Introducing CLM-FruitTree to model carbon allocation in fruit orchards with the Community Land Model

EGU22 || BG3.6 || Additional material

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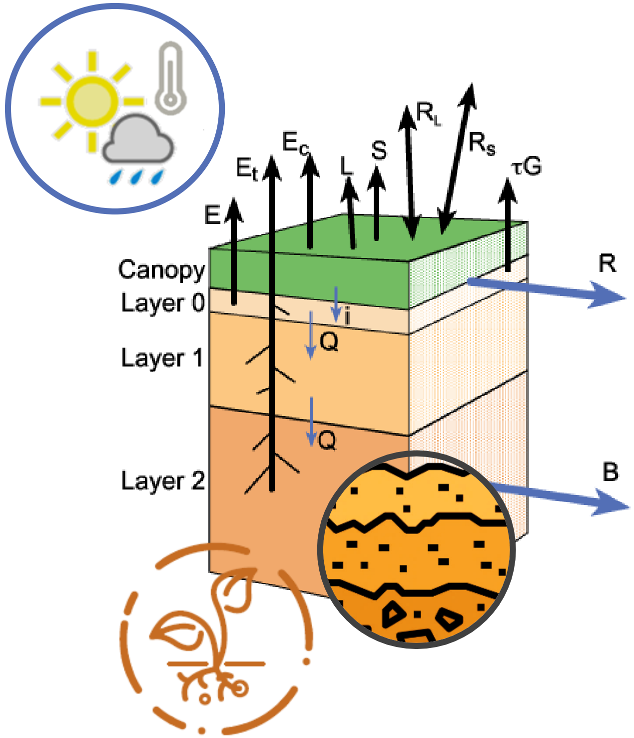
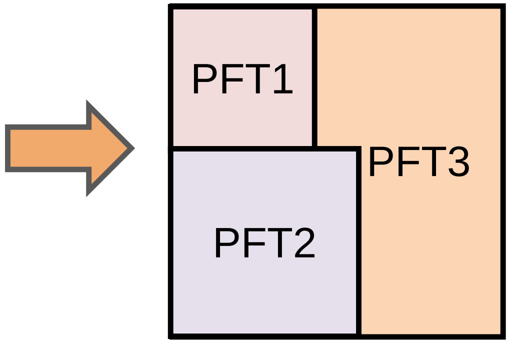
CLM5 and vegetation representation

CLM5 simulates exchanges of water, energy and matter between land and atmosphere as well as their storage and transport.
It is driven by climate variability and modulated by soil and vegetation states and characteristics.

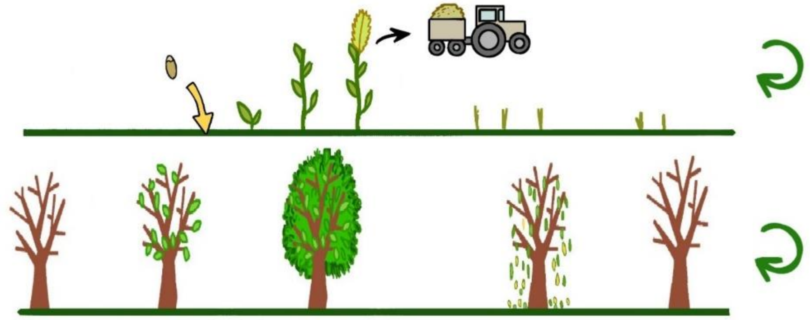


Plant functional types are represented with their own phenology, CN allocation and parameterization.

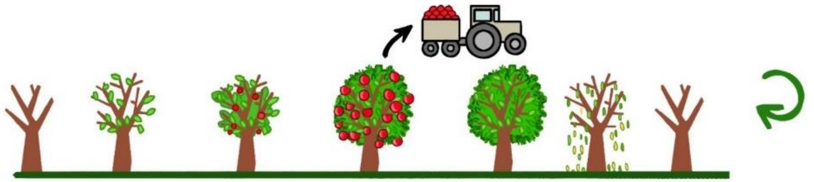


1x1 grid cell

Currently CLM5 includes annual crops and natural vegetation such as broadleaf deciduous forests. ✓

