CLM-Apple: A Perennial Plant Functional Type for the Community Land Model CLM5

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ATLAS AGRICULTURAL INTEROPERABILITY AND ANALYSIS SYSTEM

MODELING DECIDUOUS FRUIT ORCHARDS

- Lack of representation of deciduous fruit orchards in land surface models (Fader et al. 2015)
- Including these agro-ecosystems can aid answering questions related to sustainable food production, carbon (C) sequestration, crop water requirements (Ledo et al. 2020)
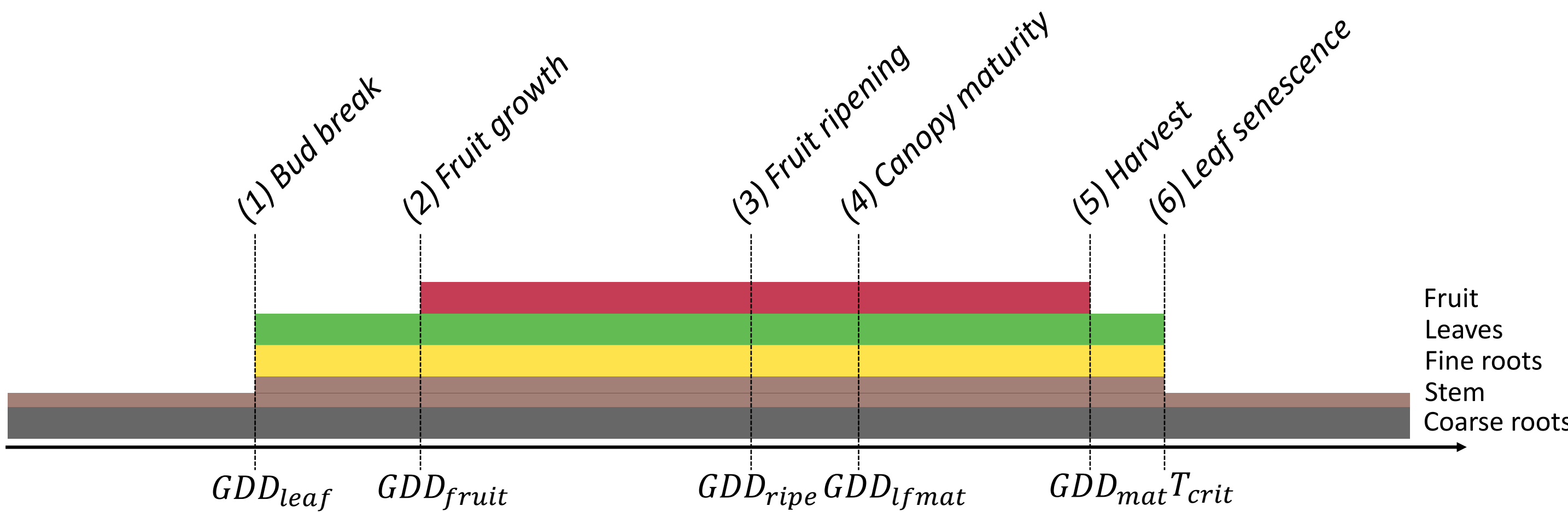
Our work therefore aims at:

- extending the Community Land Model v5.0 (CLM5) (Lawrence et al. 2018) to model deciduous fruit orchards and the associated processes.
- combining characteristics of the existing vegetation types in CLM5 with additional features into a new sub-model.
- parameterizing a new plant functional type (PFT).
- comparing model performance with field observations from an apple orchard in northern Italy (Zanotelli et al. 2013).
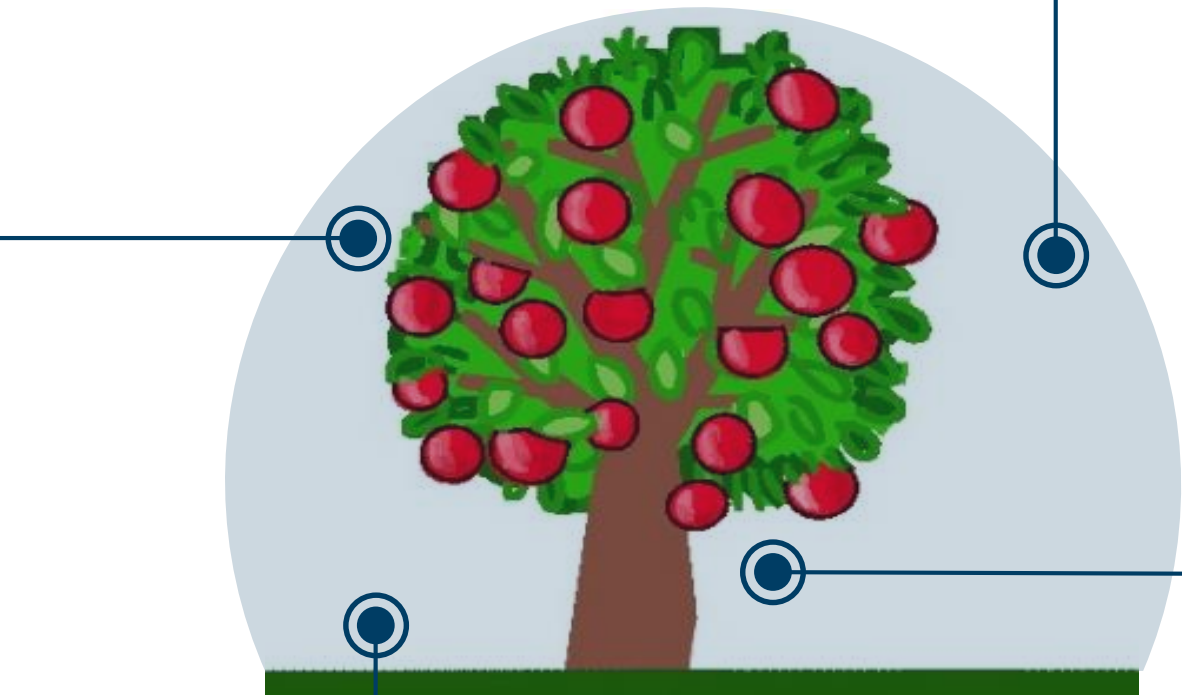
Annual managed crop (CROP)   *Natural broadleaf deciduous tree (BDT)*

