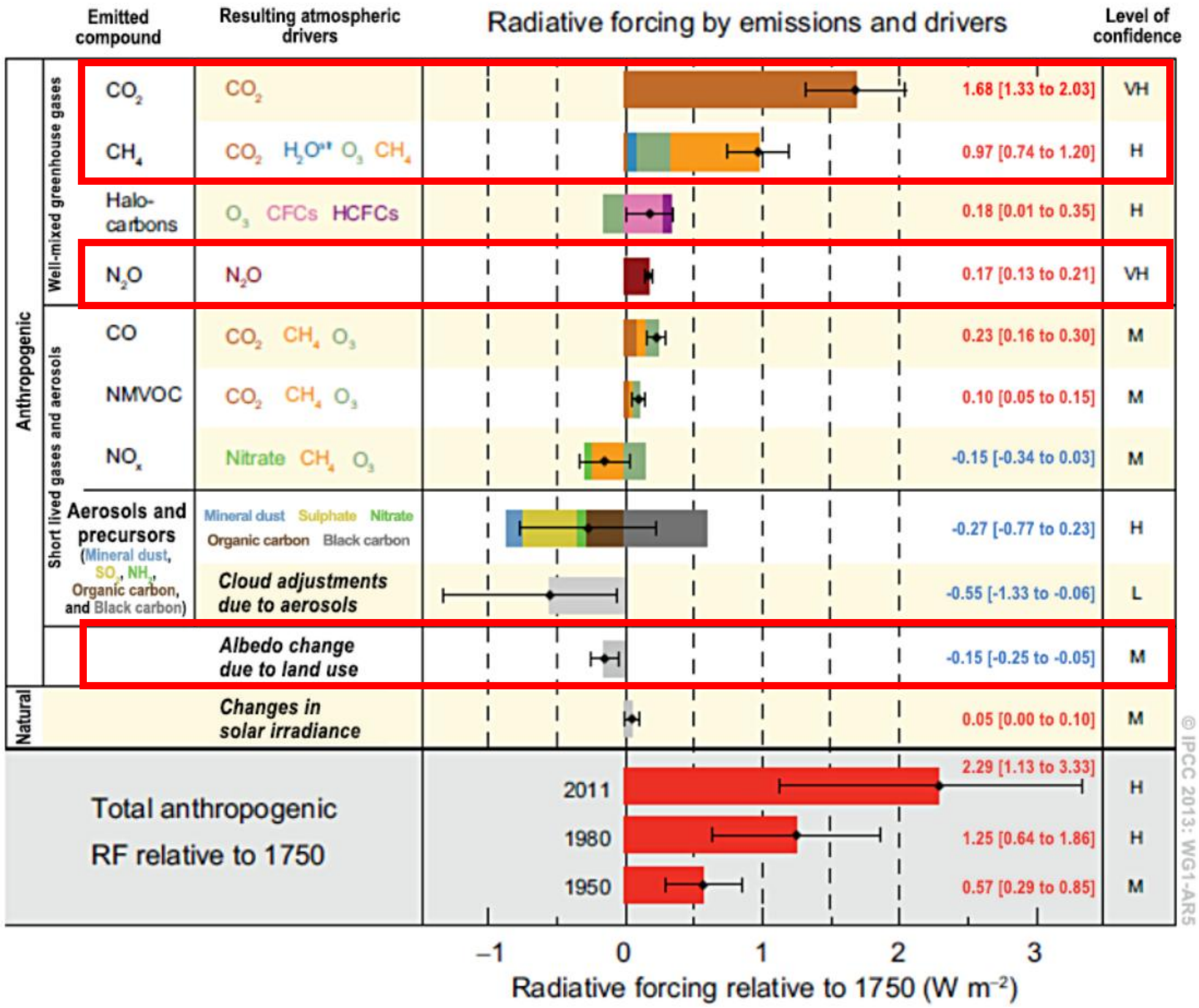
Causes of global warming

The causes of global warming

Albedo effects accounted for, but :

- IPCC models are way too simplistic & inacurate concerning continental surfaces because:
    - poor diversity in vegetation species ➔ only wheat&maize for crops in most/all models,
    - no accounting of management practices,
    - Low accuracy of input data (land use type desciption, spatial resolution of the input data…)

➔ Inacurate albedo effects & identification of associated levers for climate mitigation and very likely underestimated because…



Introduction

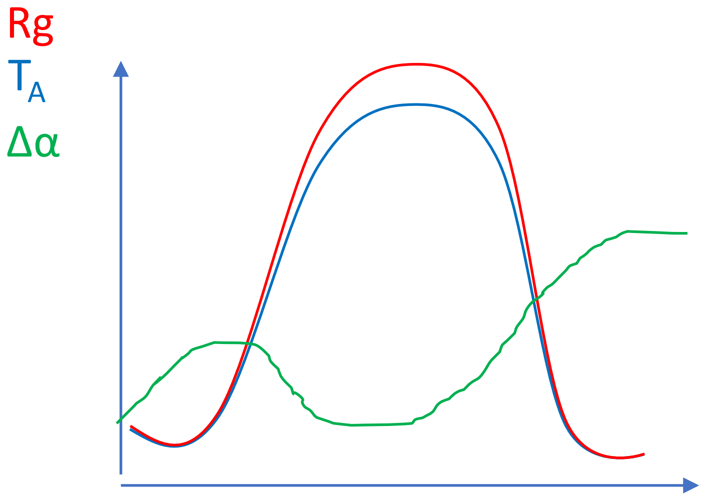
Most IPCC studies were calculating mean annual albedo induced radiative forcing (RFα) based on mean annual values of Solar global radiation (Rg), Transmittance (T_A) and changes in albedo of the land cover (Δα)

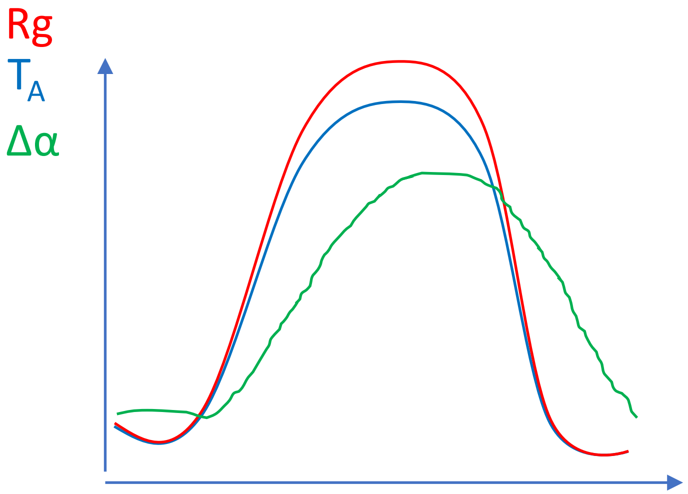
$$RF\alpha\ (W.m^{-2}) = -\ Rg \times T_A \times \Delta\alpha$$

$$T_A = \frac{Rg}{R_{TOA}}$$

$$\alpha_{new\ system} - \alpha_{old\ system}$$

However …



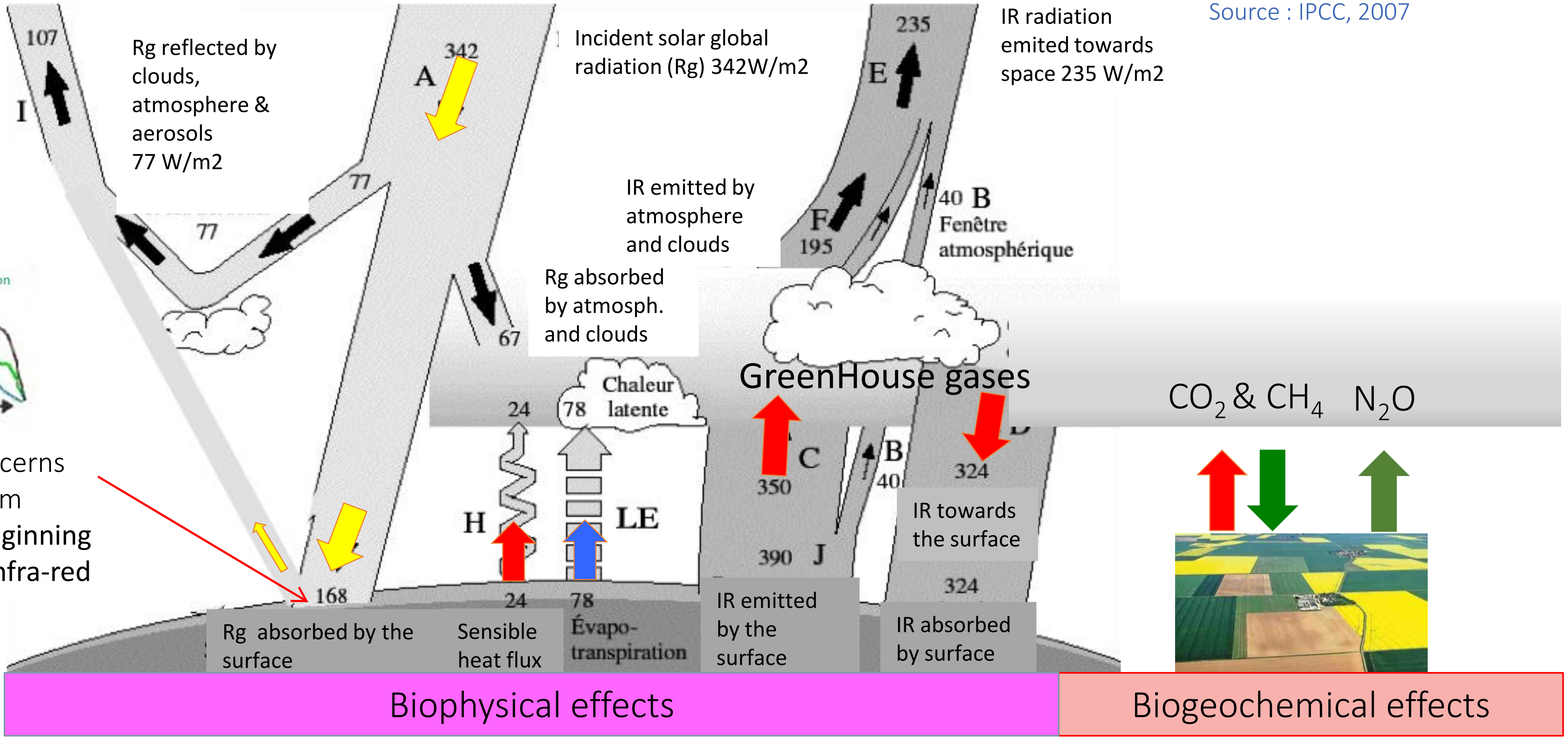


Same mean annual values but very different daily/annual RFα

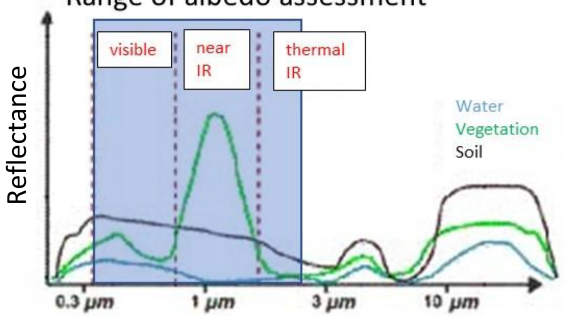
Mean annual RF calculated based on mean annual values of the 3 variables will be very different from mean annual RF calculated based on the yearly average of daily RF (calculated with daily values of the 3 variables) (Sieber et al. 2029) ➔ up to 96% underestimation of RF for cropland (Ferlicoq 2015)

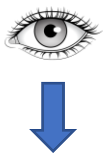
Causes of global warming

Total reflected Rg
107 W/m2



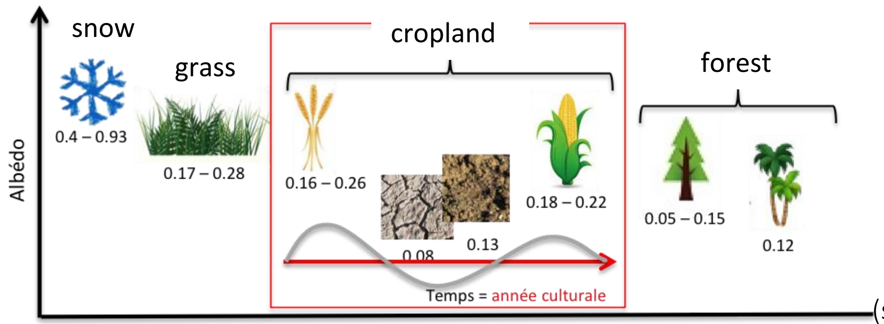
Source : IPCC, 2007





Not good at measuring albedo

Albedo : concerns radiation form visible till beginning of thermal infra-red



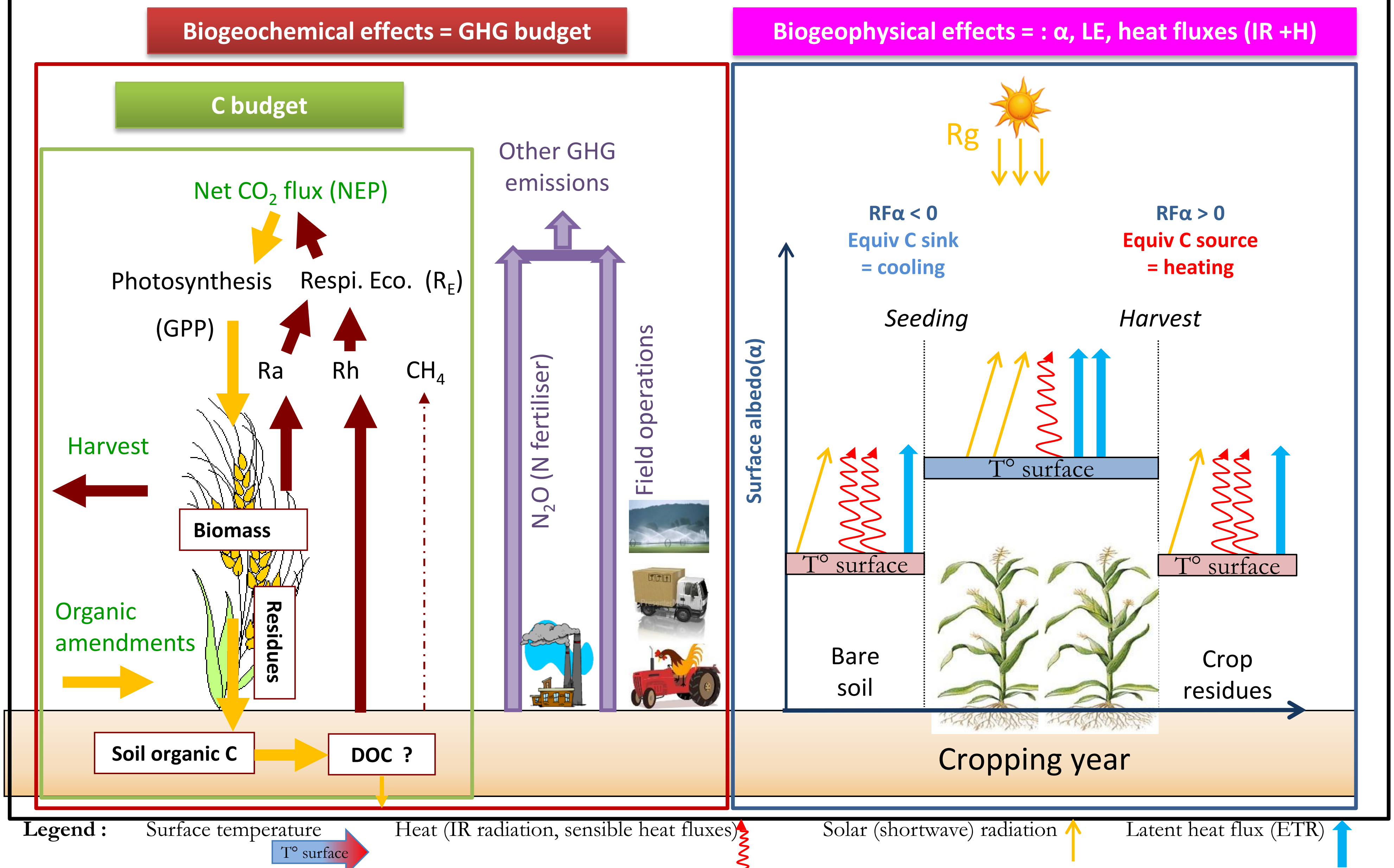
Energy available at the surface: Rn = (1-α) x Rg = LE + H + G + photosynthesis

- Photosynthesis ➔ max 4%
- Latent heat flux (LE = evapotranspiration) ➔ 70% on global average
- Sensible heat flux (H) ➔ 20 – 30 % on global average
- Soil heat flux (G) ➔ less than 10%

(source : *Carrer et al., 2013*)

Cropland net radiative forcing components

Climatic effect (radiative forcing in C-CO_2 eq) = (C budget + N_2O + OT) + (α effect + Δ H/LE)



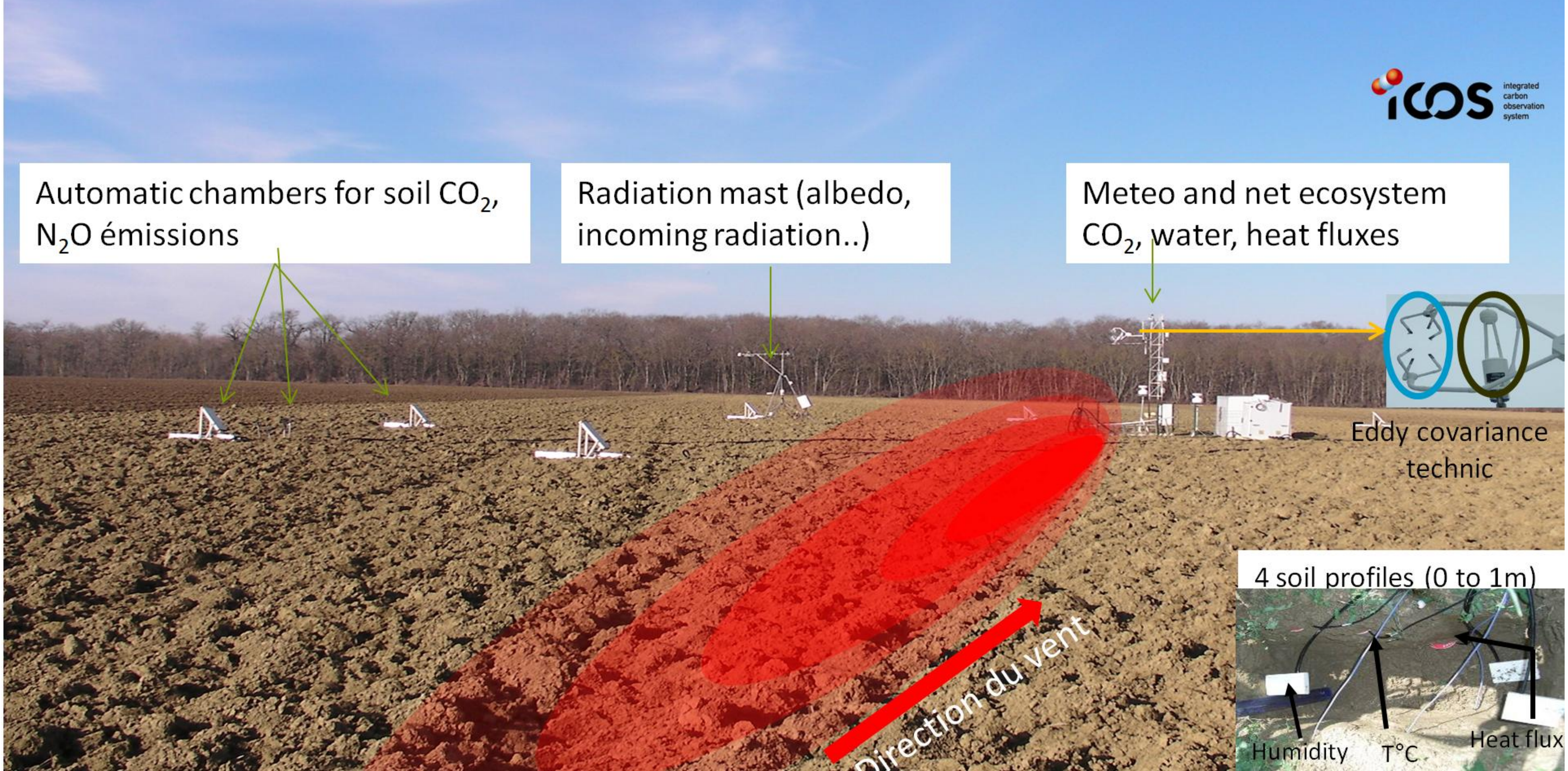
First a few words on GHG budget components