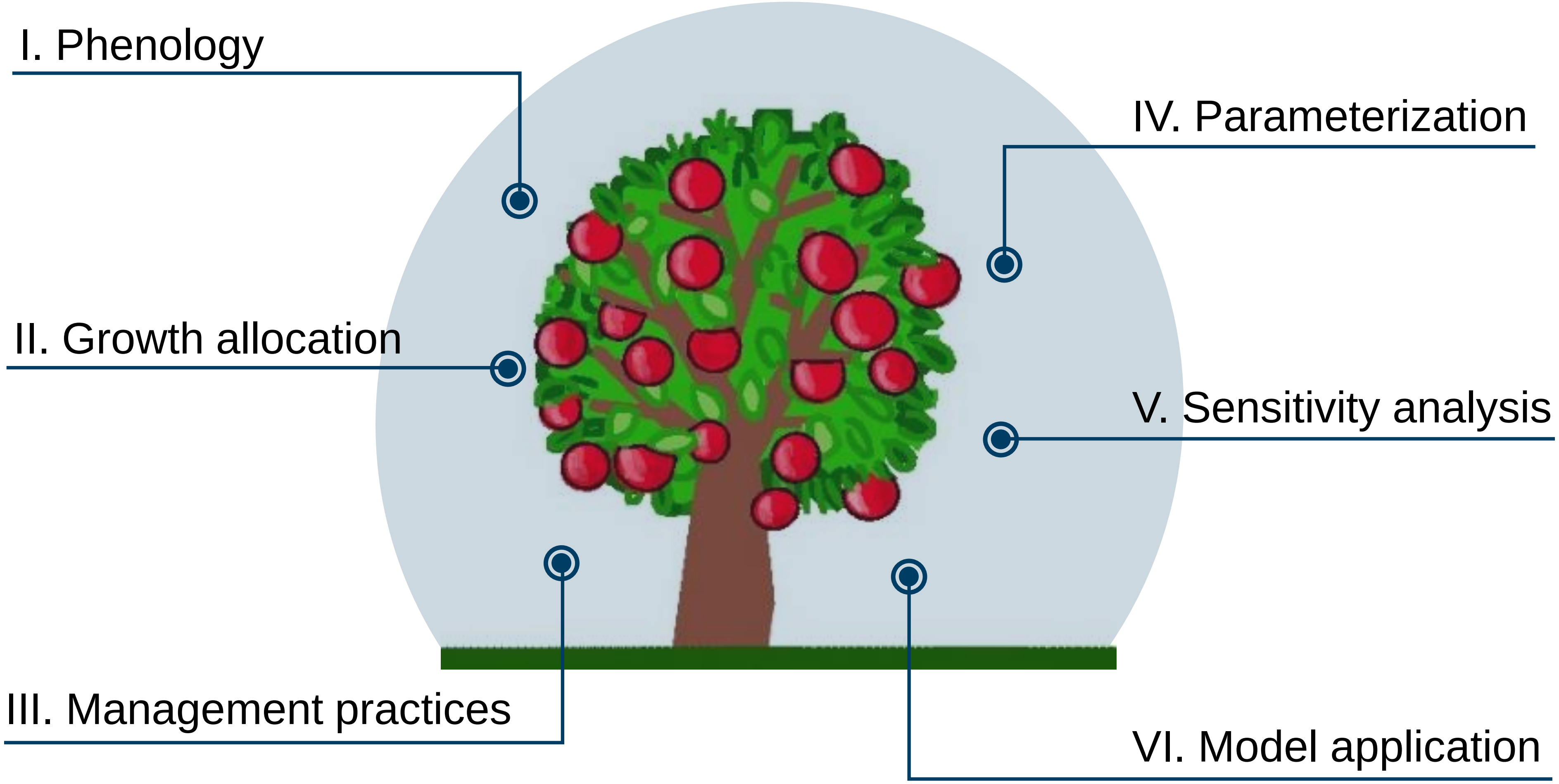


Perennial crops such as fruit orchards are missing! ✗



Development of CLM-FruitTree

The new sub-model combines characteristics of both annual crops and broadleaf deciduous forest with the addition of new characteristics unique to fruit orchards.



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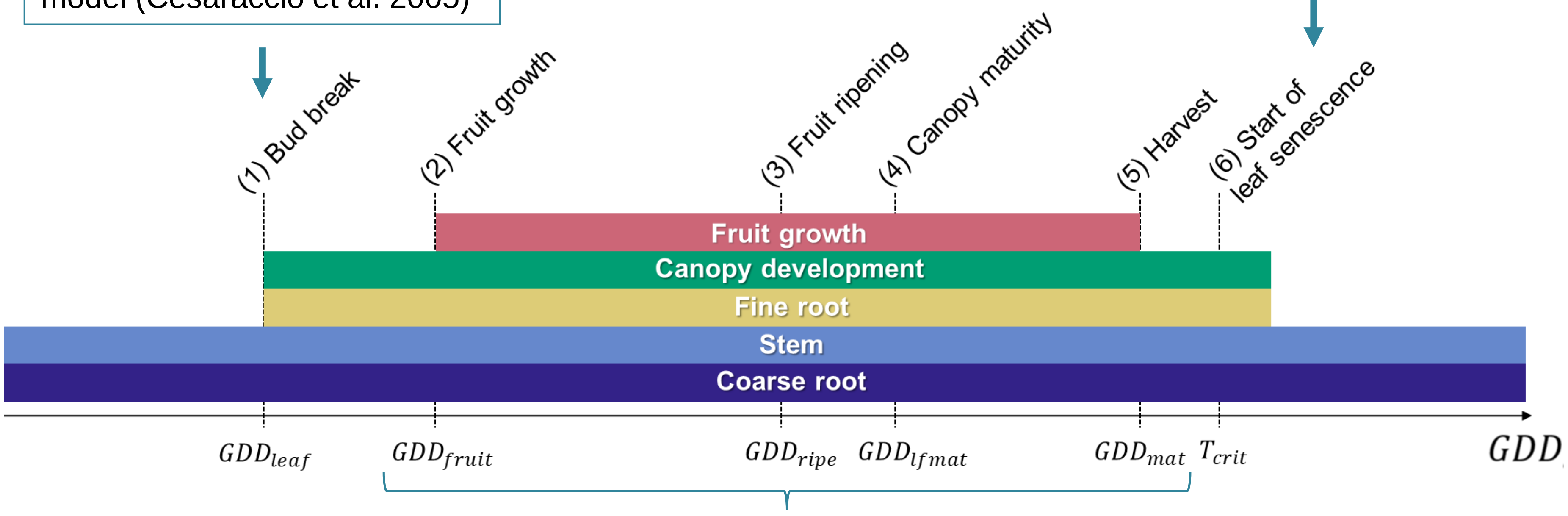
I. Phenology in CLM-FruitTree

Phenological stages and their triggers

Accumulation of chill and anti-chill days after the sequential model (Cesaraccio et al. 2005)

Triggered when air temperature drops below critical threshold (Heide and Prestrud 2005)



