ORCHIDEE-GM
(Grassland Management)

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Supervised by

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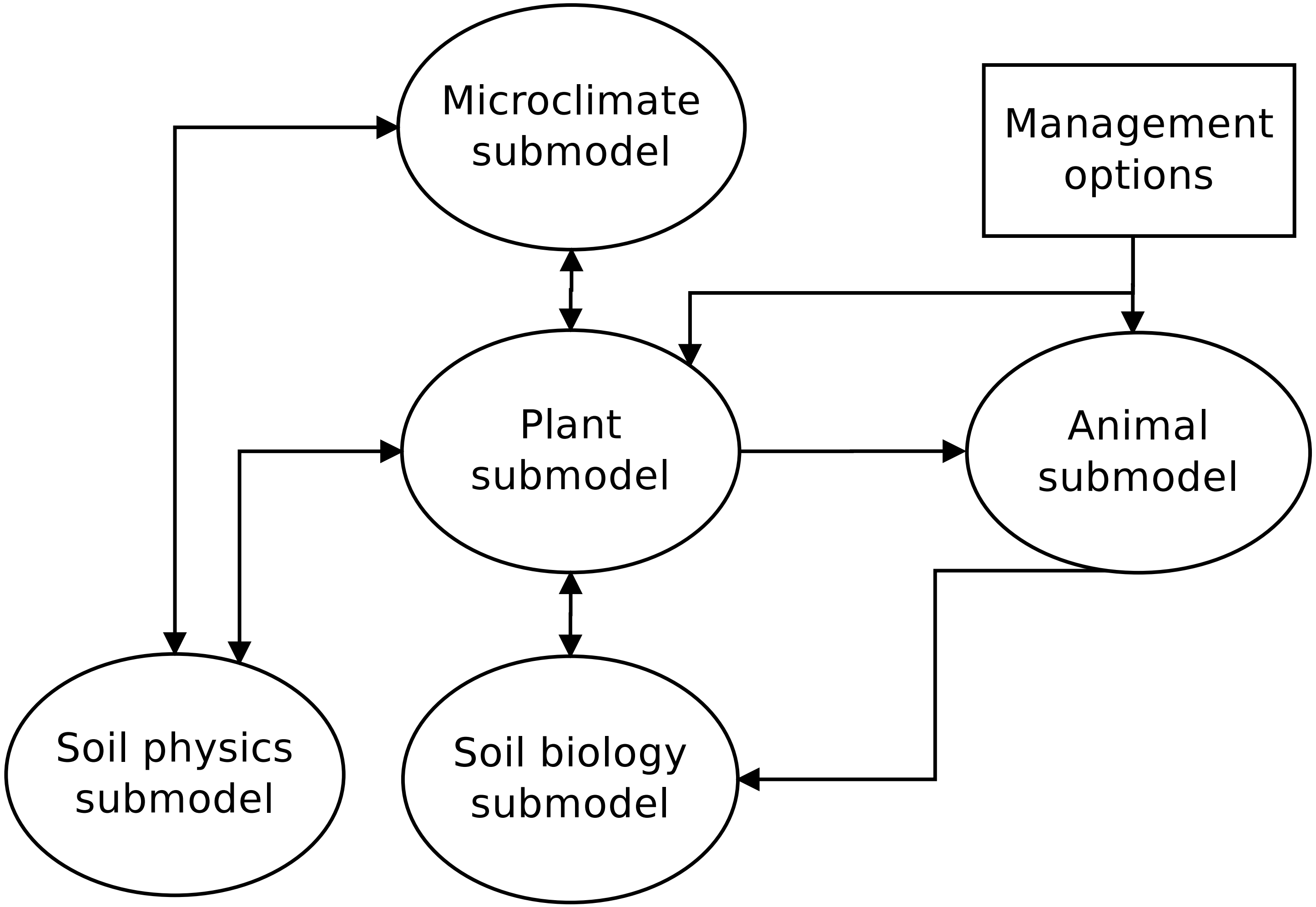
Outline

- Grassland management in ORCHIDEE
- Model evaluation at European grassland sites
- Potential yields and livestock density over European grassland
- C balance and GHG budget of European grasslands
- C balance and GHG budget affected by livestock numbers

