Building on a process-based modelling framework to assess CO_2 exchanges in a grazed grassland–maize rotation

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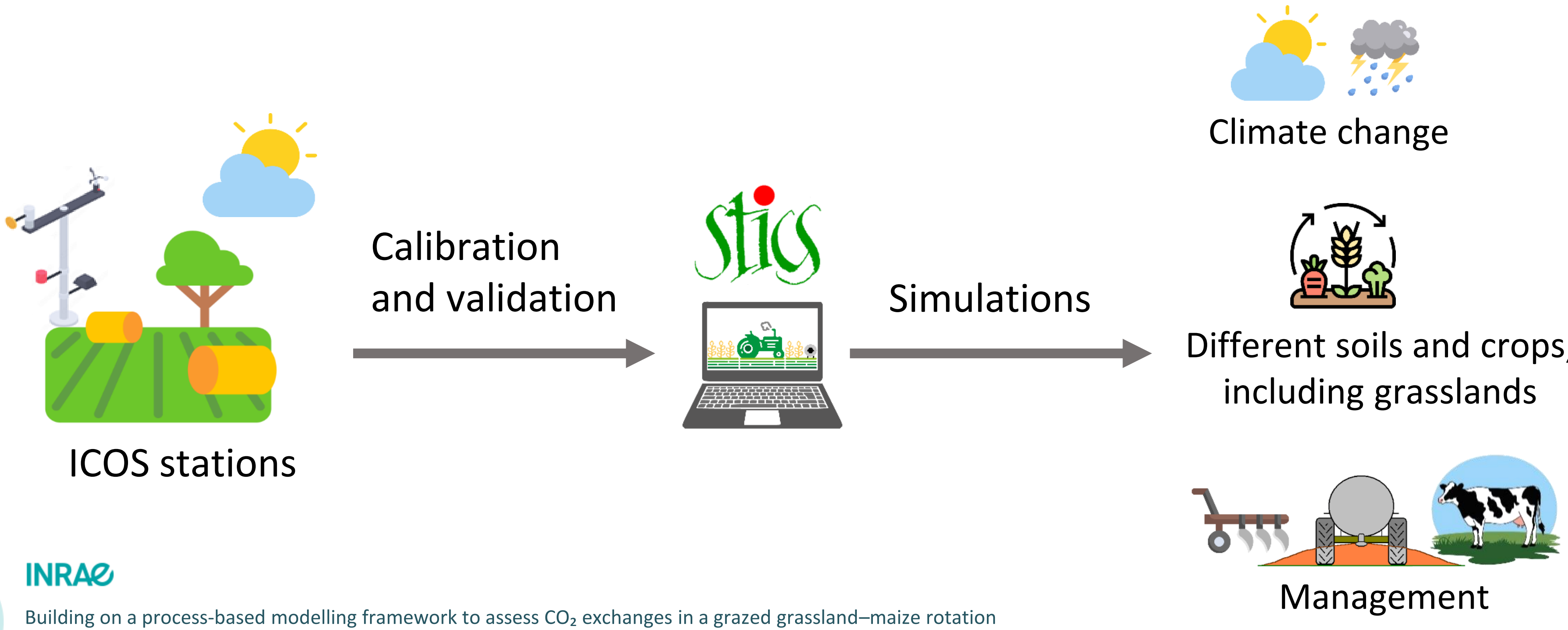
INRAE

STICS

LIÈGE université Gembloux Agro-Bio Tech

Motivations & objectives

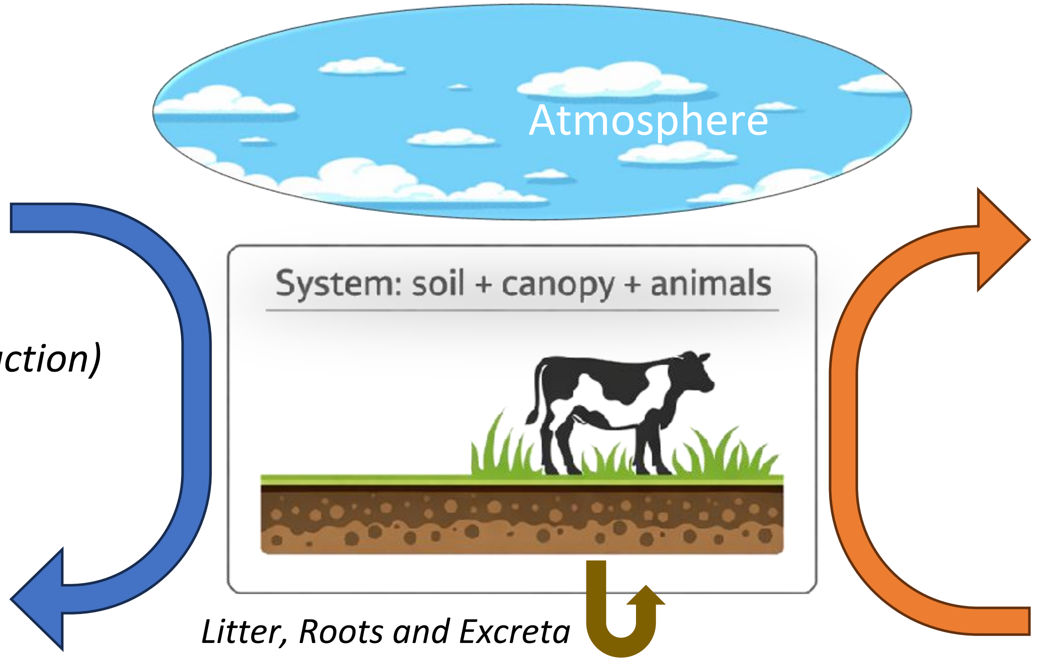
- Adapt the method proposed by Delandmeter et al. (2023) to enable the assessment, based on STICS, of net ecosystem CO_2 exchange (NEE) and its components (GPP, RECO) in the case of rotations including grazed grassland
- Use the model to simulate changes in NEE in response to changes in climate, soil conditions, crop rotations and management



Carbon fluxes in grazed grasslands

GPP *(Gross Primary Production)*
CO2 uptake by photosynthesis

NPP (Net Primary Production)
= GPP - AR



CO2 release
RECO *(Ecosystem respiration)* = **AR + HR + CR**

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MR Maintenance

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NEE ***(Net Ecosystem Exchange)*** = **RECO** - **GPP**
NEE = (AR + CR + HR) - (NPP + AR)
NEE = CR + HR – NNP

NEE > 0 source to atmosphere; NEE < 0 sink

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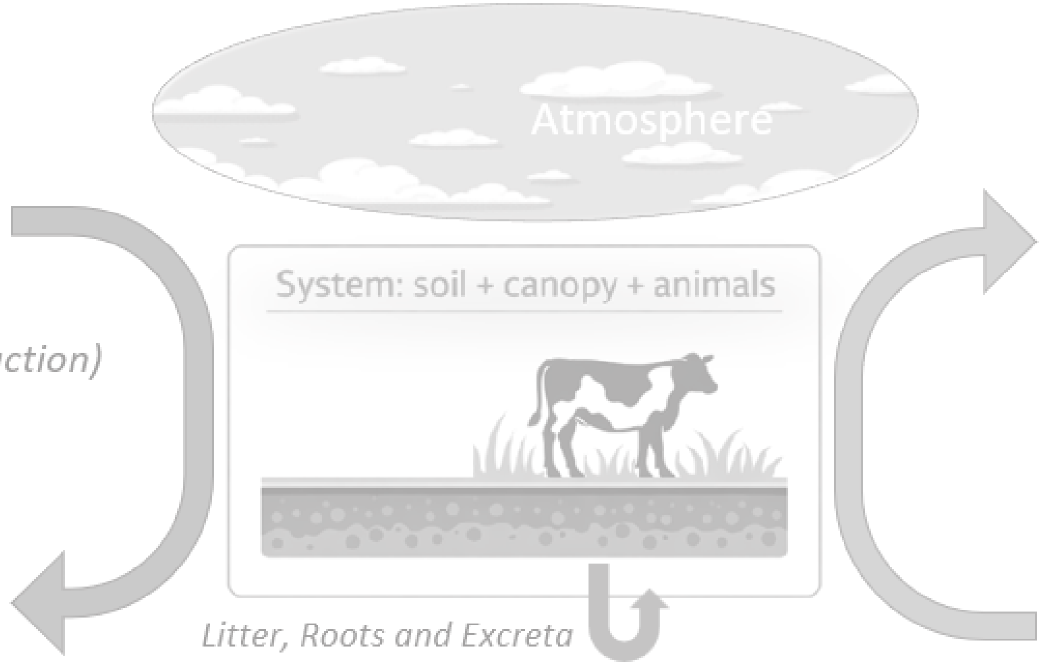

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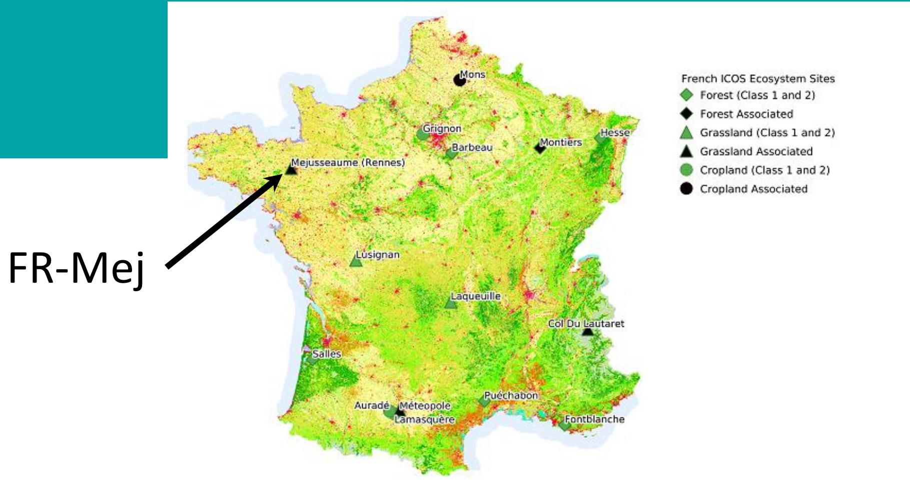
Can NEE be finely simulated for grazed glassland ?

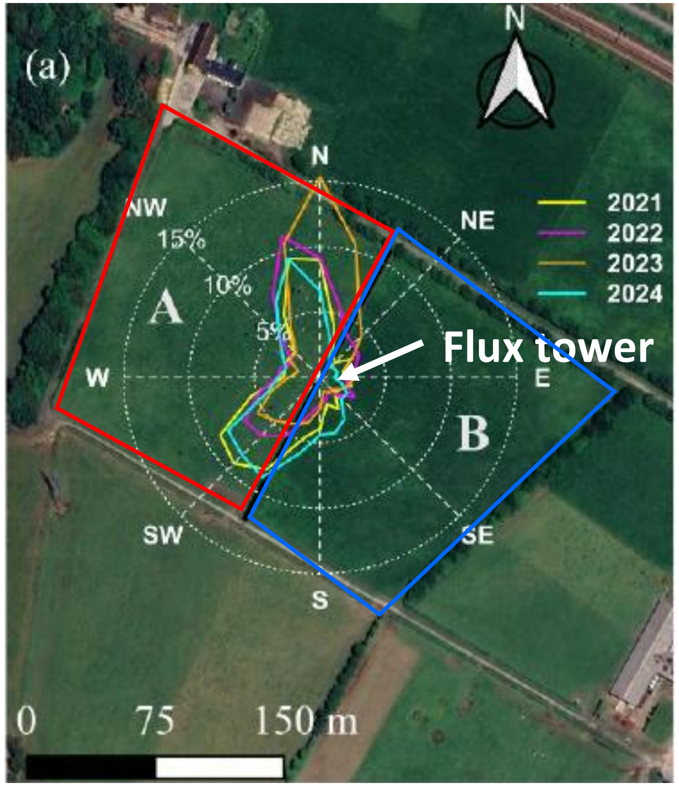
FR-Mej station of the ICOS network



Méjusseaume INRAE experimental facility (France)

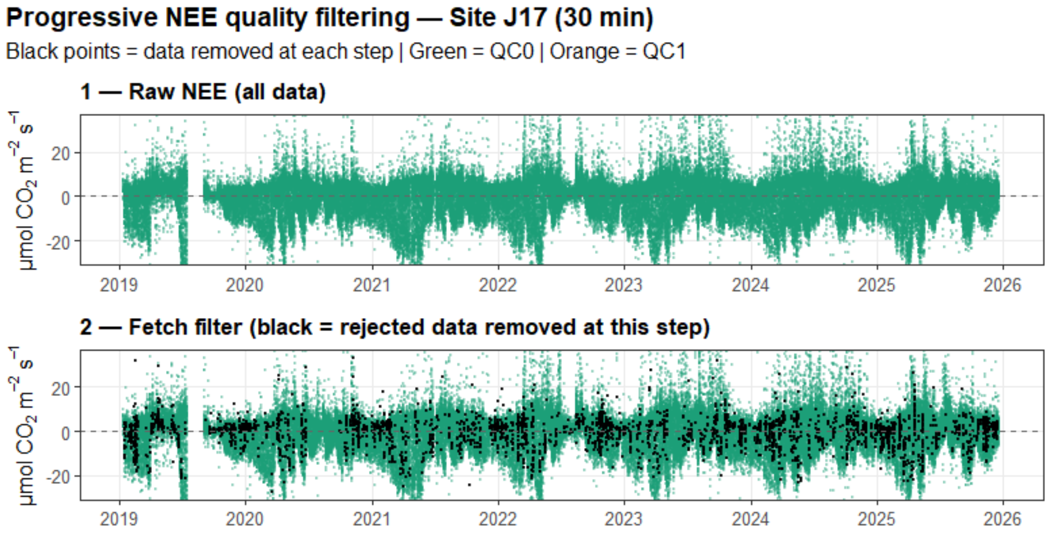
- 6-year maize – grassland rotation

- Field equipped with a **flux tower**; divided into **2 sub-plots**, the NW part (**plot A**) and the SE part (**plot B**), which are **grazed alternately** by Holstein dairy cows.
- **Grazing** most of the time **20h per day**, with supplementary feed provided during milking hours. Grazing **4 to 6 times per year**, mainly in spring.
- Application of ~70 $KgN.ha^{-1}$ twice a year of **ammonium nitrate** in spring and several application of **organic fertilisers** along the year (**cattle slurry or daily effluents**).
- Experiment **started in 2019**; **observations** available **from 2020 to 2025**: soil and climate conditions, management, silage maize yield and grassland valorisation, **surface-atmosphere exchanges of CO_2** etc.