- 15 cropland flux sites
- > 41 years of data
- > 14 crop species
- Same instrumentation
- Large gradient of pedoclimates and management practices

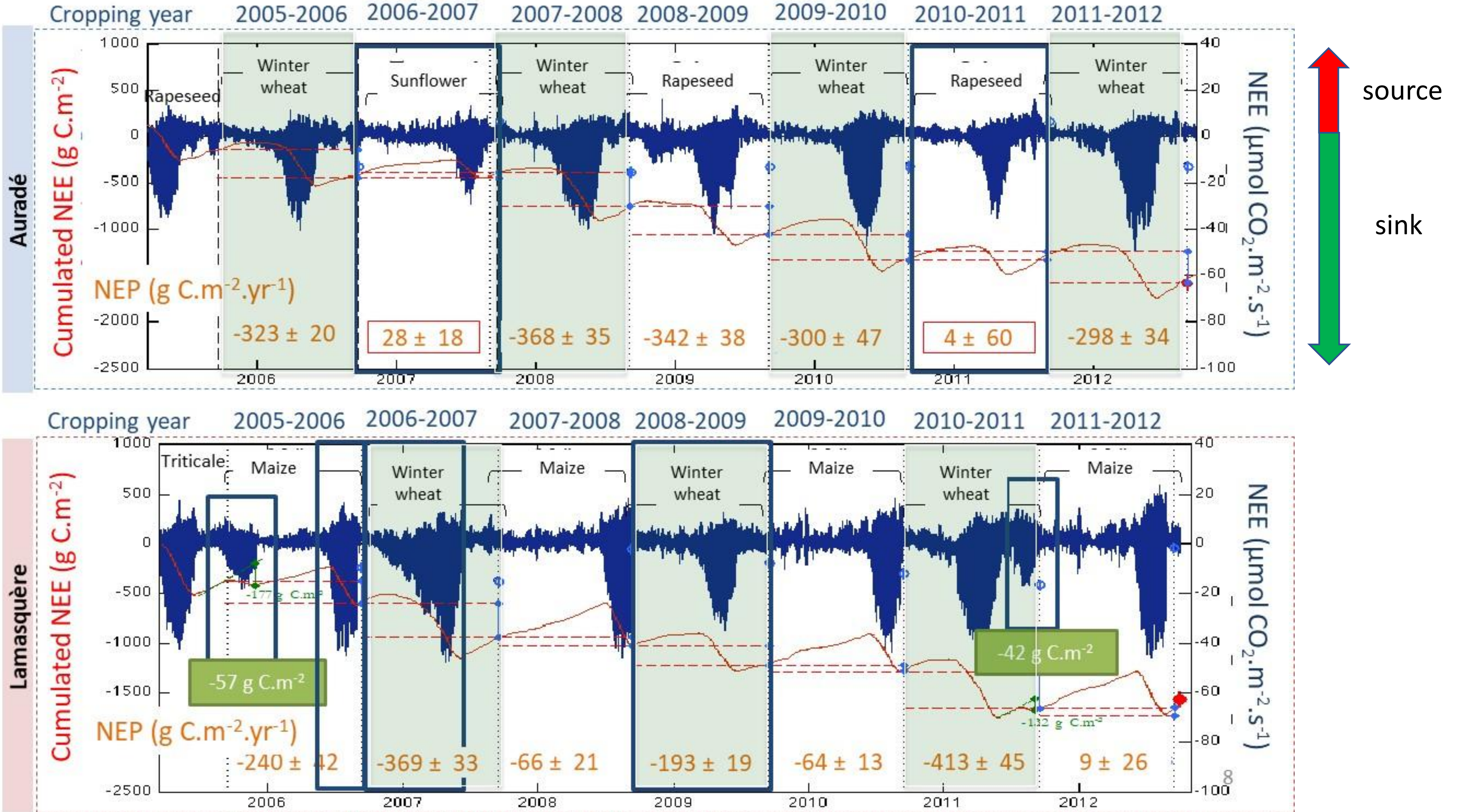
An exemple of flux site: Lamasquère (Fr)

More than 200 variables continuously measured

+ vegetation & soil sampling

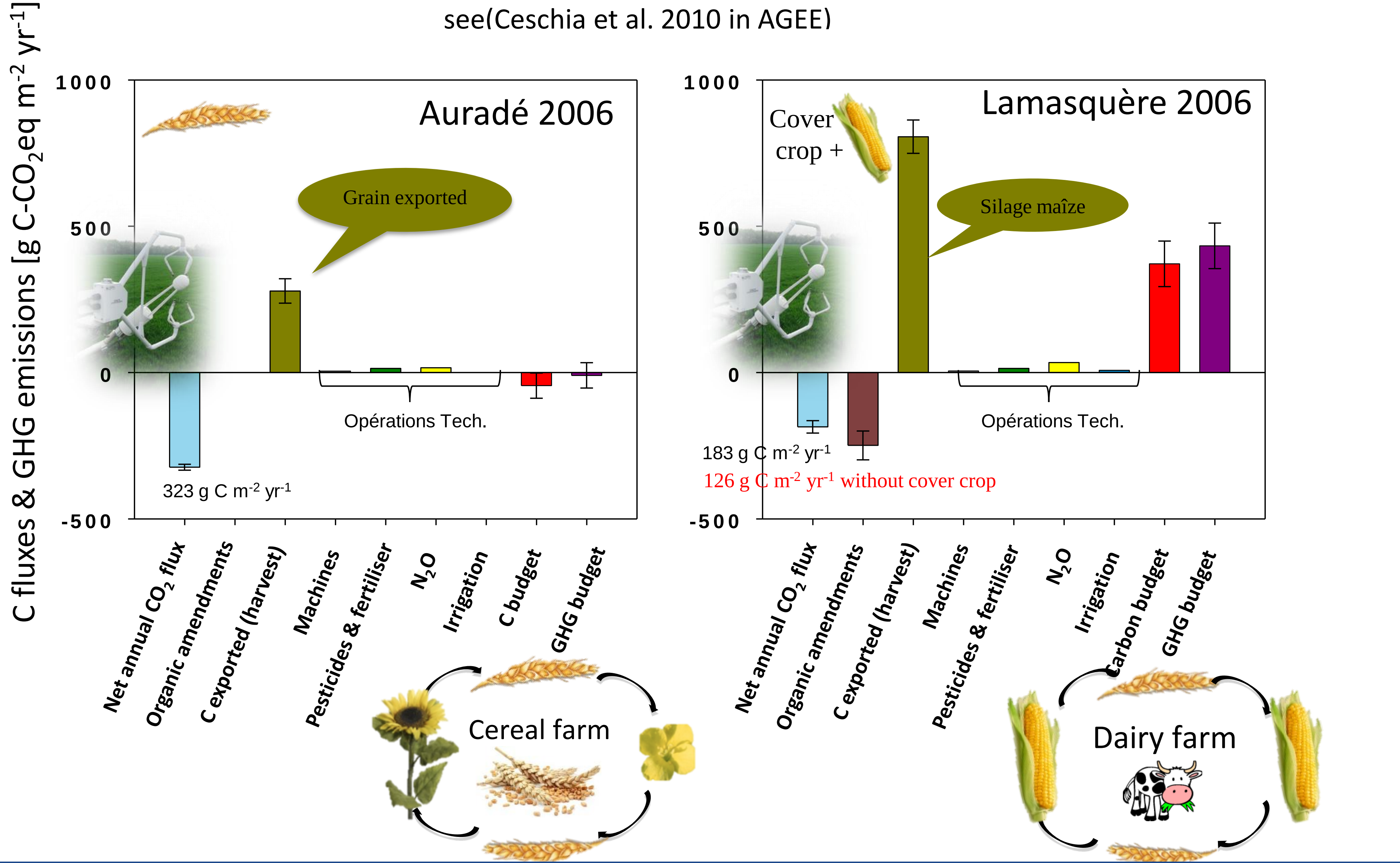


Continuous net CO_2 flux measurements at cropland flux sites



Example of result concerning the C & GHG budgets components

see(Ceschia et al. 2010 in AGEE)

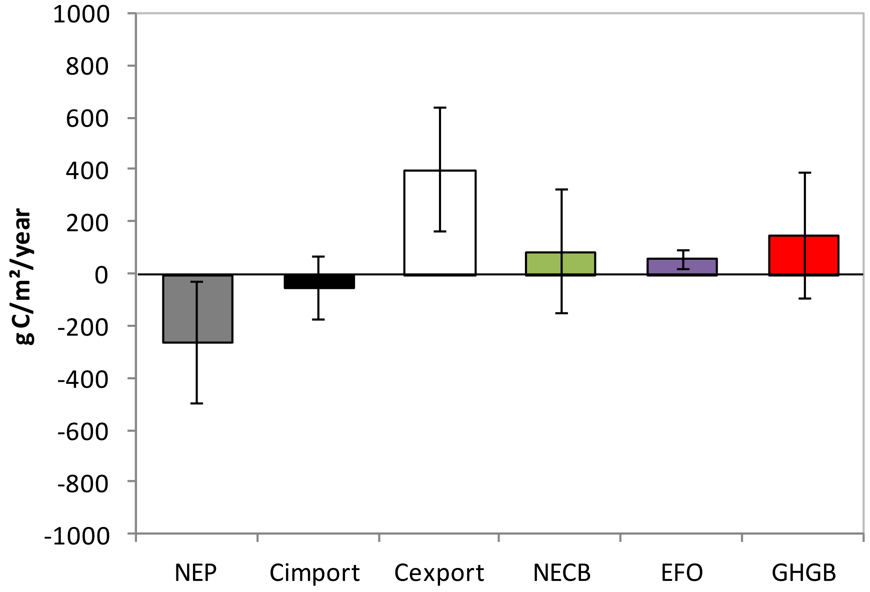


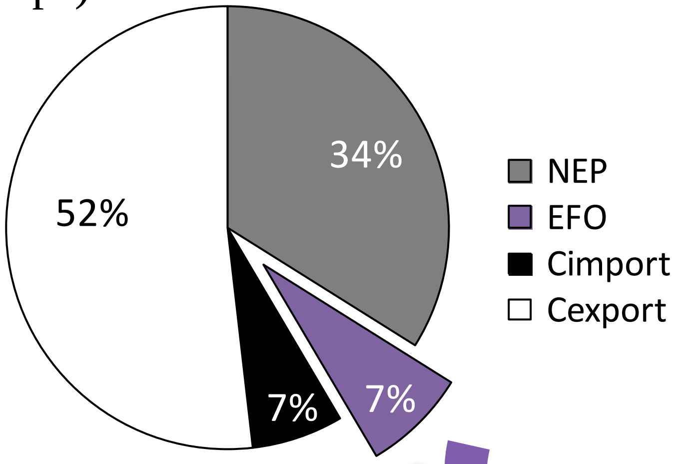
Components of the C & GHG budgets at European flux sites

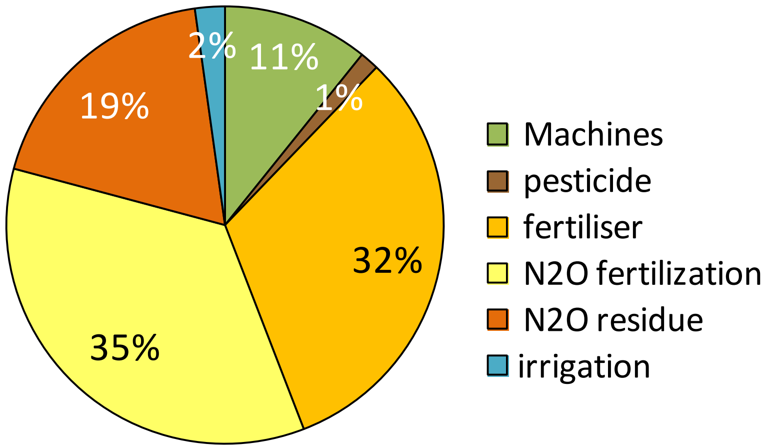
Ceschia et al (2010)

Without changing the production, it is mainly by acting on the C budget components that the C & GHG budgets can be improved:

- 1) reduce bare soil periods to fix more CO_2 (increase NEP term) ➔ cover crops
- 2) organic amendments (but limited ressource)
- 3) Straw should be returned to the soil
- 4) reduce mineral fertilisation (precision farming, leguminous cover crops)







First studies on albedo and biogeophysical effects on climate

- Among the first studies on Solar Radiation Management (i.e. modifying albedo to generate a cooling effect):
  - At the surface: e.g. Akbari (2009; 2012) estimated that painting all urban areas in white (increase in α) would lead to a 1°C cooling at mid latitudes,
  - On atmosphere: studies on atmospheric albedo ➔ e.g.. aerosol sulfate dispersion studied by Robock et al 2009 ➔ could have unintended and possibly harmful consequences on biosphere + risk of strong and imediate climatic effect if stopped

  ➔ IPCC recommends progressive & reversible combined SRM and CDR (Carbon Dioxide Removal) approaches (e.g. on land surface

- Luyssaert et al. (2014) show that Land Management Change have as much impact on climate than Land Cover Change
- Studies on afforestation & deforestation: e.g. Bonan et al. (2004) show the reduction in sensible heat flux & increase in latent heat flux (evapotranspiration) with afforestation in tropical forest, theory of the Biotic pump, importance in accounting for biogeophysical effects of forest on climate ➔ Report of World Research Institute: https://www.wri.org/research/not-just-carbon-capturing-benefits-forests-climate
- 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*) ➔ afforestation in toundra & mediteranean regions would cause such a drop in surface α that it would take 120-200 yrs of biomass productrion (CO_2 capture) to compensate for this effect,

First studies on albedo and climate mitigation

- For cropland, during many decades, studies were either focussing on :
  - Soil C storage and reduction of Green House Gases (GHG) emissions for climate mitigation,
  - Causes of albedo dynamics (Cresswell et al., 1993 ; Horton et al. 1996; Cierniewski et al., 2018…)
  - The effects of changes in management practices on biogeophysical effects (e.g. Muñoz et al. 2020; *Genesio et al., 2012; Davin et al. 2014; Luyssaert et al., 2014*),
  - The effect of Leaf Albedo Bio-geoengineering (Ridgwell et al. 2009; Sakowska et al., 2018).

Chlorophyl deficient soja ➔ high α

Normal soja ➔ low α

First studies on albedo and climate mitigation

- For cropland, during many decades, studies were either focussing on :
  - Soil C storage and reduction of Green House Gases (GHG) emissions for climate mitigation,
  - Causes of albedo dynamics (Cresswell et al., 1993 ; Horton et al. 1996; Cierniewski et al., 2018…)
  - The effects of changes in management practices on biogeophysical effects (e.g. Muñoz et al. 2020; *Genesio et al., 2012; Davin et al. 2014; Luyssaert et al., 2014*),
  - The effect of Leaf Albedo Bio-geoengineering (Ridgwell et al. 2009; Sakowska et al., 2018).

- But to compare biogeochemical effects with the RF_{α} caused by cropland management changes, the latter had to be converted in CO_2-eq ➔ 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_{α} on climate mitigation (see *Bright et al. 2015*).
- As a consequence, recent studies showed that for some management changes RF_{α} had impacts of the same order of magnitude than biogeochemical effects (Ferlicoq & Ceschia 2015; Carrer et al. 2018, Kaye & Quemada 2018; Lugato et al. 2020…).

Analysis of α dynamics and RF components

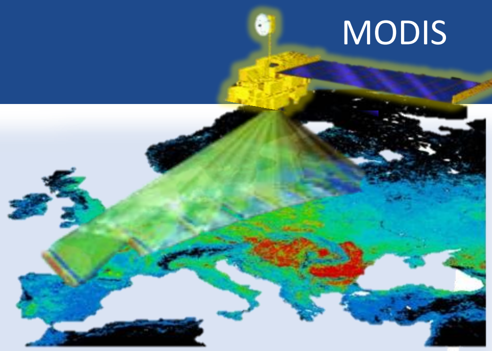
In this presentation we will :

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

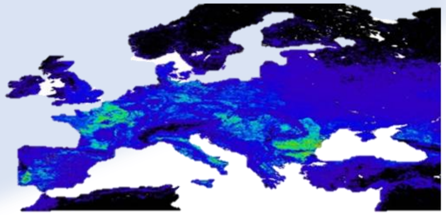
- Then we will compare short term and long terms biogeophysical and biogeochemical effects of some management changes at larger scale to analyse their direct and undirect effects on the net radiative forcing.

Various spatial and temporal scales of study

MODIS



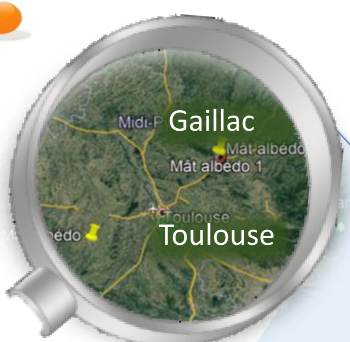
Surface albedo dynamics



RFα

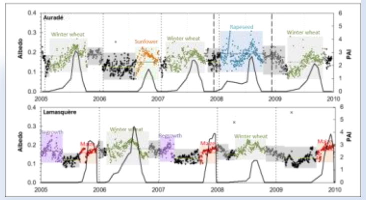
Gaillac (81)

Biogeophysical effects of cropping sytems



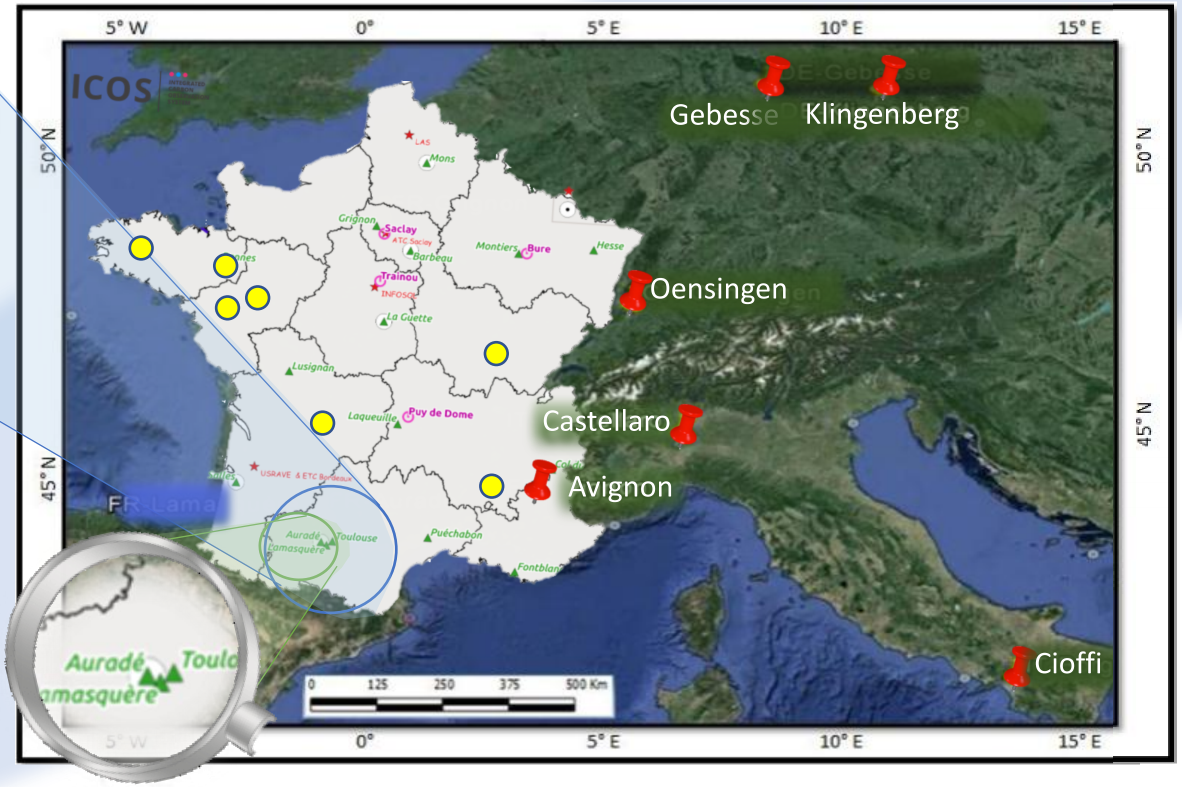
Lamasquère (31)