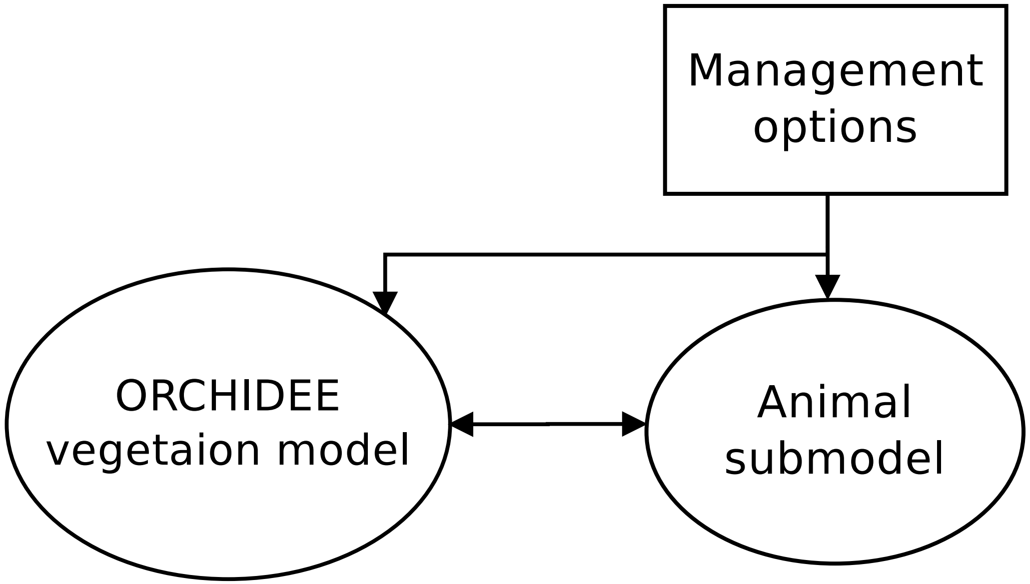
Model: ORCHIDEE-GM

PaSim



Model: ORCHIDEE-GM

ORCHIDEE-GM



Model performances at sites

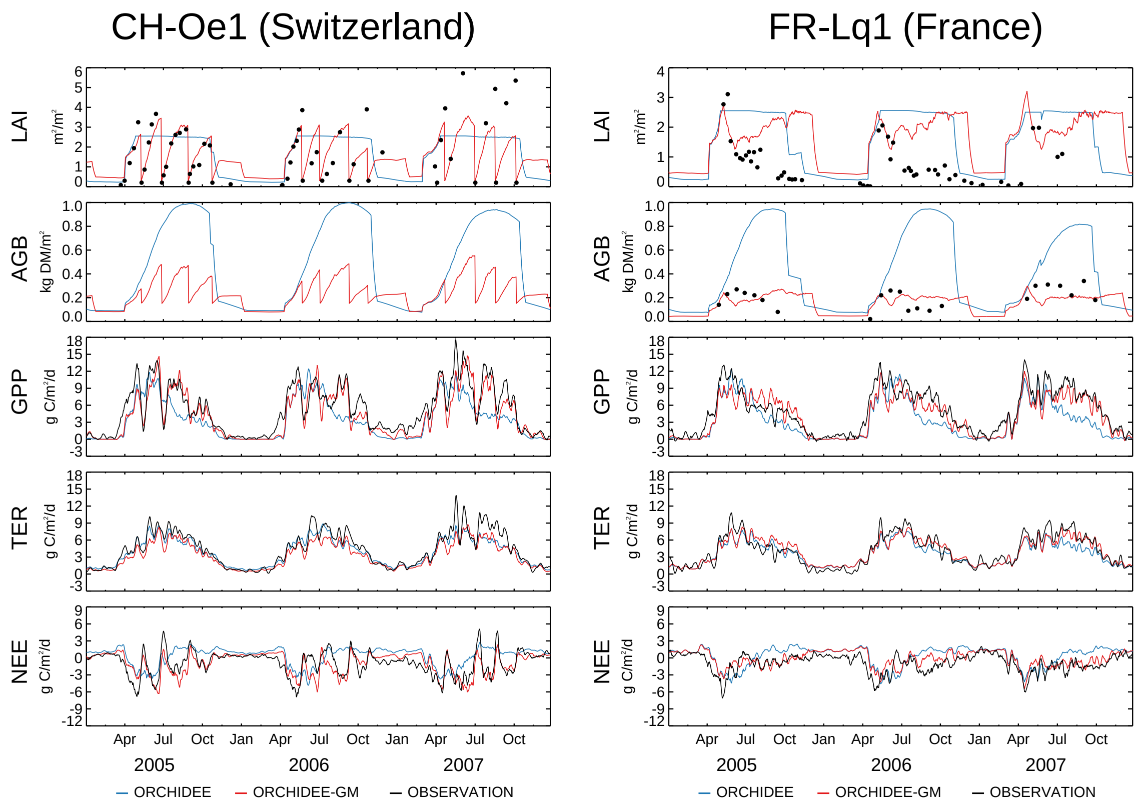


Figure 1. Comparison of simulated / observed biometric variables and carbon fluxes for the two example grassland sites.

- ORCHIDEE-GM can capture realistically the cut-induced seasonal variation in biometric variables and in CO_2 fluxes.
- Regrowth stimulated by grazing during later growing season can be reproduced.