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Deciduous fruit tree (CLM-Apple)
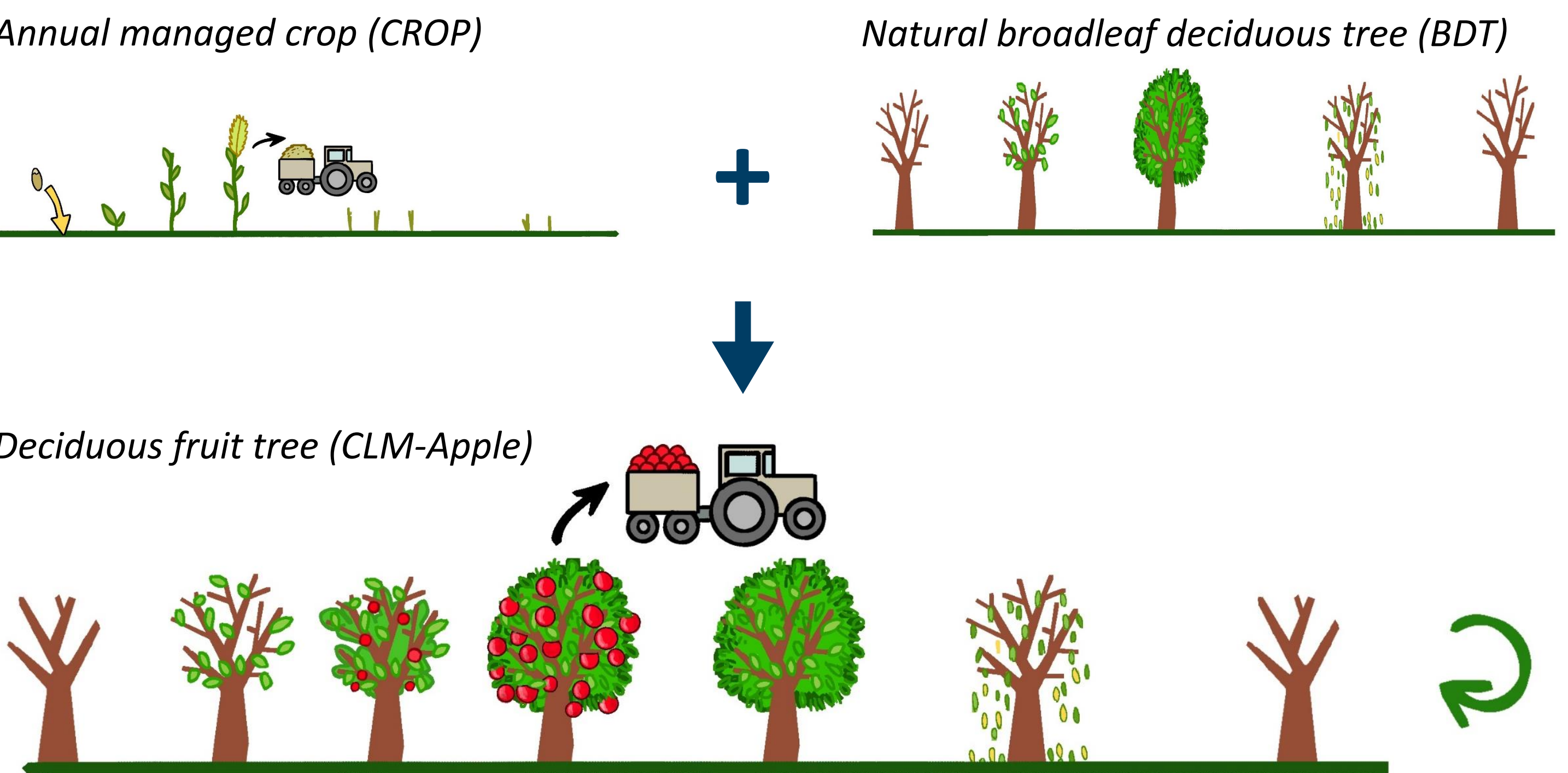
CLM-Apple main features

- 20-30 years lifespan after orchard establishment
- Seasonal deciduous phenology: standing woody biomass and annual leaf shedding similar to BDT
- During growing season: phenological stages describe organ growth similar to CROP
- Last season temperatures and cold temperature thresholds control seasonal leaf onset and offset period
- Growth occurs out of reserves and current season photosynthates and is controlled by a growing degree day summation (GDD)
- C and nitrogen allocation to vegetative and reproductive organs, and woody tissue

MODEL DEVELOPMENT

(1) Bud break
(2) Fruit growth
(3) Fruit ripening
(4) Canopy maturity
(5) Harvest
(6) Leaf senescence

Fruit
Leaves
Fine roots
Stem
Coarse roots

GDD_{leaf} GDD_{fruit} GDD_{ripe} GDD_{lfmat} GDD_{mat} T_{crit}

Phenology

- 6 post planting stages
- Long canopy development stages *(1)-(4)*
- 2-stage fruit growth: rapid cell division *(2)*, slower cell expansion *(3)*
- GDD calculated with base temperature of 4°C

Growth Allocation

- Allocation coefficients and allometric relationships describe allocation to growth of new tissue
- C storage: ensures next season growth resumption from reserves
- C display: current season growth of vegetative organs and fruits