Post-processing of NEE recorded by the flux tower

- **Different qualities** of observed NEE data
  - Filtered according to **microclimatic conditions**



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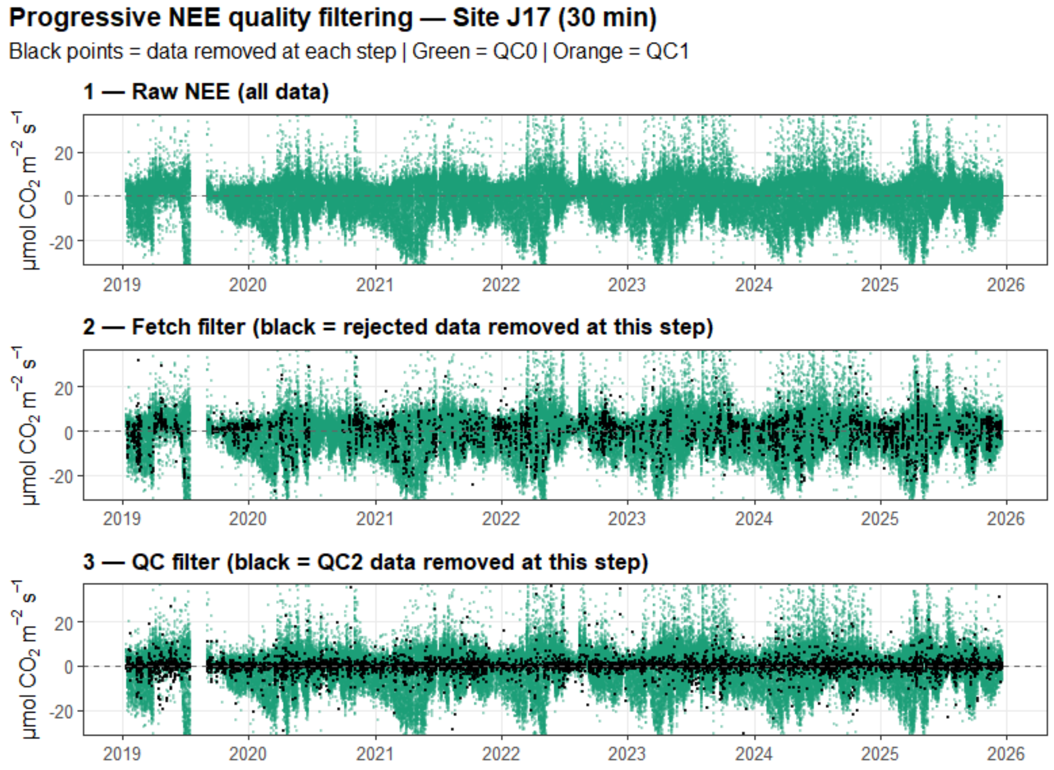

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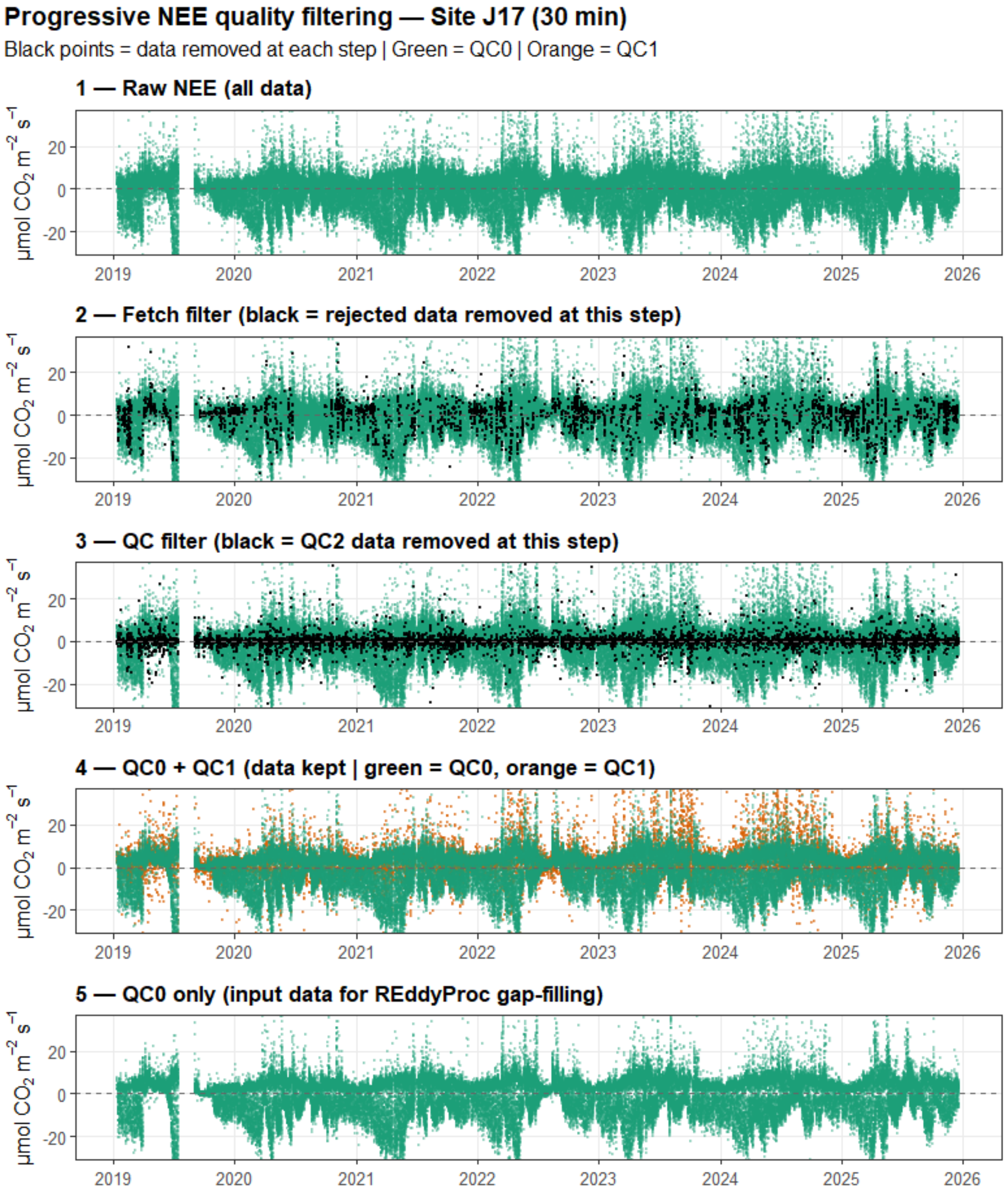

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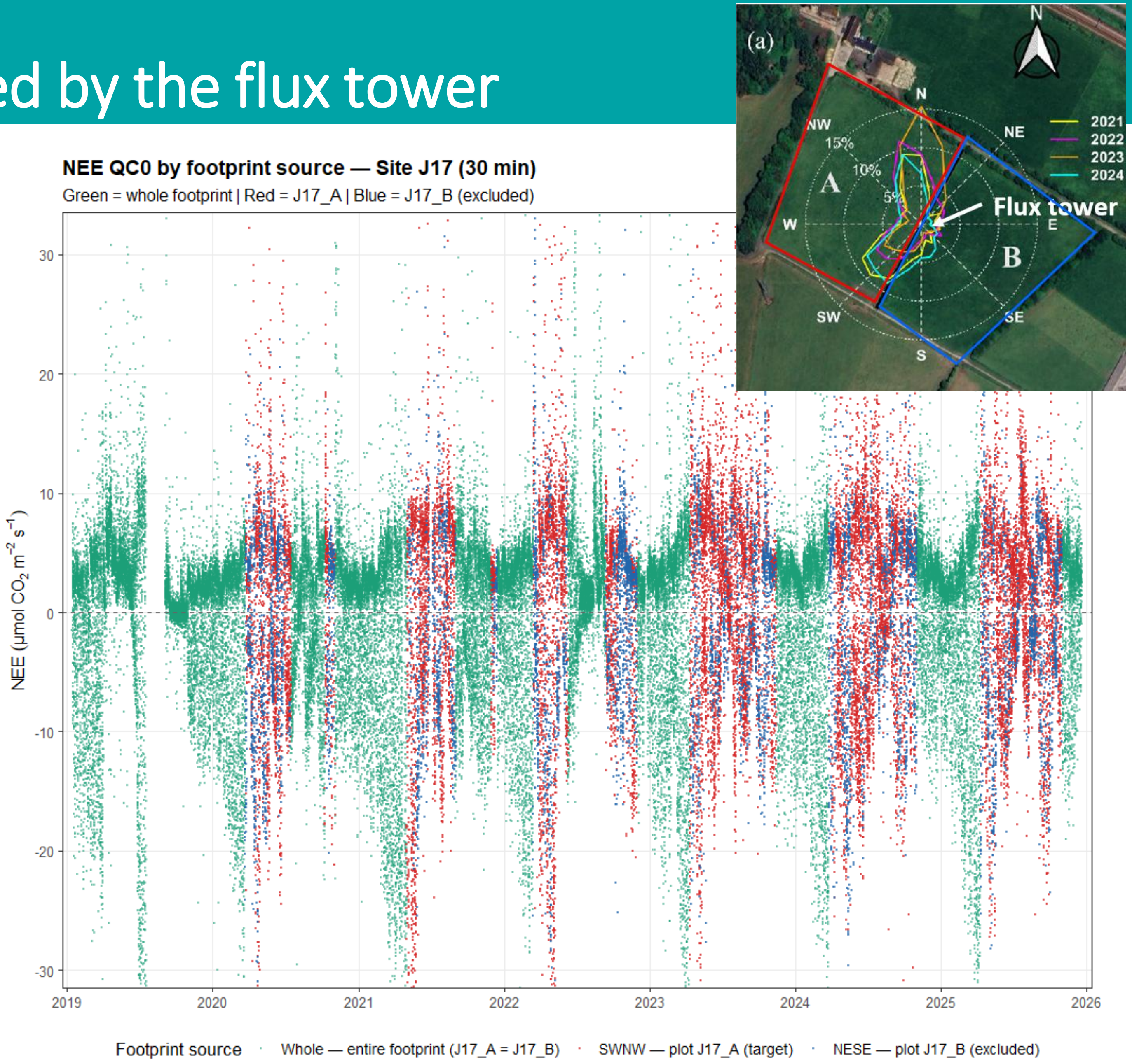

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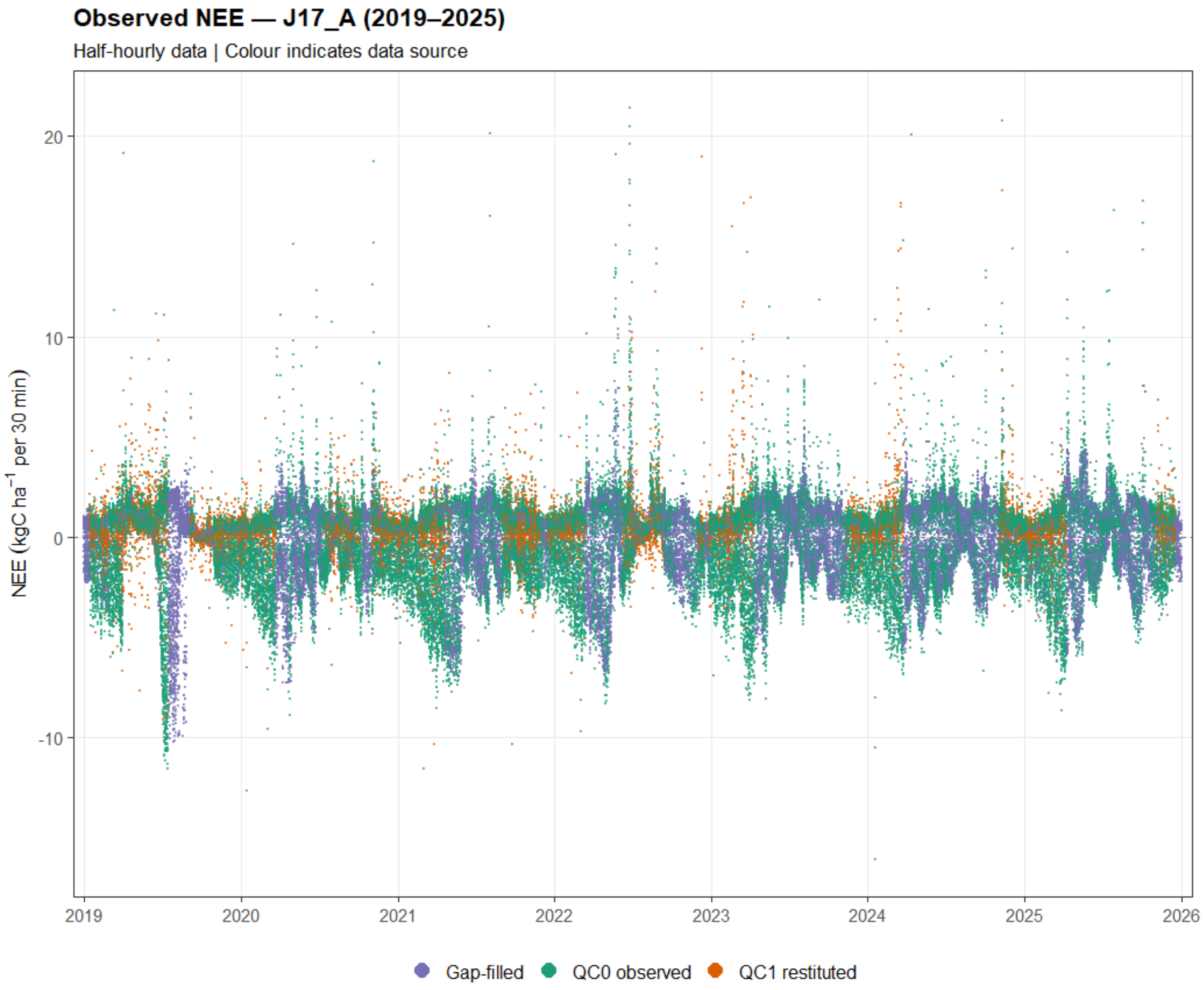

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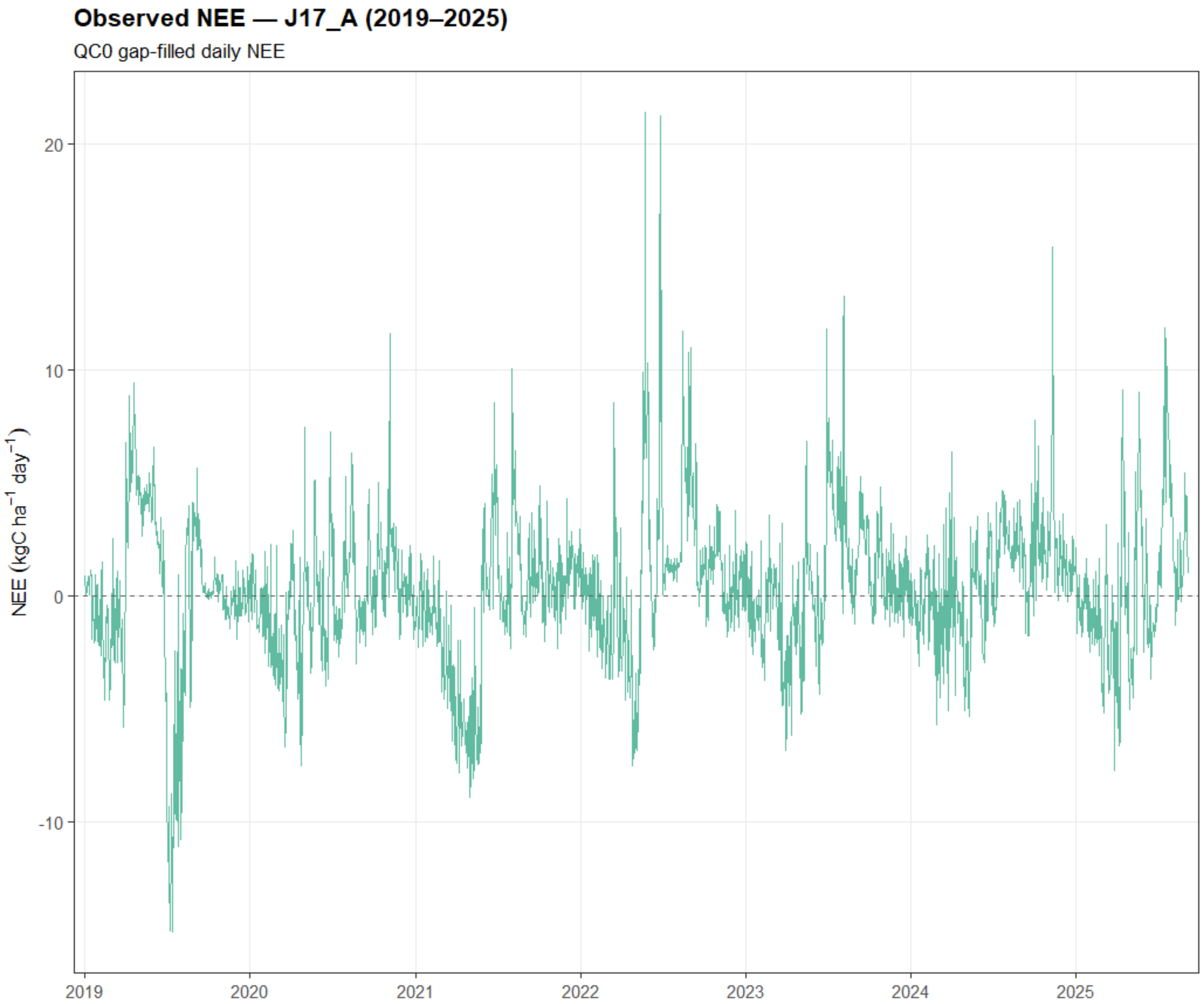
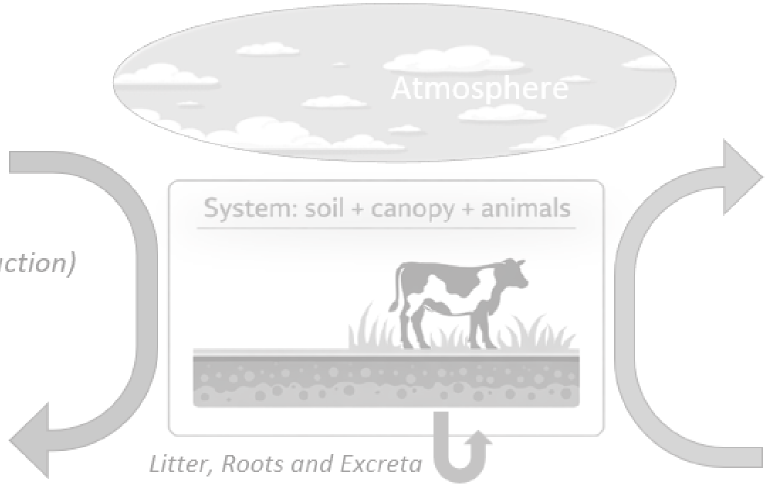
  - Daily summed aggregation (NEE $kgC.Ha^{-1}.d^{-1}$)