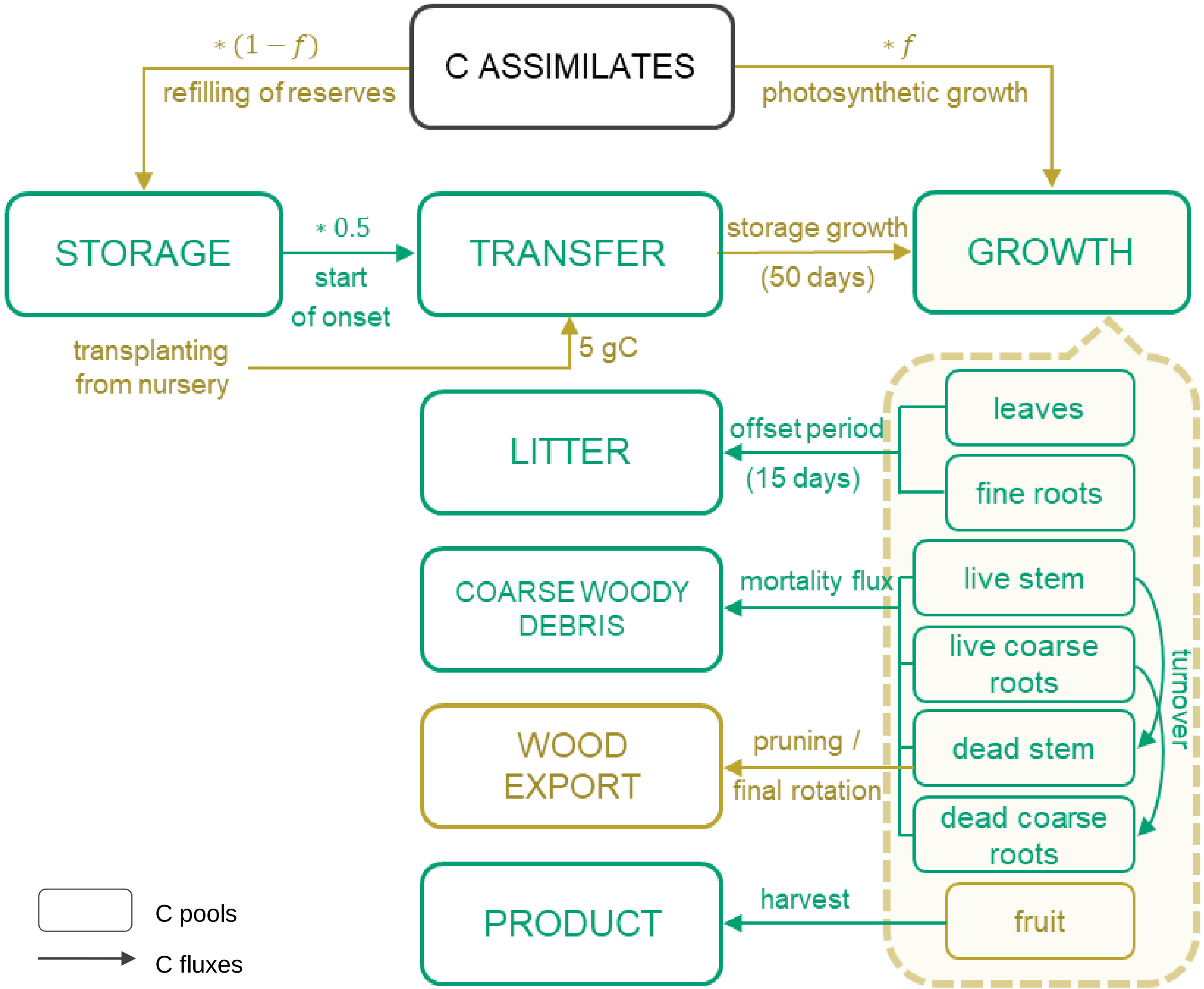
Accumulation of growing degree days (GDD)

$$GDD_{leaf} = 0$$

$$GDD_{T2m} = GDD_{T2m} + T_{2m} - 4 \qquad \text{where} \quad 0 \leq T_{2m} - 4 \leq 26\ °days$$

II. Growth allocation in CLM-FruitTree

Modelling the fate of assimilated carbon within the fruit orchard



C assimilates are mostly used for growth of plant organs but also partially to refill C storage.

At the start of a new season, plant growth is supported by C reserves.

Carbon allocation to individual plant organs varies based on the different phenological stages.

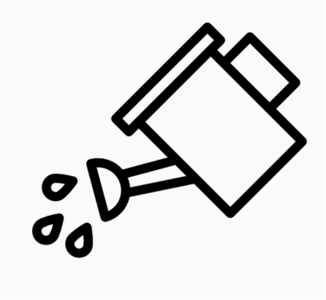
Fruits are exported from the field during harvest.

At the end of the growing season, annual plant parts feed the litter cycle while woody parts are mostly retained.

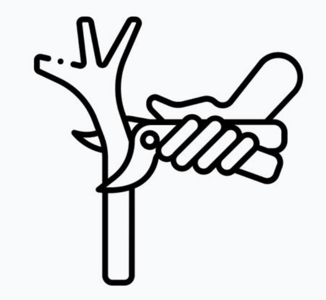
(Carbon pools and fluxes in green were reused from existing CLM5 structure, while pools and fluxes in brown were modified or newly added.)

III. Management practices

Nitrogen fertilization is performed once a year at the beginning of the growing season. The amount can be specified by the user.



Irrigation can be enabled for fruit orchards using the standard irrigation routine in CLM5 that responds dynamically to simulated soil moisture conditions (Lawrence et al. 2018).



Winter pruning is performed once a year by removing a user-defined fraction of the seasonal stem growth. Pruning residues can either be exported from the field (conventional agriculture) or mulched back into the soil (organic agriculture).

VI. Parameterization

Parameterization was performed using field data collected by D. Zanotelli et al. between 2010 and 2015 from an apple orchard in the Adige Valley, Italy.

Adjusted parameters include:

- Phenological parameters
- CN allocation parameters
- Photosynthetic parameters
- Vegetation structure
- Optical parameters
- Respiration