Carbon allocated to plant organ

Refilling of reserves   Photosynthetic growth

$* (f - 1)$ $* f$
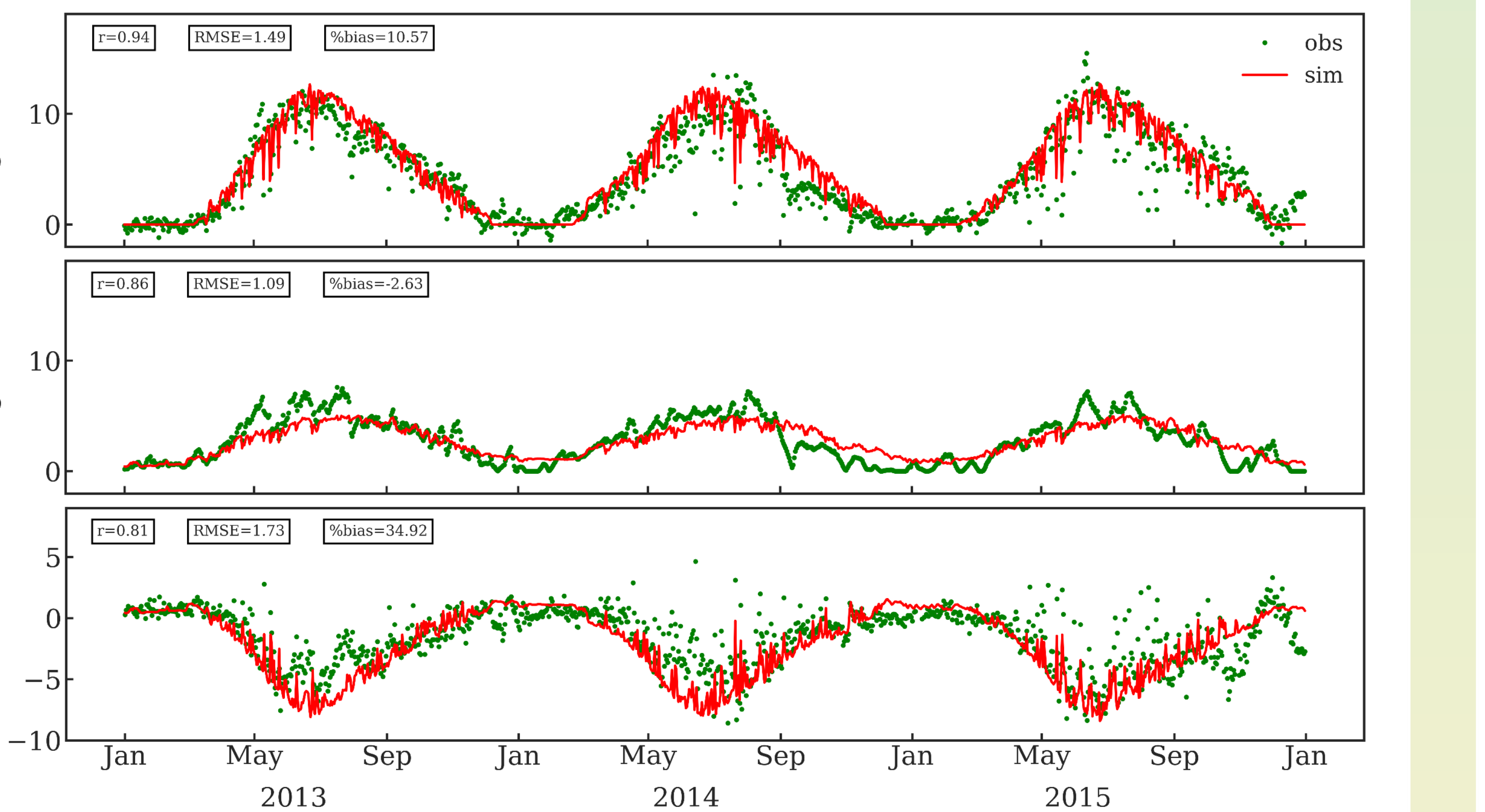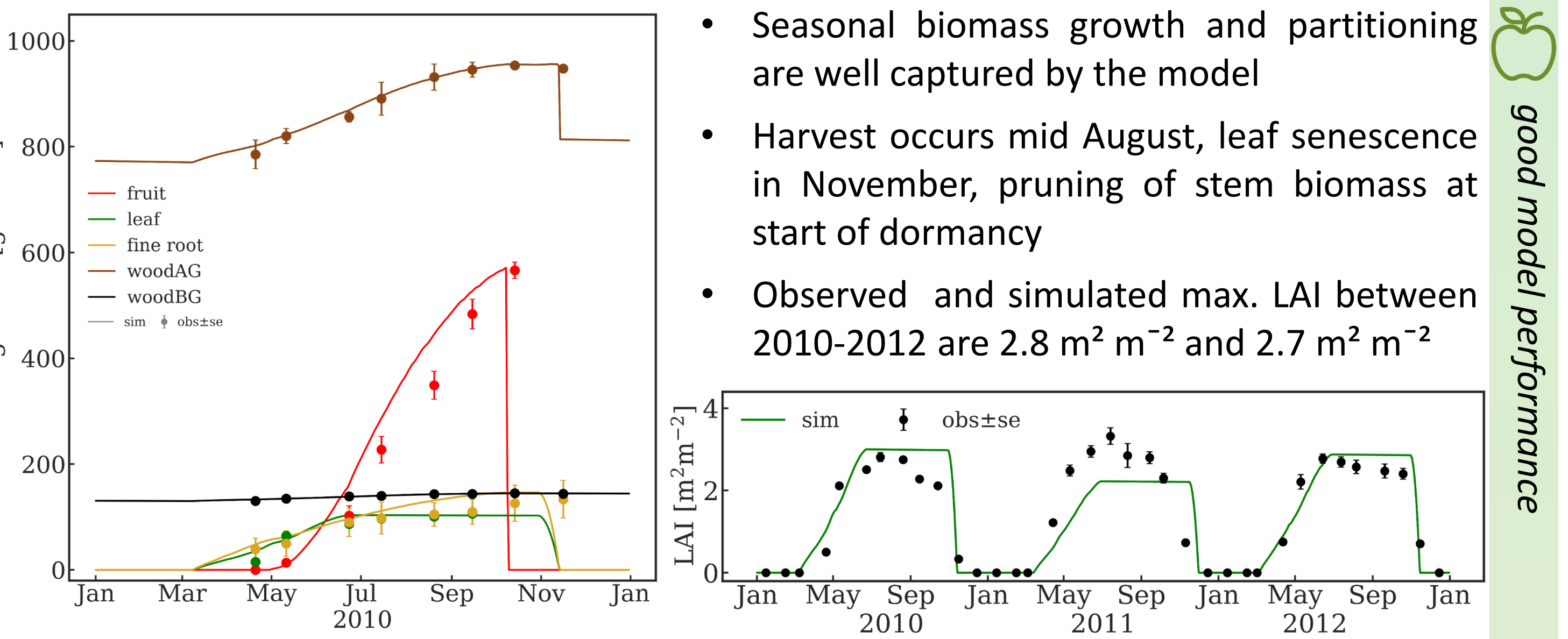
C Storage   → Storage growth →   C Display

