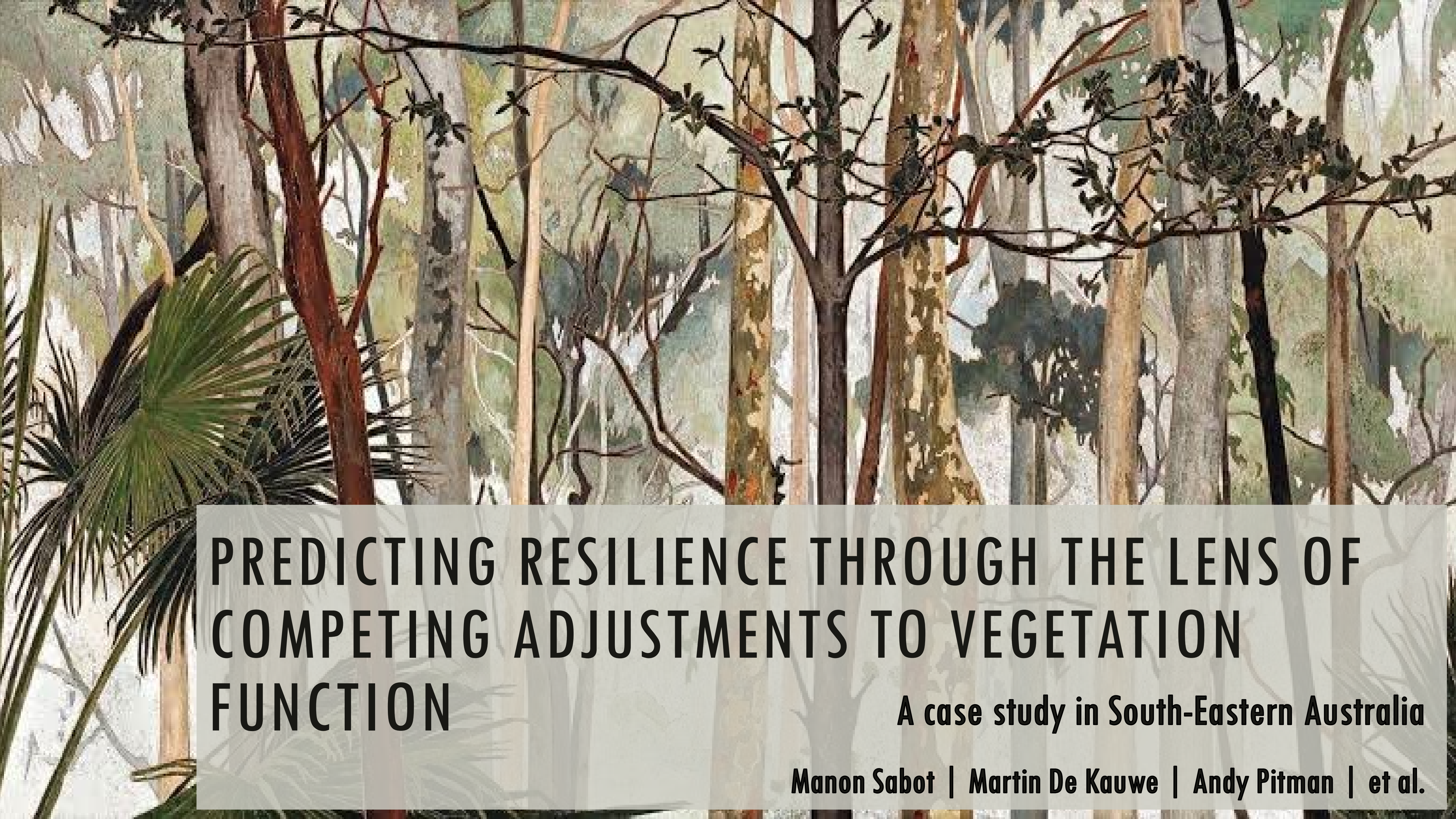


PREDICTING RESILIENCE THROUGH THE LENS OF COMPETING ADJUSTMENTS TO VEGETATION FUNCTION

A case study in South-Eastern Australia

Manon Sabot | Martin De Kauwe | Andy Pitman | et al.

PLANT OPTIMALITY THEORY IS ADVANCING THE REPRESENTATION OF ECOSYSTEM FLUXES IN LAND SURFACE MODELS (LSMs)

New Phytologist
Research

Whole-plant optimality predicts changes in leaf nitrogen under variable CO_2 and nutrient availability

Silvia Caldararu[1], Tea Thum[1], Lin Yu[1] and Sönke Zaehle[1,2]

Geosci. Model Dev., 11, 2995–3026, 2018
https://doi.org/10.5194/gmd-11-2995-2018

Geoscientific Model Development
Open Access
EGU

A new version of the CABLE land surface model (Subversion revision r4601) incorporating land use and land cover change, woody vegetation demography, and a novel optimisation-based approach to plant coordination of photosynthesis

Vanessa Haverd[1], Benjamin Smith[1,2], Lars Nieradzik[3], Peter R. Briggs[1], William Woodgate[4], Cathy M. Trudinger[5], Josep G. Canadell[1], and Matthias Cuntz[6]

New Phytologist
Research

Stomatal optimization based on xylem hydraulics (SOX) improves land surface model simulation of vegetation responses to climate