Simulation of NEE from STICS outputs (based on Delandmeter and al., 2023)



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- **NPP** Net primary production (NPP) can be estimated by simulating the fixation of C during above-ground and root growth using STICS (explicit in v.10)

(masecveg, mafeuilletombe, mafruit,
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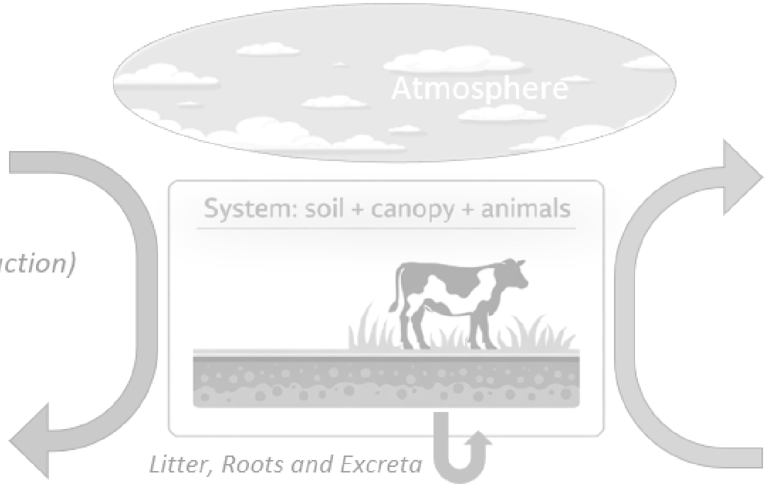

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- **HR directly provided by STICS**

(CO2Sol)

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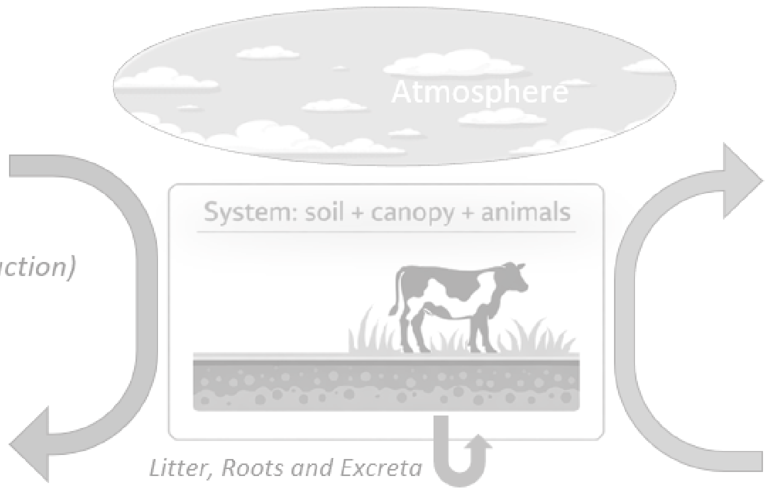

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- HR directly provided by STICS *(CO2Sol)*
- **CR estimated through STICS cut simulations**

CR estimated as a fixed percentage of the carbon ingested by the animals, (Faverdin et al. 2007)

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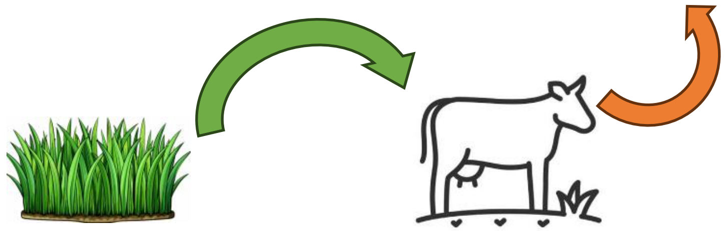

Model performances: **abiotic parameters**

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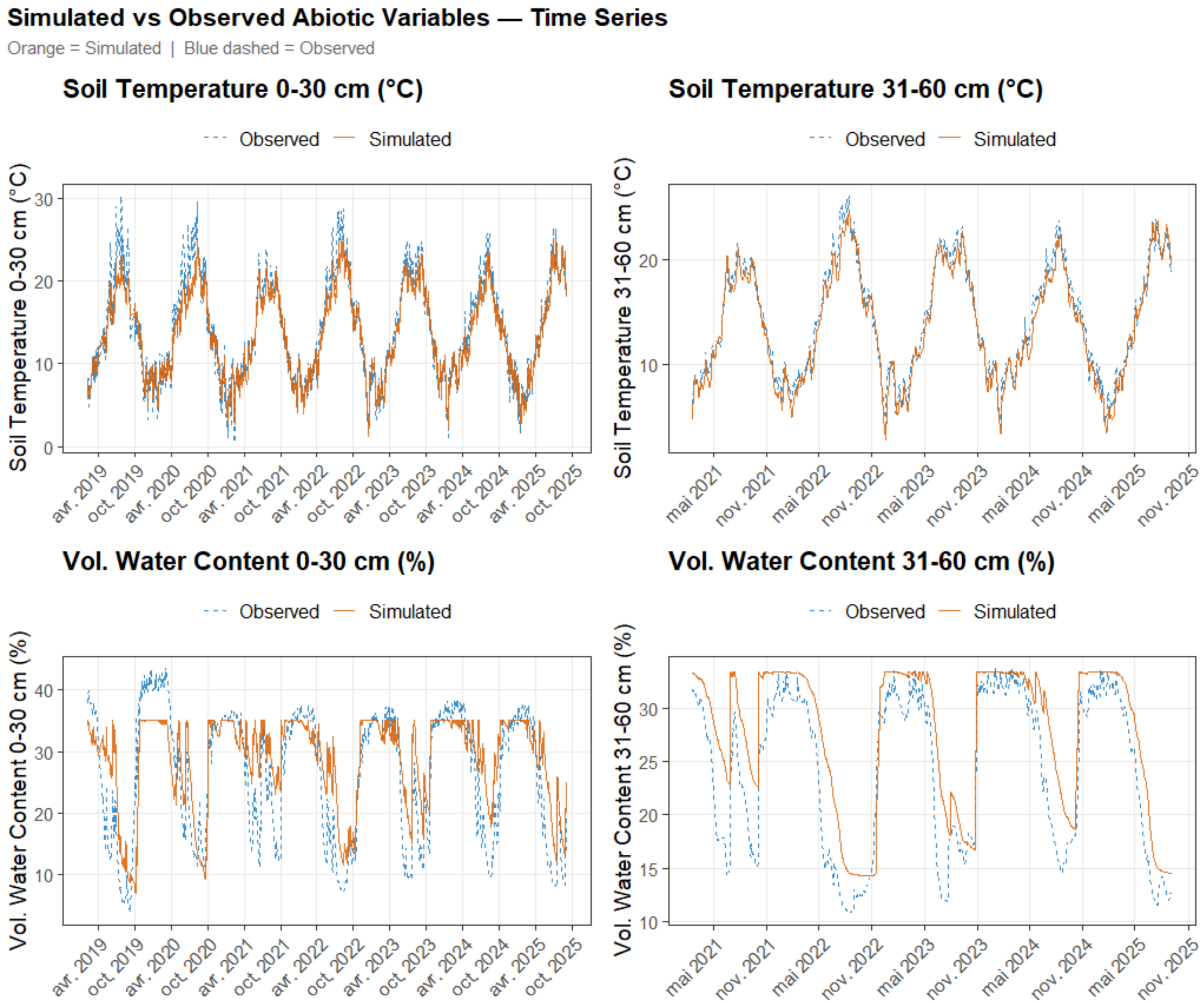
- Overall soil parameters were well simulated

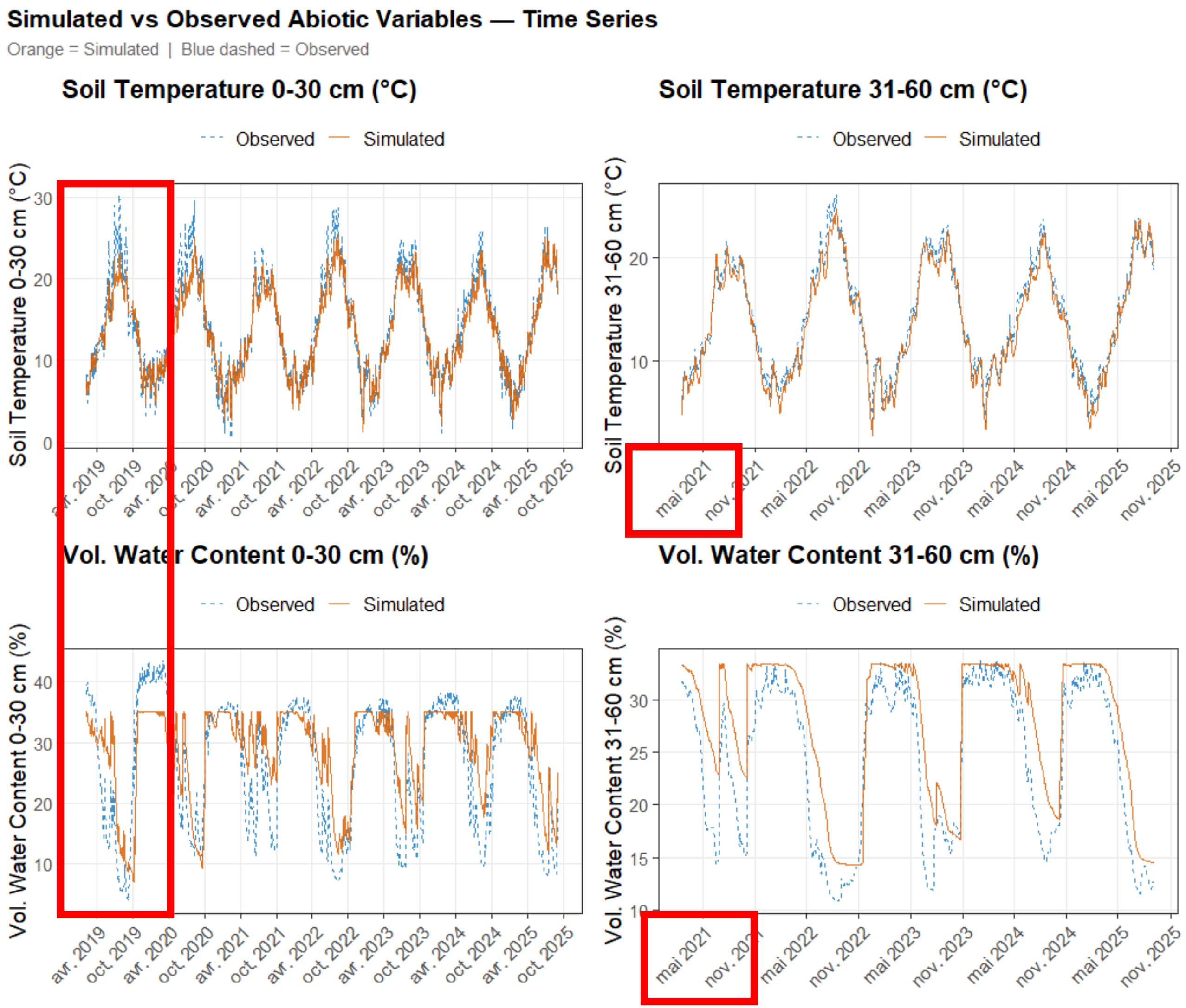


Results

Model performances: **abiotic parameters**

- Overall soil parameters were well simulated

- Early set-up averaged 4 captors at 5 and 10 deep cm explaining slight differences. After early 2020 : 2 captors each 5 – 15 -35 – 50 cm deep



Model performances: **Silage maize yield and Herbage valorisation (mowing and grazing)**

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Model performances: **Silage maize yield and Herbage valorisation (mowing and grazing)**

- Maize: 12,705 $t.ha^{-1}$ Observed

  10,675 $t.ha^{-1}$ Simulated

Underestimation most likely resulting from starting simulations just before the maize implementation (i.e., no fertilization from previous rotations)