Model performances at sites

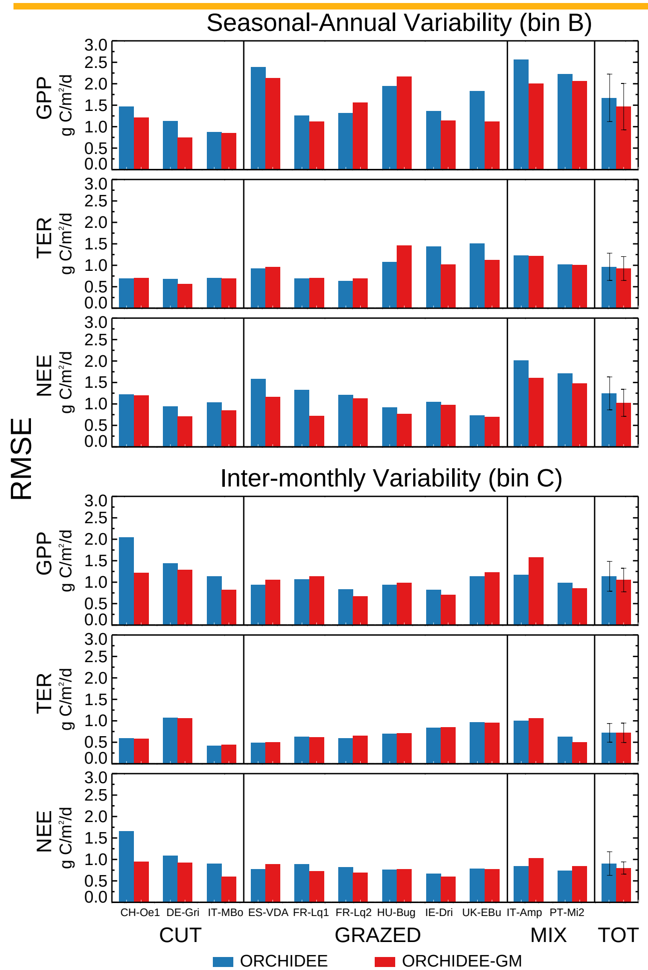


Figure 2. Root mean squared error (RMSE) between modeled and observed CO_2 fluxes (GPP, TER and NEE) on seasonal-annual variability and inter-monthly variability.

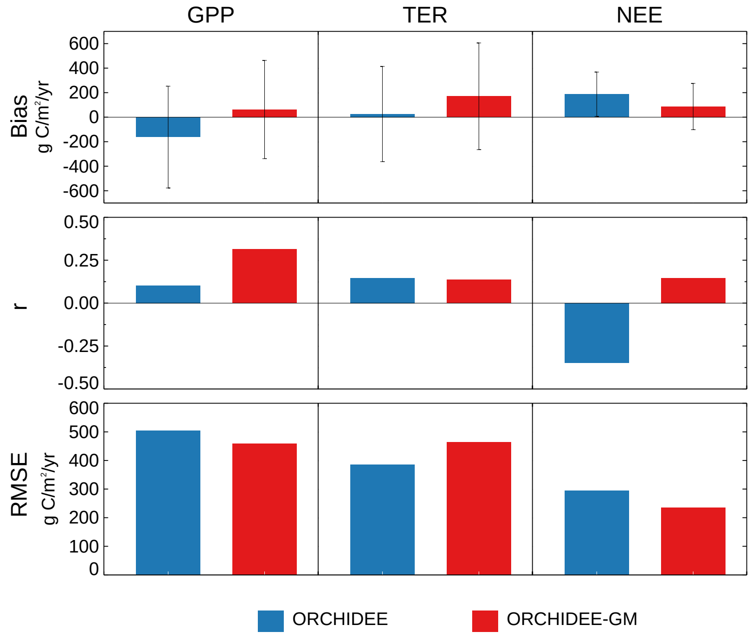


Figure 3. Statistical performance of models on an interannual scale for CO_2 fluxes (GPP, TER and NEE).

- Pooling all the site-years, ORCHIDEE-GM performs better (lower bias, higher r and lower RMSE) than ORCHIDEE for GPP and NEE.
- Both NEE and GPP on monthly to annual timescales can be better simulated in ORCHIDEE-GM than in ORCHIDEE without management.