Cleiton B. Eller[1,2], Lucy Rowland[1], Maurizio Mencuccini[3,4], Teresa Rosas[3,4], Karina Williams[5], Anna Harper[6], Belinda E. Medlyn[7], Yael Wagner[8], Tamir Klein[8], Grazielle S. Teodoro[9], Rafael S. Oliveira[2], Ilaine S. Matos[10], Bruno H. P. Rosado[10], Kathrin Fuchs[11], Georg Wohlfahrt[12], Leonardo Montagnani[13], Patrick Meir[14,15], Stephen Sitch[1] and Peter M. Cox[6]

New Phytologist
Research

Plant profit maximization improves predictions of European forest responses to drought

Manon E. B. Sabot[1], Martin G. De Kauwe[1,2], Andy J. Pitman[1], Belinda E. Medlyn[3], Anne Verhoef[4], Anna M. Ukkola[5] and Gab Abramowitz[1]

AND IT IS ALSO BEING USED TO FORECAST ECOSYSTEM RESILIENCE IN THE FACE OF CLIMATE CHANGE

ECOLOGY LETTERS
Ecology Letters, (2018) doi: 10.1111/ele.13136

LETTER

Tree carbon allocation explains forest drought-kill and recovery patterns

A. T. Trugman,[1]* M. Detto,[2]
M. K. Bartlett,[2] D. Medvigy,[3]
W. R. L. Anderegg,[1] C. Schwalm,[4,5]
B. Schaffer[6] and S. W. Pacala[2]

Geosci. Model Dev., 11, 2995–3026, 2018
https://doi.org/10.5194/gmd-11-2995-2018

Geoscientific Model Development

A new version of the CABLE land surface model (Subversion revision r4601) incorporating land use and land cover change

The impact of rising CO_2 and acclimation on the response of US forests to global warming

John S. Sperry[a,1], Martin D. Venturas[a,1,2], Henry N. Todd[a], Anna T. Trugman[a,b], William R. L. Anderegg[a], Yujie Wang[a], and Xiaonan Tai[c]

Phytologist

Stomatal optimization based on … improves land surface model sim… to climate

Cleiton B. Eller[1,2], Lucy Rowland[1], Maurizio Mencu…
Anna Harper[6], Belinda E. Medlyn[7], Yael Wagner[8] …
Rafael S. Oliveira[2], Ilaine S. Matos[10], Bruno H. P. R…
Leonardo Montagnani[13], Patrick Meir[14,15], Stephen…

New Phytologist
Research

Towards species-level forecasts of drought-induced tree mortality risk

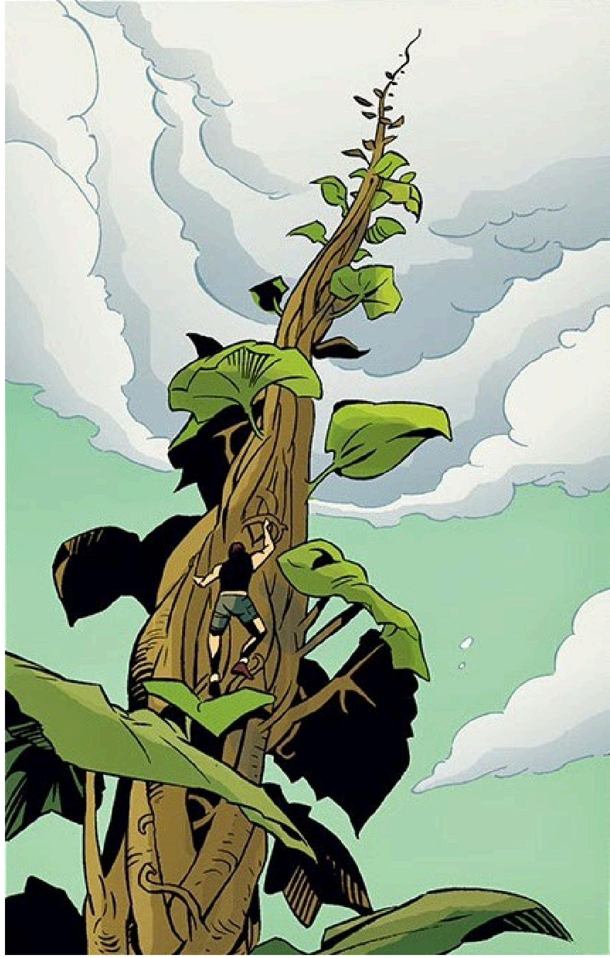
Martin G. De Kauwe[1], Manon E. B. Sabot[2,3], Belinda E. Medlyn[4], Andrew J. Pitman[2,3], Patrick Meir[5], Lucas A. Cernusak[6], Rachael V. Gallagher[4], Anna M. Ukkola[2,3], Sami W. Rifai[2,3] and Brendan Choat[4]

Research

…nproves predictions of European

…, Andy J. Pitman[1], Belinda E. Medlyn[3], Anne Verhoef[4],
Anna M. Ukkola[5] and Gab Abramowitz[1]

SO, WHAT IS PLANT OPTIMALITY THEORY?



From the C perspective:

More photosynthesis ⇒ More growth

But what about limitations to growth? Need to account for:

H_2O
Nutrients
Drought legacies

Optimisation theories typically trade off a photosynthetic or growth ‘gain’ function with a ‘cost’ function accounting for one or multiple limiting factors.