Biogeophysical & biogeochemical effects on RFnet



Causes of fast surface albedo changes

In situ measurements/Southwest France



French grassland sites

European cropland ICOS sites

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 & grasslands (arbitrary reference).**

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

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

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

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)

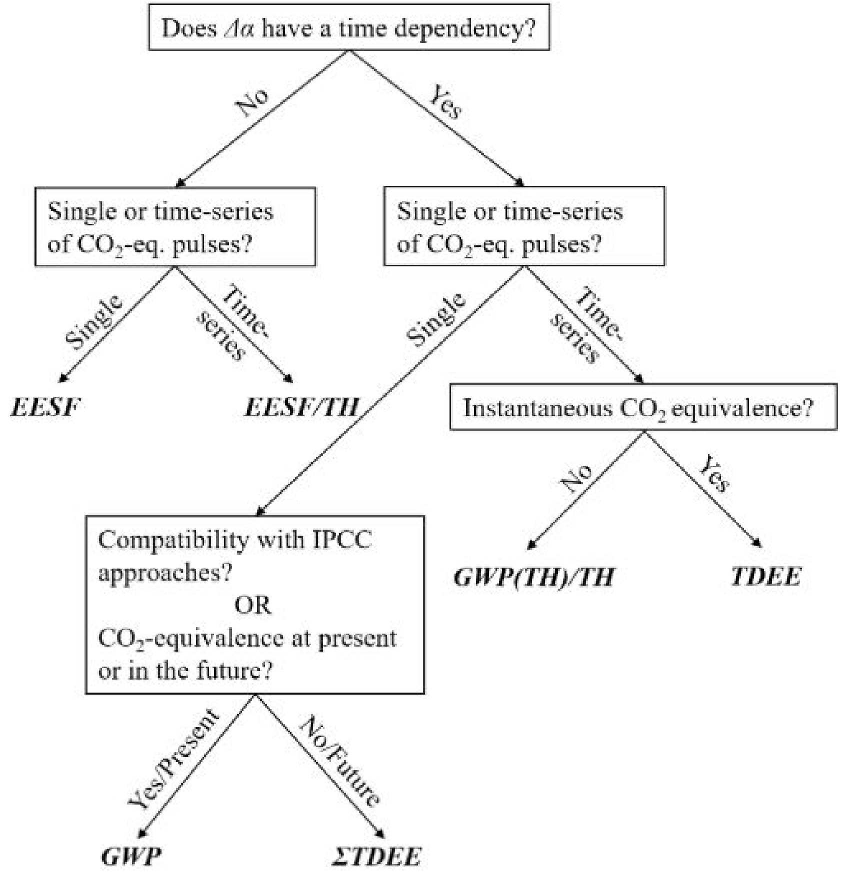
④ **Conversion in CO_2-eq based on AF method (*Betts et al. 2000*)**

$$RF_{\alpha y}(in\ Kg\ CO_2 - eq) = \frac{A\ RF_{\alpha y}(W \cdot m^{-2}) \ln 2\ pCO_{2,\mathrm{ref}}\ M_{CO_2} m_{\mathrm{air}}}{A_{\mathrm{Earth}}\ \Delta F_{2X}\ M_{\mathrm{air}}\ AF}$$

AF depends on the time horizon considered

Other methods of conversion of the RFα in CO_2-eq

More complex methods based on Bright & Lund (2021): To choose the more appropriate method, analyse this figure



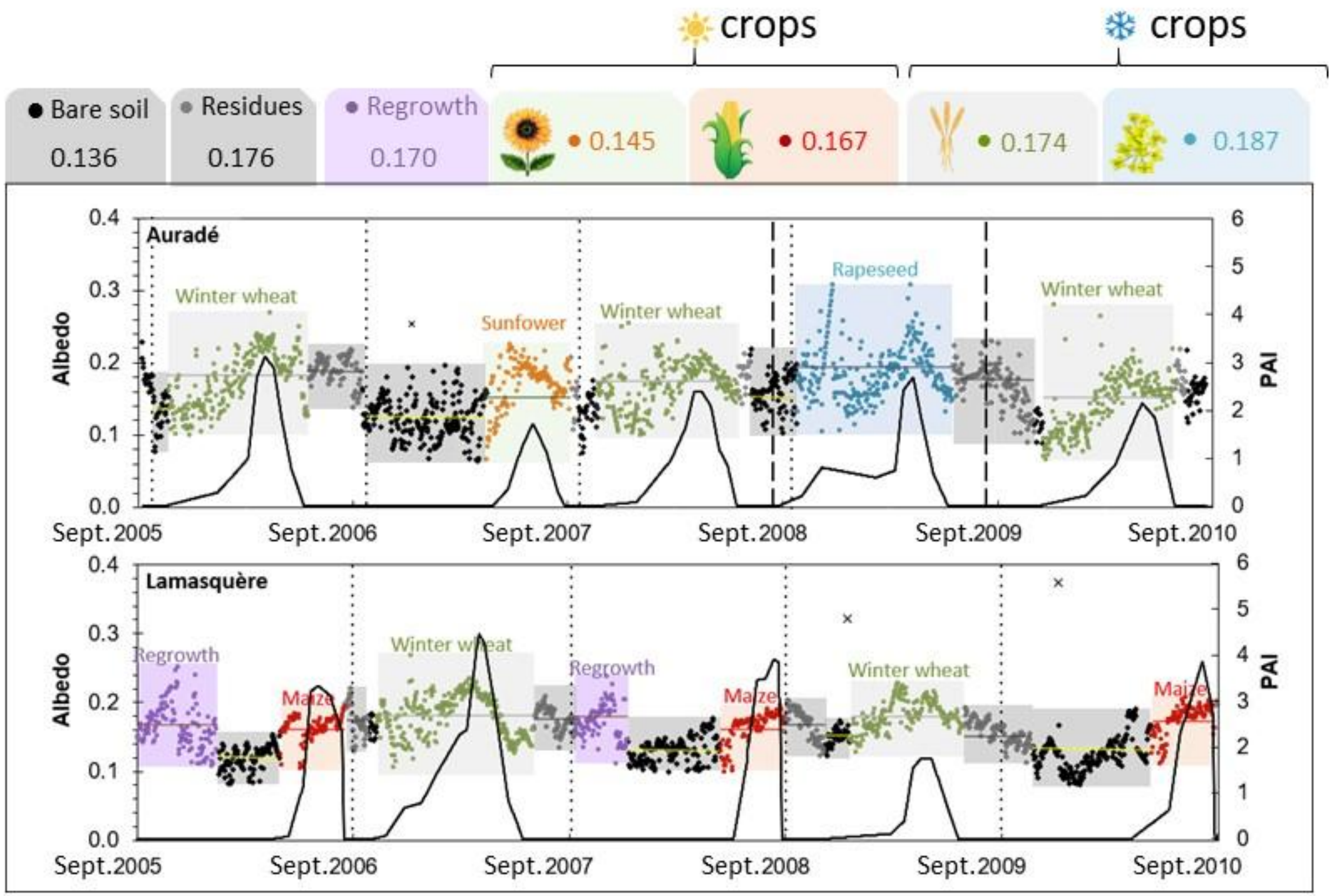
TDEE for « Time-Dependent Emissions Equivalent »

This method avoids a possible overestimation of the CO_2 equivalents encountered in methods that do not take into account the temporal albedo variation. For its application, it requires not only a pulsed CO_2 emission time series (difficult to obtain), but also the user's definition of a priori scenario of inter-annual temporal variation of surface albedo.

GWP pour « Global Warming Potential»

Widely used to compare the climatic effect of surface albedo radiative forcing with that of other GHG emissions, GWP, is also a time-dependent conversion method. It represents the accumulation of radiative forcing (RF$\Delta\alpha$) following a pulsed emission of CO2 over a time horizon (TH). The user will have to define a priori scenario of inter-annual temporal dependence of the albedo variation.

How do cropland status affects surface albedo ?



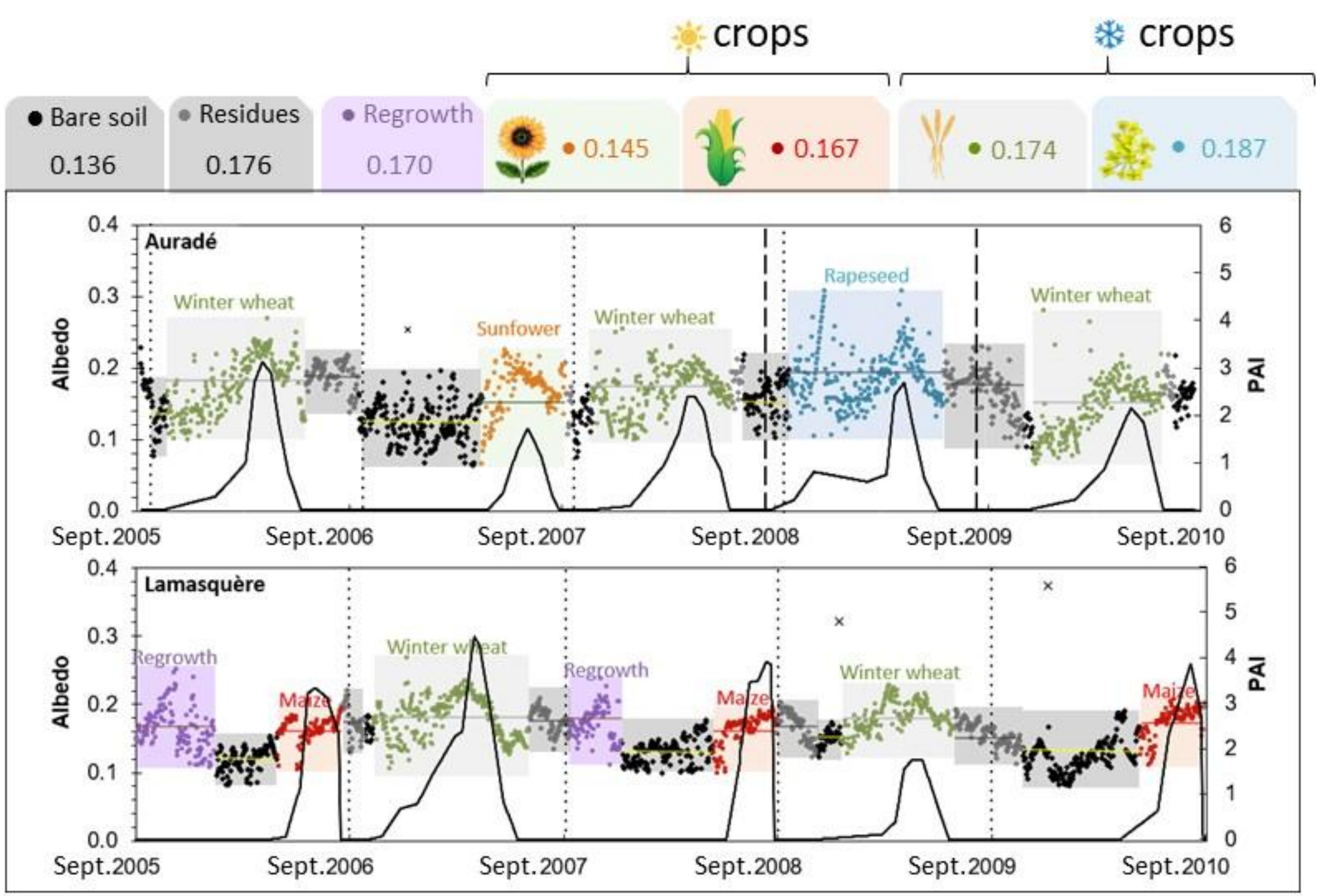
The rapeseed suffered from November **drought and frost** that increased surface albedo because of leaf damage + snow.

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

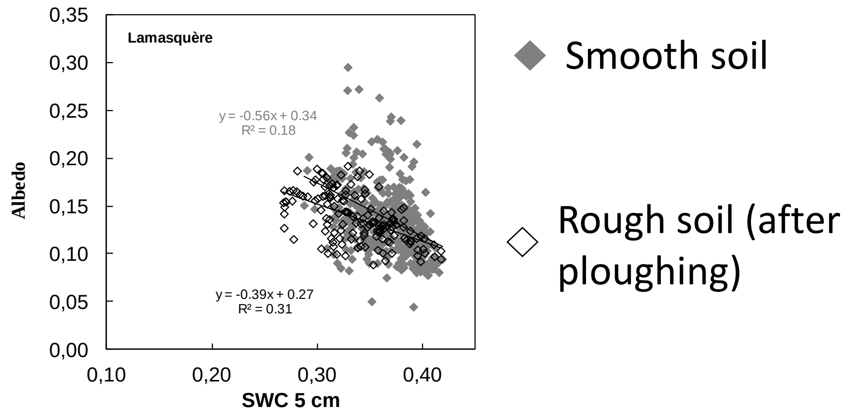
Crop type: $\alpha_{rapeseed} > \alpha_{WW} > \alpha_{maize} > \alpha_{sunflower}$

Avoid bare soil periods ➔ adapt crop rotations, cover the soil with crop residues or cover crops during fallow

How do cropland status affects surface albedo ?



Rain decreases the albedo of the soil as water darkens the soil's

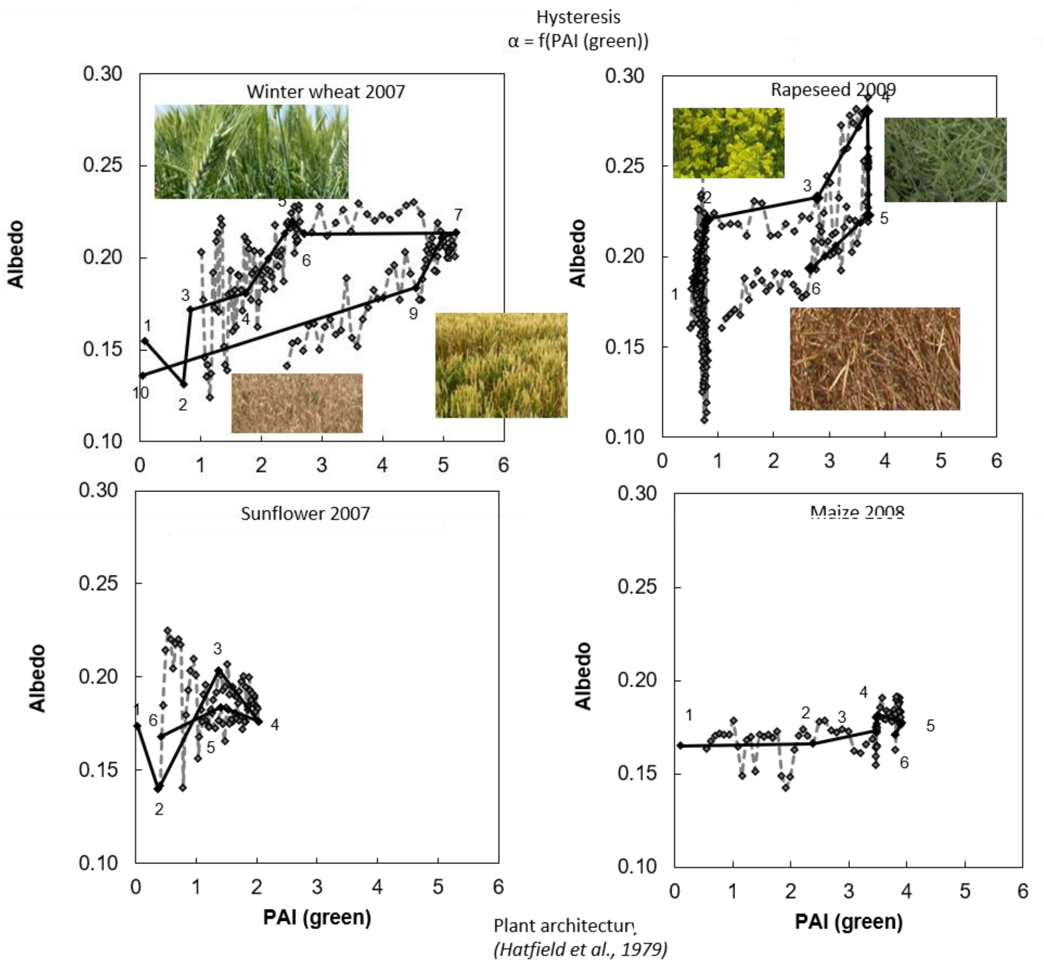


In general, surface albedo increases with the green plant area index (PAI) but the response is crop dependant;

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

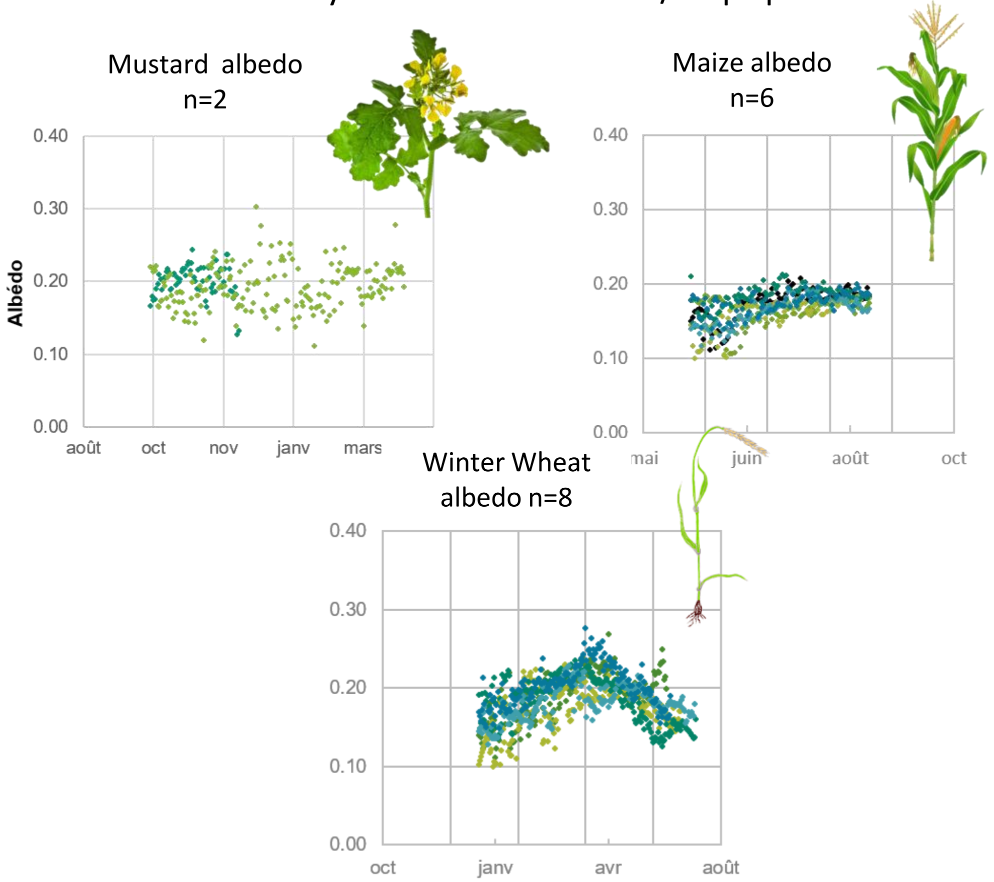
How do crop development affects surface albedo ?