Management practices

- Transplanting of seedlings
- Winter pruning of stem biomass
- Fertilization (default CLM5)
- Irrigation (default CLM5)
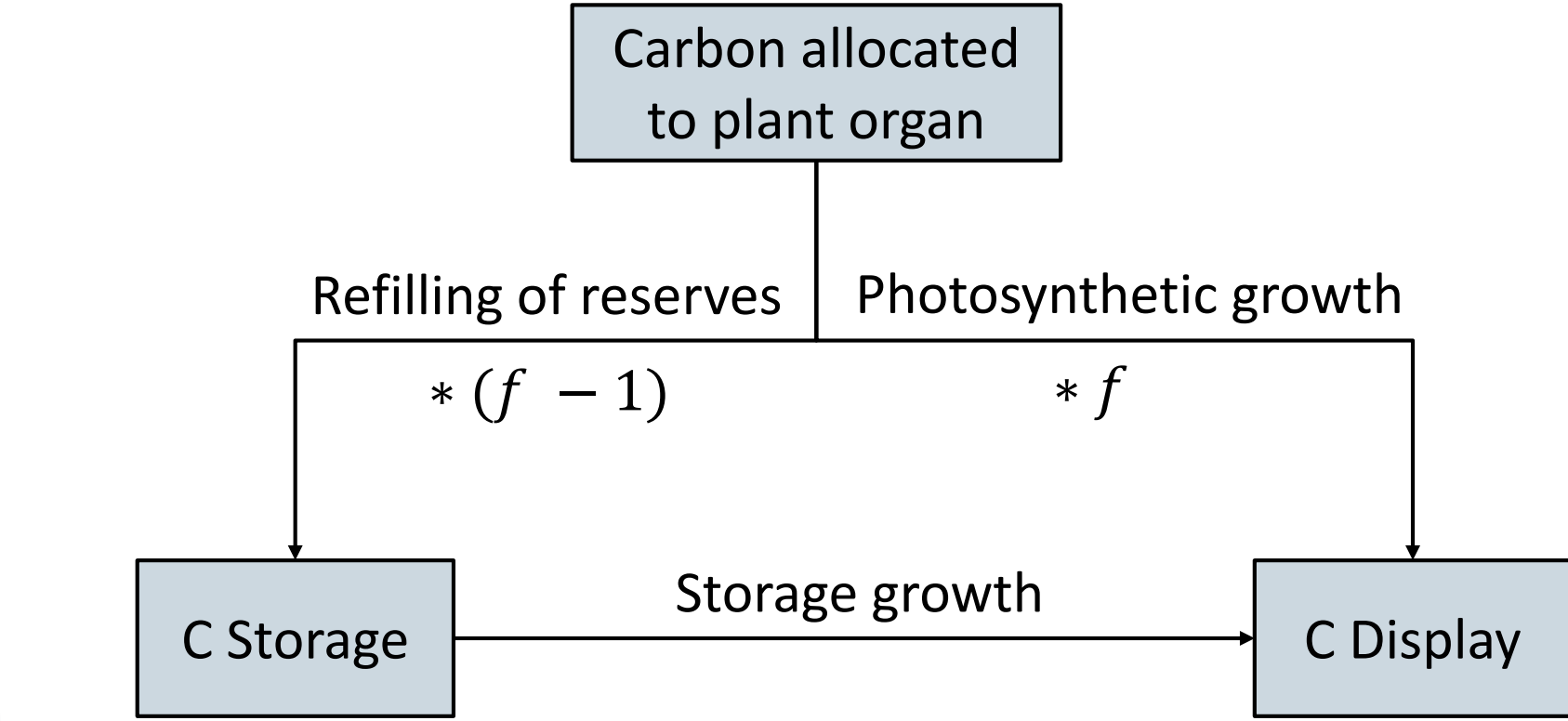
Parameterization

- Apple PFT added to actively managed crops
- Adjustment of key parameters related to phenology, allocation, photosynthesis, and others with field observations and one-by-one parameter sensitivity analysis

MODEL APPLICATION

good model performance

- Seasonal biomass growth and partitioning are well captured by the model
- Harvest occurs mid August, leaf senescence in November, pruning of stem biomass at start of dormancy
- Observed and simulated max. LAI between 2010-2012 are 2.8 m² m⁻² and 2.7 m² m⁻²