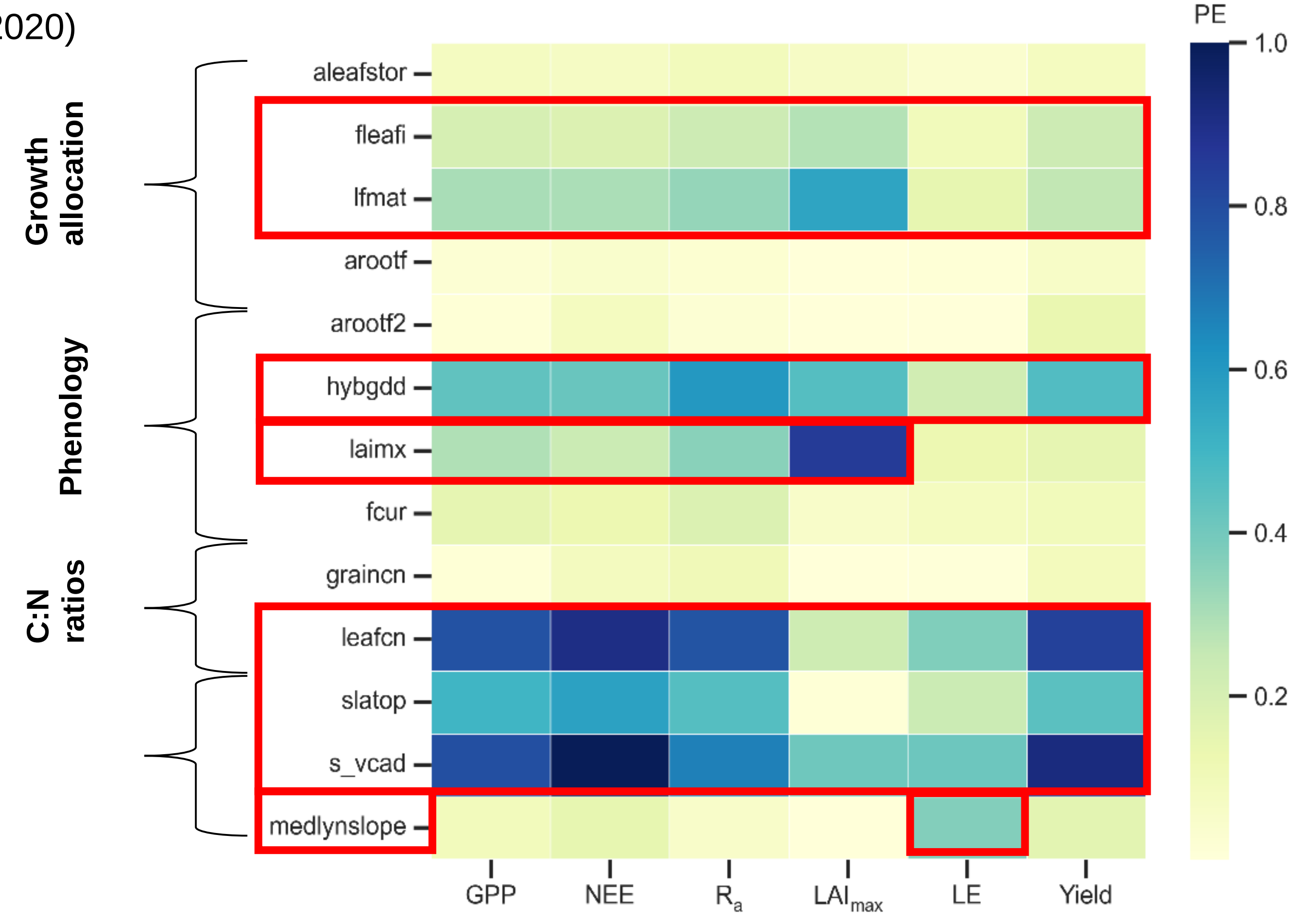
Apple PFT

Apple orchard, Adige Valley, Italy

V. Sensitivity analysis

Parameter perturbations by ±10, 20, 30 % were performed.

Parameter effect (PE) was calculated as a measure of the relative sensitivity of an output variable to a selected parameter (adjusted based on Luo et al. 2020)



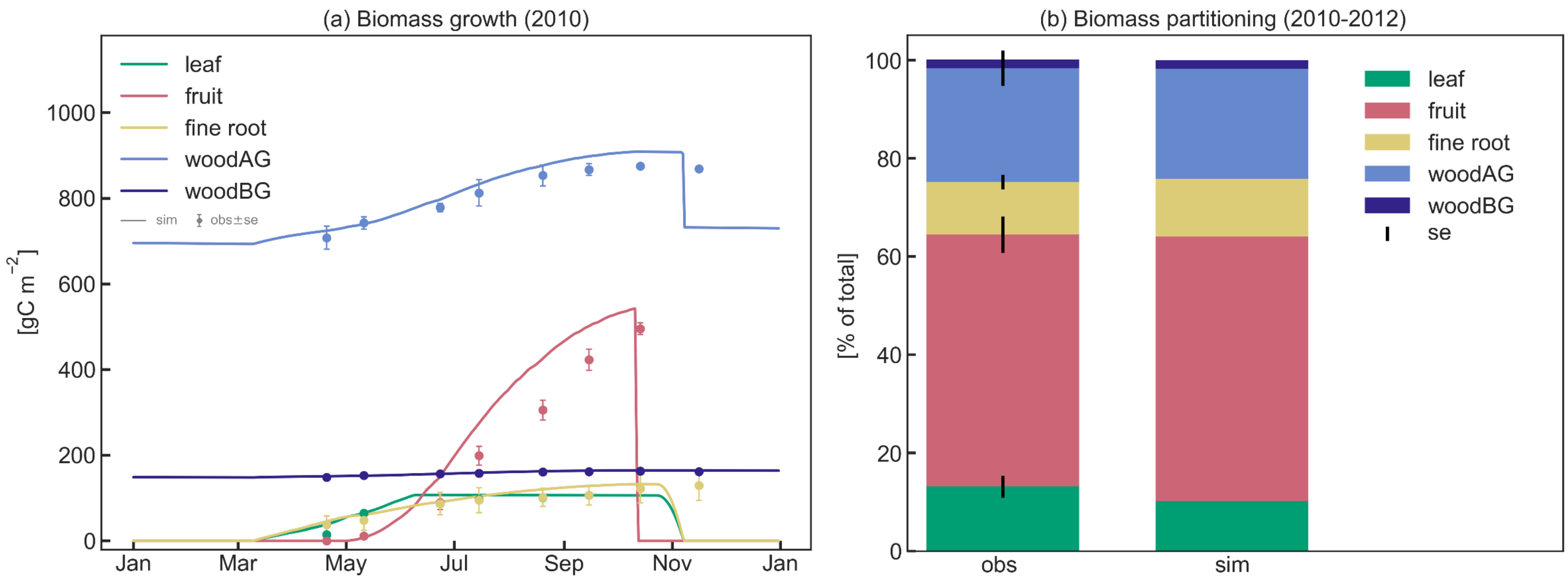
$$\Delta X_{i,j} = \sum_{k=1}^{n} \frac{\left|\overline{X_{i,j,k}} - \overline{X_{i,control}}\right|}{\left|\overline{X_{i,control}}\right|}$$

$$PE_{i,j} = \frac{\Delta X_{i,j}}{max\left[\left(\Delta X_{i,j}\right)_{1 \le i \le n; 1 \le j \le m}\right]}$$

X is a simulated value of the control or a perturbation run, ΔX is the summed absolute difference between the control and the perturbation run across all perturbations, k is the parameter perturbation factor, i is the ith variable across $n = 6$ selected output variables including: GPP, NEE, R_a, LE, maximum LAI, and yield, j is the jth parameter across m selected parameters. $PE_{i,j}$ is a number between 0 and 1 that represents the sensitivity of an output variable i to the parameter j, with 1 meaning high and 0 meaning low sensitivity