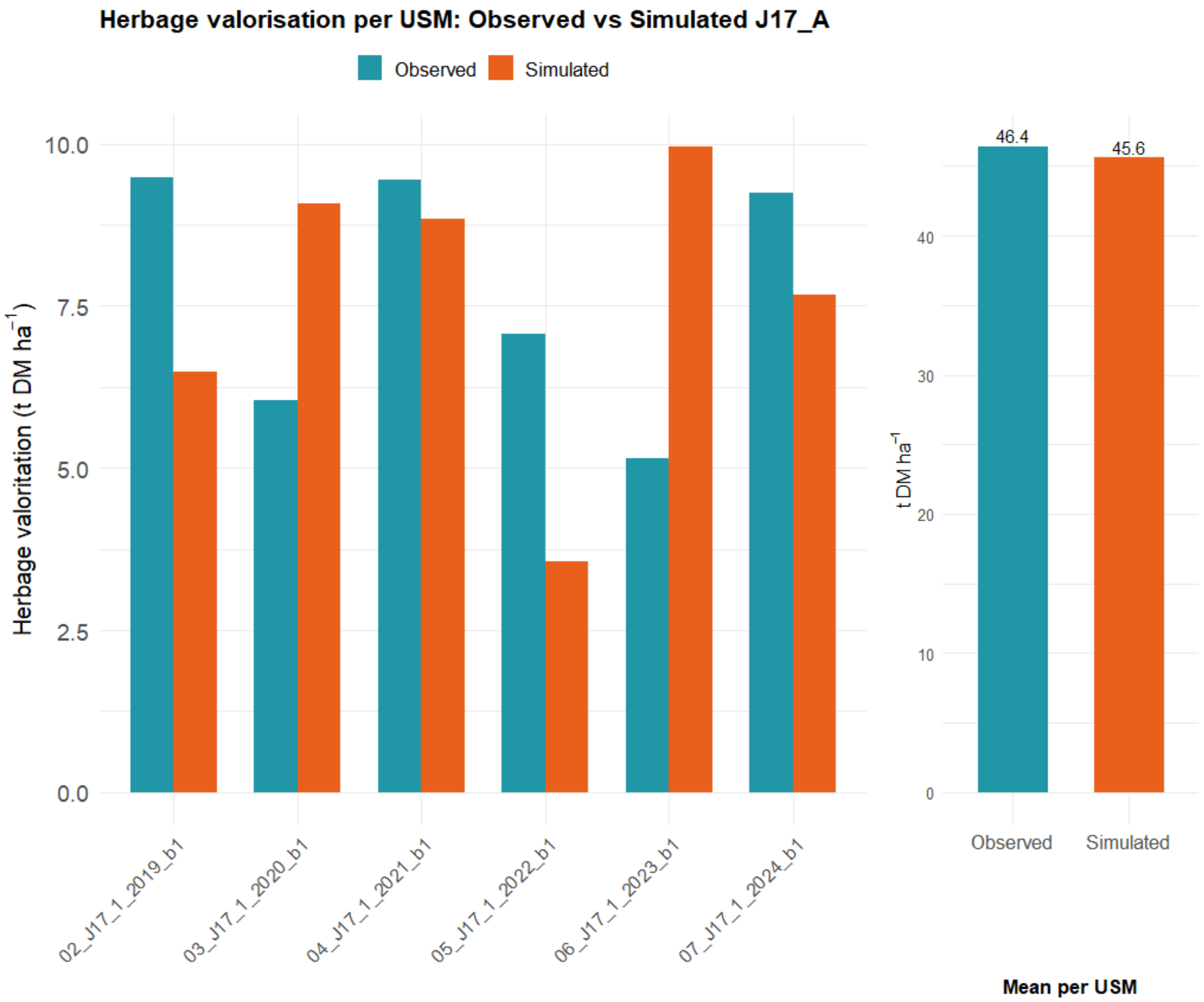
Results

Model performances: **Silage maize yield and Herbage valorisation (mowing and grazing)**

- Maize: 12,705 $t.ha^{-1}$ Observed

  10,675 $t.ha^{-1}$ Simulated

- Grazed grassland : Consistent cumulative values across USMs but differences at the USM scale



Model performances: **Net Ecosystem Exchange (NEE)**

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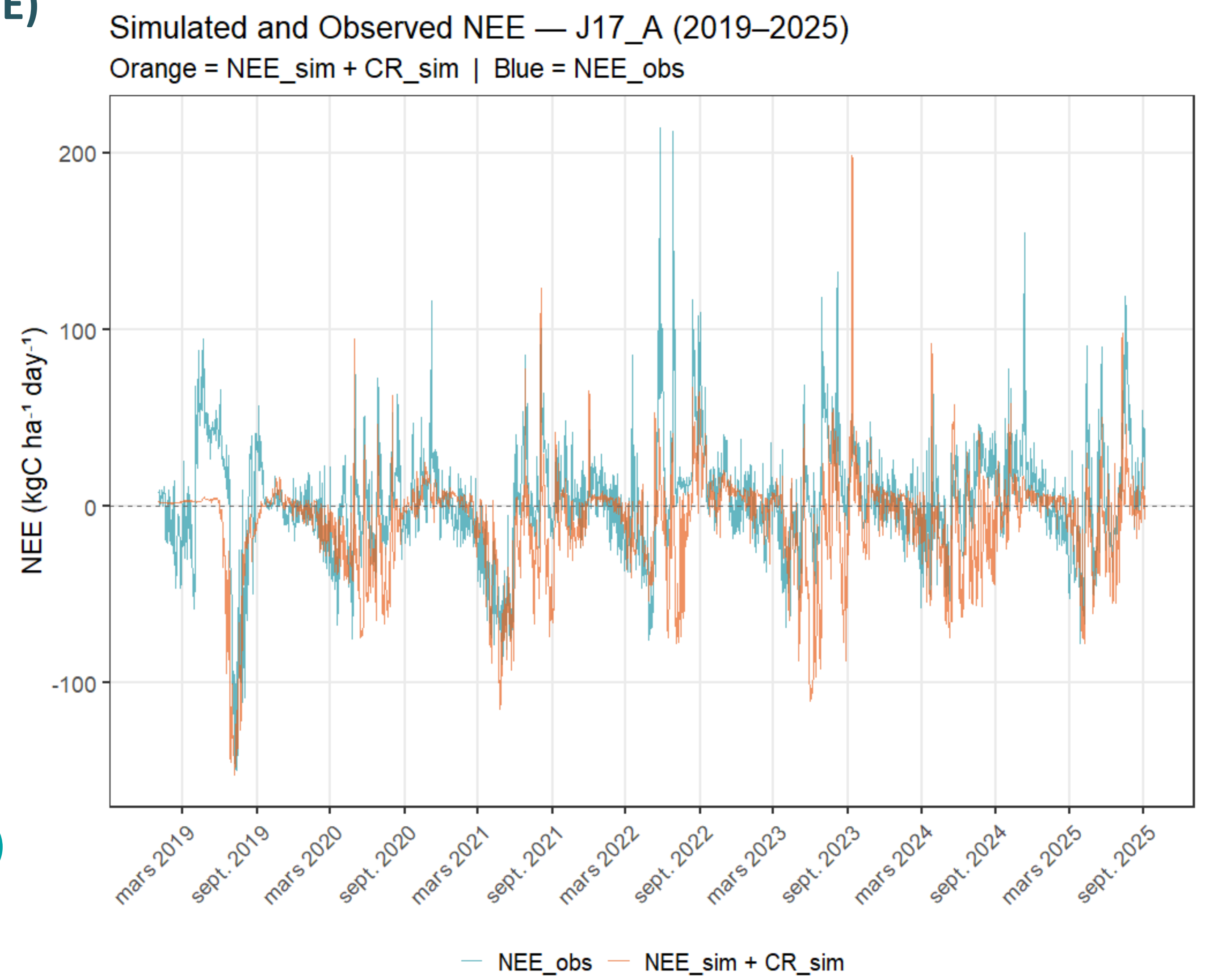
Model performance — NEE J17_A (2019–2025)

Daily NEE | NEE_v4 vs NEE_qc0

Metric	Value	Unit	Interpretation
R^2	0.302	—	20% variance explained
RMSE	32.080	kgC ha^{-1} d^{-1}	Mean absolute error
Bias	−12.682	kgC ha^{-1} d^{-1}	Model overestimates sink
EF	0.003	—	Near-zero model efficiency
Slope	0.510	—	Flux amplitude compressed
Intercept	−11.449	kgC ha^{-1} d^{-1}	Systematic offset
pMSEs	0.397	—	Systematic error share
pMSEu	0.603	—	Random error share
rRMSE	12.736	%	Normalized error



- The order of magnitude and dynamics of the NEE are generally well represented
- Model catch 30% of daily NEE variability
- Overestimation of carbon uptakes (-12,7 $KgC.ha^{-1}.j^{-1}$)
- Systematic vs Random error 40/60 : Seasonal bias ?

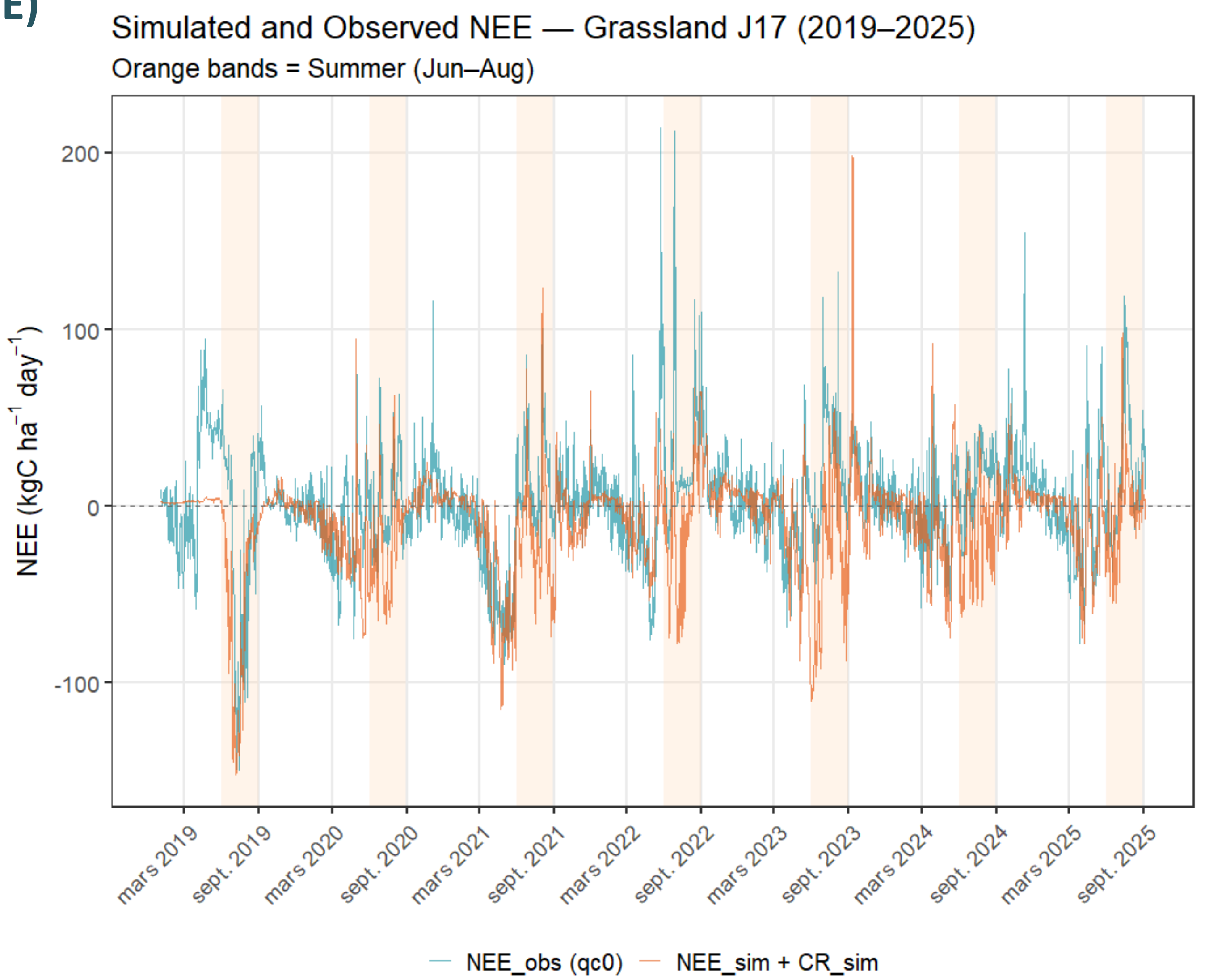
Model performances: **Net Ecosystem Exchange (NEE)**

Seasonal model performance — NEE J17_A

Daily NEE | NEE_v4 vs NEE_qc0 | kgC ha^{-1} d^{-1}

	Season	Bias (kgC ha^{-1} d^{-1})	RMSE (kgC ha^{-1} d^{-1})	EF	pMSEs
March/April/May	Spring	−10.90	35.13	0.19	0.50
June/July/August	**Summer**	**−33.54**	**45.58**	**−0.34**	**0.60**
Sept/Oct/Nov	Autumn	−8.10	21.61	−0.23	0.48
Dec/Janua/Feb	Winter	3.56	14.19	0.11	0.72

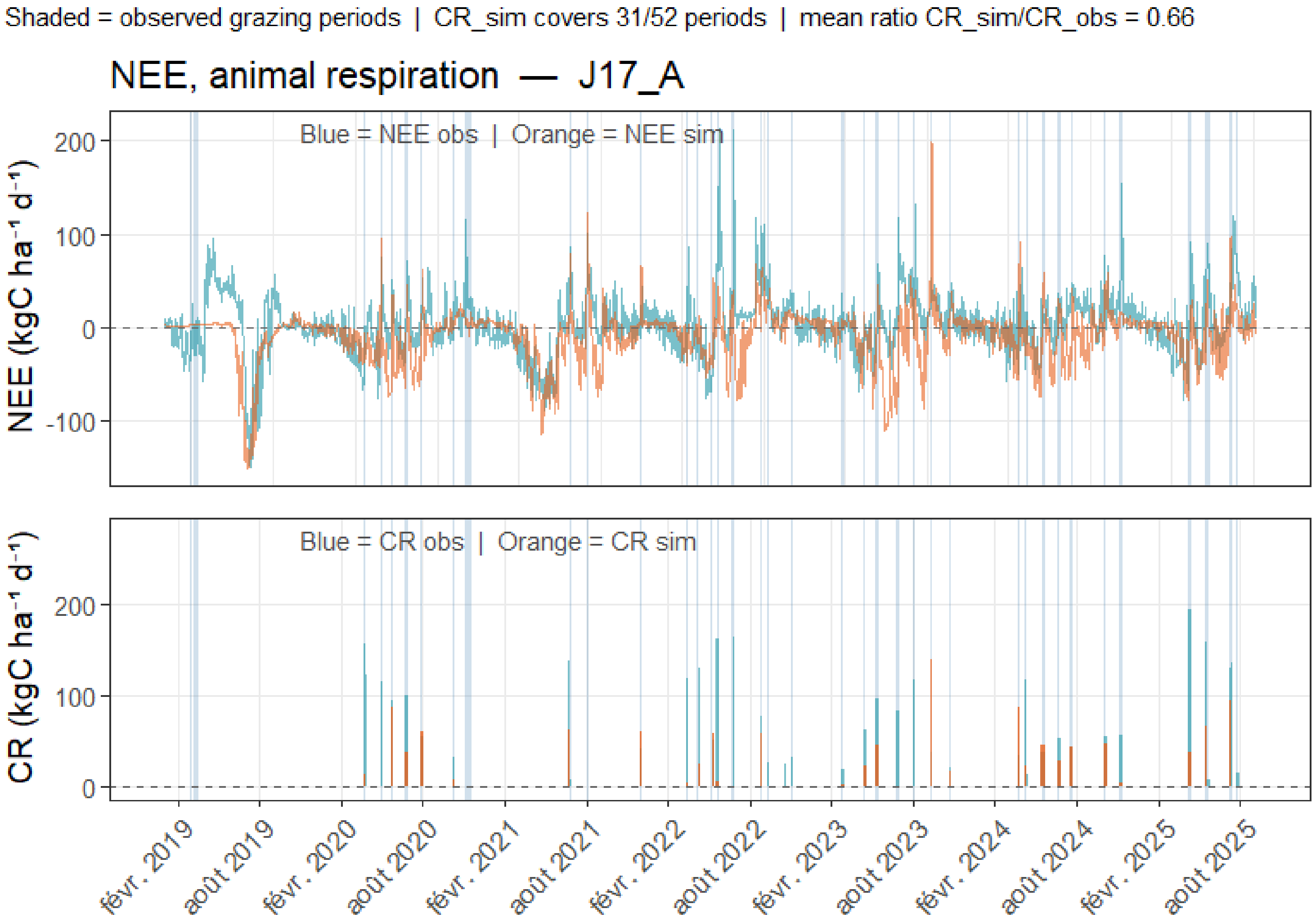
- Winter : low activity but slight over-estimation of CO2 release
- Strong bias in Summer with systematic error and overestimation of carbon uptake
- Hypothesis: Higher plant growth simulated than observed under summer conditions and/or soil activity under-estimated? (In progress)