Potential yields of European grasslands

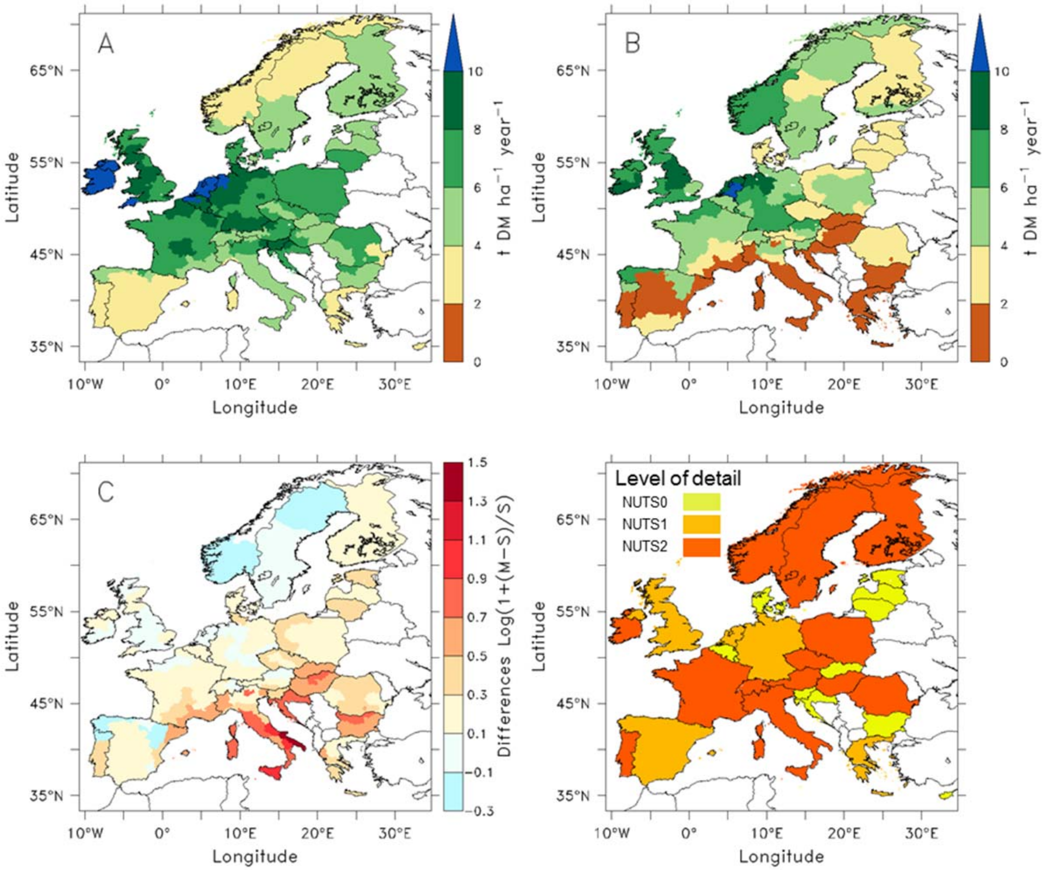


Figure 4. Spatial distribution of (A) biological potential grassland productivity simulated by ORCHIDEE-GM, of (B) actual grassland productivity from statistics (Smit et al., 2008), and of discrepancy between A and B. Simulated and statistical data of 10-year average from 1995 to 2004 were used to represent regional productivity.

Incorporating effect of N addition on photosynthesis

$$N_{add} = N_{add\,\max} \times (1 - a^{N_{amount}/30})$$

$$Vc_{\max} opt = (1 + N_{add}) \times Vc_{\max} opt *$$

$$J_{\max} opt = (1 + N_{add}) \times J_{\max} opt *$$

- ORCHIDEE-GM tends to simulate higher productivity than Eurostat
- Similar spatial pattern were found (R = 0.60, 167 regions).
- The discrepancy is larger in Mediterranean regions and in Eastern Europe.

Temporal evolution of grassland yields

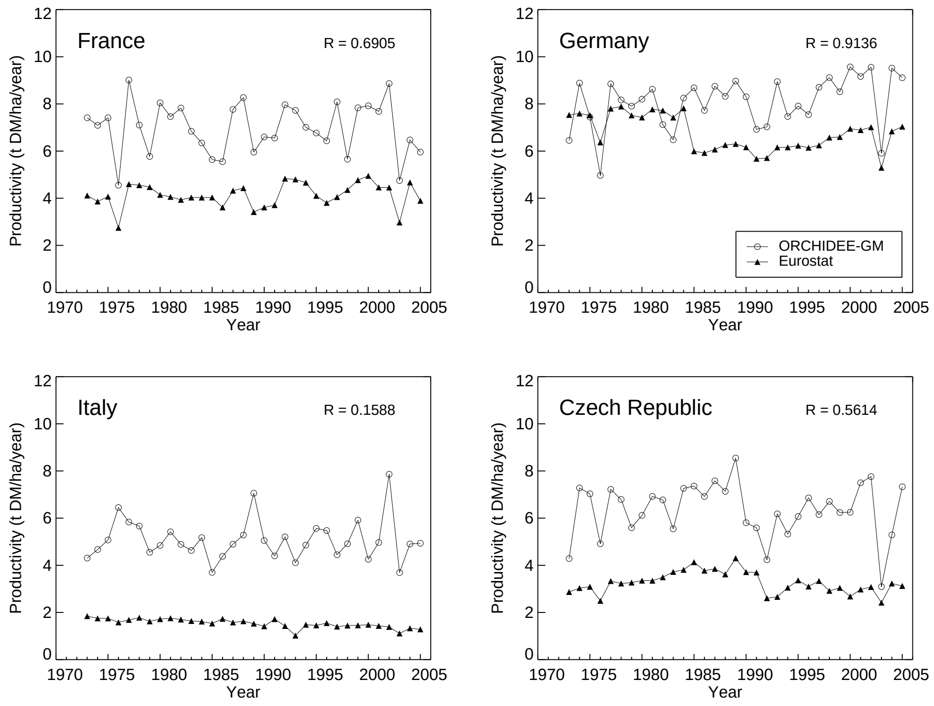


Figure 5. Temporal evolution of modeled and observed productivity of grassland in four European countries between 1973 and 2005.

- The model can capture the productivity drops observed during the 1976 and 2003 droughts.
- Capability to reproduce the interannual variability (series detrended) of productivity (as well as summer NDVI) except for Italy.

Temporal evolution of livestock carrying capacity

- Hypothesis: sustainable self-sufficient pasture system
- Output: optimized livestock density (Dopt)

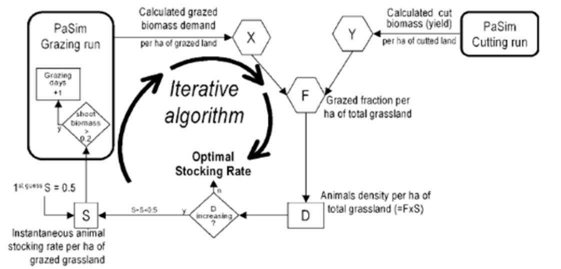
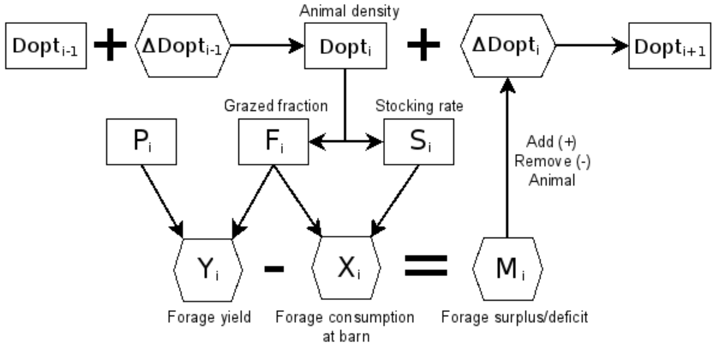


Figure 1. Diagram of the optimization procedure used for defining optimal animal stocking rate and optimal proportion of grazed grasslands.