Optimisation theories typically trade off a photosynthetic or growth ‘gain’ function with a ‘cost’ function accounting for one or multiple limiting factors.

BUT IN LSMs…

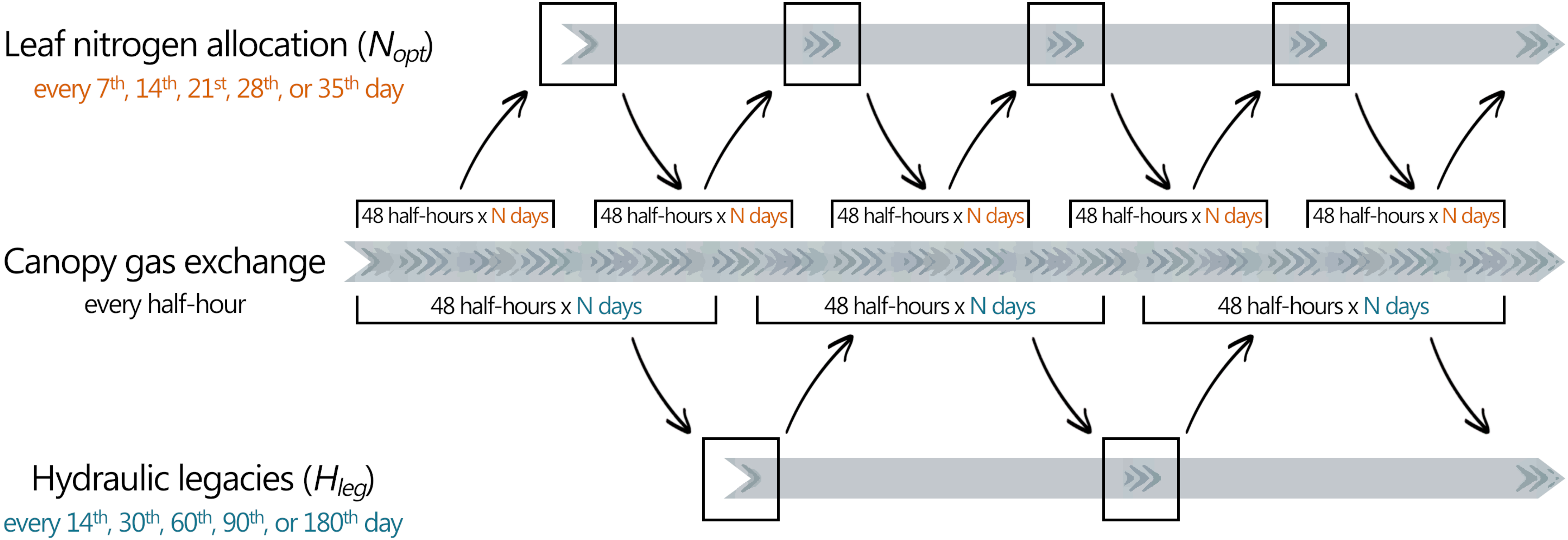
Structural limitations may prevent the effective combination of multiple limiting factors into a single ‘cost’ function and may also prevent reliance on a single overarching optimisation objective.

Testing has focused on optimality principles accounting for a given limiting resource in isolation, e.g., the cost of limited water supply OR that of limited nitrogen availability.

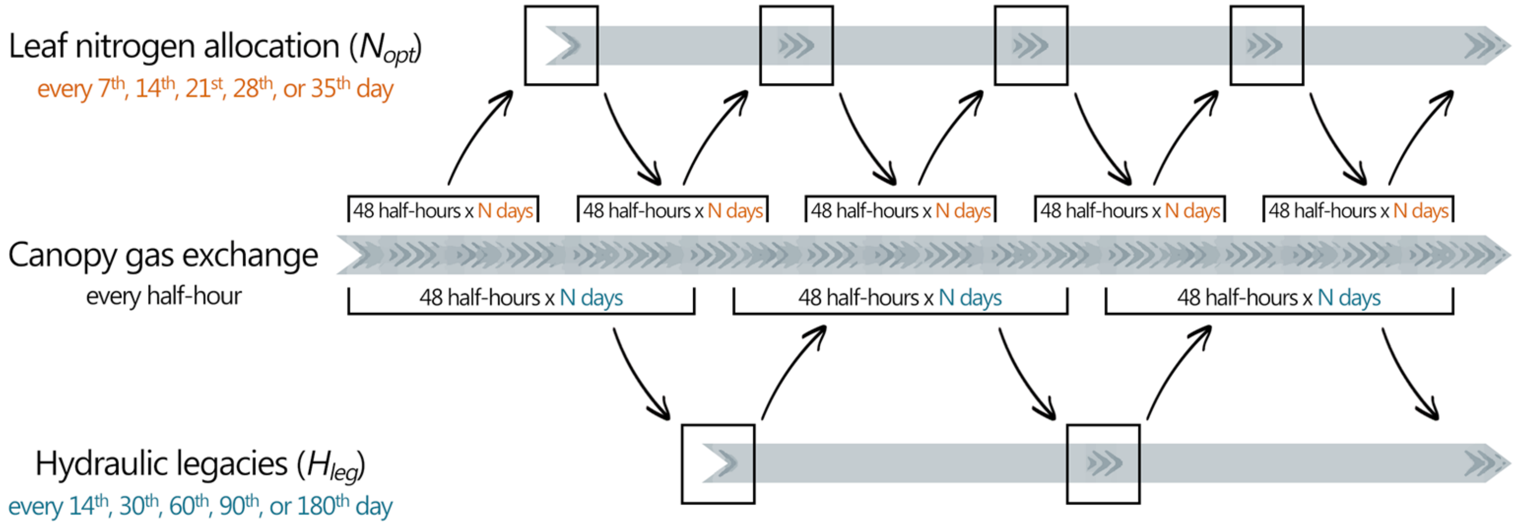
WE WANTED TO:

- Know whether contrasting optimisation approaches could be applied together, including when hydraulic legacies from climate extremes affect optimisation outcomes.
- Know whether we could infer the timescales over which vegetation functions adjust to maximise resource investment and/or resilience.
- Explore the relationship between drought-driven foliage dynamics and plant hydraulic function.

WE INCORPORATED COMPETING OPTIMISATION PRINCIPLES AND HYDRAULIC LEGACIES IN A LSM



WE INCORPORATED COMPETING OPTIMISATION PRINCIPLES AND HYDRAULIC LEGACIES IN A LSM



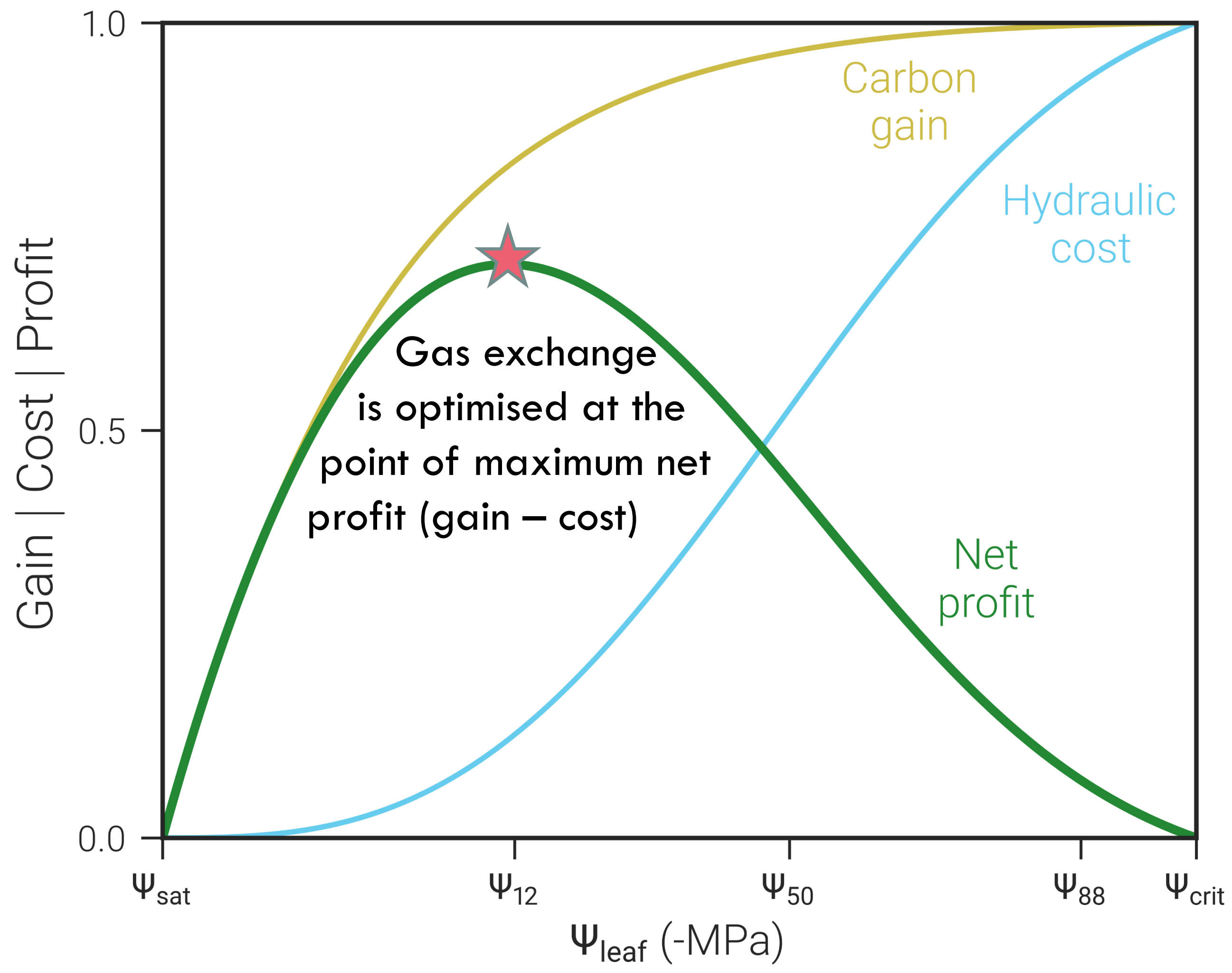
optimisation of leaf nitrogen allocation (5 possible timeframes of application, optional routine)

+ canopy gas exchange optimisation (every half hour, mandatory / default routine)

+ hydraulic legacies (5 possible timeframes of application, optional routine)