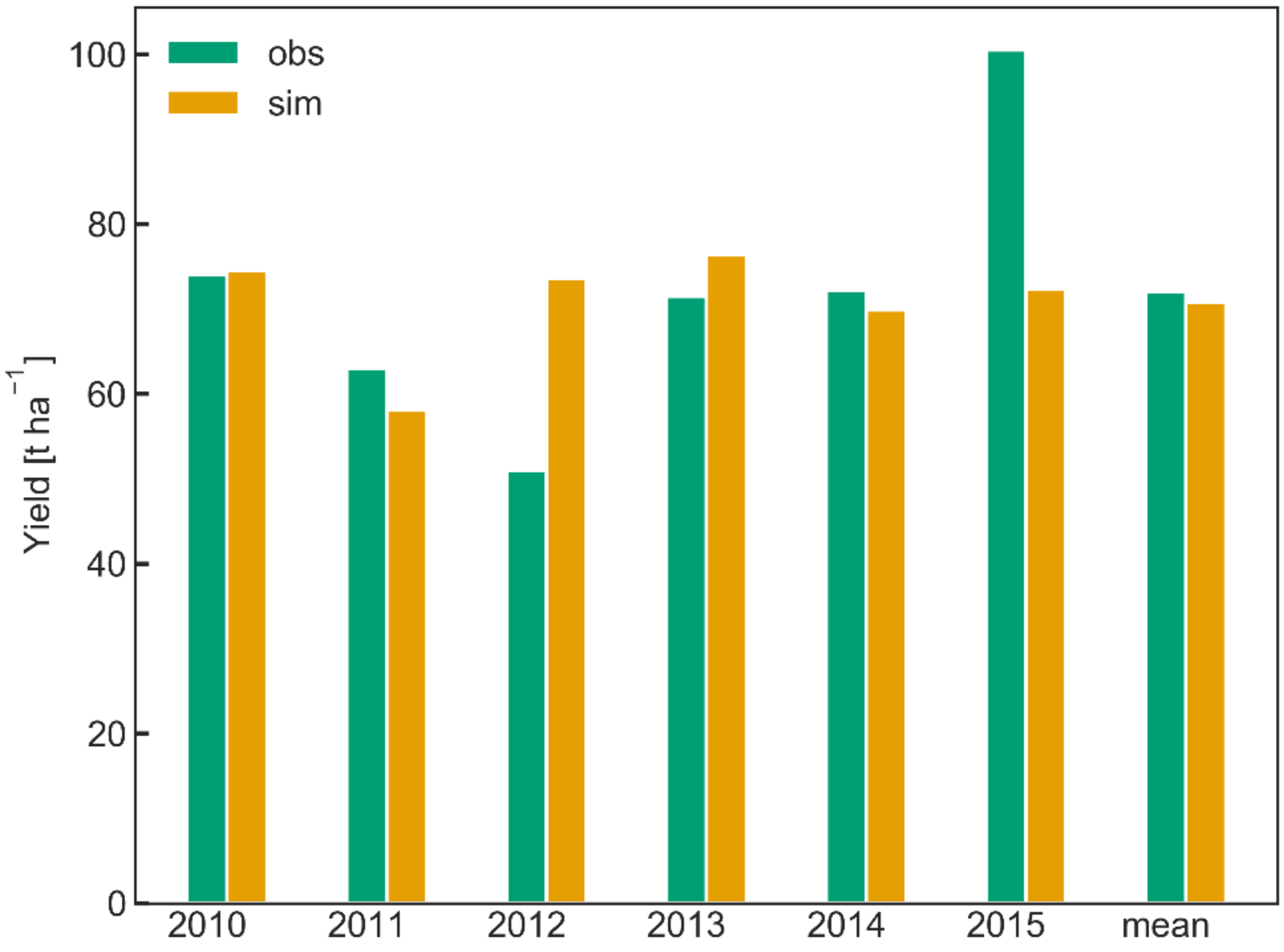
→ Photosynthetic parameters are most influential!

VI. Model application: Biomass growth and allocation



(a) Simulated growth patterns show good agreement with monthly measurements.
Phenological stages including: bud break, start of fruit development, canopy maturity, senescence are well captured.
Effect of management (harvest and pruning) is visible.
(b) Modelled percentage of biomass allocation to plant organs is in good agreement with the observations with differences ranging between 1 and 5 % for fruits, leaves, aboveground wood (woodAG), and belowground wood (woodBG)

VI. Model application: Yield



Simulated mean yield is in good agreement with observations (within 2.3% of observed values).

Simulated inter-annual yield variability is lower than observed one:

- Alternate bearing behaviour of Fuji apple variety is not represented in the model and causes natural fluctuations.
- CLM5 does not capture extreme environmental conditions (heat, frost) and the plant physiological response to them with sufficient detail.