Management optimization in PaSim (Vuichard et al., 2007)



Management adaptation in ORCHIDEE-GM

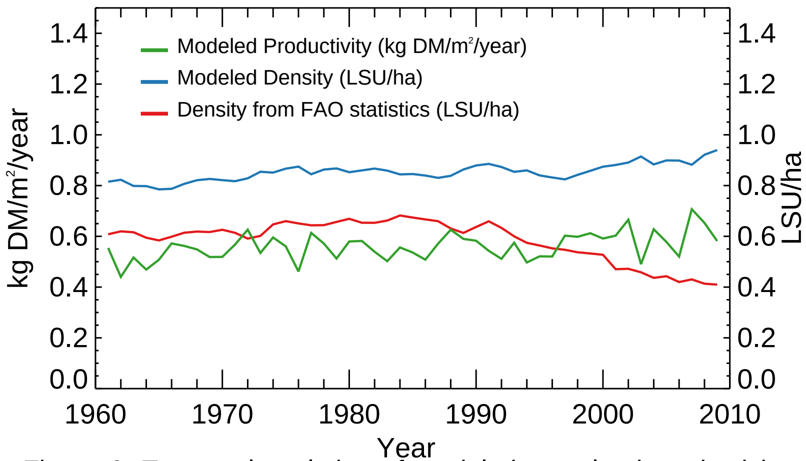


Figure 6. Temporal evolution of modeled grassland productivity, and of livestock density from model simulations and statistics (FAO) respectively. All variables are mean value over European grassland.

- The small annual increase ($P < 0.01$) of potential productivity is driven by climate and CO_2, as well as the potential livestock density ($P < 0.001$).
- Livestock density from FAO shows an increase between 1960 and 1990, then a rapidly decline from early 1990s, which may be attributed to the European Common Agricultural Policy (CAP) and the Nitrate Directive (1991).

Grass-fed livestock numbers in Europe

Livestock numbers from Eurostat

✖

Table 1 Fraction of grass fed in ruminant livestock diet (%, dry matter basis)

	Beef cattle	Dairy cattle	Sheep and Goats
Eastern Europe	71,1	70,2	81,5
Western Europe	64,1	49,1	77,5

⬇

Statistical grass-fed livestock numbers

VS.

Simulated livestock density (Dopt)

✖

Area of grassland
- Temporary grassland (100% Dopt)
- Permanent grassland (80% Dopt)
- Rough grazings (10% Dopt)

⬇

Simulated grass-fed livestock numbers

Grass-fed livestock numbers in Europe

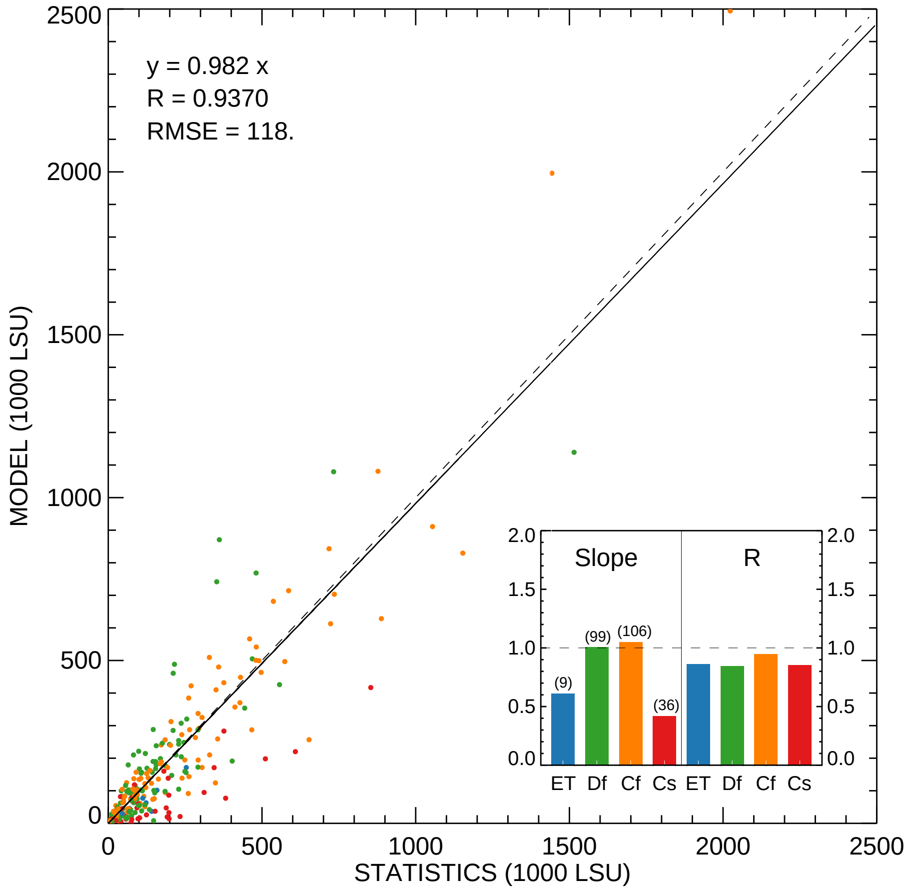


Figure 7. Comparison of modeled and statistical ruminant livestock numbers fed with grass by NUTS2 regions (1990-2010).