- Overall good agreement (r > 0.81, RMSE < 1.73 gC m⁻² d⁻¹) for simulated and observed gross primary productivity (GPP), ecosystem respiration (Reco), and net ecosystem exchange (NEE) despite larger bias for NEE
- Orchard acts as a carbon sink (negative NEE) from Mar-Oct, max. GPP occurs in July
- Observed yearly sums of GPP, Reco, and NEE averaged 1.58, 1.02 and -0.56 kgC m⁻² year⁻¹, simulated sums were 1.74, 0.99, and -0.75 kgC m⁻² year⁻¹ on average
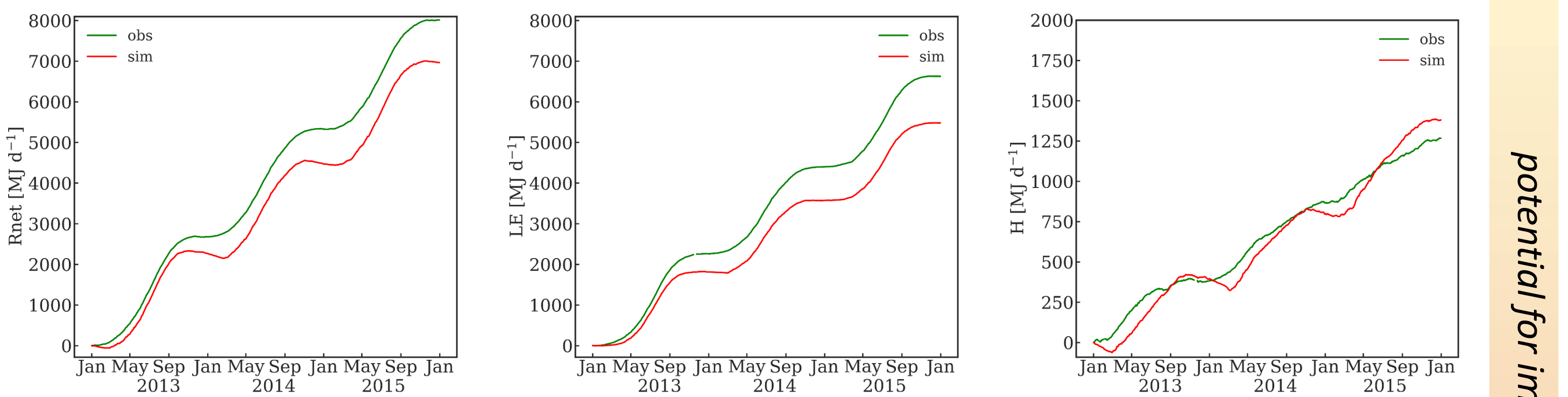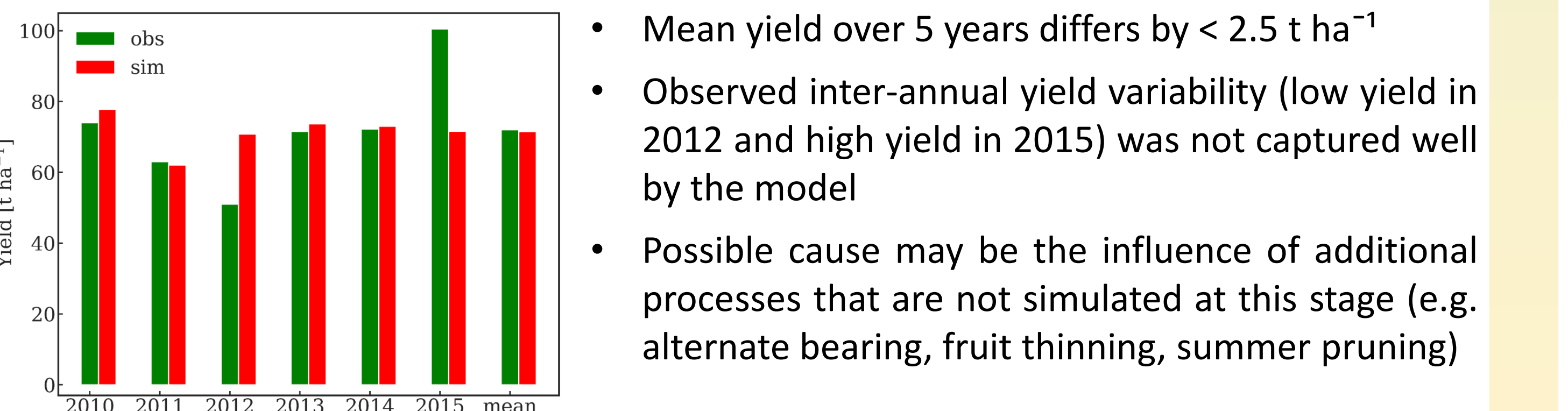
- Mean yield over 5 years differs by < 2.5 t ha⁻¹
- Observed inter-annual yield variability (low yield in 2012 and high yield in 2015) was not captured well by the model
- Possible cause may be the influence of additional processes that are not simulated at this stage (e.g. alternate bearing, fruit thinning, summer pruning)

potential for improvement

- Underestimation of cumulative net radiation (Rnet) by 13.1% and latent heat flux (LE) by 17.3% on average
- Simulated sensible heat flux (H) on average 10% larger than observed values
- Likely reasons for discrepancies could be simplified assumptions in the simulation of radiative transfer and representation of surface albedos

CONCLUSIONS & OUTLOOK

- We developed and applied a new sub-model for deciduous orchards in CLM5.
- Dynamics and magnitudes of biomass growth and C fluxes were well represented.
- CLM5 simulated lower inter-annual yield variability than the observed one.
- The underestimation of net radiation suggests limitations of the model to accurately represent radiative transfers and surface albedos in the orchard.

REFERENCES AND ACKNOWLEDGMENTS

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