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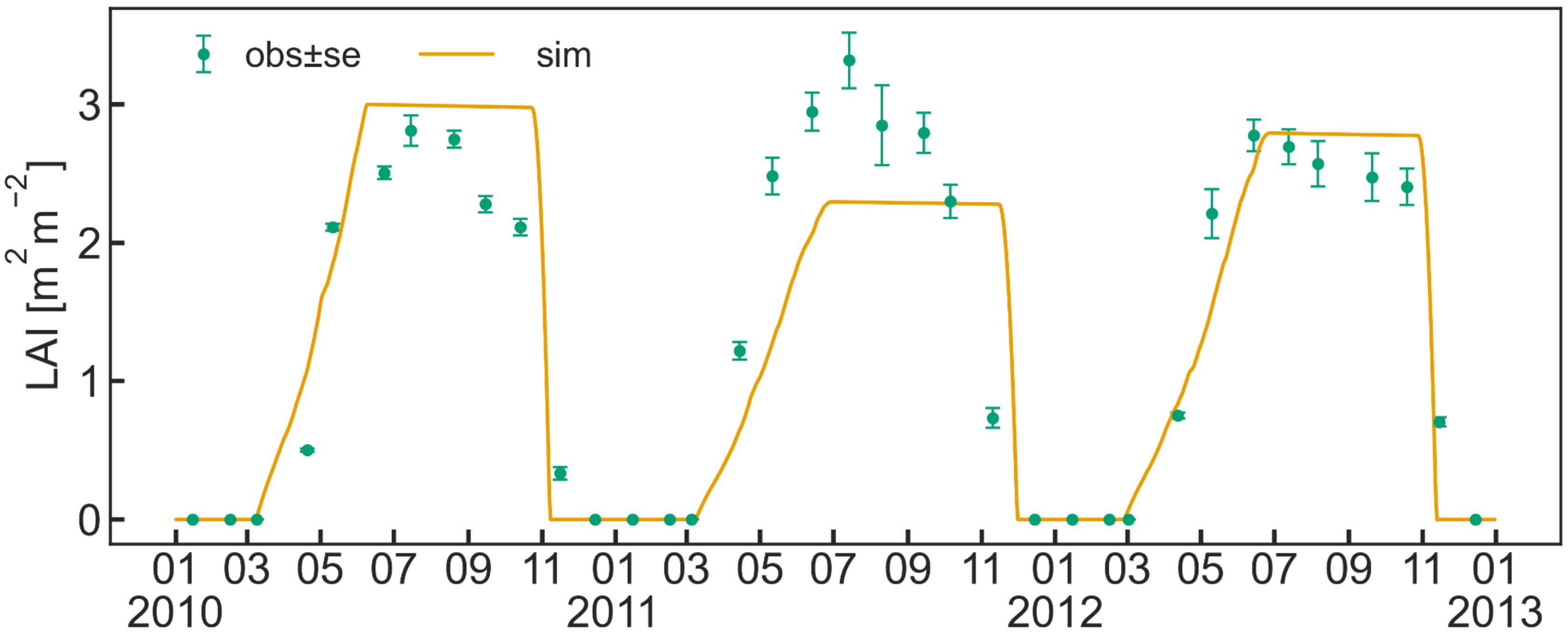
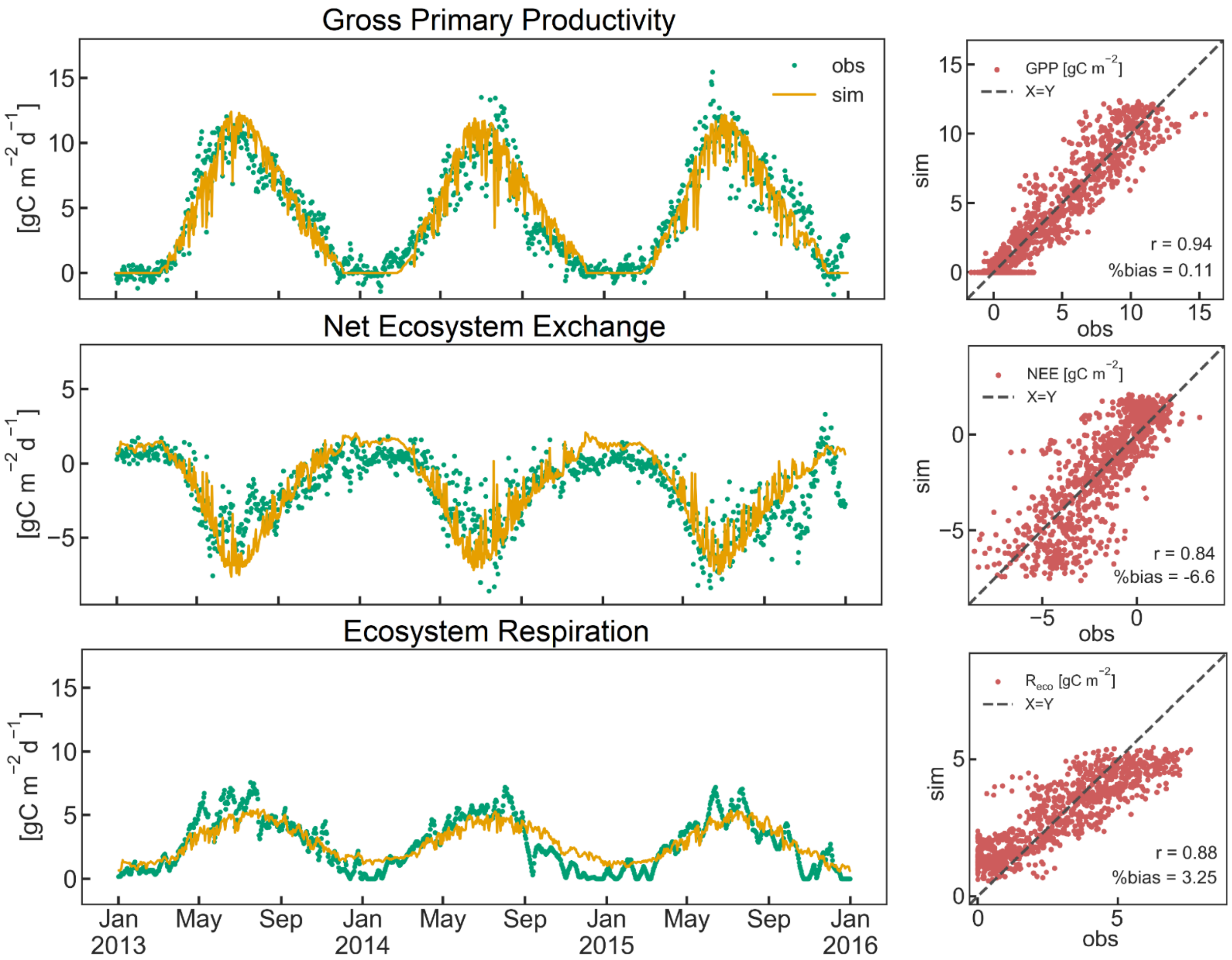
VI. Model application: Leaf area index



Observed and simulated leaf area index (LAI) are in good agreement in 2010 and 2012. LAI is underestimated by the model in 2011 possibly due to additional management practices and adjusted pruning amount (less pruning to counteract alternate bearing behaviour of the Fuji apple) that are not represented in the model due to necessary simplifications.