Crop phenology effect on surface albedo



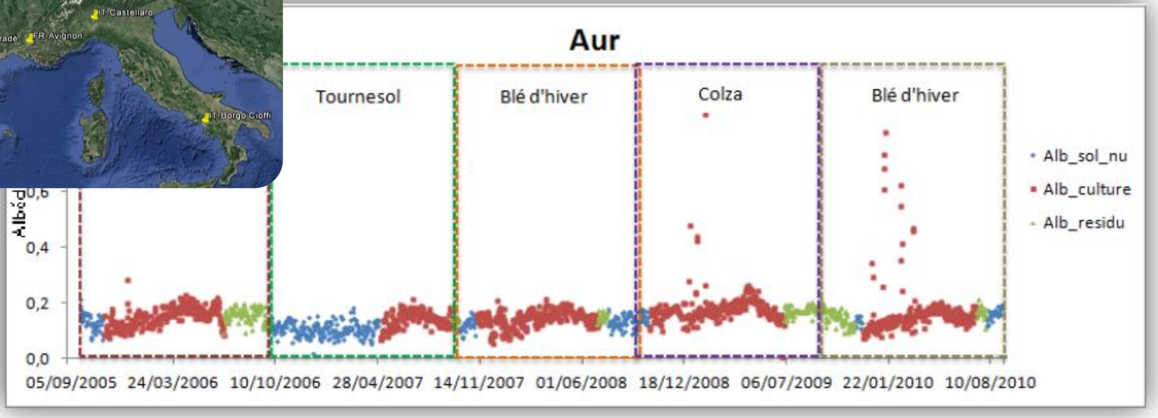
Albedo dynamics differ accroding to crop species

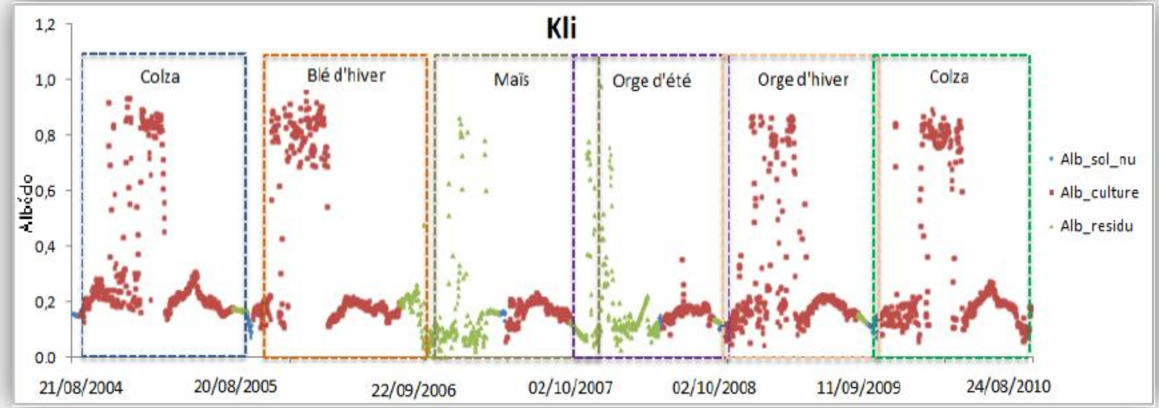
Several years of measuremets/crop specie

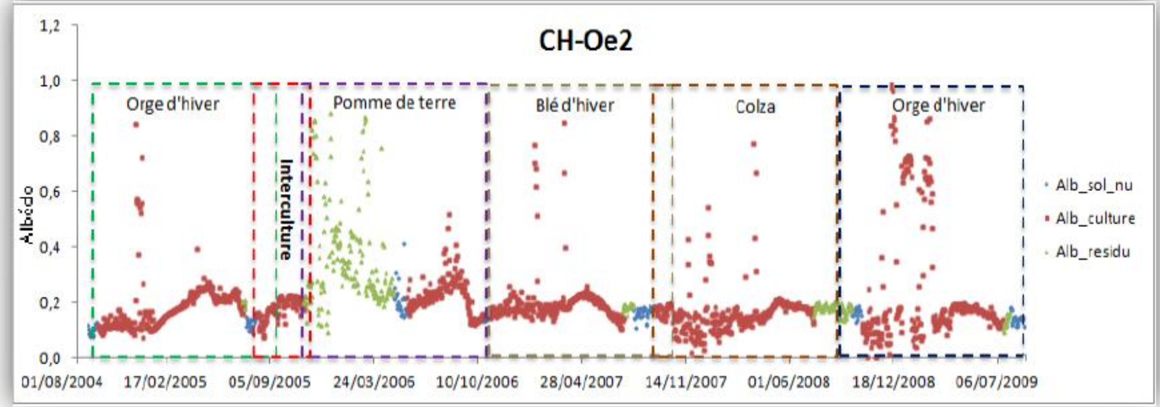


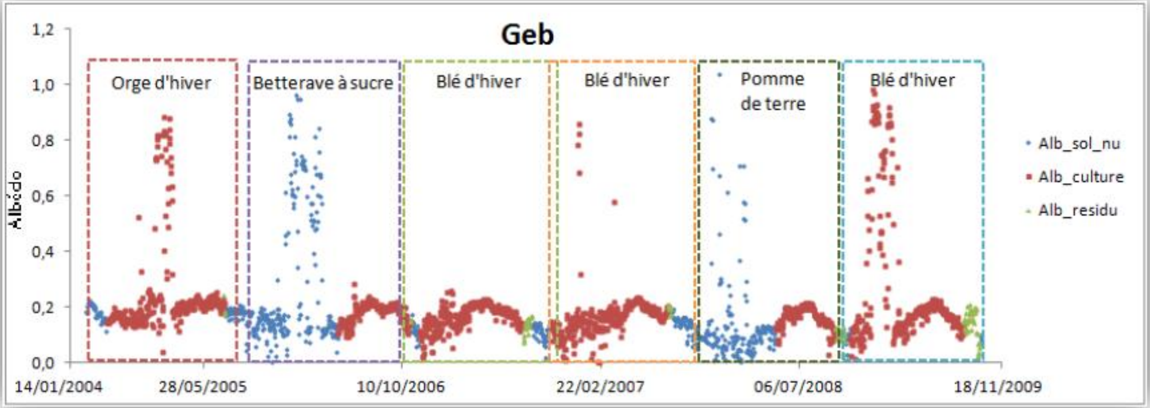
European multi-site analysis

Master training Niama Boukachaba









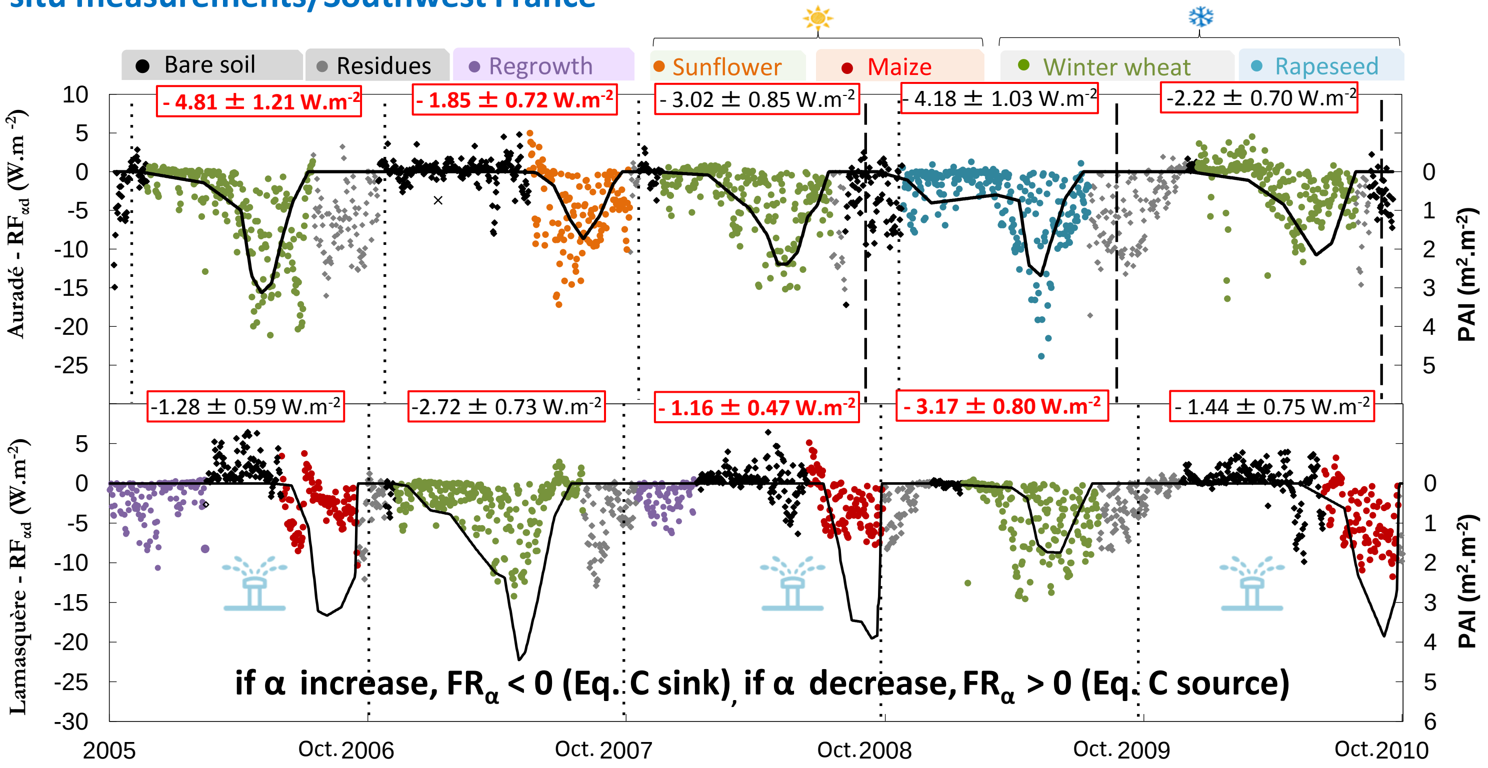
Values > 0,4 correspond to snow periods

Similar analysis compared to previous slides (low α of bare soil…)

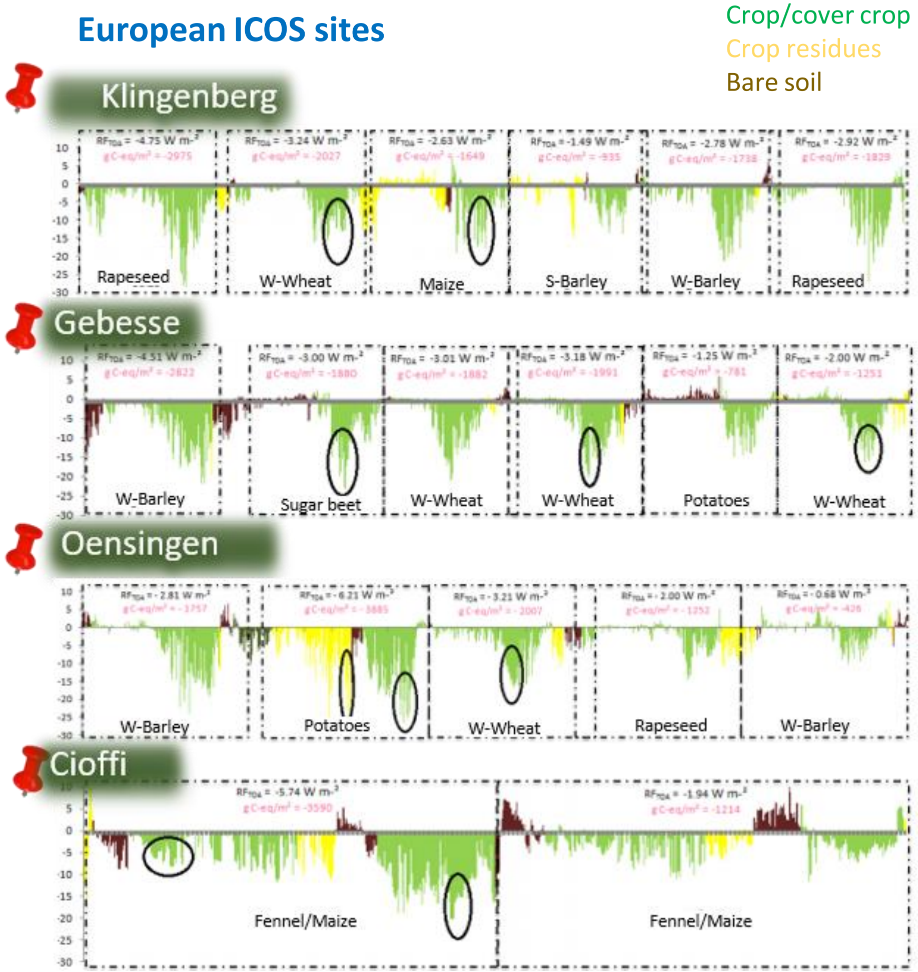
RFα induced by cropland albedo dynamic in reference to bare soil

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

In situ measurements/Southwest France



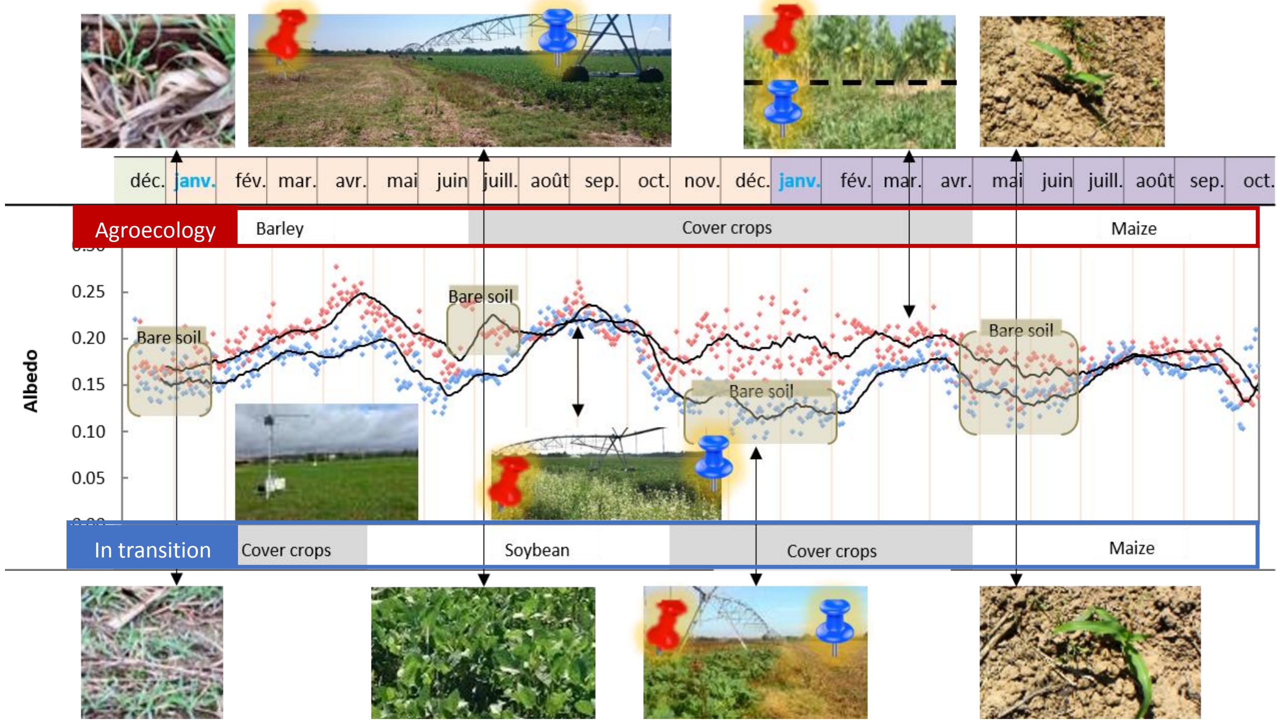
European ICOS sites



- Soil coverage may contribute to a "cooling" albedo effect,
- Same observations at all European flux sites
- **But !!! arbitrary reference albedo**

Comparison of albedo effects between cropping systems

Gaillac (France)



- The two subplots are adjacent:
  - (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

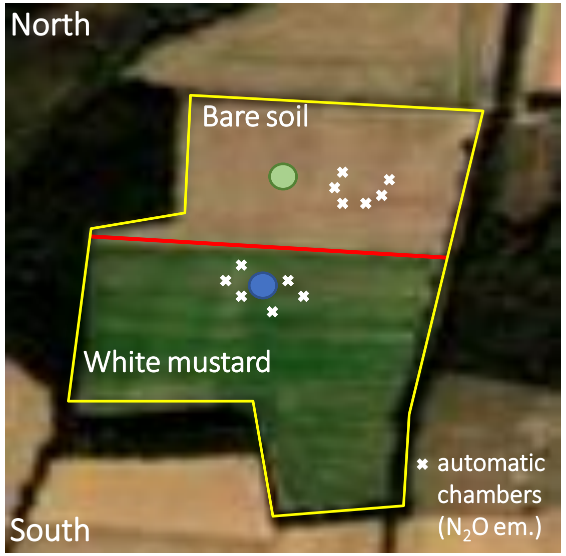
- Cover crop growing duration were about 6 to 9 months (common in our area).

- 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 **Infrared radiation that overwhelmed the albedo effect** at the “agroecology “ site during summer at the beginning of CC development (not shown here).

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

ICOS Lamasquère site



Measured variables :

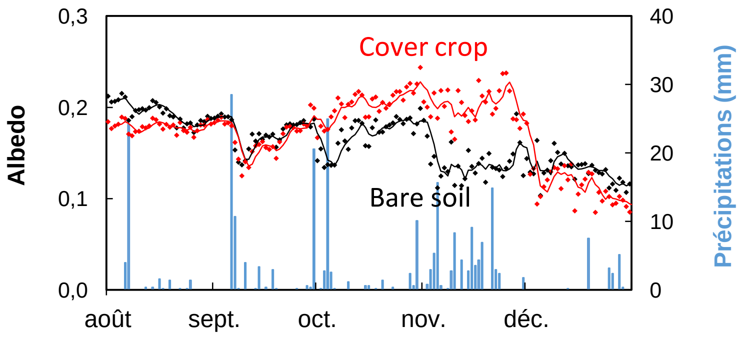
- CO_2, N_2O, water & energy fluxes
- Soil temperature & humidity at 0-5 cm
- Soil heat fluxes
- Solar incident/reflected radiation (short & longwave)

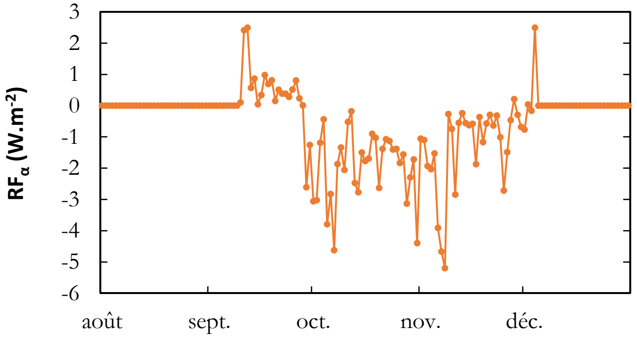
Objectives :

- 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

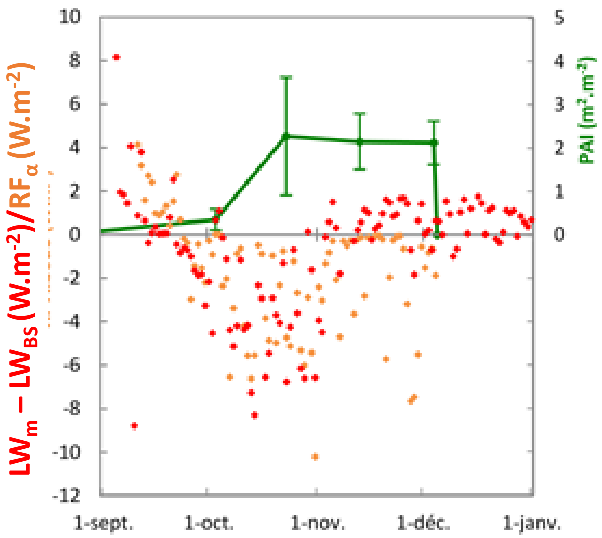
1. Shortwave (albedo) effect (RFα)