⇒ 36 simulation experiments were run to identify the timescales over which competing adjustments to vegetation function interact most consistently

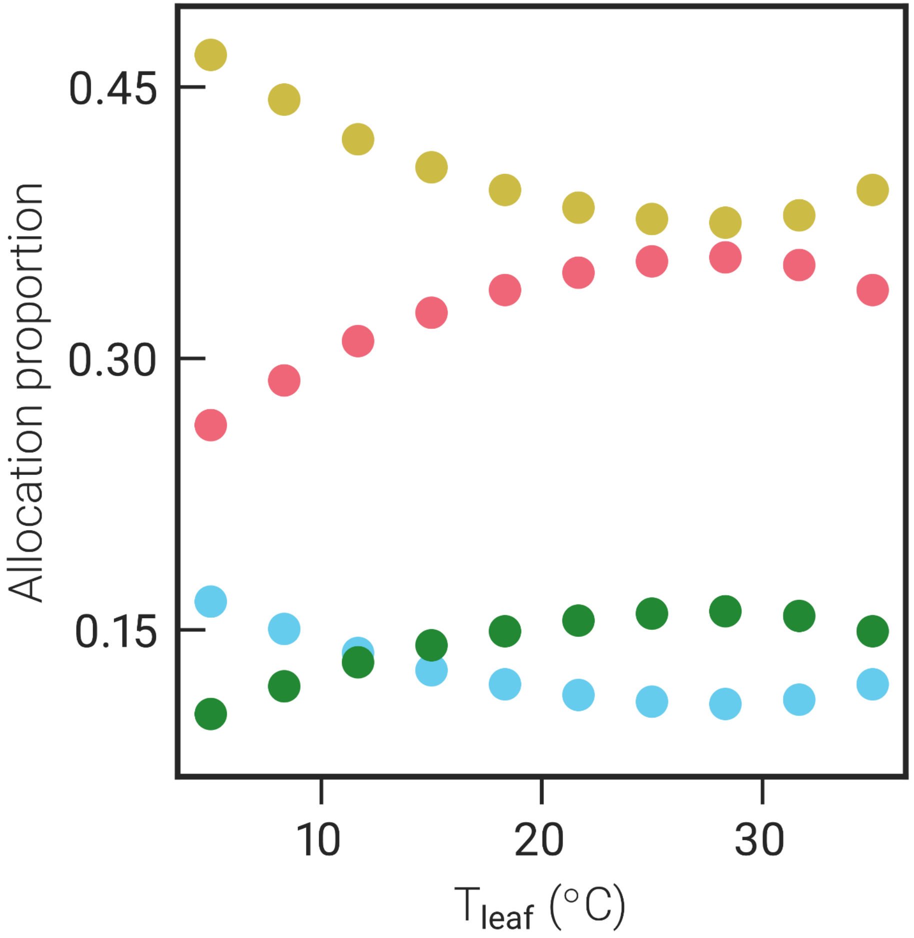
CANOPY GAS EXCHANGE

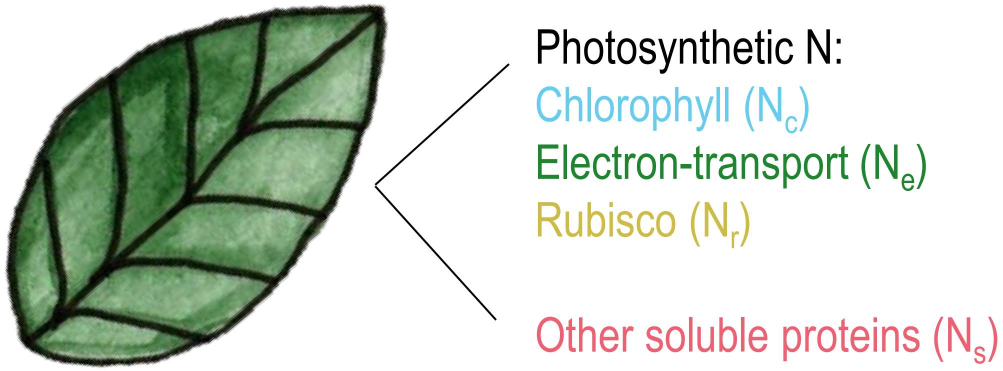


Canopy transpiration and photosynthesis are set by an instantaneous stomatal optimisation principle which trades off possible carbon gains with a hydraulic cost associated with maintaining leaf stomates open.

See Sperry et al., PC&E, 2017 and Sabot et al., New Phytol., 2020 for further information on this optimality principle.