Model performances: Net Ecosystem Exchange (NEE)

CR : Animal Respiration

- Animal contribution to NEE and can be detected and simulated
- **CR_sim = 43% of CR_obs** : partly due to scope difference (grazing vs total ration)
- **CR_sim captures grazing export timing** but misses 21/52 observed events



Results & Discussion

Take home messages:

- **STICS performance:** The model accurately reproduced environmental conditions and biomass production for Plot A.
- **Observed data of NEE required heavy post-processing** to provide quality data to compare model simulations
- **NEE Dynamics:** Simulations captured seasonal trends but showed lower amplitudes and systematic errors
- **Summer Bias:** Significant overestimation of carbon uptake in summer suggests a need for refined model parameterization (NPP or HR ?)
- **Grazing Impact:** Animal respiration is a significant driver of NEE in grazed grassland systems
- **Model Synergy:** STICS outputs provide valuable inputs for potential mechanistic modeling of animal respiration and overall NEE assessment

Perspectives

- Estimation of the **components of observed and simulated NEE** (GPP, RECO and its components) (work in progress)

- **To improve simulations and parametrization** of experimental plot by STICS:
  - Starting simulations earlier to consider previous rotations on maize
  - Improving de decomposition of dairy effluents
  - Improving grazing events simulation

To estimate observed and to simulate animal respiration more accurately by

- taking into account the cows' diet and milk production
- using the equations proposed by Kjeldsen et al., 2004.
- the location of animals within the plot (currently assuming a homogeneous distribution)

- Comparison of **simulated versus observed SOC** trends (only one measurement point in 2019 so far)

- **Application** of the simulation workflow to the additional plot J17_B

Thank you for listening

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Additional slides

Additional slides

Animal respiration

(Faverdin et al. 2007)

0,42 - Carbon content of ingested herbage

0,39 – Fraction of ingested C respired as CO2 (remainder partitioned to urine, methane, faeces and milk)

CR observed

from field measurements

msit

Live weight (kg DM $animal^{-1}$)

↓

temp_paturage / 24

Fraction of day on pasture (6h / 10h / 20h)

↓

frac_C × frac_resp

0.42 × 0.39 (Faverdin et al. 2007)

↓

CR_obs [KgC $Animal^{-1}$ d^{-1}]

↓

Number of animals

↓

CR_obs [KgC .d^{-1}]

↓

Plot area

↓

CR_obs [KgC. Ha^{-1} .d^{-1}]

CR simulated

from STICS output

Δmafauchetot

Herbage consumed (STICS output) x 1000 : Kg DM .ha^{-1}

↓

Tsej

Stay duration (days) of animals from field data associated to STICS cuts simulation

↓

Δmafauchetot / Tsej

STICS simulates grazing only once: Kg DM ha^{-1}.d^{-1}

↓

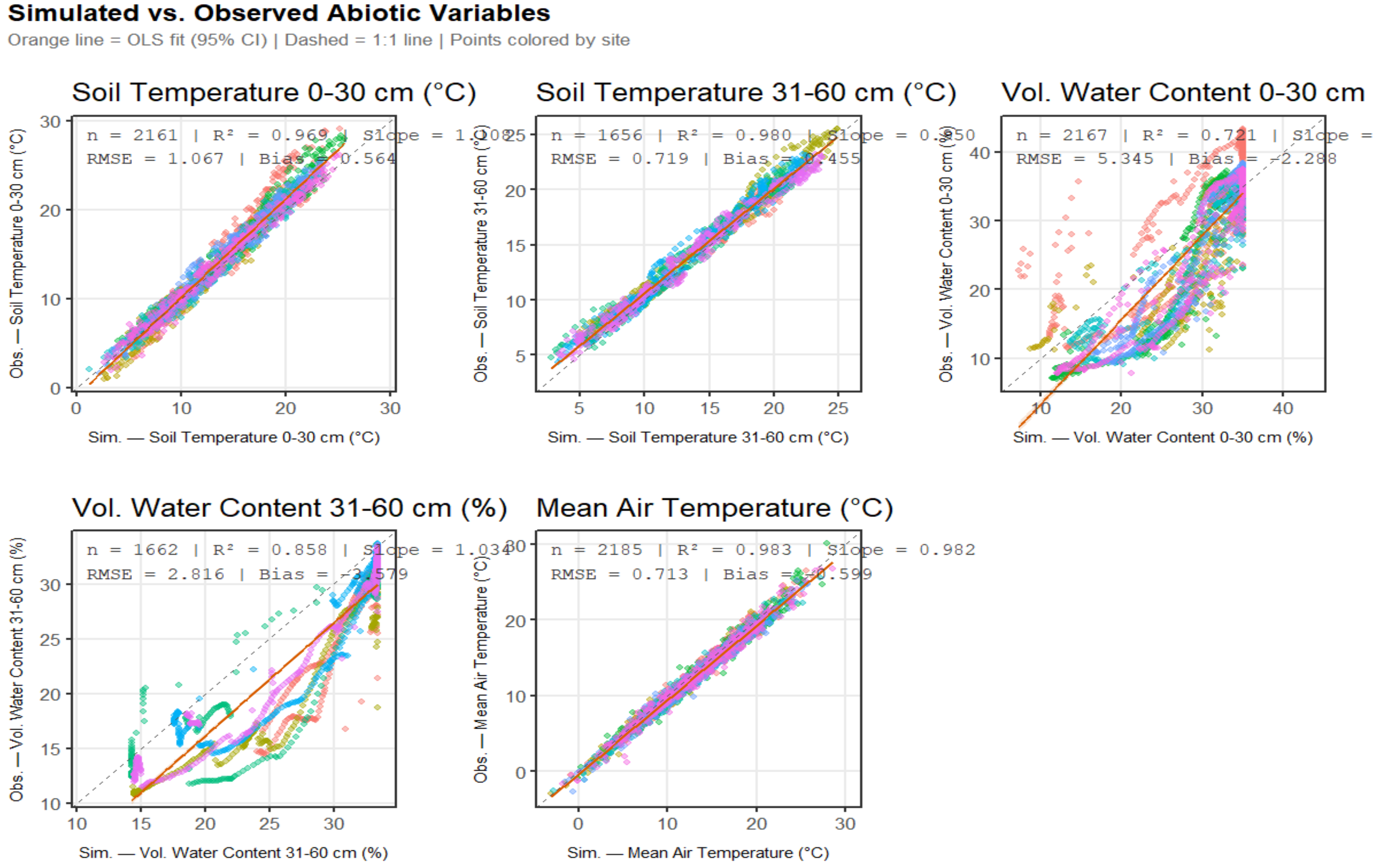
frac_C × frac_resp

0.42 × 0.39 (Faverdin et al. 2007)

↓

CR_sim [KgC ha⁻1 d^{-1}]

Comparison of simulated vs observed soil conditions



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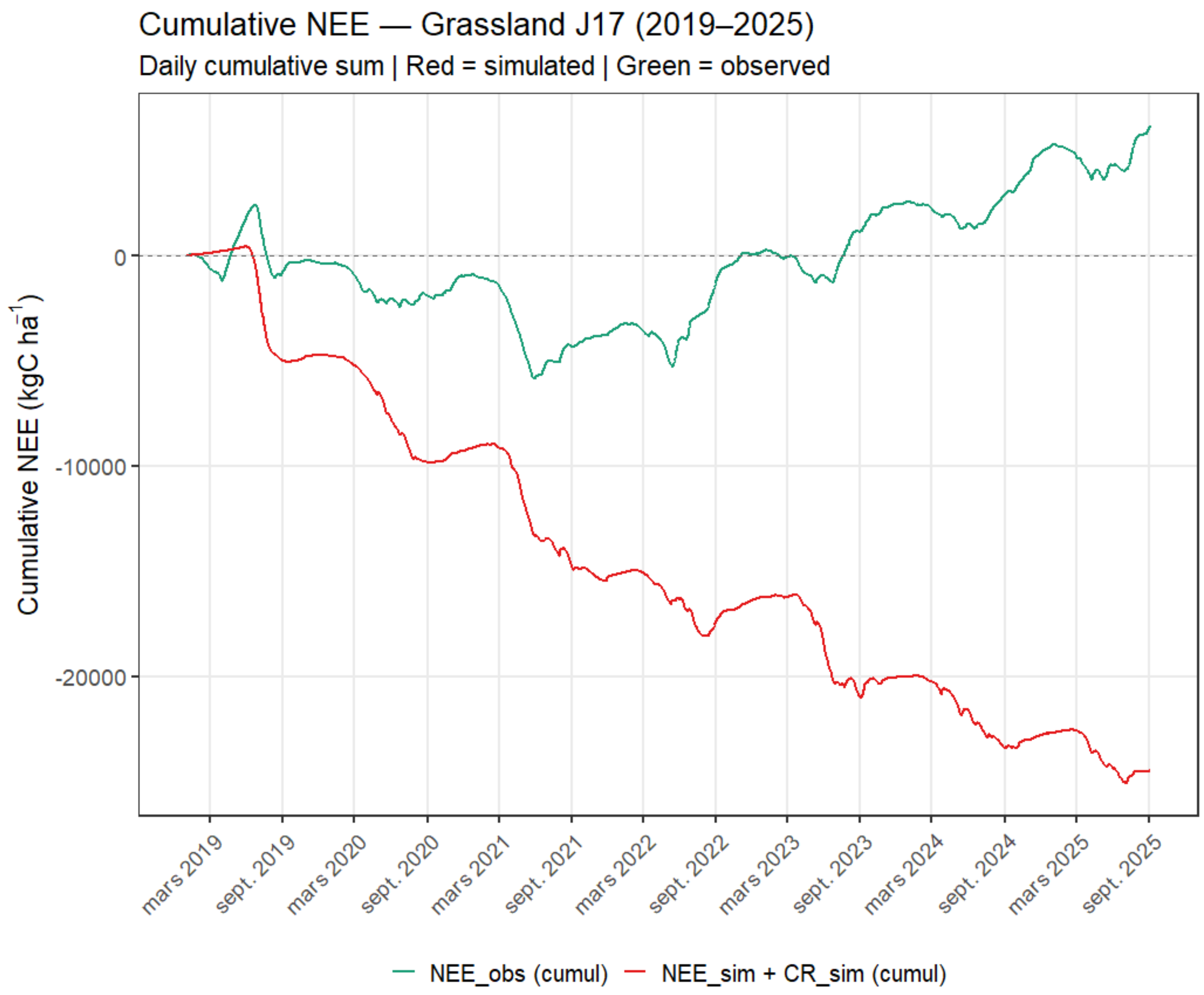

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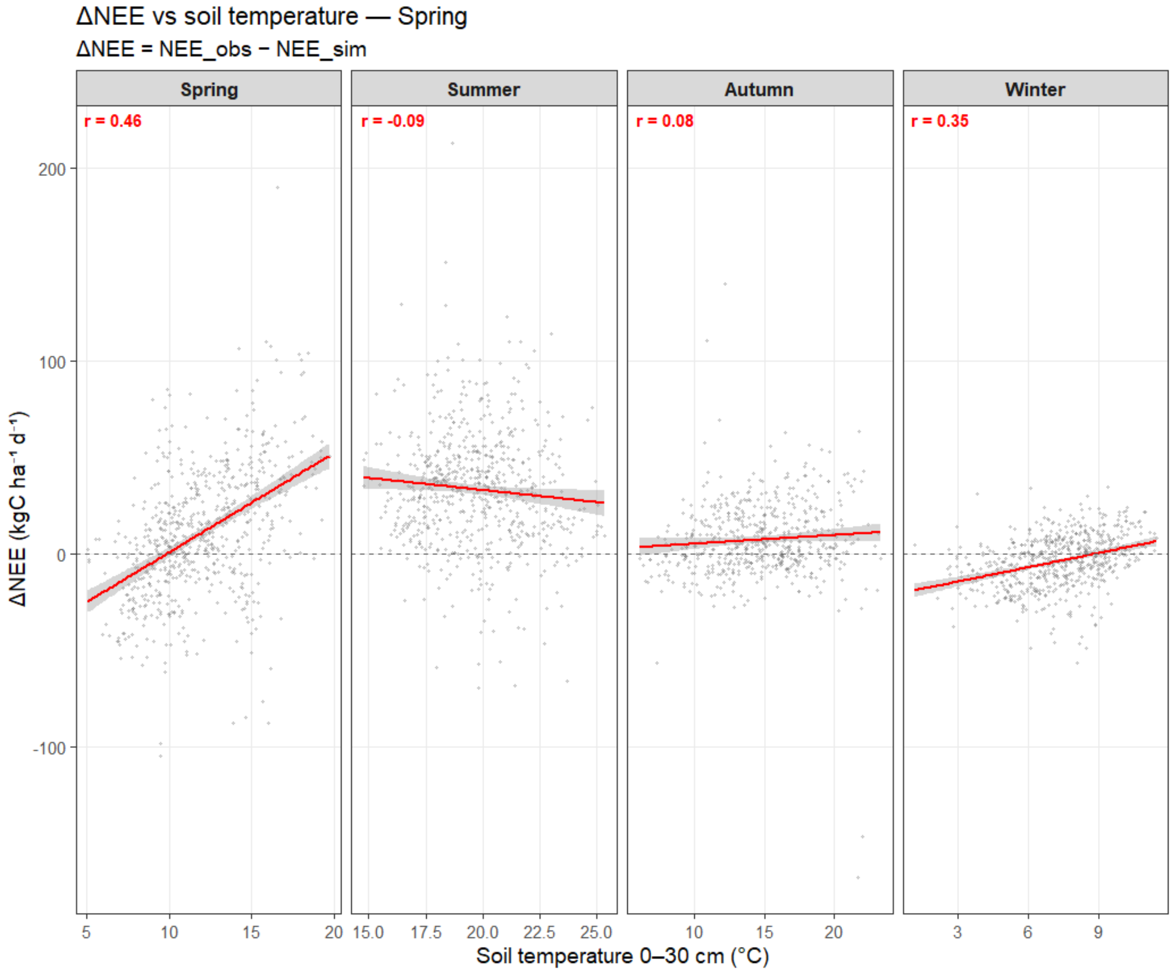

Pearson correlations between ΔNEE (NEE_obs − NEE_sim) and abiotic drivers by season

	Temperature			Soil moisture 0–30 cm		Soil moisture 30–60 cm	
saison	**T air**	**T sol sim**	**T sol obs**	**HR1 sim**	**HR1 obs**	**HR2 sim**	**HR2 obs**
Spring	**0.39**	**0.46**	**0.48**	**-0.24**	**-0.37**	**-0.25**	**-0.27**
Summer	**-0.04**	**-0.09**	**-0.02**	**0.20**	**0.06**	**0.22**	**-0.03**
Autumn	0.10	0.08	0.11	0.00	-0.11	0.07	0.01
Winter	0.35	0.35	0.41	0.18	-0.04	-0.02	-0.08