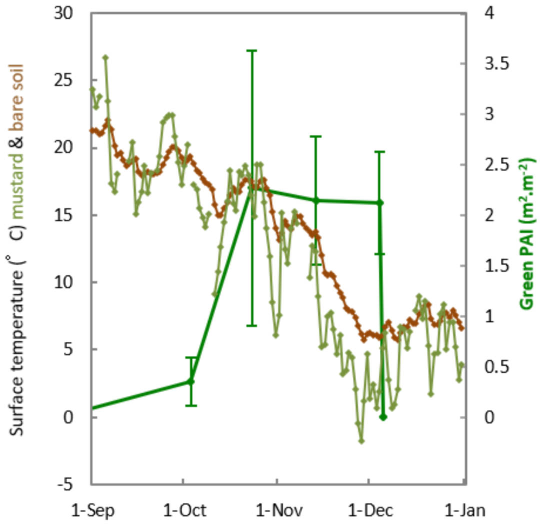
➔ Δα causes a cooling effect

2. Longwave effects



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

3. Soil temperature



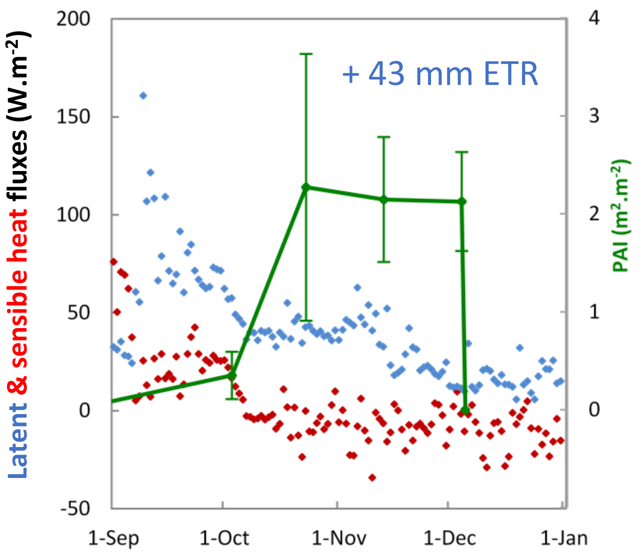
➔ Mean difference of 2.5°C

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

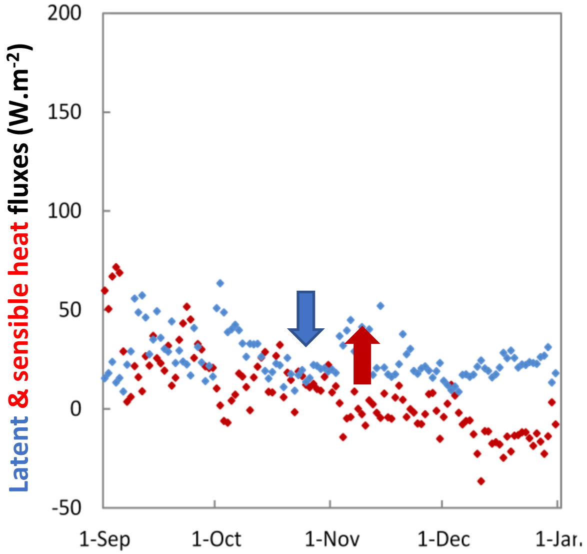
Comparative in situ analysis – Non Radiative effects of cover crops

Effects on latent and sensible heat fluxes

Cover crop (mustard)



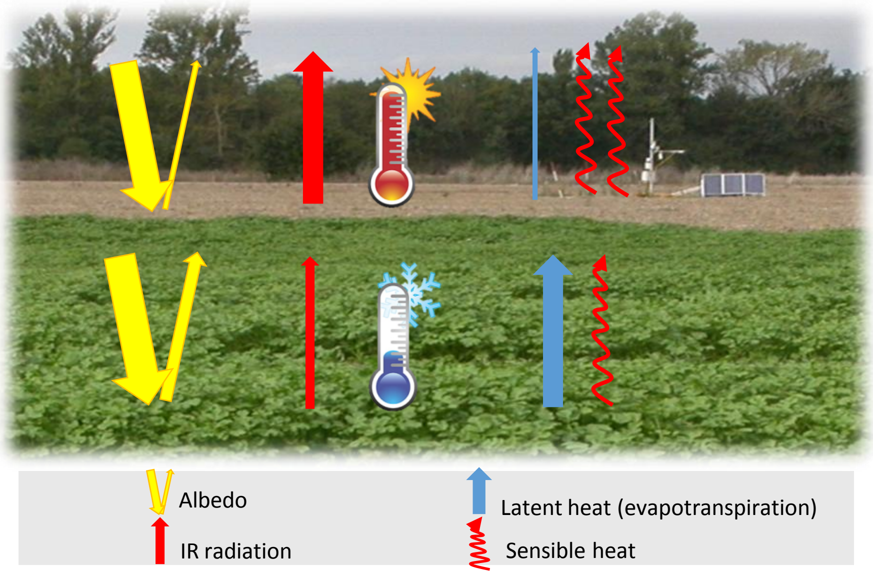
Bare soil



- ↑ 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*

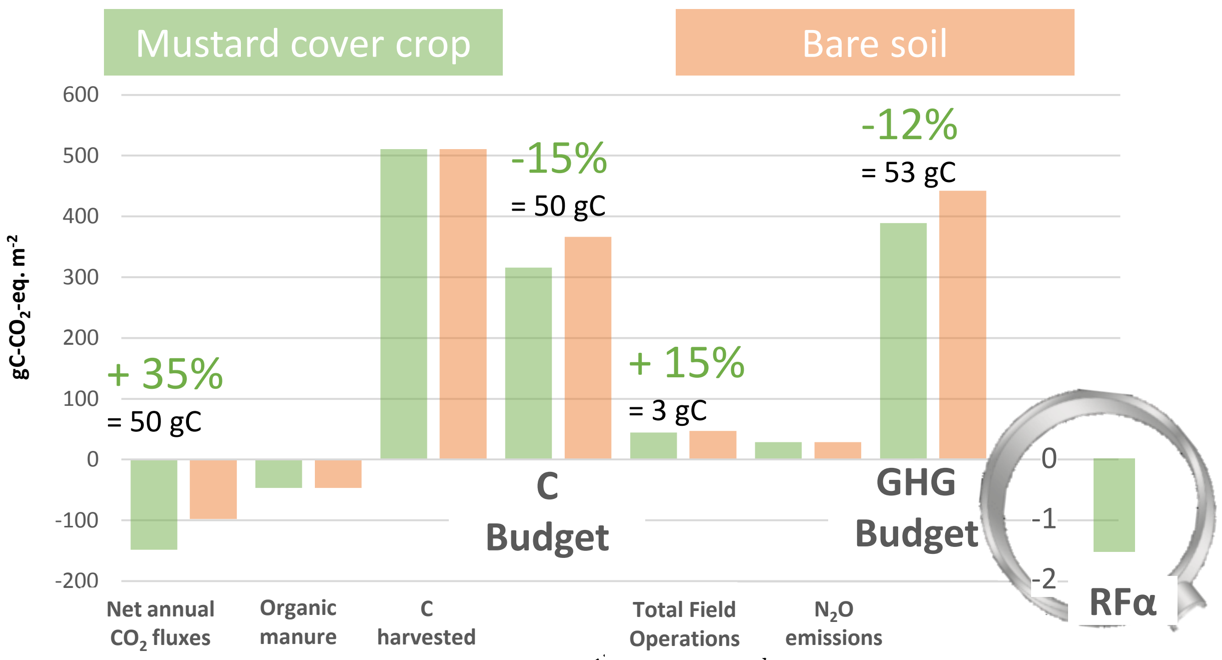
Summarizing cover crop biophysical effects

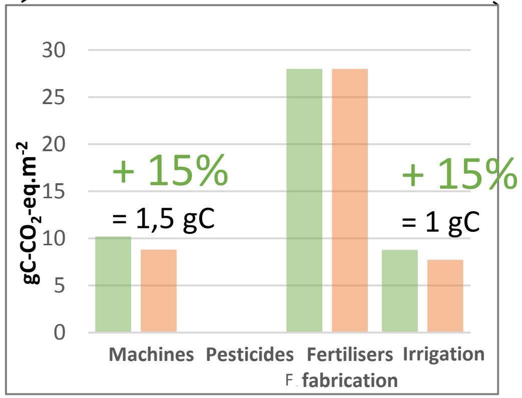
Radiative effects **Non Radiative effects**



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.

Sate of the art concerning grasslands albedo effects

According to Rosset et al. (2001) & Li et al. (2000), managed grasslands have lower albedo than unmanaged/native grasslands due to changes in vegetation phenology (senescent plant matter fraction), the visible soil fraction and the presence of shrub vegetation associated with low grazing intensity ➔ true in areas where soil has a very high albedo (e.g. Mongolia),

According to Ketzer et al (2008) mowing and grazing more or less increase albedo depending on the intensity/duration of these practices. For example, albedo increases with grazing intensity due to removal of green cover, indicating potential overgrazing and desertification when critical value exceeds (Li et al., 2000).

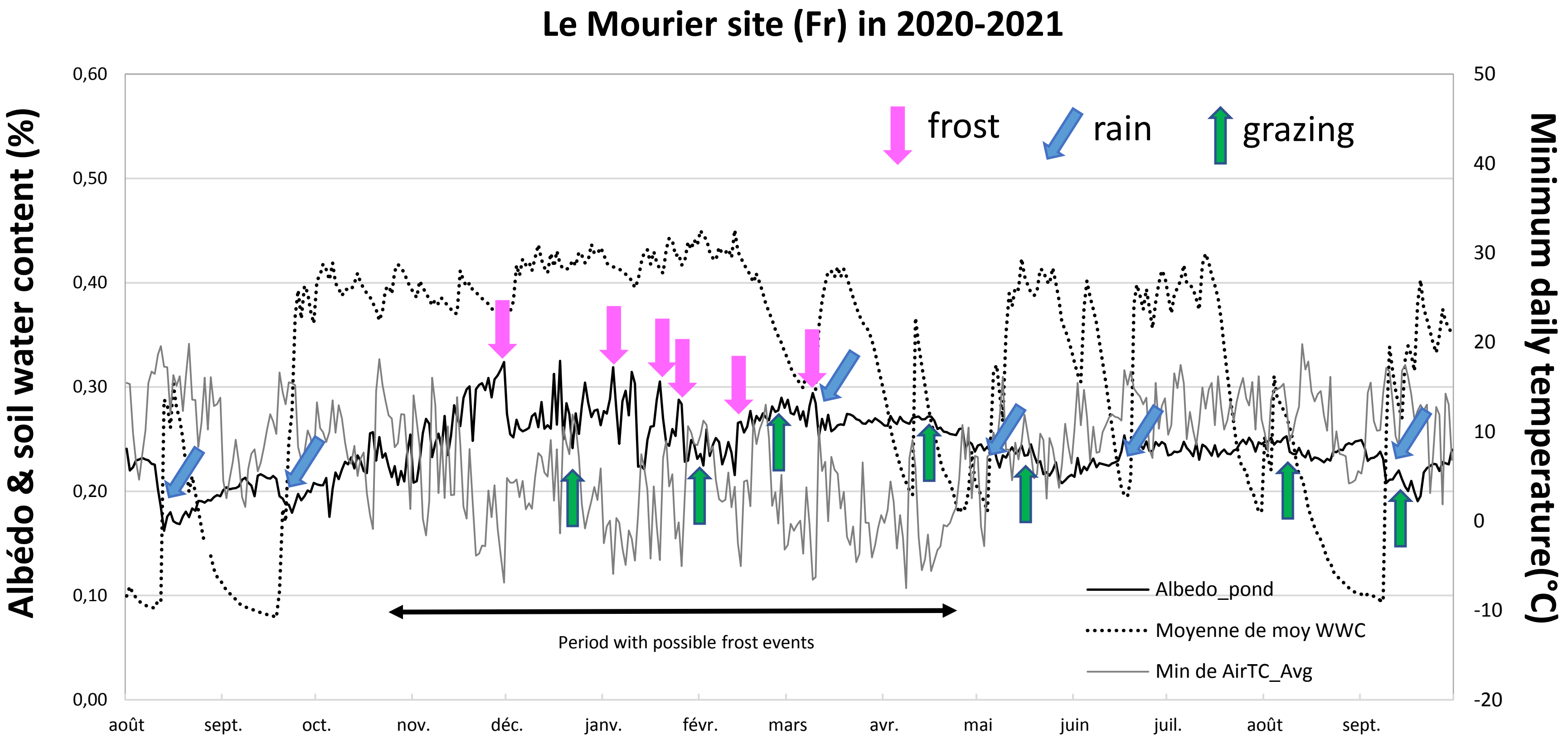
As grassland growth is affected by fertilization, a close linear relationship was found between grassland albedo and leaf nitrogen concentration (albedo=0.02+0.067 x N%) according to Holinger et al. (2010)

The application of slurry could have temporary but very strong effects on albedo (reduction) due to the darkening of the surface (Stock et al 2019).

Fire that suppresses senescent plant matter has strong effects on energy balance and reduces albedo (Bremer et al. 1999).

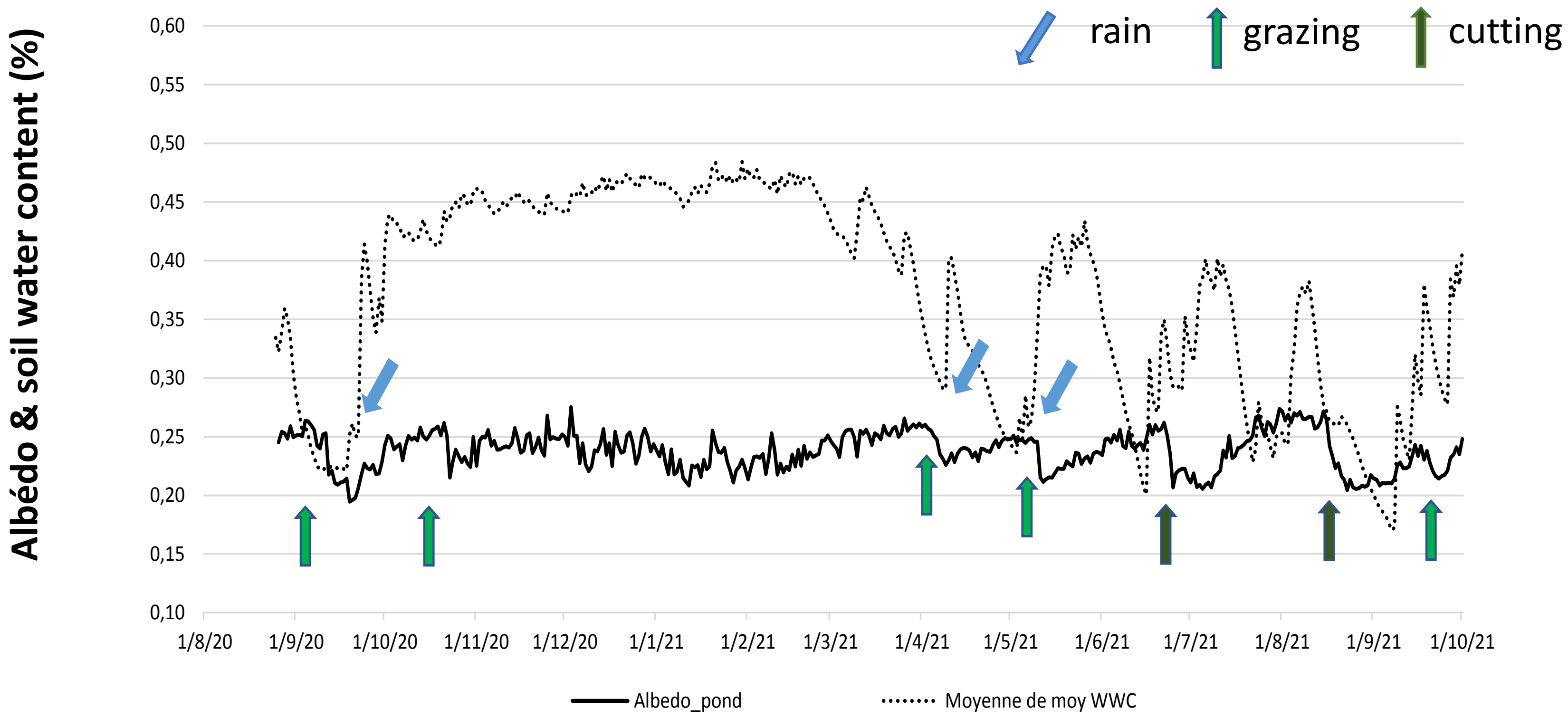
Grassland composition and species affect surface properties such as albedo and roughness (Aguiar et al. 1996).

Effect of climate & management on grassland α dynamics



Effect of climate & management on grassland α dynamics

Trevarez site (Fr) in 2020-2021

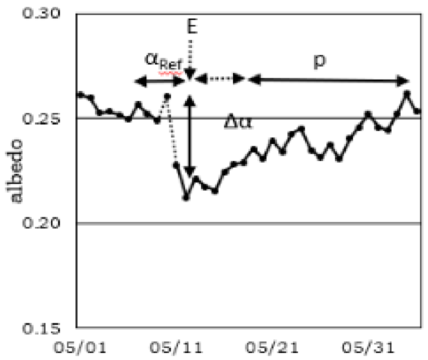


- Higher α values and less variability in α dynamics compared to cropland, however in Sweden unimproved grassland had lower α
- Rain decrease α when grass is covering less the soil,
- Little effect of grazing (low & temporary decrease in α), cutting has more effect.

Effect of climate & management on grassland α dynamics

ALBEDO Prairies

Analysis of the intensity and duration of a disturbance



αref = the 5 day mean daily albedo value before the event

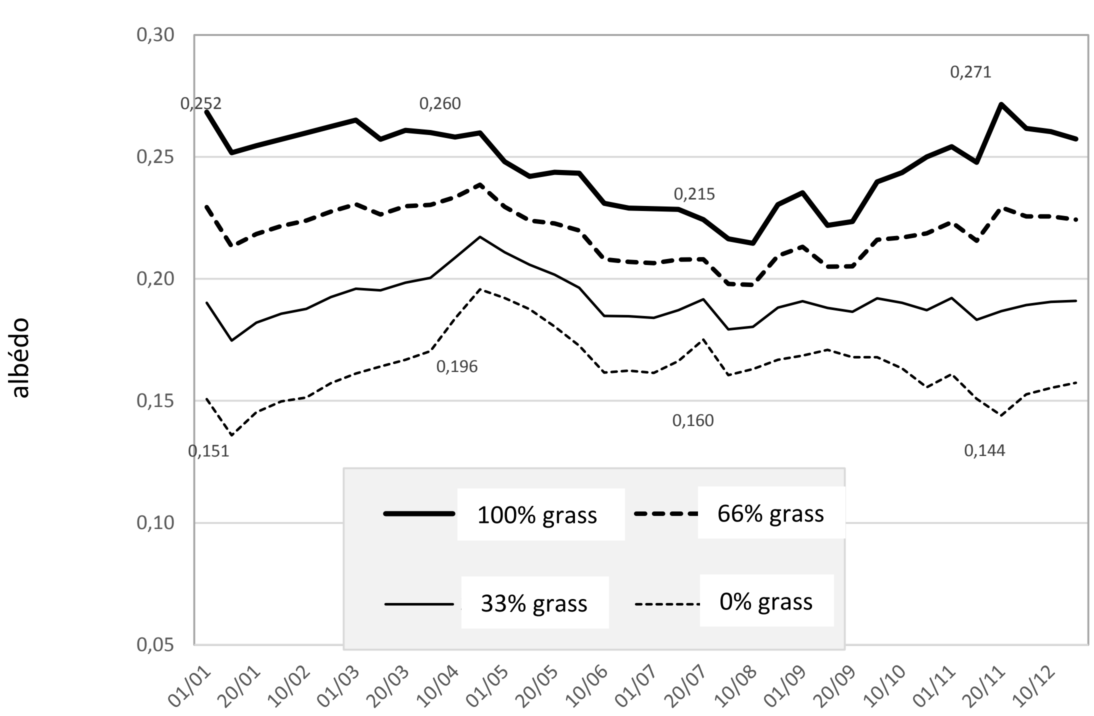
	2020-21	2020-22	
Grazing	-3.9%, 15 days, n=37	-4.2%, 9.2 days, n=58	
Cutting	-14%, 27.7 days, n=3	-14%, n=3 +1 Mourier*	*Mourier = hay the rest = wrapping
Refusal reap	-3.5%, 4 days, n=6	-3.6%, 3.7 days, n=7	
Rain after a dry period	-7%, 10.5 days, n=30	-5.3%, 9.2 days, n=41*	*up to 30/06/22
Organic amendments	Not enough events	Not enough events	