OPTIMAL LEAF N ALLOCATION

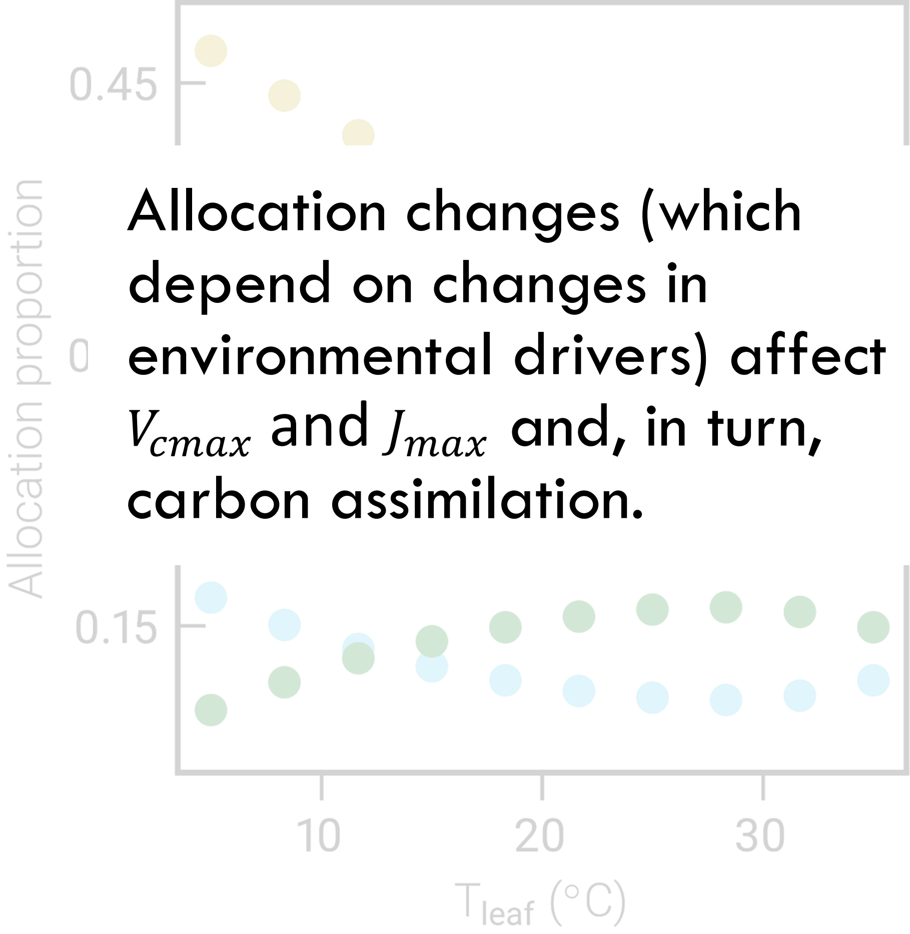




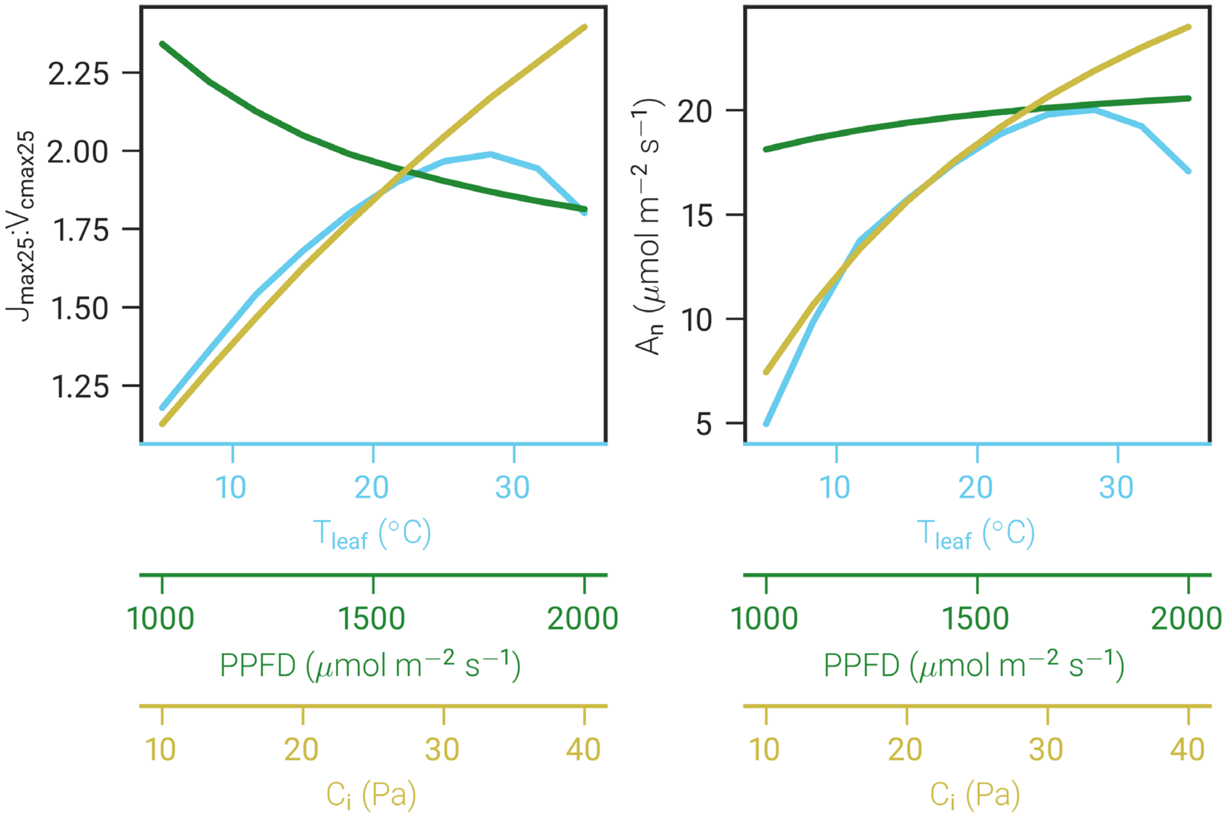
The amount of leaf nitrogen involved in photosynthesis and its allocation to photosynthetic compounds are optimised to account for antecedent environmental conditions (light, temperature, water availability) and leaf phenology (LAI) over a chosen period (N preceding days).