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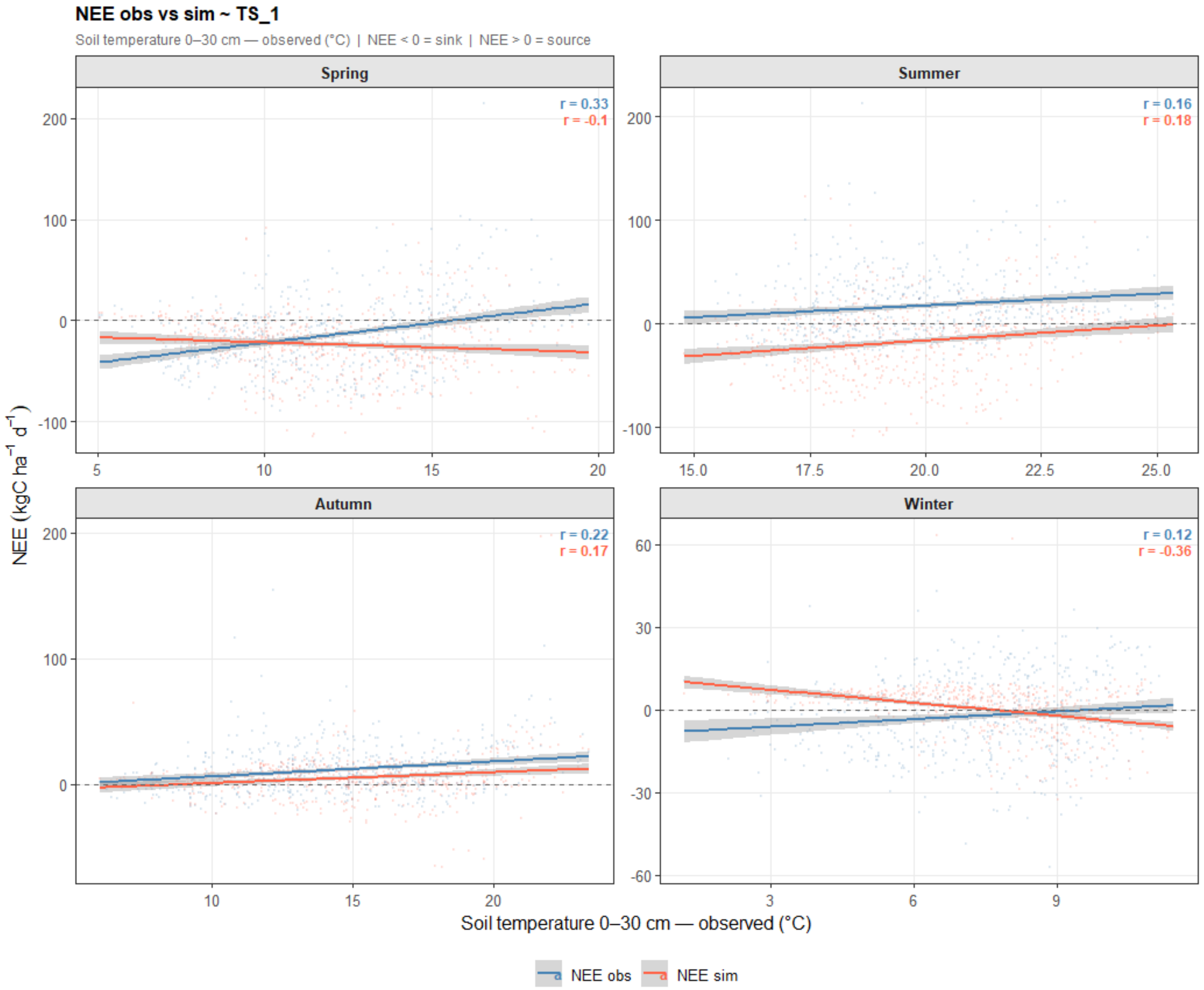

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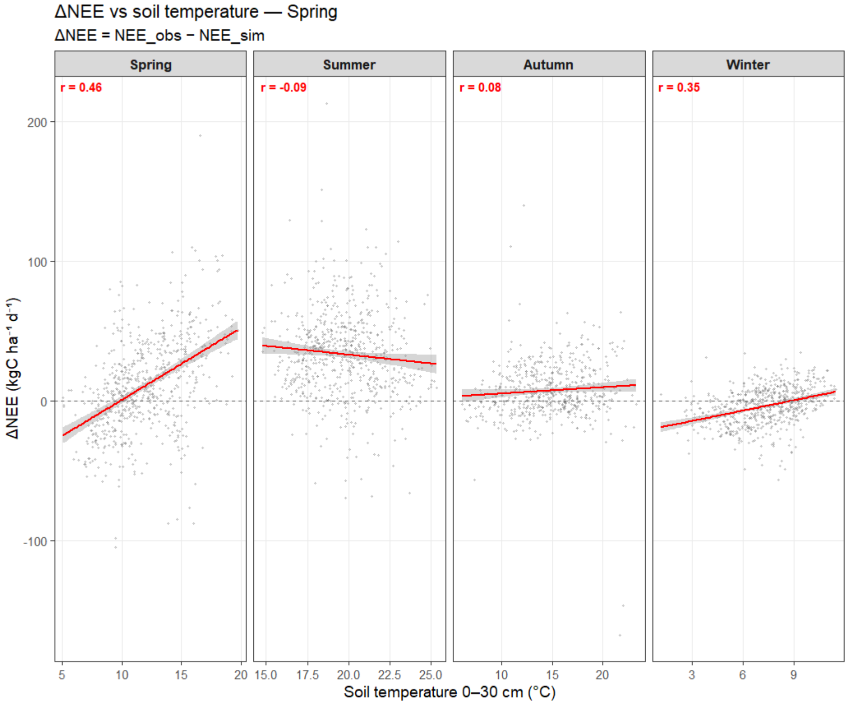

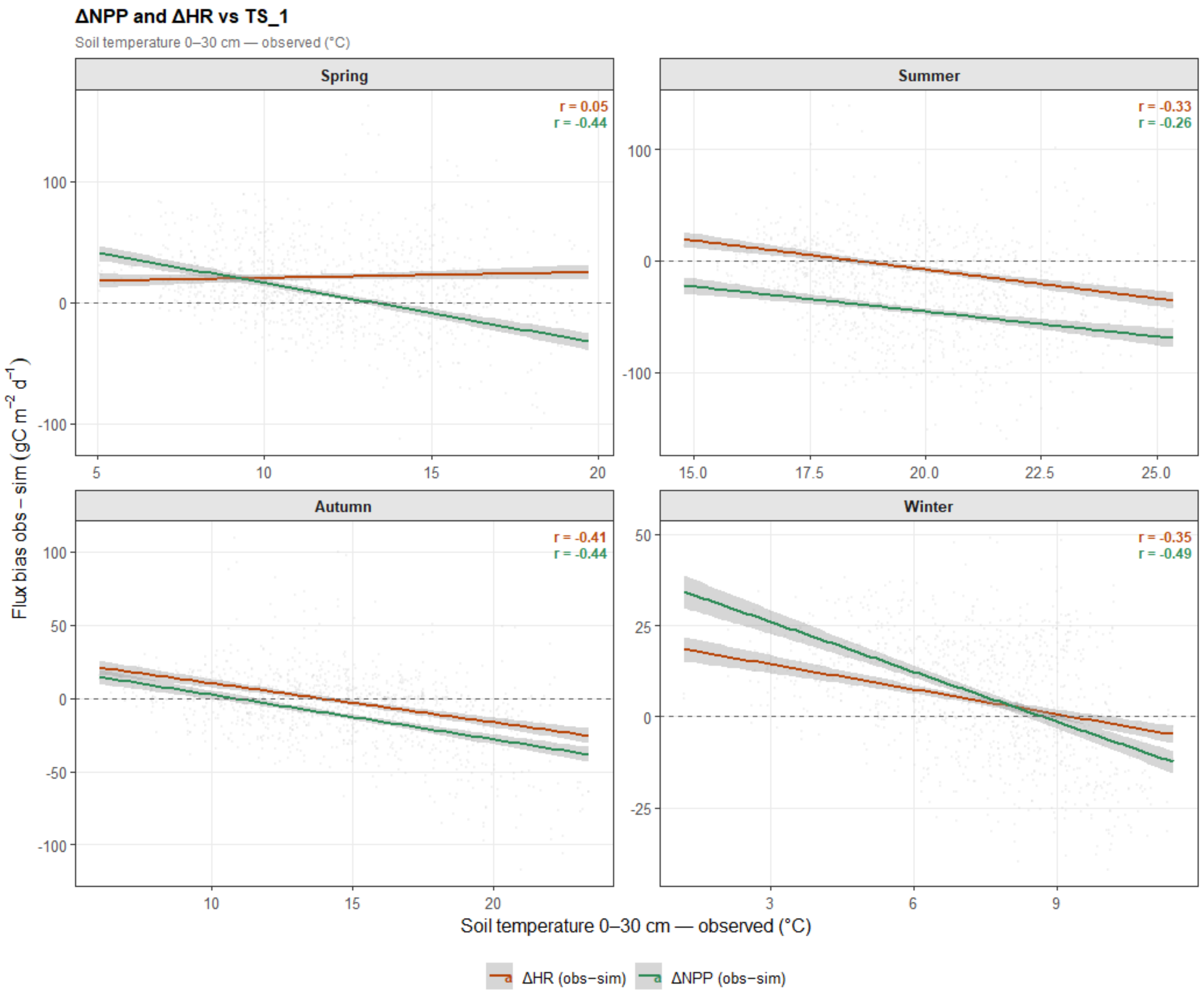

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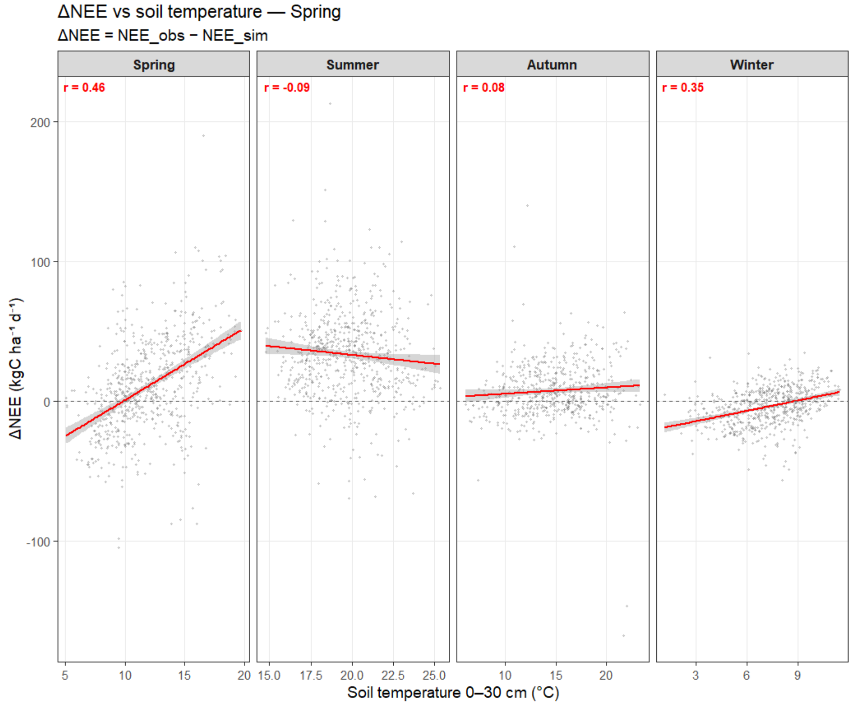

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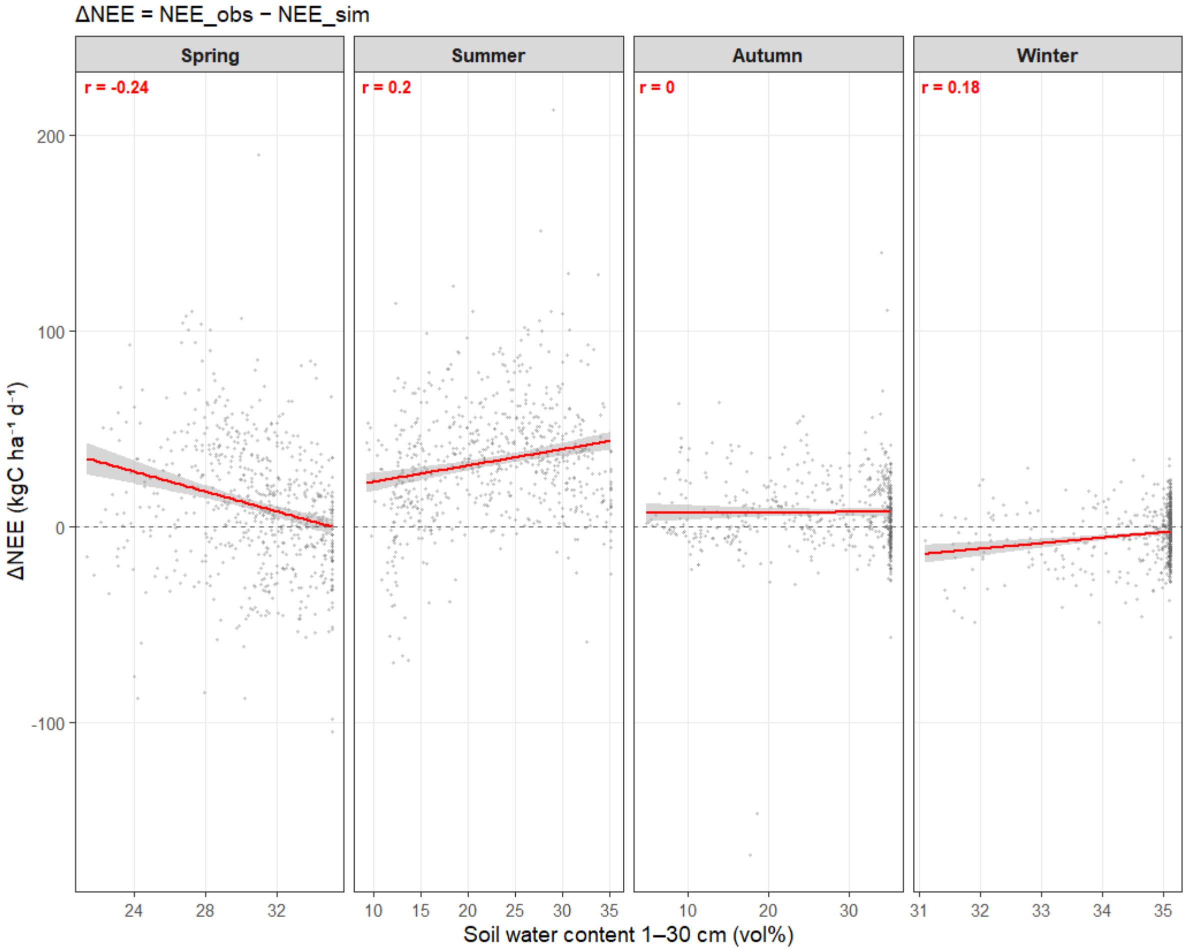