VI. Model application: Daily ecosystem carbon fluxes



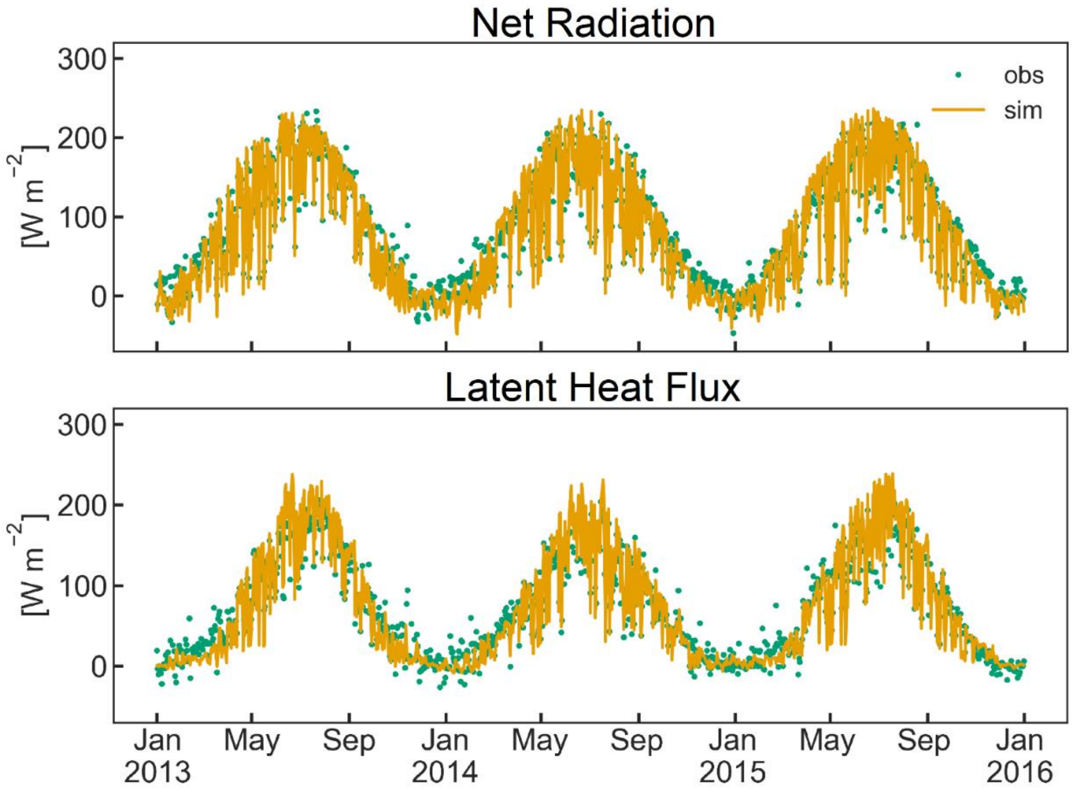
Beginning and end of growing season are well captured.

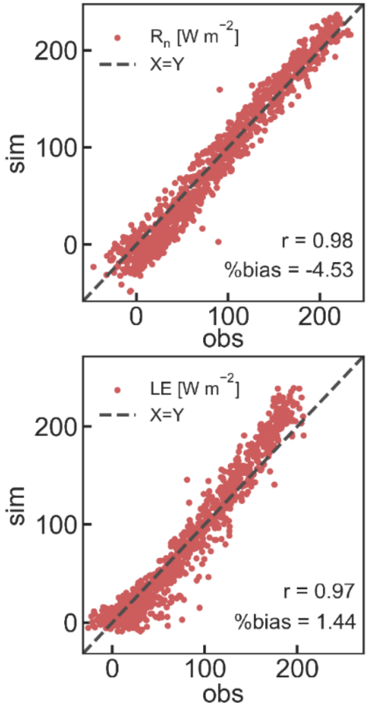
Magnitude of fluxes is mostly well captured.

Observed values of ecosystem respiration show higher fluctuations.

- Simplifications in microbial respiration, orchard structure (grassed alleys are not explicitly represented), and management (mowing of grassed alleys and mulching is not represented)
- Soil temperature bias