This optimality principle is based on earlier work by Medlyn, Aust. J. Plant Physiol., 1996 (but it is not identical).

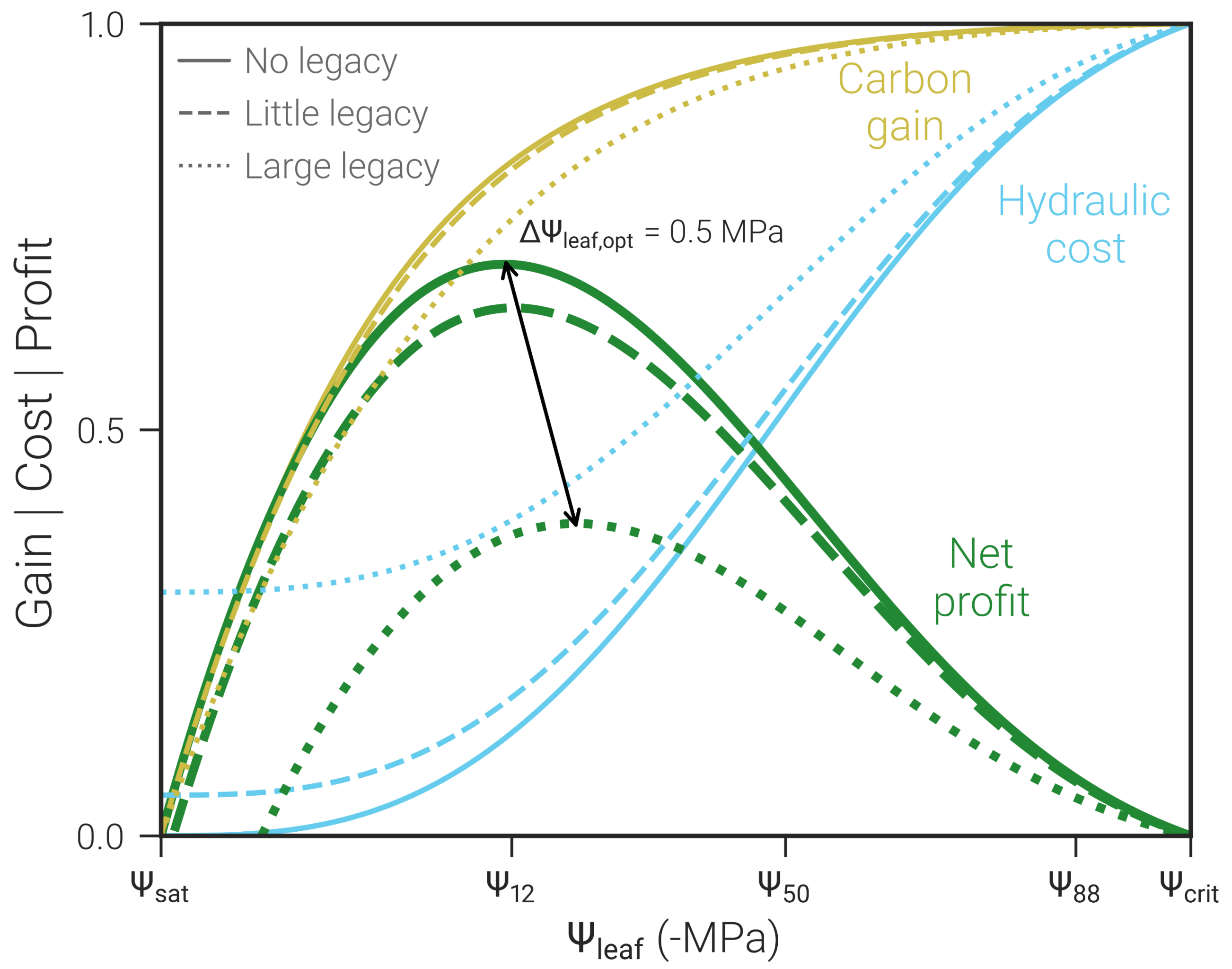
OPTIMAL LEAF N ALLOCATION



Allocation changes (which depend on changes in environmental drivers) affect V_{cmax} and J_{max} and, in turn, carbon assimilation.



HYDRAULIC LEGACIES



Delayed and imperfect xylem recovery from past embolism are accounted for as 'damage' to the hydraulic pathway. Hydraulic legacies directly affect canopy gas exchange, and they indirectly affect the leaf nitrogen allocation routine via feedback through the canopy gas exchange routine.

See Lu et al., New Phytol., 2020 for the expression of a 'damaged' vulnerability curve.

WE TESTED OUR MODEL AT EucFACE

Water- & nutrient-limited site

+ 3 ambient and 3 elevated [CO_2] plots

+ variable LAI and soil texture (moisture) across plots

+ lots of observational data (2013 – 2020)

PREDICTABLE AND COHERENT ADJUSTMENTS TO FUNCTION

- Compared to our default model (canopy gas exchange alone), accounting for leaf N allocations (N_{opt}) and/or hydraulic legacies (H_{leg}) reduced the simulated WUE (ratio of carbon assimilation to transpiration) across site plots, to varying degrees depending on soil moisture, LAI, and [CO_2].