- High correlation was found between modeled and statistical livestock numbers.
- But with regional differences.
- ORCHIEEE-GM tends to overestimate livestock numbers in Central Europe, and to underestimate it in the Netherlands, Belgium, Mediterranean countries (Spain, Portugal), and in some Scandinavia countries (Denmark and Norway).

Grassland C balance and GHG budget

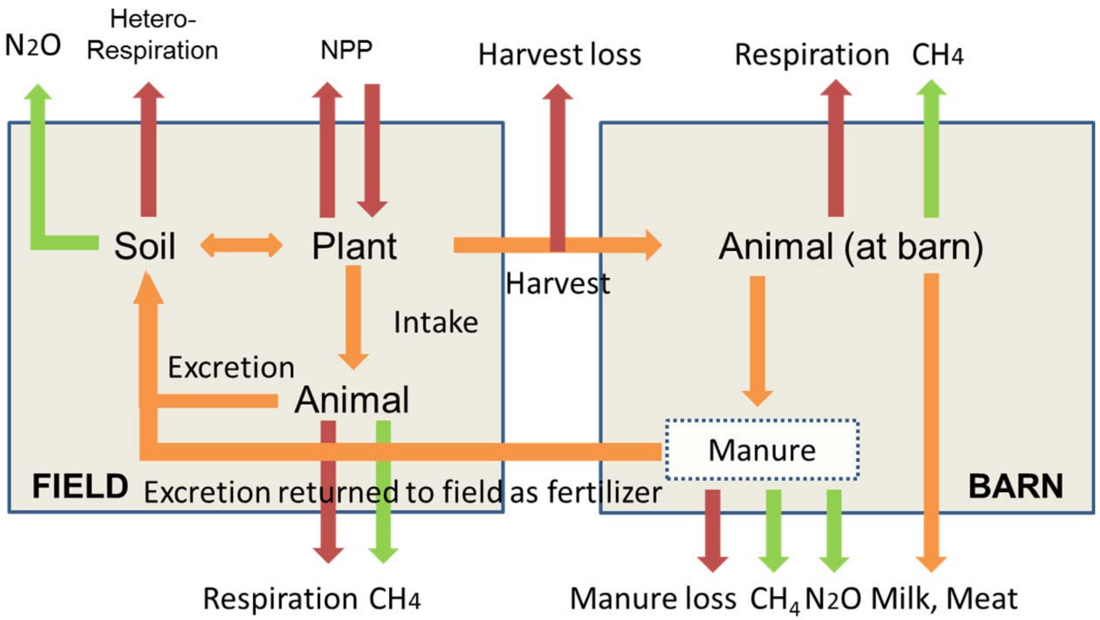


Figure 8 Carbon and GHG (CO_2, CH_4 and N_2O) fluxes in managed European grassland farm systems. Green arrows represent non-CO_2 green house gases fluxes; red arrows represent CO_2 fluxes; and orange arrows represent carbon fluxes other than CO_2 form.

Land use map of grasslands

Strategy for accounting for grass-fed livestock numbers

$$N_{sim} = \sum D_i \times A_i$$

vs.

$$N_{stat} = N_{FAO} \times F_{diet}$$

N_{stat} / N_{sim} — Managed grassland: Cut grassland, Grazed grassland

$1 - (N_{stat} / N_{sim})$ — Abandoned grassland

→ Land use map of European grasslands

- These fractions will be applied in every grid of this country.
- Usually, potential livestock density simulated by GM is larger than the real one ($N_{sim} > N_{stat}$), except in some countries such as Netherlands, Belgium. In this case, all grassland is assumed to be managed (fully used).

NBP of European grasslands

$$NBP = -NEE + F_{input} - F_{harvest} - F_{milk/LW} - F_{CH_4} - F_{leach}$$

$$NEE = R_h - NPP + R_{animal}$$

- Our estimate:

22.5 $\pm$?? (gC m^{-2}year^{-1},1991-2010) not account for C loss by leach/runoff (~ 7 $\pm$ 3.5 gC m^{-2}year^{-1})

- Literature:

104 $\pm$ 73 (Greengrass sites; Soussana et al., 2007);
5 $\pm$ 30 (SOC inventory);
22 $\pm$ 56 (Fluxes balance);
66 $\pm$ 90 (Jenssens et al., 2003);
57-74 (Ciais et al., 2010);
36 $\pm$ 18 (Smith et al., 2005)