VI. Model application: Daily ecosystem energy fluxes part 1

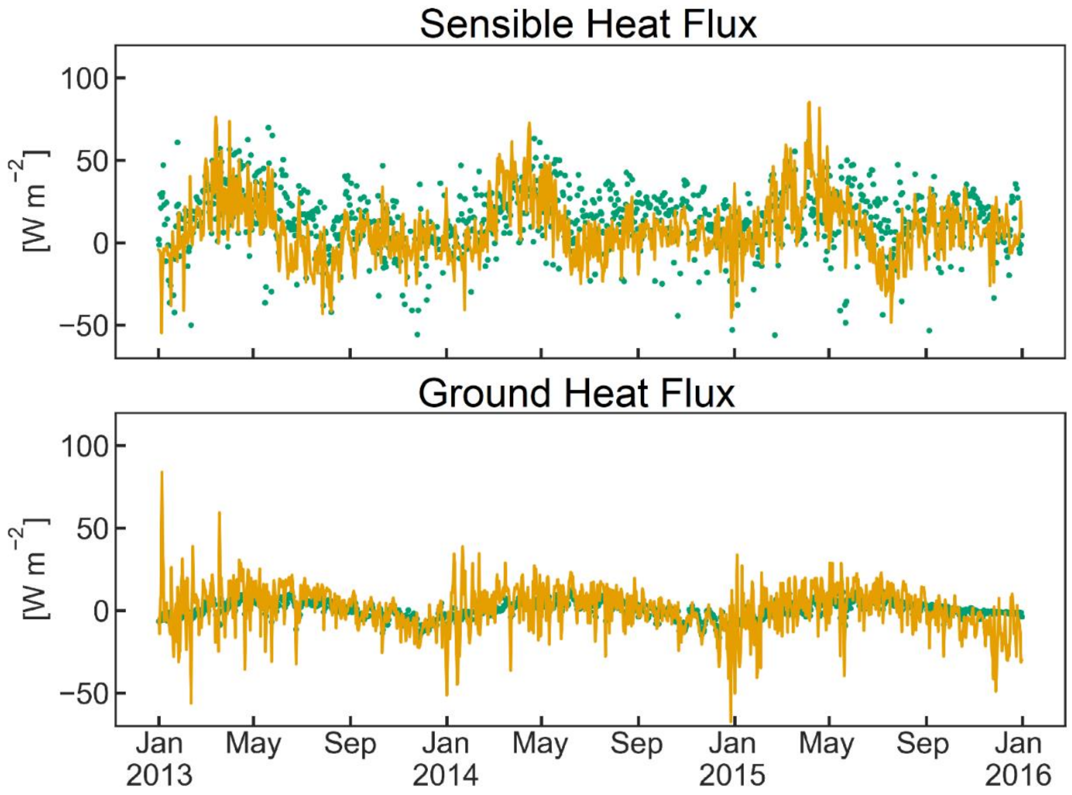


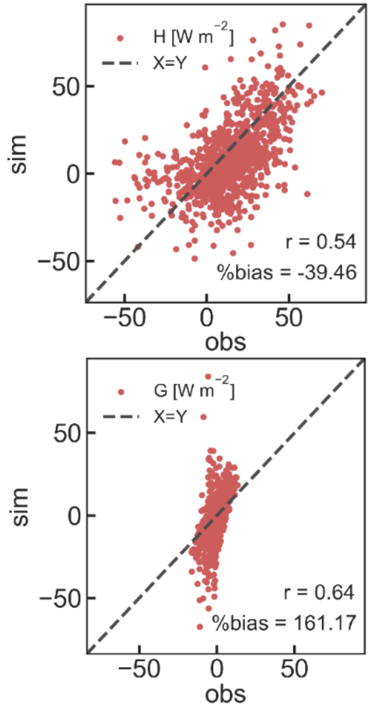


Beginning and end of growing season are well captured.

Magnitude of fluxes are well captured.

VI. Model application: Daily ecosystem energy fluxes part 2





Simulated sensible heat flux is negative in summer:

- Effect of strong irrigation
- Energy partitioning errors

Model shows higher variability in ground heat flux.

- Dampening effect of grass cover in alleys (not simulated)

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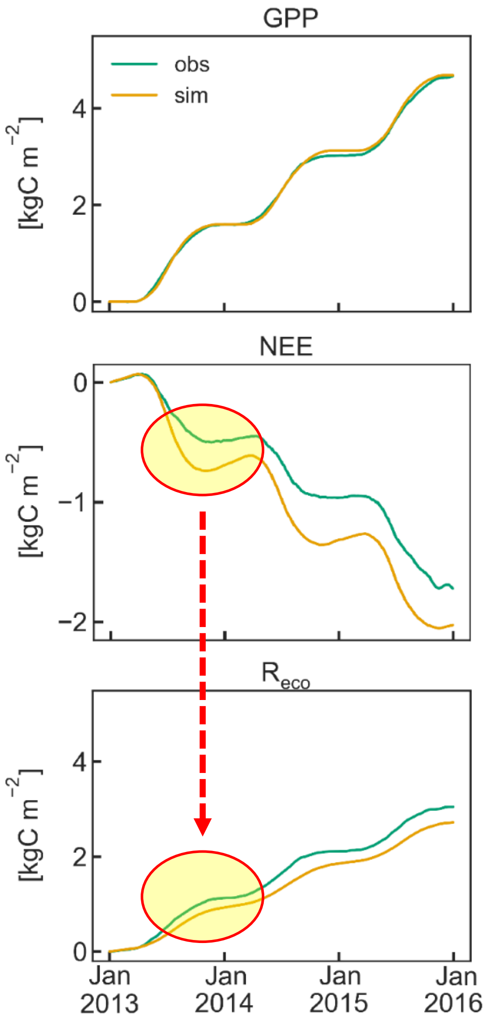
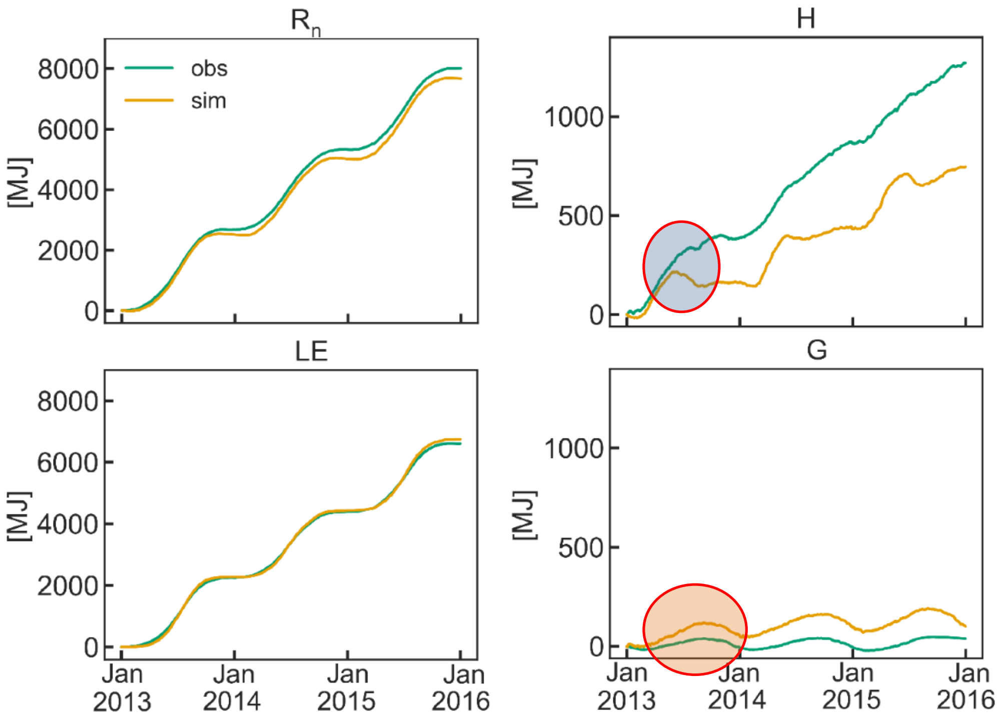
VI. Model application: Cumulative ecosystem carbon and energy fluxes

Carbon fluxes



Energy fluxes



- Irrigation effect
- Energy partitioning in discontinuous orchard canopy (grassed alleys and tree rows)

- Dampening effect of grass-covered alleys

- Simplified microbial respiration
- Soil temperature bias
- Missing management practices

Conclusions

- New sub-model CLM-FruitTree was developed to model perennial deciduous fruit orchards
- A new apple PFT was parameterized to test the model
- High model sensitivity to photosynthetic parameters
- Good representation of biomass growth and seasonality of ecosystem fluxes
- Model weaknesses in respiration and energy partitioning in complex canopies
- Simplifications in management practices and orchard structure (tree rows, grassed alleys)
- The sub-model should be further tested to confirm its applicability for different types of fruit orchards and geographical regions!

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CLM-FruitTree: A new sub-model for deciduous fruit trees in the Community Land Model (CLM5)

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Paper is available as preprint!

Preprint available under:

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Source code available under:

https://zenodo.org/record/6025014

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