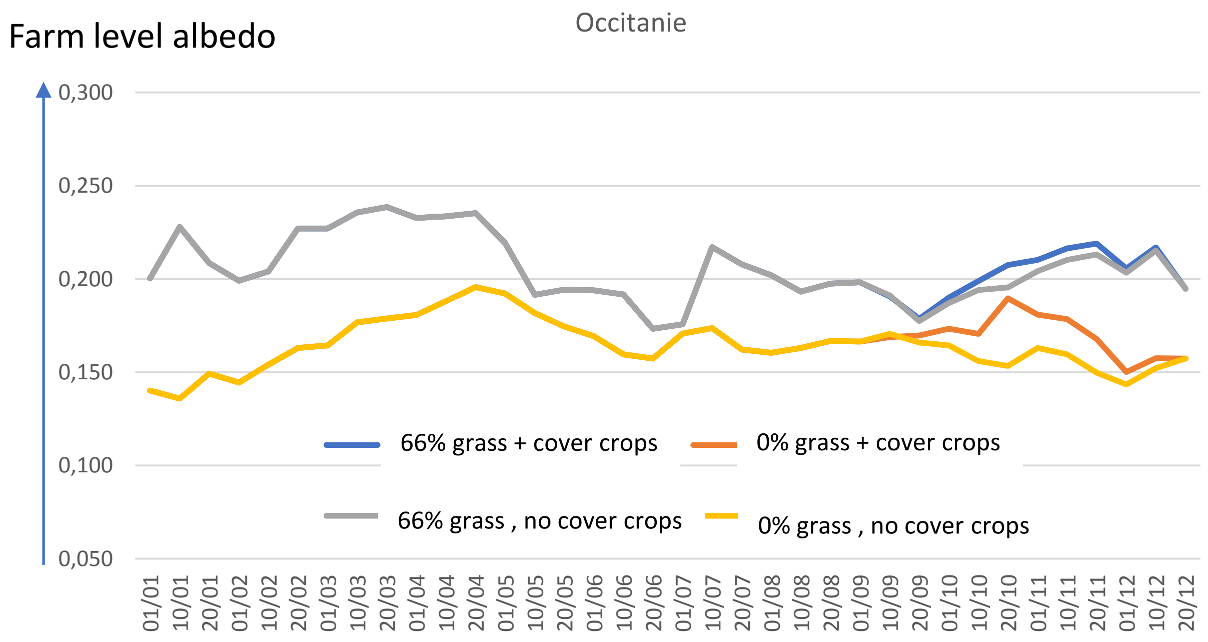
- Confirmation with additional 2022 data of effects observed in 2020-21. The 4th mowing event at the Mourier, is not yet integrated: the hay remained long in place, compared to the mowings of Trévarez and Méjusseaume (wrapping, quickly removed)

Effect of the type of fodder produced on farm level α dynamics

ALBEDO Prairies

Simulations with Sim'α **of the impact of the proportion grass (versus crop) in the fodder production at farm level & effect of cover crops**





- A simple tool (excel, decadal time scale…) based on existing albedo dynamics (grass, wheat, corn, sunflower, rapeseed, mustard, straw, bare soil) with α dynamics "manualy" adapted to local phenology.
- Strong differences in albedo dynamics between the fodder systems ➔ strong effect in terms of RFα and CO_2eq effect (to be compared soon with the effect of the fodder system on the farm level C & GHG budget)…better feed the animal with grass ;-)

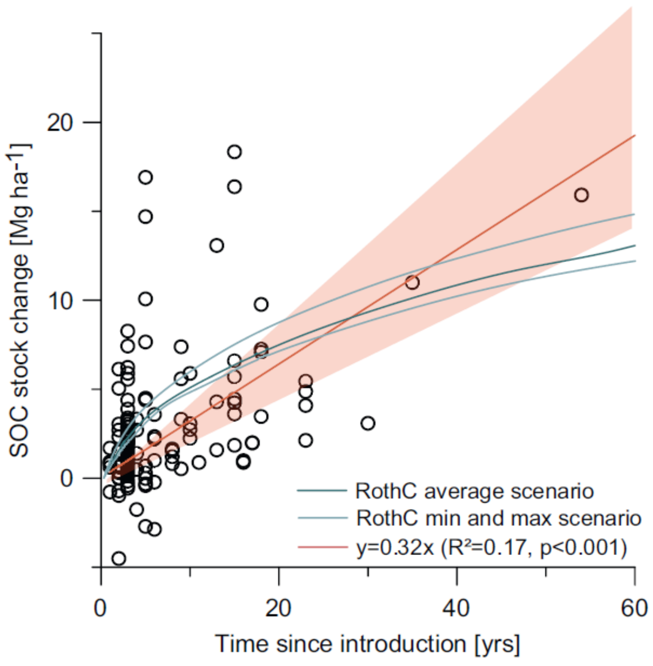
What do studies at larger spatial and temporal scales teach us ?

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

Several studies tend to show that :

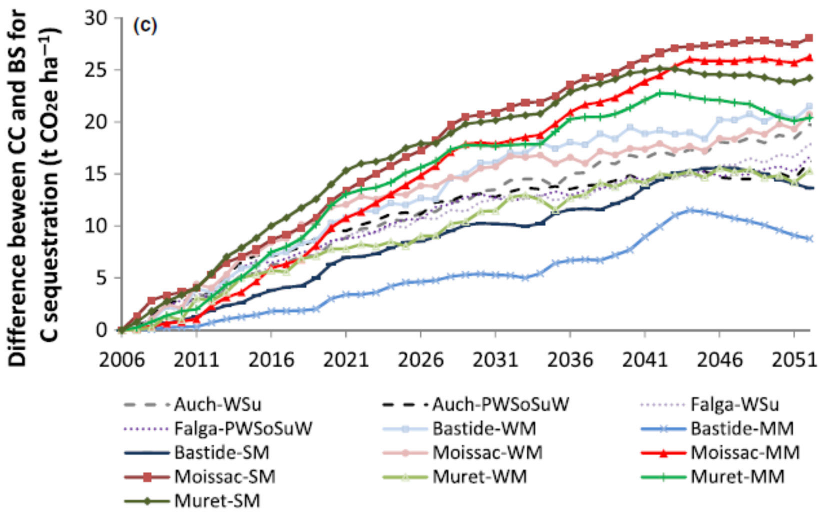
- the carbon storage effect of the CC could be limited in time : new equilibrium reached after 45-50 year,

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

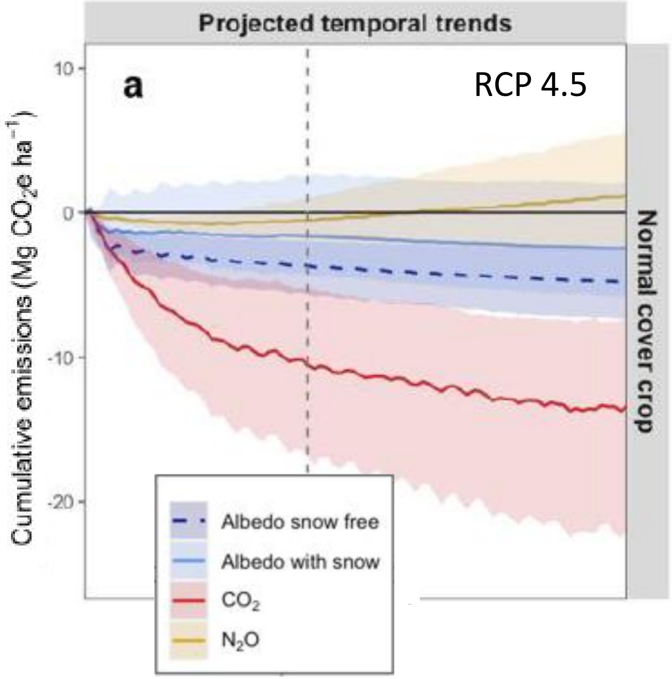


STICS simulations in France (*Tribouillois et al., 2018*)

RCP 4.5



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

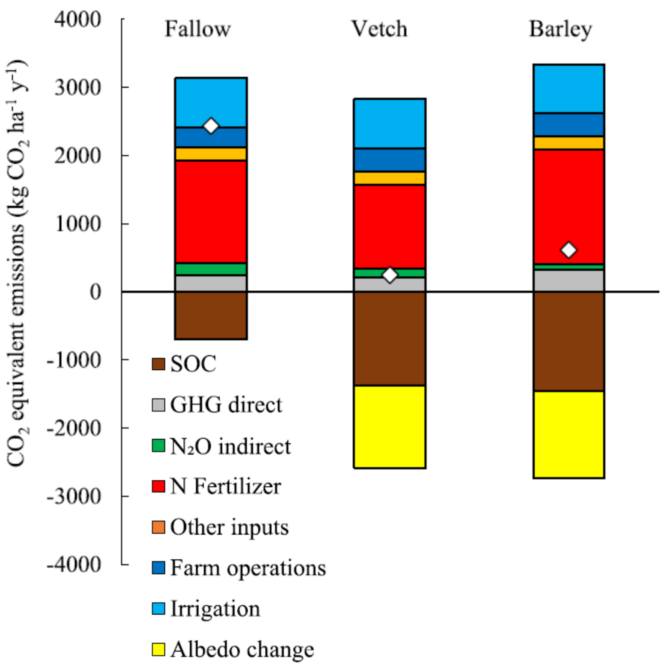


GHG budget of cover crops (vs bare soil) in time

Several studies tend to show that :

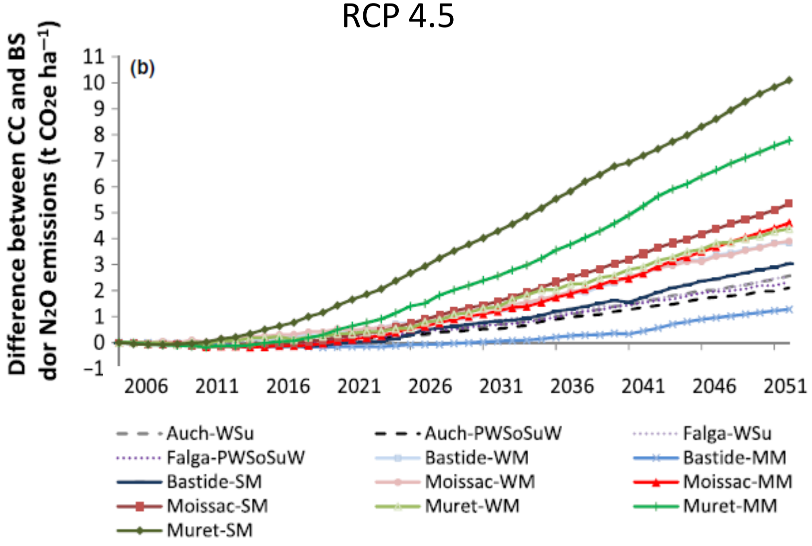
- the carbon storage effect of the cover crops could be limited in time : new equilibrium reached after 45-50 year,
- N_2O emissions may decrease on the short term but then increase 15-50 years after cover crop introduction ➔ Adapt N fertilisation after cover crop destruction ➔ integrated soil fertility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

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

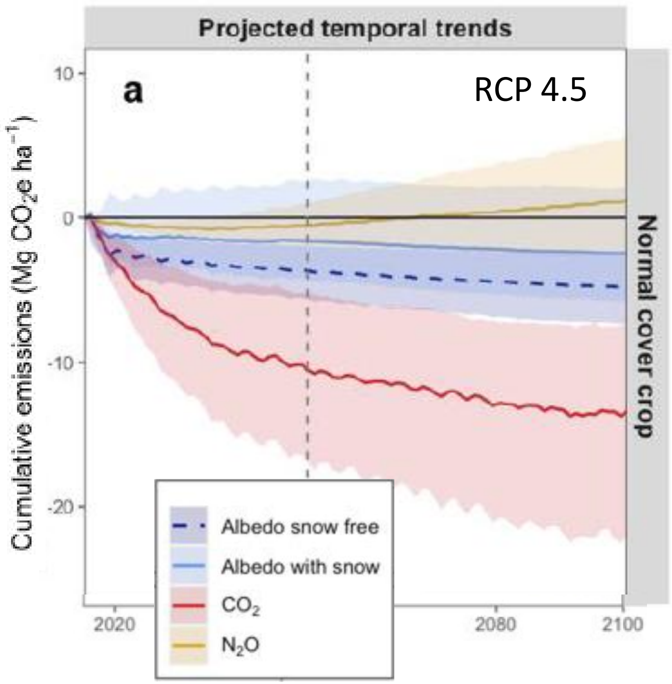


STICS simulations in France (*Tribouillois et al., 2018*)

RCP 4.5



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

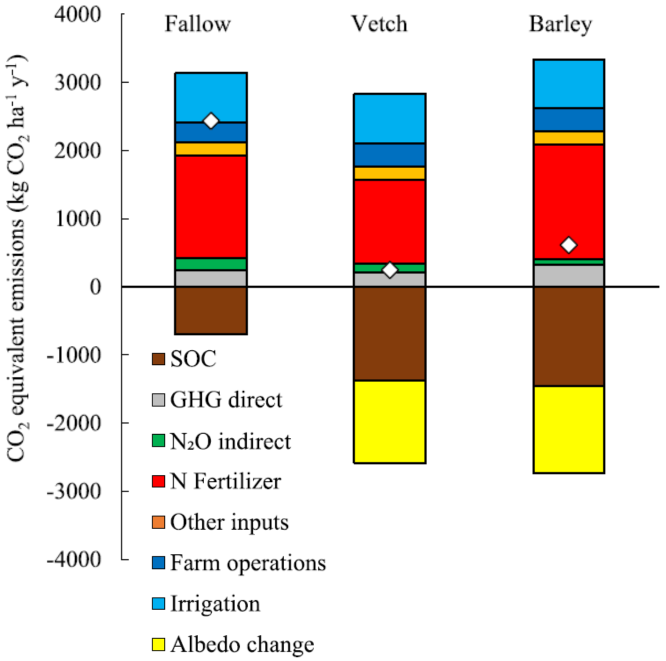


GHG budget of cover crops (vs bare soil) in time

Several studies tend to show that :

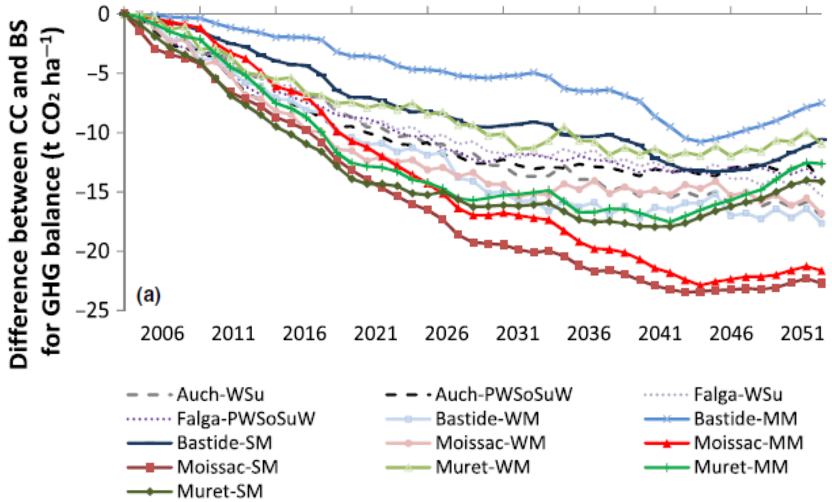
- the carbon storage effect of the cover crops could be limited in time : new equilibrium reached after 45-50 year,
- N_2O emissions may decrease on the short term but then increase 15-50 years after cover crop introduction ➔ Adapt N fertilisation after cover crop destruction ➔ integrated soil fertility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

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

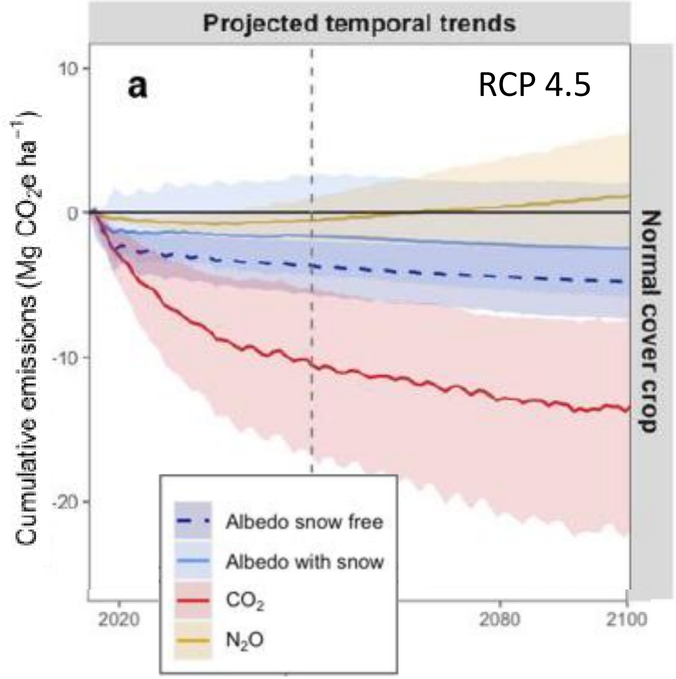


STICS simulations in France (*Tribouillois et al., 2018*)

RCP 4.5



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



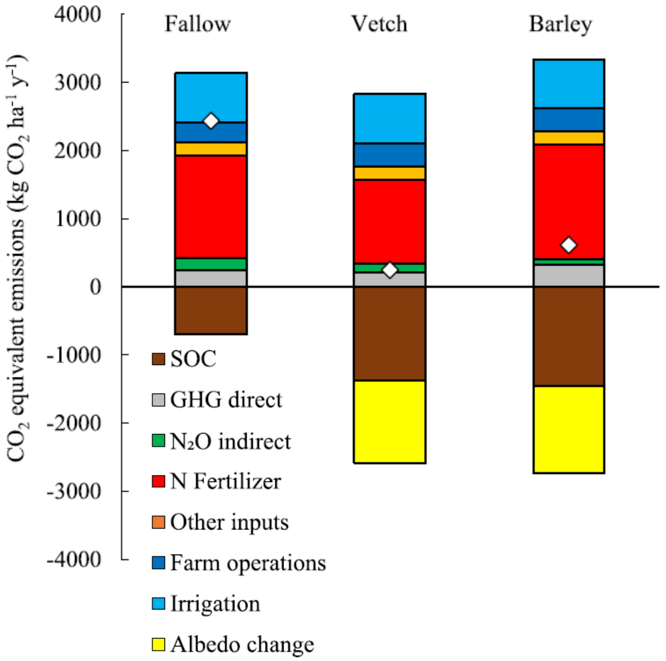
Albedo effects in the same range as C storage effect

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

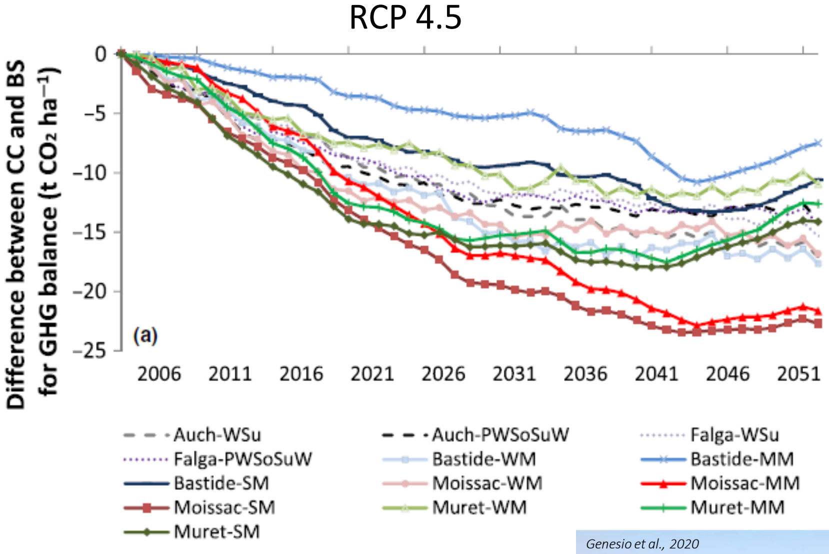
Several studies tend to show that :

- 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*)