- C sequestration mainly came from the abandonment of grassland

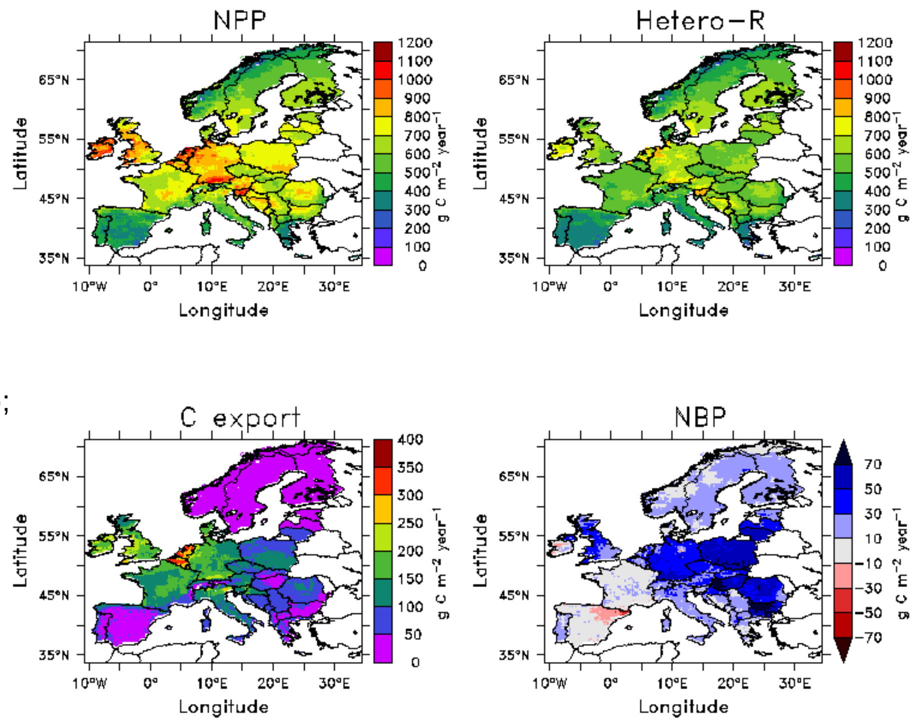


Figure 9. Spatial pattern of NBP over European grasslands (1990-2010), and its components.

GHG budget of European grasslands

The net GHG exchange of grasslands

$$NGHGE = NEE + F_{CH_4-field} \times GWP_{CH_4} + F_{N_2O-field} \times GWP_{N_2O}$$

- Our estimate:
  -82.2 $\pm$?? (gCO2-C equiv. m^{-2}year^{-1}, 1991-2010)

- CH_4 and N_2O offset 23.4% of CO_2 sink

- Literature
- -202 $\pm$ 76 (Soussana et al., 2007)
- -14 $\pm$ 18 (Schulze et al., 2009)

- Spatial pattern is consistent with productivity

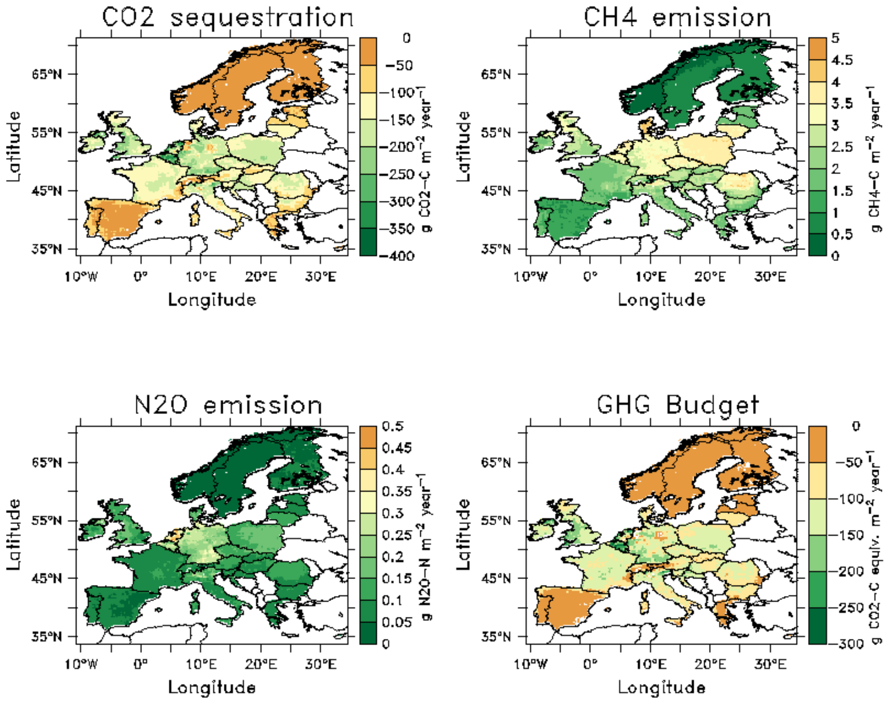


Figure 10. Spatial pattern of greenhouse gases (GHGs) emissions / sequestrations over European grasslands (1990-2010).