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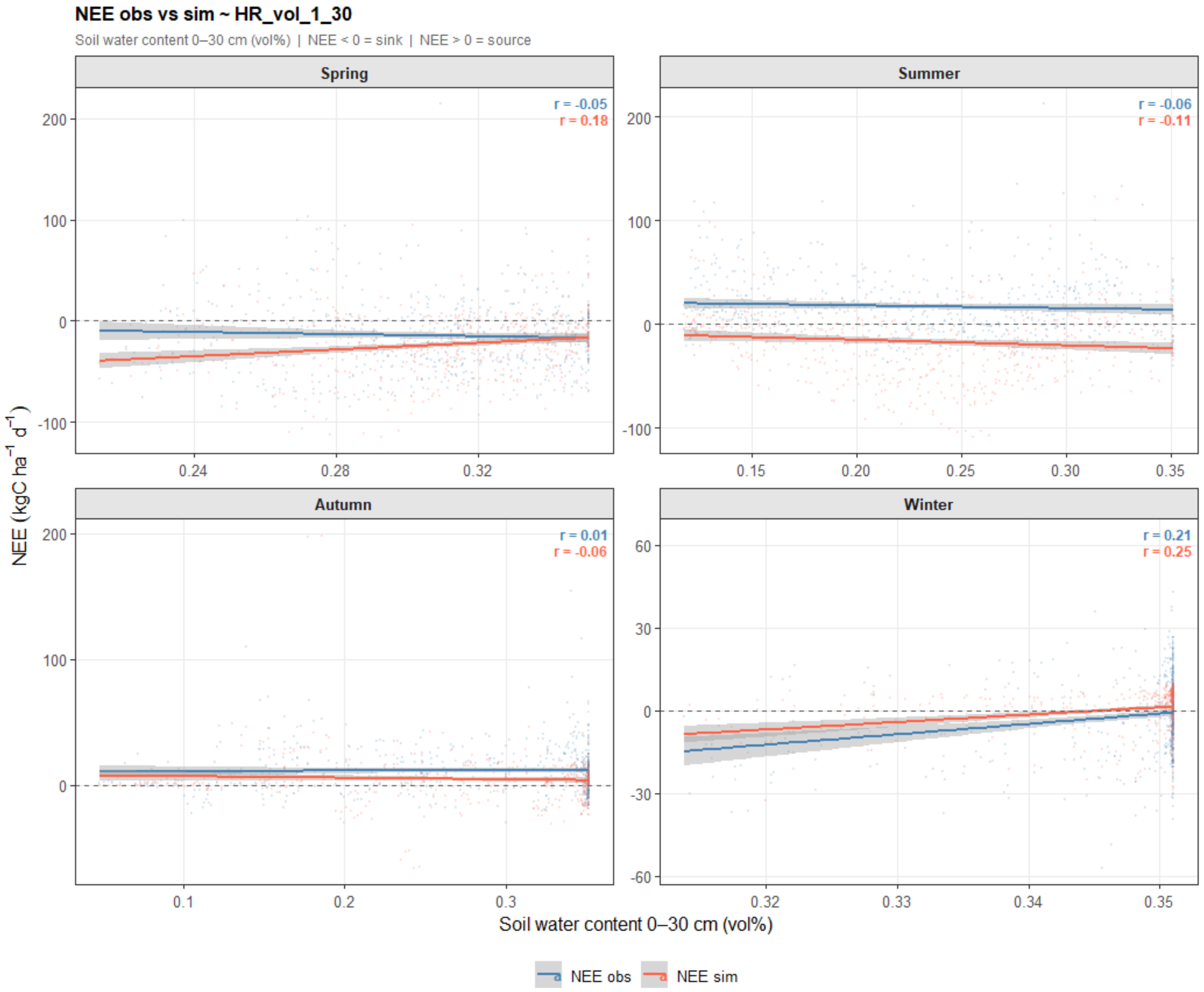

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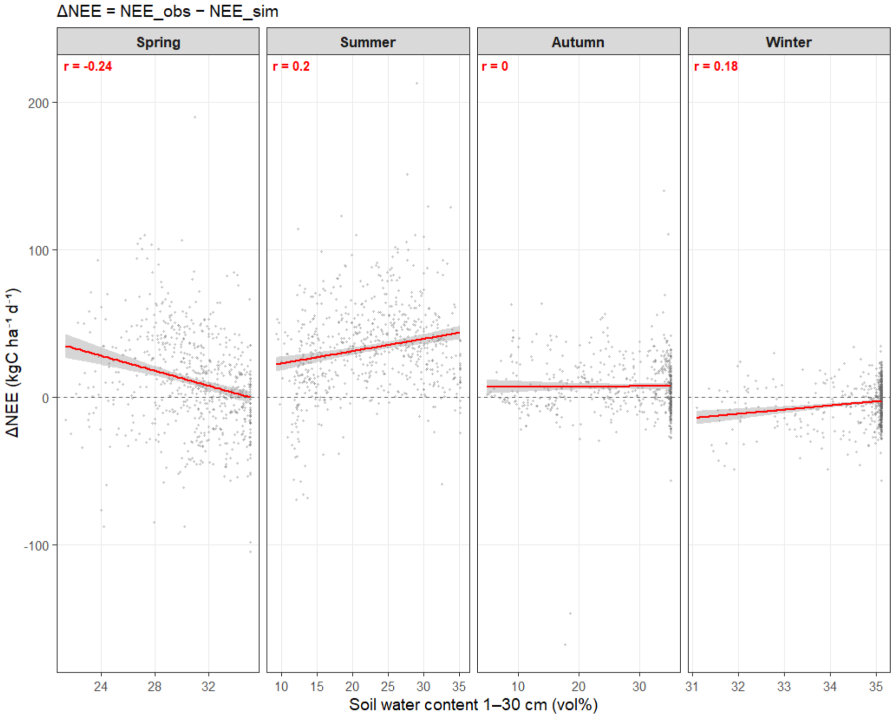
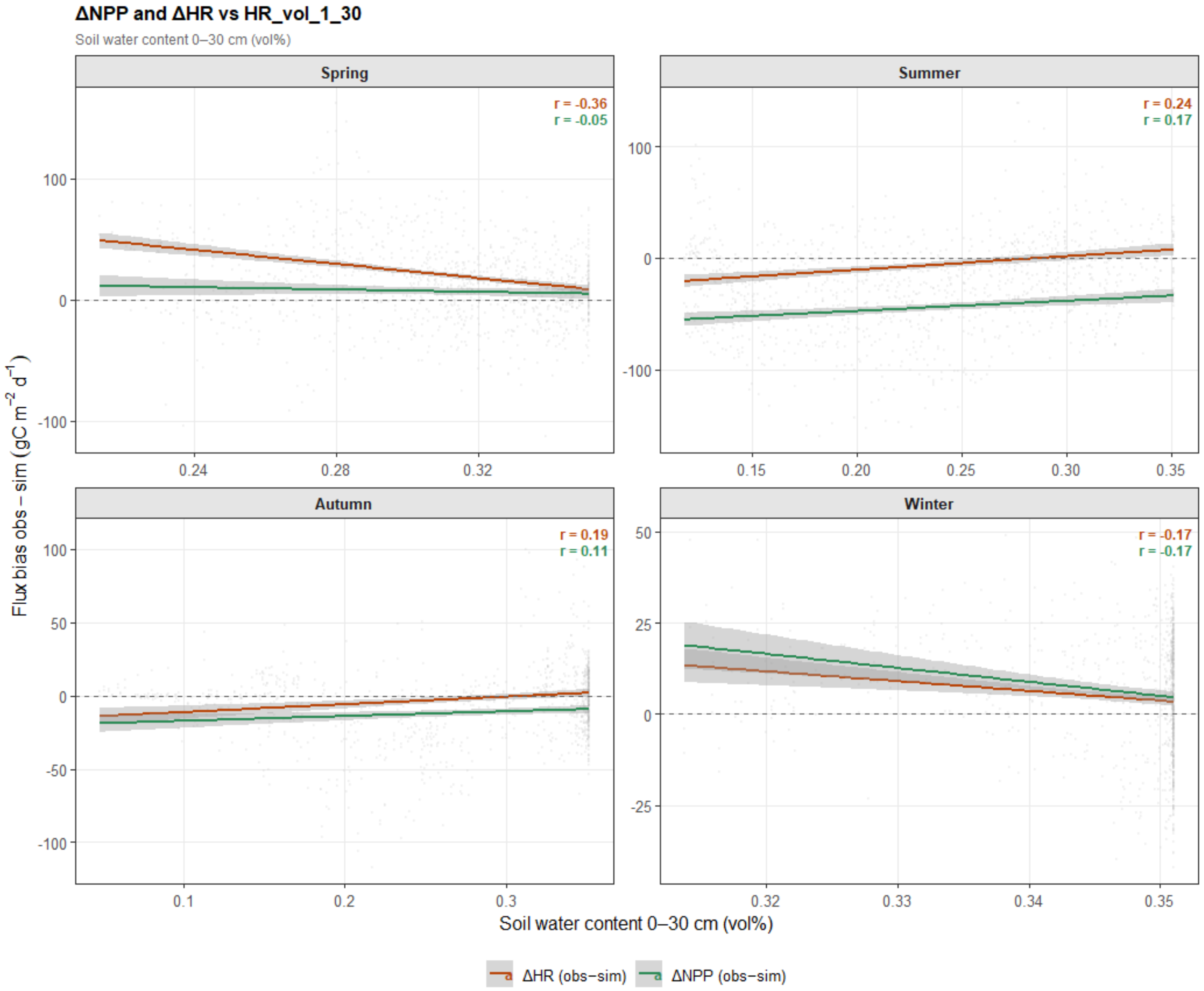
saison	**T air**	**T sol sim**	**T sol obs**	**HR1 sim**	**HR1 obs**	**HR2 sim**	**HR2 obs**
Spring	**0.39**	**0.46**	**0.48**	**-0.24**	**-0.37**	**-0.25**	**-0.27**
Summer	**-0.04**	**-0.09**	**-0.02**	**0.20**	**0.06**	**0.22**	**-0.03**
Autumn	0.10	0.08	0.11	0.00	-0.11	0.07	0.01
Winter	0.35	0.35	0.41	0.18	-0.04	-0.02	-0.08



Additional slides



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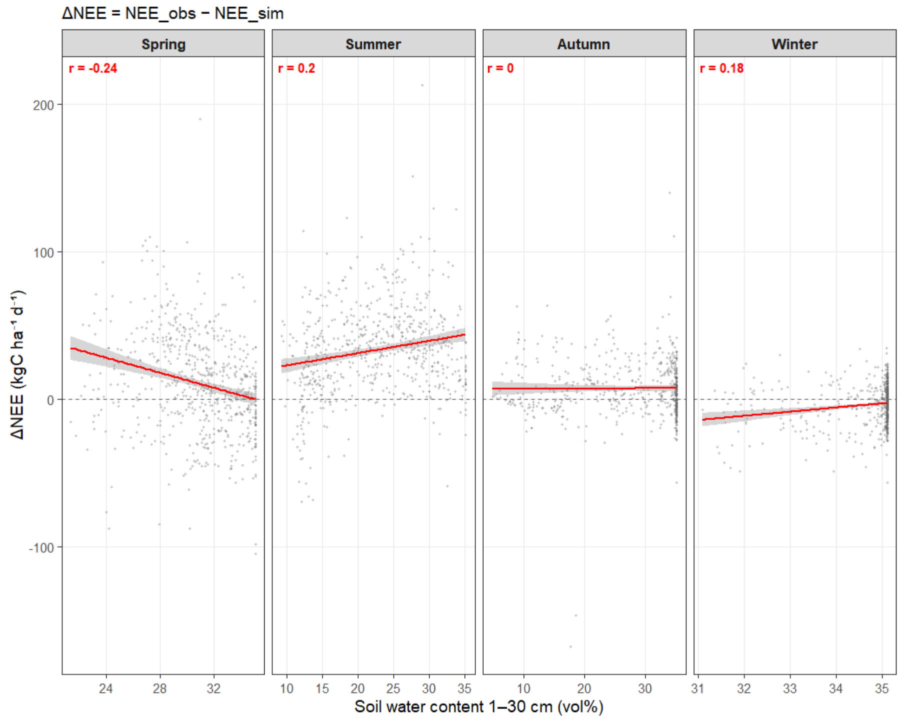
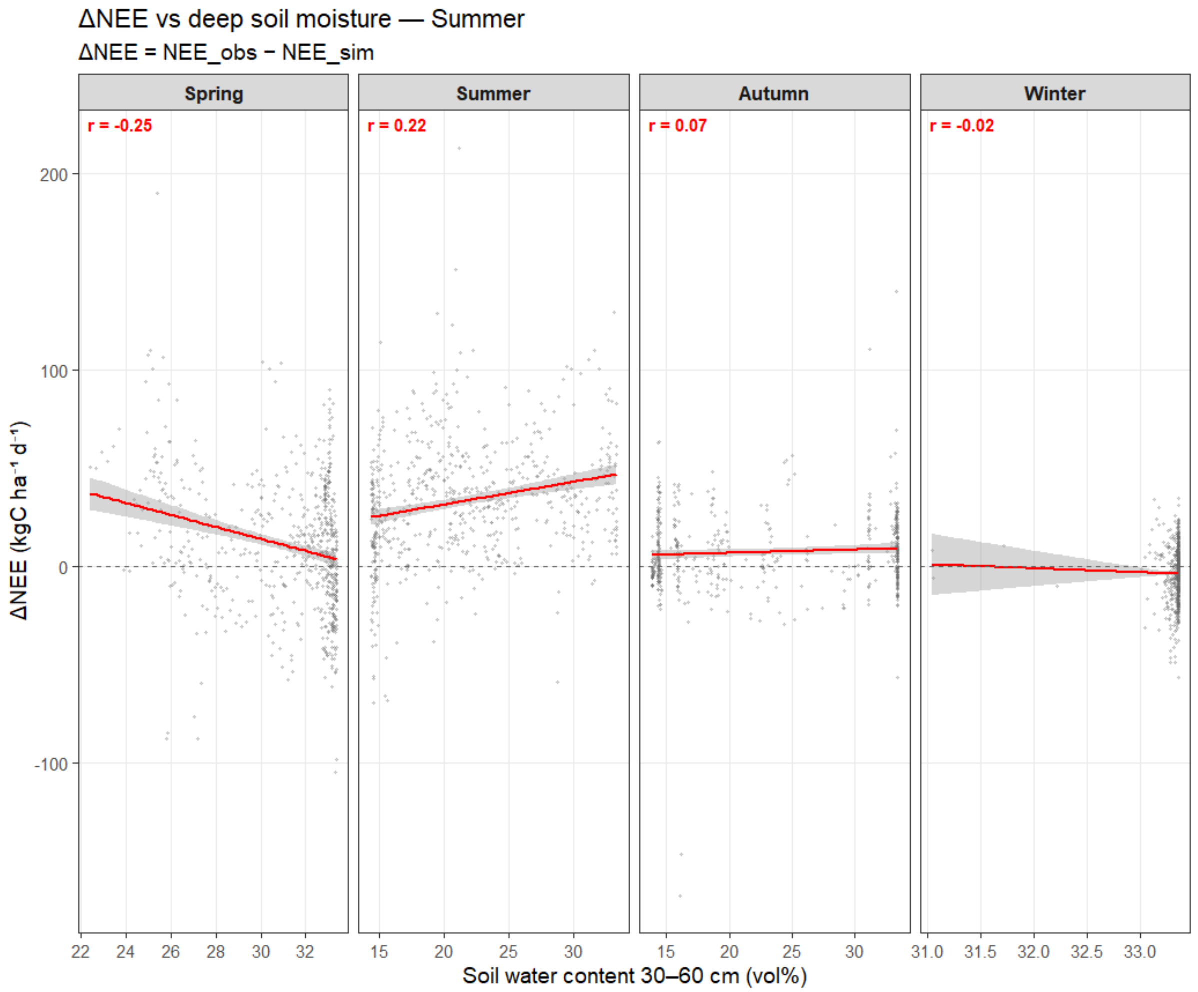