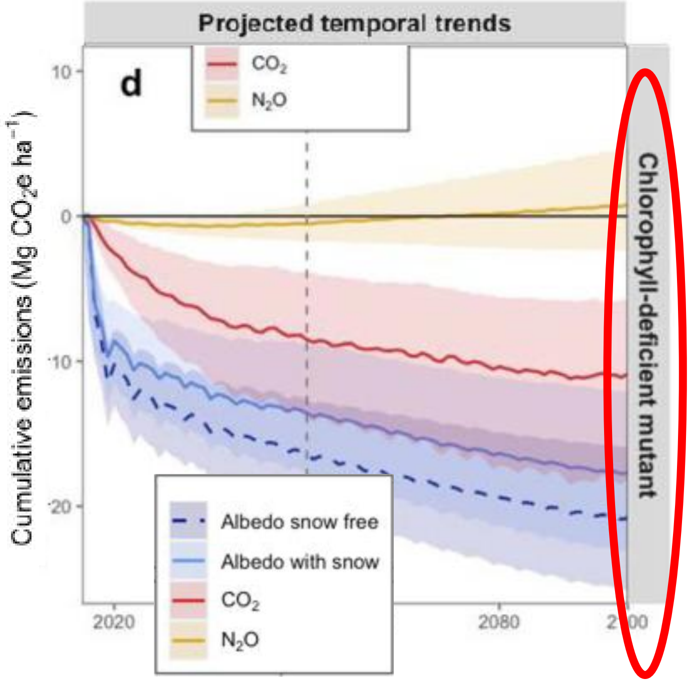


STICS simulations in France
(*Tribouillois et al., 2018*)



Albedo effects in the same range as C storage effect

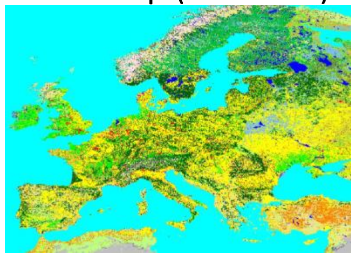
DayCent simulations over Europe
(*Lugato et al., 2020*) : red + orange

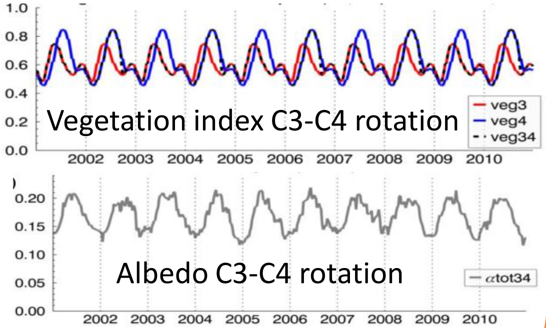


Analysis of the cover crop albedo effect (vs bare soil) over Europe

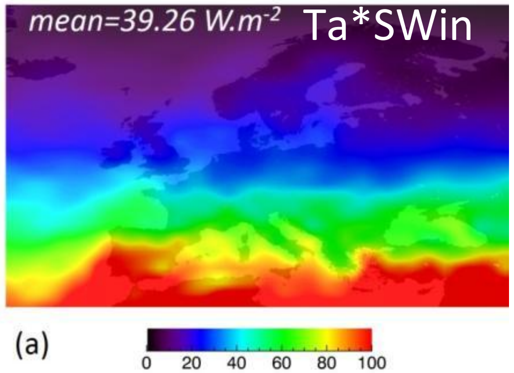
Carrer et al. (2018) in ERL

Ecoclimap (Land use)

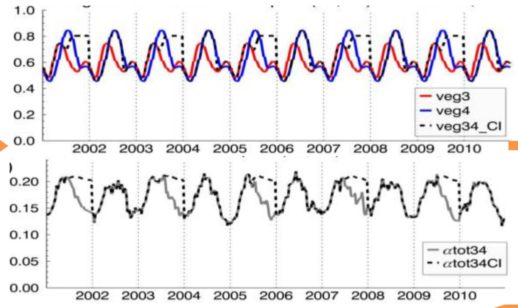




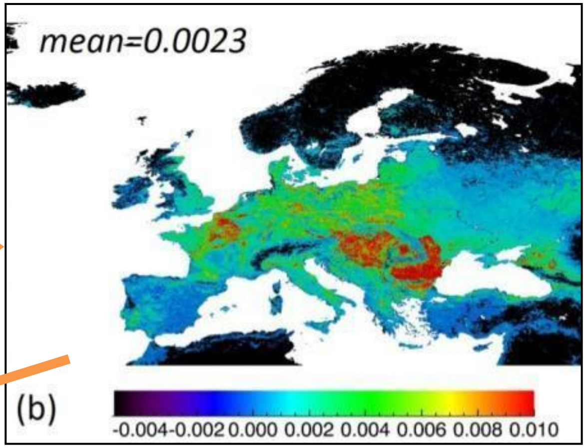
Desagregated vegetation index, bare soil albedo & vegetation albedo (snow free) derived from MODIS data at 5*5 km (Kalman filter ; *Carrer et al., 2014*) ➔ albedo of C3-C4 crop rotation



Analysis of where and when cover crops are introduced



Daily albedo increase with cover crops



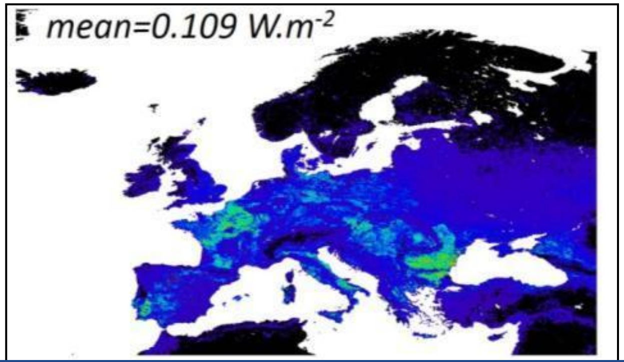
Daily global radiation& atmospheric transmittance (ERA-INTERIM)

RFCC

Radiative Forcing of Cover Crop

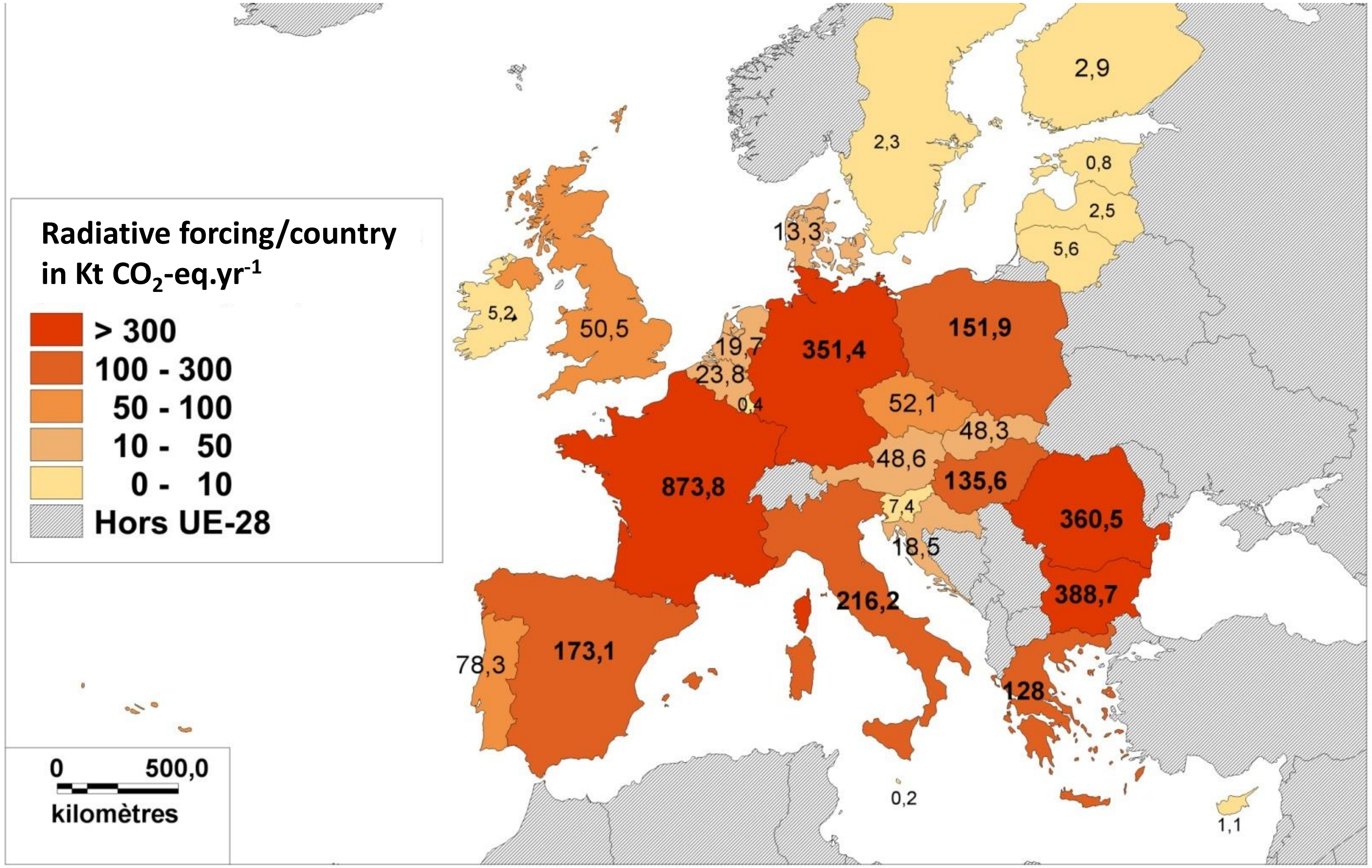
$$RF\alpha = - Rg \times TA \times \Delta\alpha$$

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.$year^{-1}$.

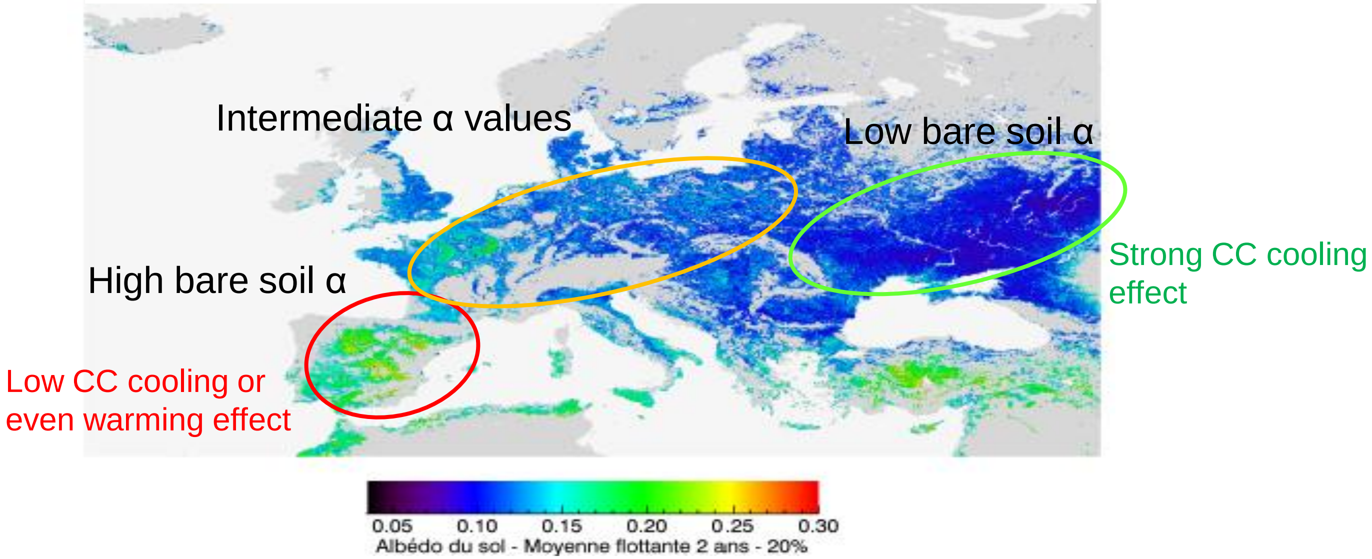
- Same but accounting for rain limitation ➔ the cumulative RFα over EU-28 was 2.3 (2.1) $MtCO_2$-eq.$year^{-1}$

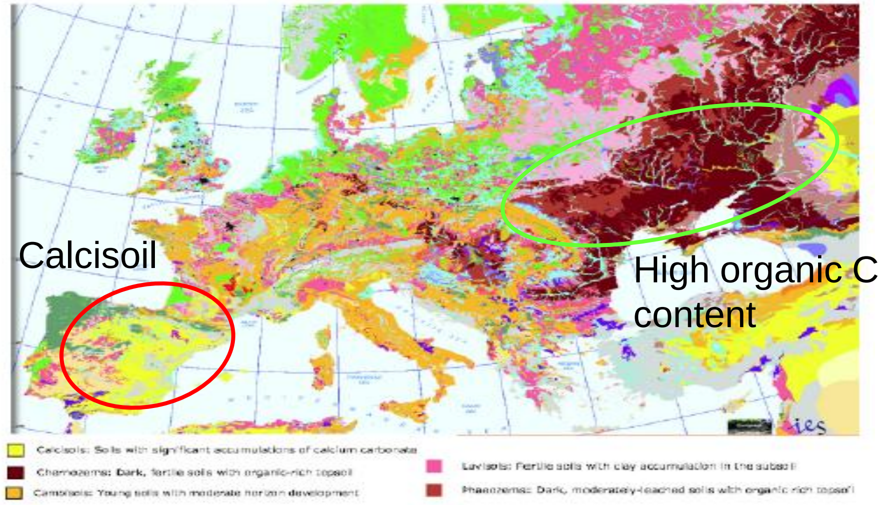
- 6 month duration cover crop scenario + rain limitation ➔ the cumulative RFα over EU-28 was 4.3 (4.0) $MtCO_2$-eq.$year^{-1}$ *i.e.* a compensation of up to 1.0 (0.9)% of the EU-28 agricultural GHG emissions.

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)



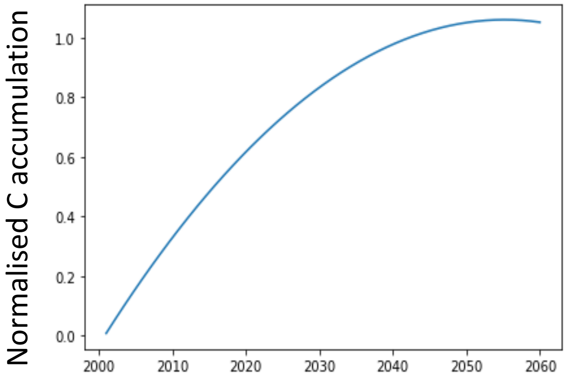


➔Remote sensing data are usefull to identify where/when cover crops should be introduced (or not) in order to increase the current surface albedo (even better when high resolution products available)

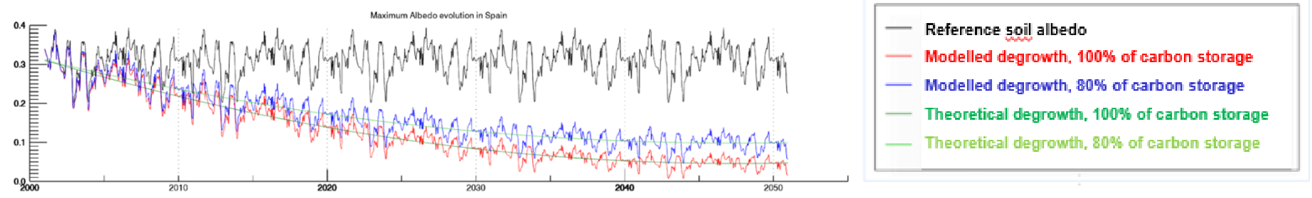
Analysis of the cover crop albedo effect (vs bare soil) over Europe

However…

Gaétan Pique's PhD (paper in prep)



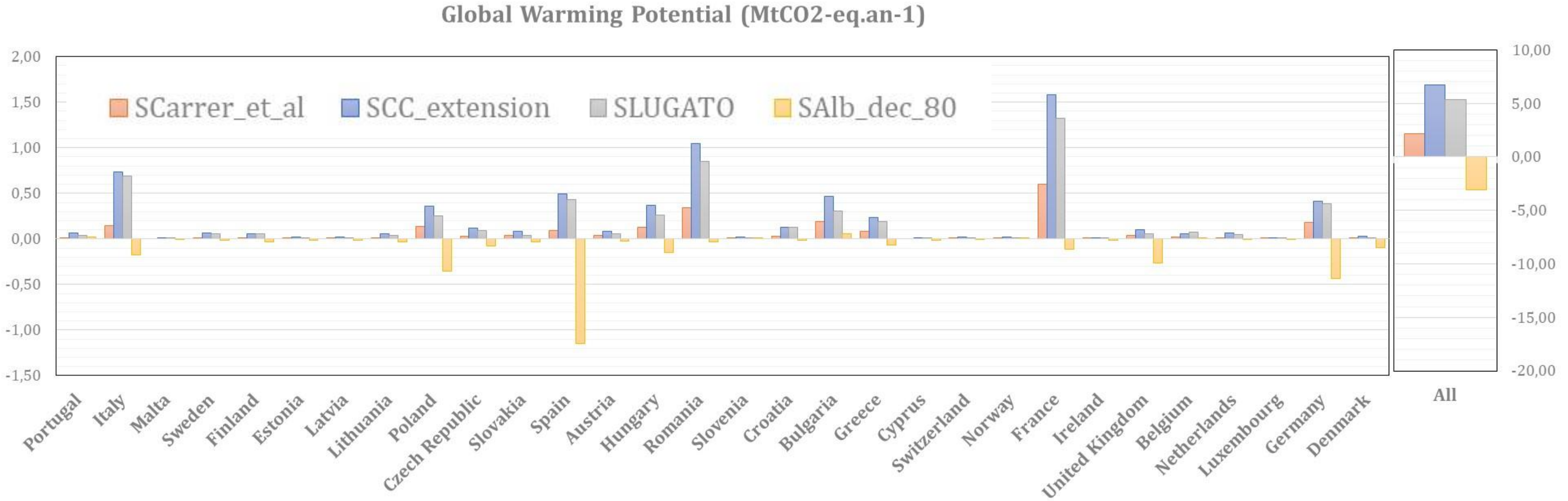
Adapted from Tribouillois et al (2018) and considering Corg max similar to Romanian soils



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) considering several scenarii:

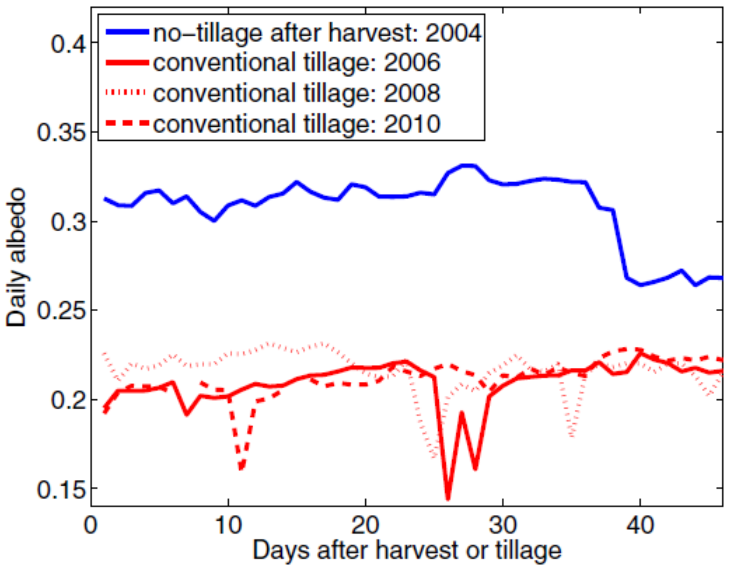
- 3 month CC
- Extension cover crop (as in *Pellerin et al. 2019*)
- Extension CC + soil darkening with a realistic scenario (modelled with DayCent as in Lugato et al. 2020),
- Extension CC + soil darkening considering albedo decrease till 80% of the lowest soil albedo value in Europe