The attributed net GHG balance (NGHGB) at farm scale

- Our estimate:

15.2 $\pm$?? (gCO2-C equiv. m^{-2}year^{-1}, 1991-2010)

$$NGHGB = NGHGE + F_{CO_2-barn} + F_{CH_4-barn} \times GWP_{CH_4} + F_{N_2O-barn} \times GWP_{N_2O}$$

Impact of livestock numbers on grassland NBP

Scenarios of grass-fed livestock numbers

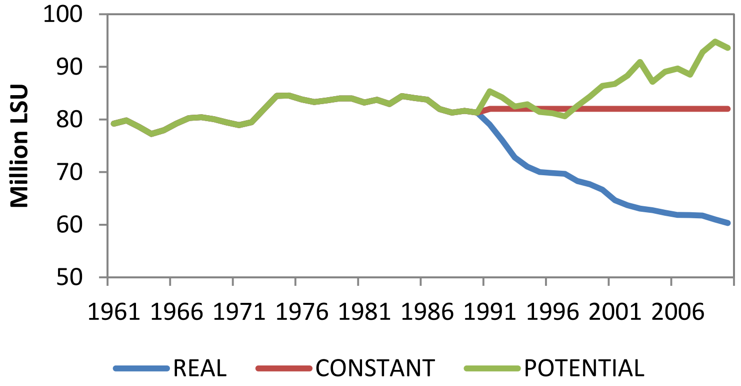


Figure 11. Scenarios of grass-fed livestock numbers over European grasslands assumed in simulations.

Scenarios of land use map of grassland

- REAL : grassland abandonment
- CONSTANT : grassland feeding the same livestock numbers as in later 1980s
- POTENTIAL : livestock numbers change along the increasing livestock carrying capacity simulated by ORCHIDEE-GM

Impact of livestock numbers on grassland NBP

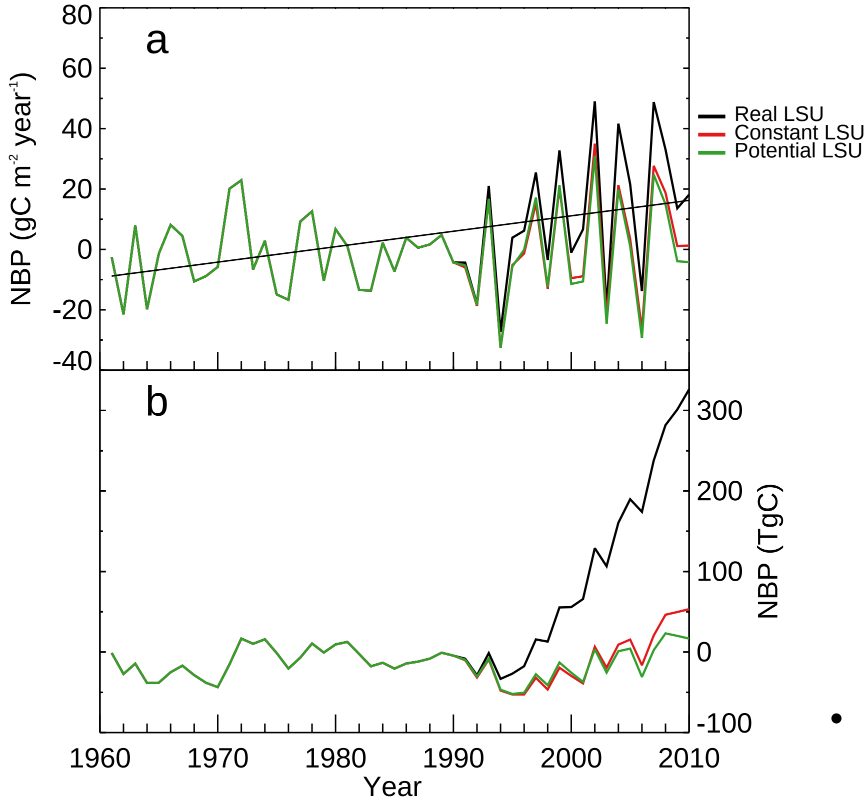


Figure 12. Evolution of NBP and accumulated NBP simulated by ORCHIDEE-GM with the 3 senarios.

- Increased NBP with REAL scenario (P<0.01), but not with other 2 scenarios.

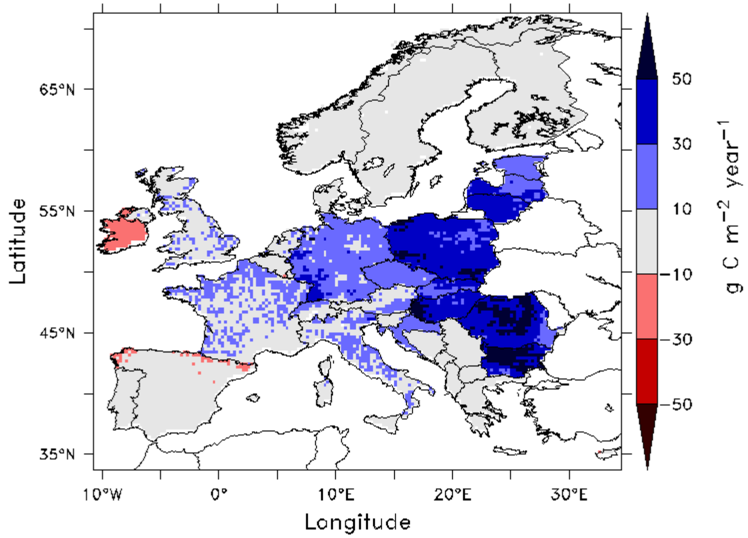


Figure 13. NBP differences between REAL and CONSTANT senarios.

- Reduction of livestock numbers over European grasslands has enhanced C sequestration (stored in soil) by **273 TgC** in recent 20 years.

- At farm scale, the GHG emissions reduced by **477 TgCO_2-C equiv.** due to the reduction of livestock numbers.

THANK YOU!