Additional slides



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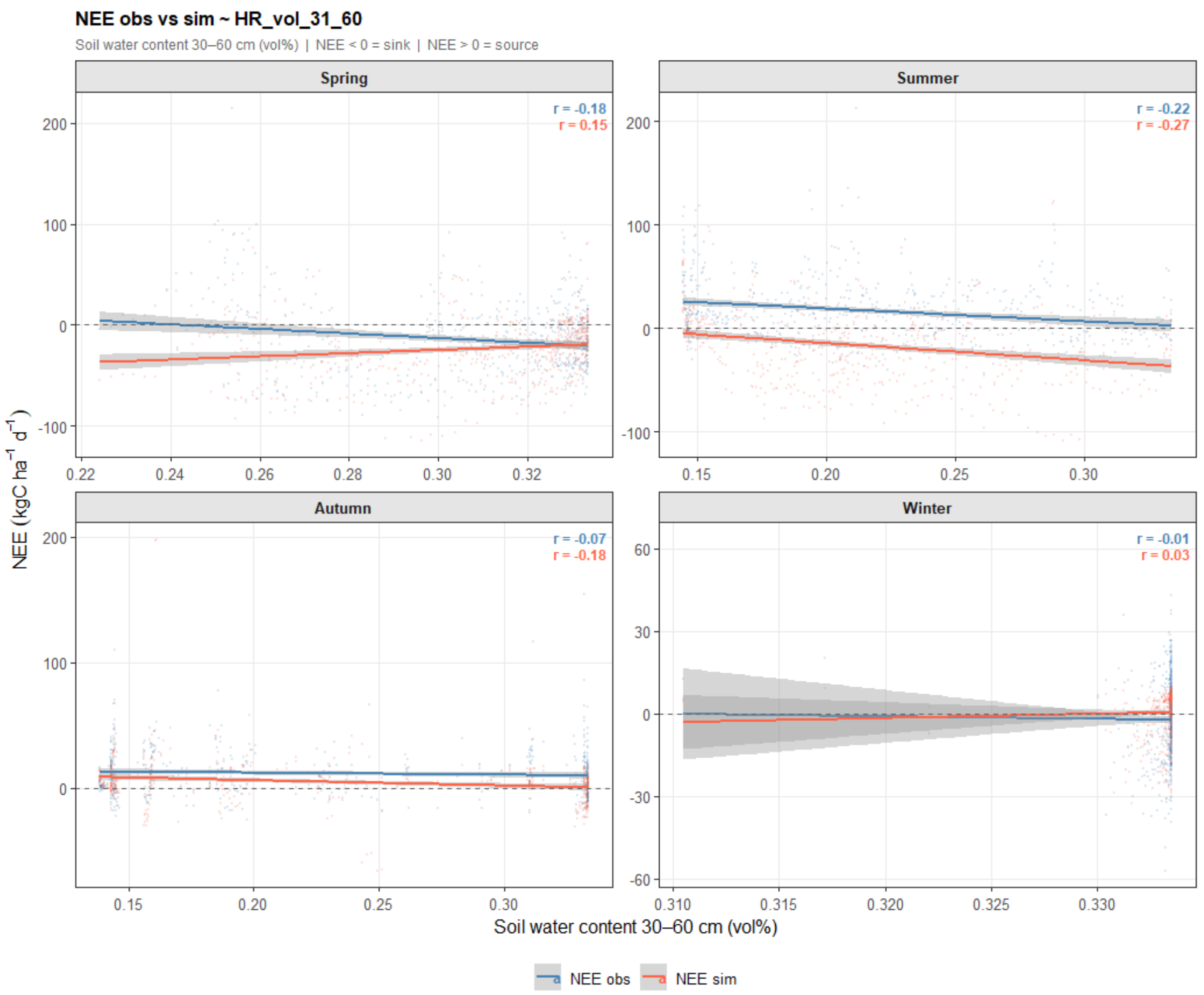

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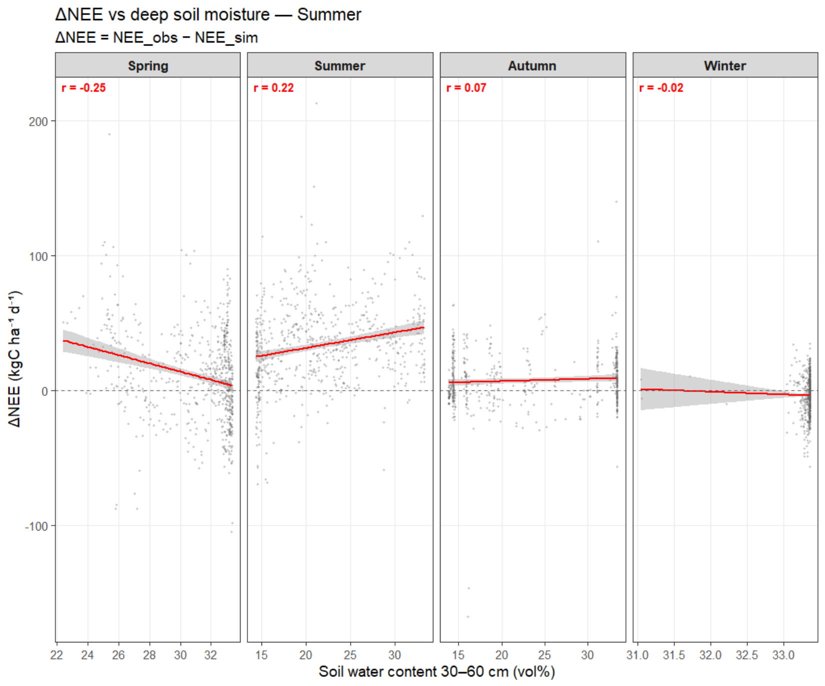
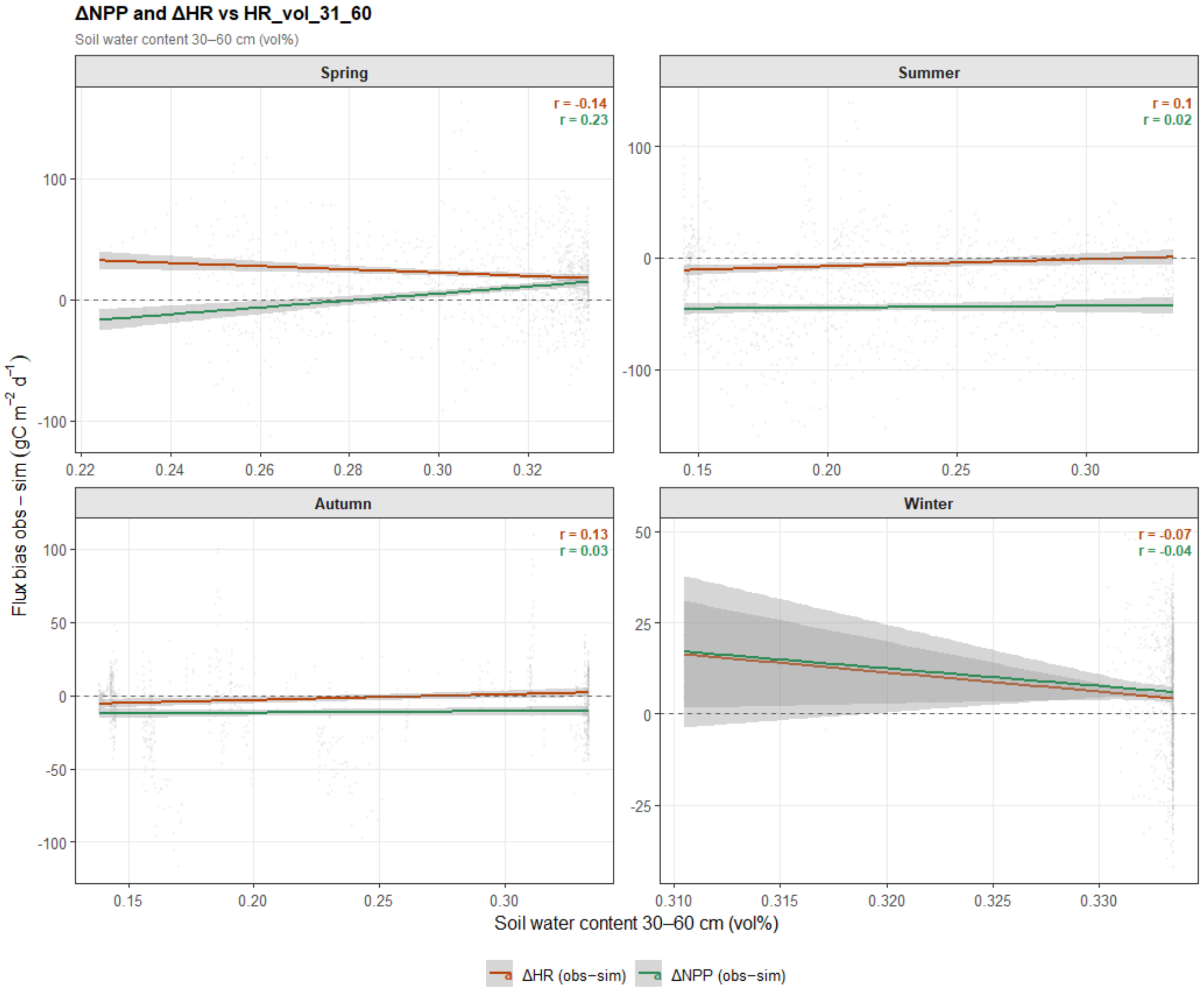


Additional slides



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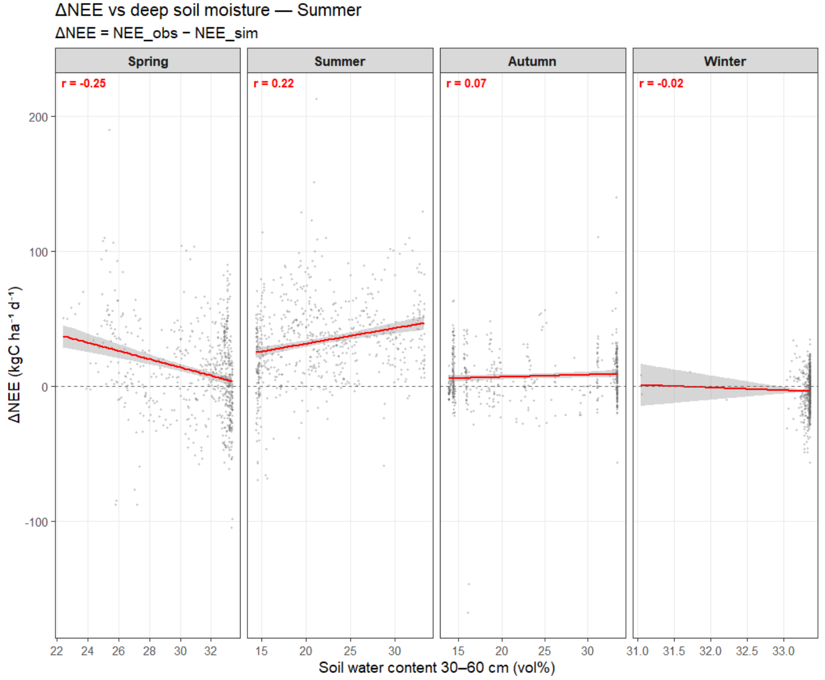
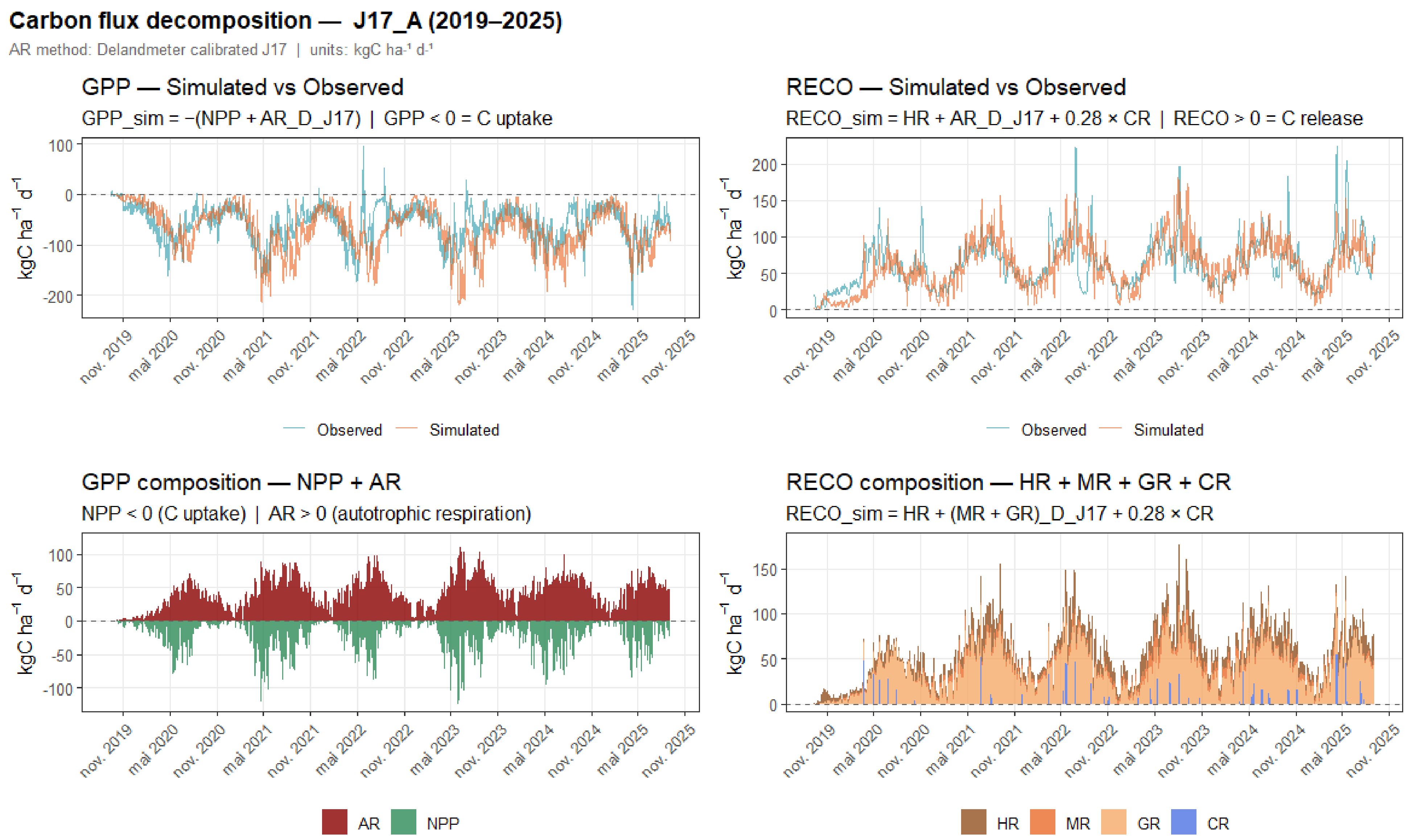


Additional slides

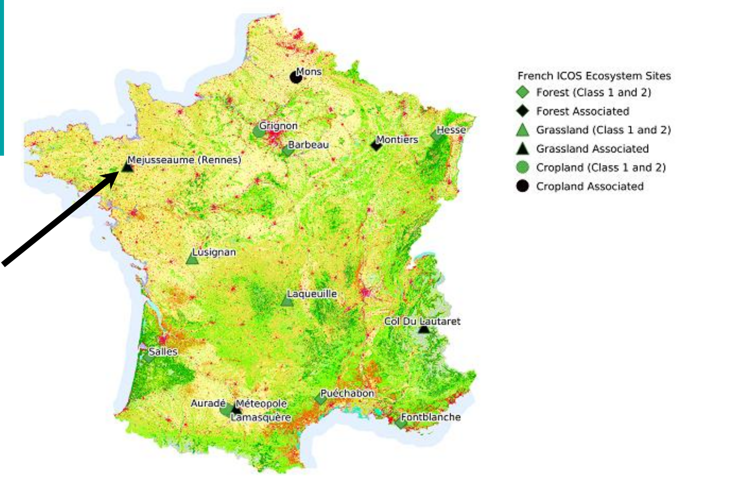


Additional slides

Animal Respiration estimation

FR-Mej station of the ICOS network

Méjusseaume INRAE experimental facility (France)



- 6-year maize – grassland rotation

- Field equipped with a **flux tower**; divided into **2 sub-plots**, the NW part (**plot A**) and the SE part (**plot B**), which are **grazed alternately** by Holstein dairy cows.
- **Grazing** most of the time **20h per day**, with supplementary feed provided during milking hours. Grazing **4 to 6 times per year**, mainly in spring.
- Experiment **started in 2019**; **observations** available **from 2020 to 2025**: soil and climate conditions, management, silage maize yield and grassland valorisation, **surface-atmosphere exchanges of CO_2** etc.