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

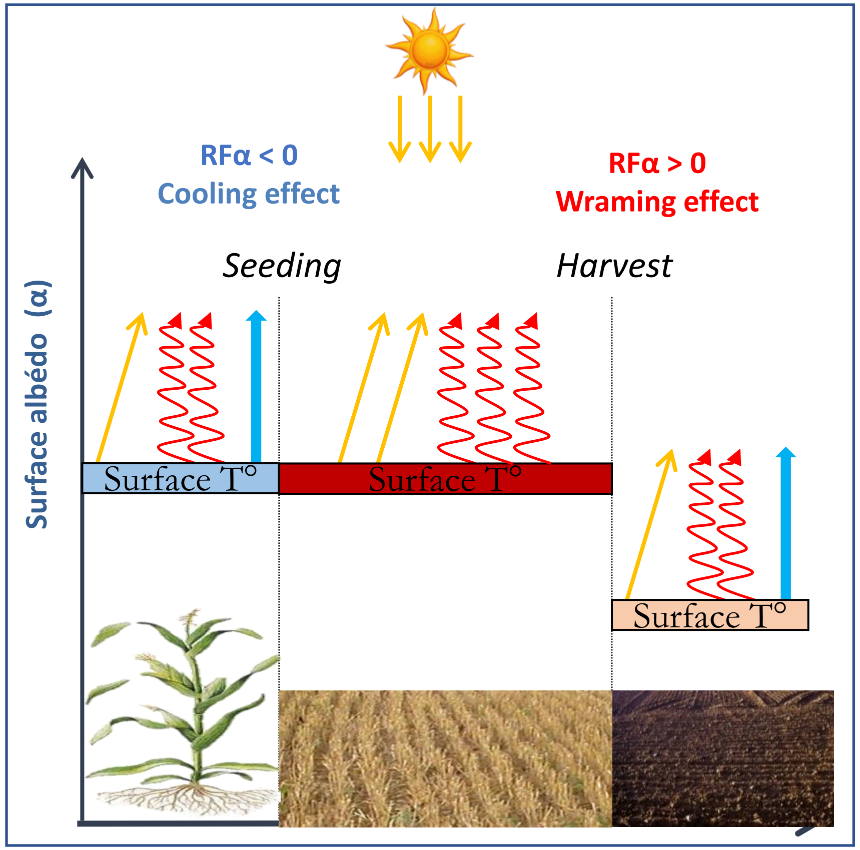
Biophysical effects induced by soil coverage with crop residues vs ploughing

Davin et al. (2014)



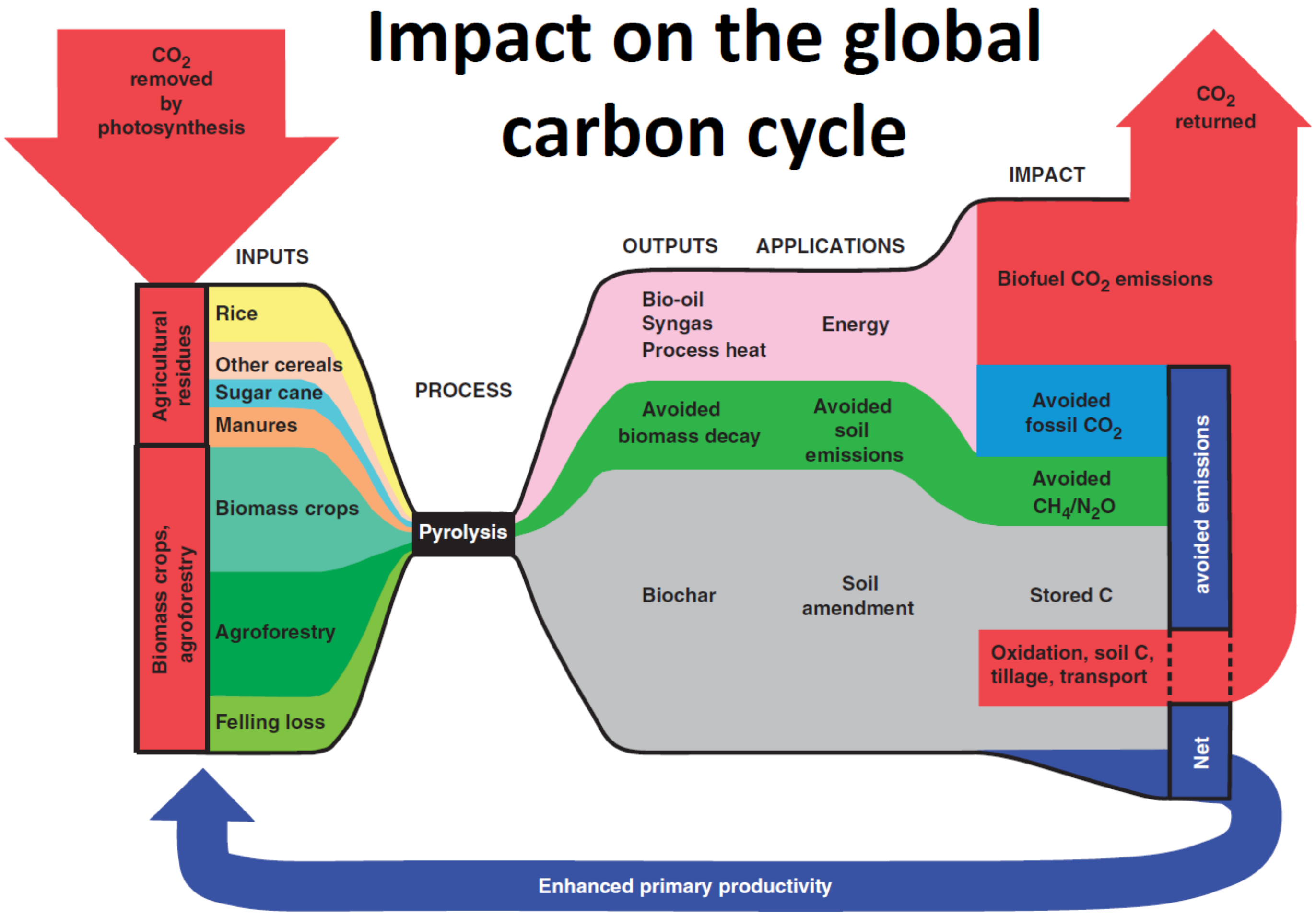
- Generalising this practice to the whole Europe could decrease air temperature during summer heat waves by ≈2°C,
- However most of the albedo cooling effect is lost : why ?

- 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).

Biogeochemical effects induced by biochar



MSTP = 1.8 Pg CO_2-C_e per year = 12% anthropogenic emissions

"..without endangering food security, habitat or soil conservation."

(Woolf et al., 2010)

FACTS

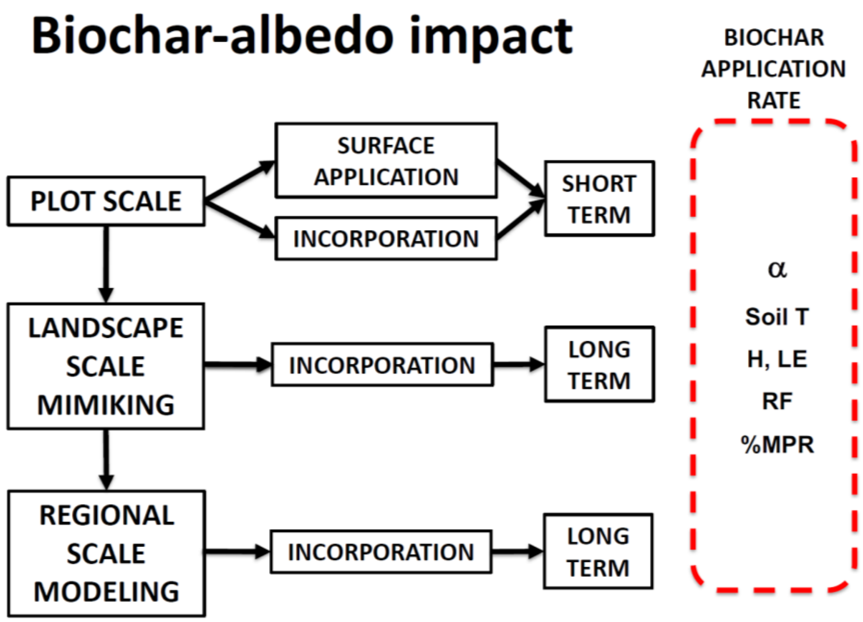
- Biochar is effective for CC mitigation,
- it increase yield (Jeffery et al. 2011)

Biophysical effects induced by biochar (drawbacks)

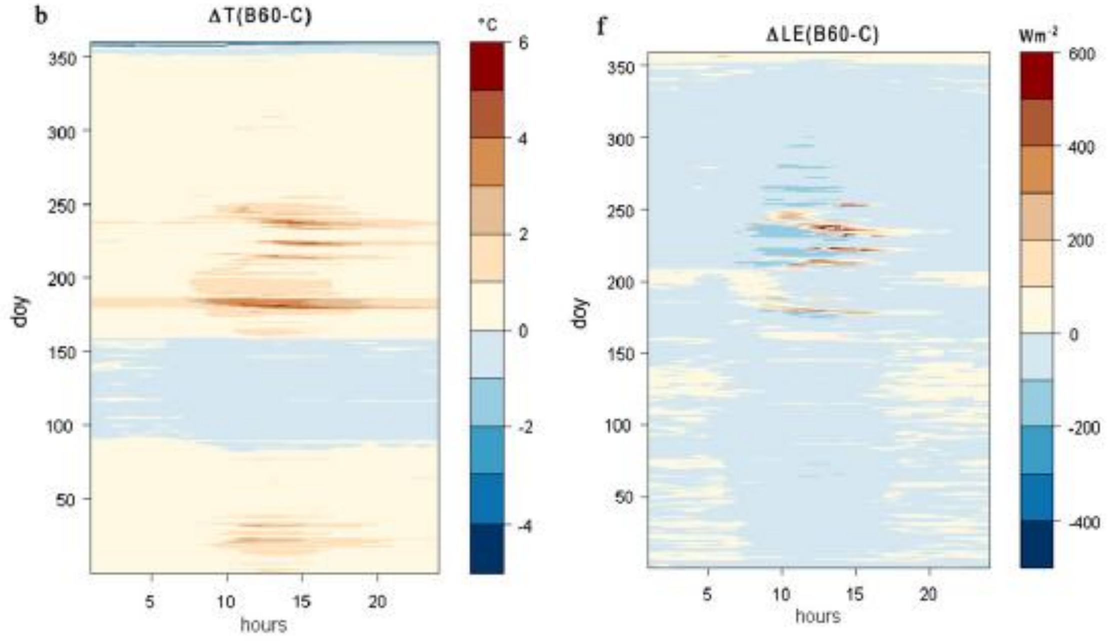
See Genesio (2012; 2016) Bozzi et al (2015) and https://www.youtube.com/watch?v=eph3hCUlRNY

Changes in Surface Albedo

Release of BCa



- 40% albedo changes (yearly mean 0.08-0.12 for 30-60t ha^{-1})
- Anomaly in surface temperature (seasonal mode)
- Increased evapotranspiration
- Changes in energy partitioning



Implications

- Accelerated germination
- Reduction of mitigation benefit of biochar

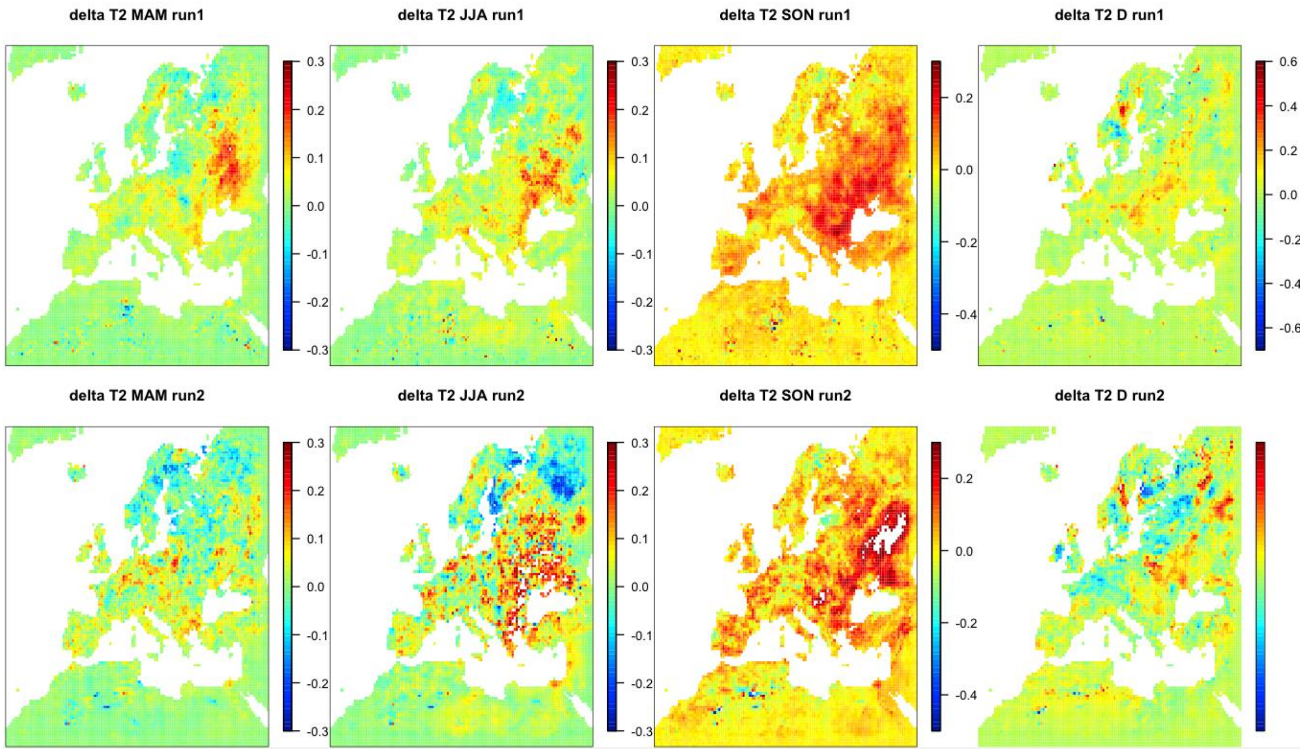
Biophysical effects induced by biochar

See Genesio (2012; 2016) Bozzi et al (2015) and https://www.youtube.com/watch?v=eph3hCUlRNY

Regional modeling of biochar application

• perturbing the arable land albedo scheme in WRF model (1 year)

• significant impact on surface temperature in Eastern Europe



RECOMMENDATIONS

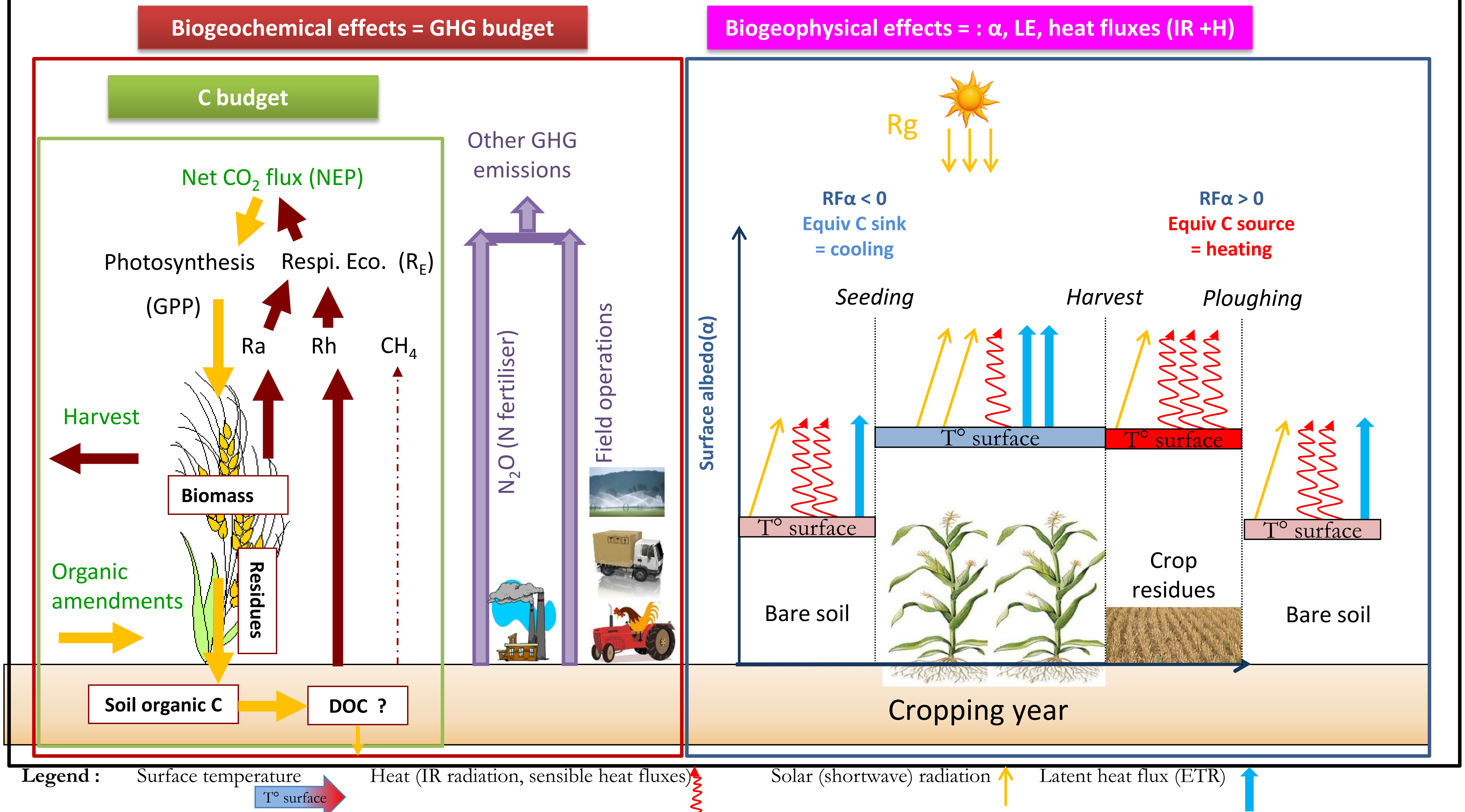
• Biochar application with Cover Crops and residue management,

• Optimize agronomic practices and choose the appropriate locations (dark soils YES, bright soils NO),

• Avoid Black Carbon aerosol release during production and application.

Cropland net radiative forcing components

Climatic effect (radiative forcing in C-CO_2 eq) = (C budget + N_2O + OT) + (α effect + Δ H/LE)



Discussions

• Other ecosystem services, trade offs and drawbacks of changes in management practices (including economical aspects) : for cover crops…see *Justes et al. (2012), Kaye & Kemada (2017), Pellerin et al. (2019), Runk et al. (2020), Bamière et al. (2023)*.

• They are still many things to investigate :

- What is the potential increase in albedo cooling effect and other biogeophysical effect on RF net through varietal selection (see Pielke et al. 1990; 2012 ; Sakowska et al., 2018) ?

- Whats are the Cover Crop/other management changes effects on soil temperature/humidity ➔ consequences for soil mineralisation, CO_2 and N_2O emissions ?

- Consequences of Carbon Farming on soil water retention & water ressources for the following cash crop ? ➔ see Triboullois et al. (2018)

- What is the durability of the C stored in the soil by carbon farming practices and the long term soil darkening effect on RFα ?

• Appart from CC, no till and biochar for cropland and cutting, grazzing for grassland, what are the biogeophysical effects of other agricultural management changes ?

-Perenial crops/bioenergy crops see Sieber et al. (2020) and https://www.youtube.com/watch?v=fai1Ob4nq-o as well as https://youtu.be/qqVkURrOQ-w

- What about agroforestry ?...

Discussions

What is/will be the net climatic effect of management changes ?

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 RF 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 some practices in a realistic way (e.g. cover crops) ➔ makes the overall biogeochemical + biogeophysical effects of agricultural management changes 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 agroecosystems at a range of sites over Europe and identified solutions for climate change mitigation through natured based solar radiation management (SRM) approaches, mainly for cropland.

• In several studies, cover crops appear as a very good 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),

• For biochar and no till + mulch they are antagonist effects,

•Biogeophysical effects of some key Carbon farming practices are unknown (e.g. agroforestry) !!

• In general once C farming practices (e.g. Cover Crops, biochar) are introduced ➔ permanent soil cover to avoid the soil darkening effect,

• Better feed animal with grass in animal farming systems (both good for soil C storage & albedo effects)

• Yet, the net mitigation effect (+ retroaction) of most C farming practices 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 for key C farming practices as Earth System models do not account for them.

Key messages

- So yes, we should consider biogeochemical and biogeophysical effects to prioritize changes in cropland & grassland 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 more realistic quantification of the true climatic effect of cropland grassland management changes,

- We should push toward policies that account for biogeophysical effects to reach climate neutrality.

Many thanks for your attention !!!

ClieNFarms

Please contact me at eric.ceschia@inrae.fr

Want to learn more : look at the presentations from the CLand « Albedo & Climate mitigation » workshop at http://albedocc.lsce.ipsl.fr/index.php/presentations