- N_{opt} drove change in the simulated WUE, contributions from H_{leg} were small.

- The higher the frequencies of simulated functional adjustments (e.g., N_{opt} applied every 7th day rather than every 35th day), the less water-use efficient the model.

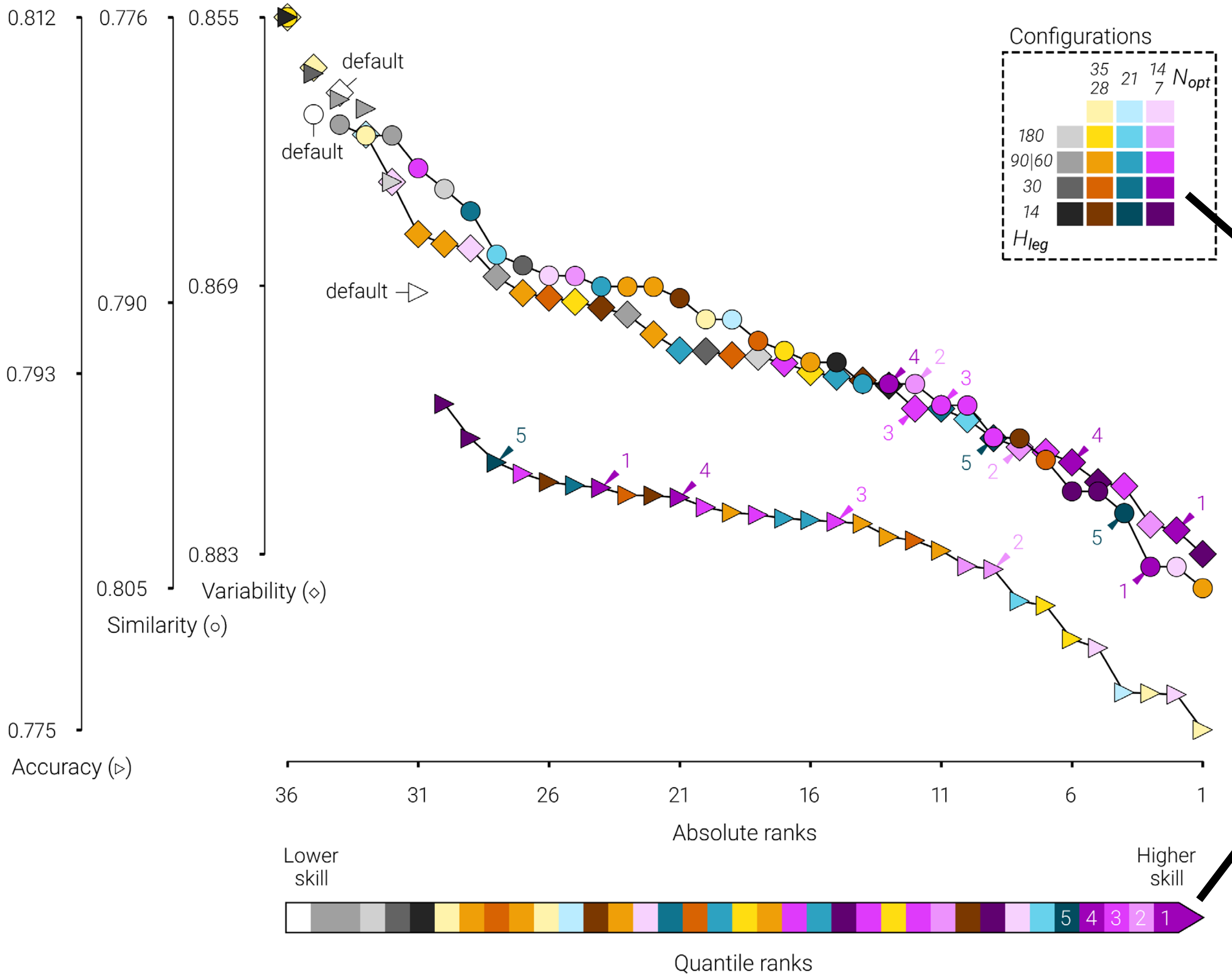
MORE FREQUENT ADJUSTMENTS TO FUNCTION = INCREASED MODEL PERFORMANCE

Three statistical metrics were used to assess the model configurations' ability to capture daily observations of canopy transpiration:

- Accuracy: Mean Absolute Scaled Error, i.e., whether model predictions are more skilful than one-step forecasts of the observations
- Similarity: overlap between modelled and observed binned distributions
- Variability: ratio of modelled to observed sample deviation

Skill across these three metrics was summarised by quantile ranks, which consider a model configuration's performance relative to that of all other model configurations within each metric.

MORE FREQUENT ADJUSTMENTS TO FUNCTION = INCREASED MODEL PERFORMANCE



The best overall model configuration combined H_{leg} applied every 30th day with N_{opt} applied every 7th day, in addition to accounting for canopy gas exchange every half-hour.

WE WANTED TO KNOW:

- Whether contrasting optimisation approaches could be applied together, including when hydraulic legacies from climate extremes affect optimisation outcomes.

Different model configurations affected WUE simulations in a predictive and interpretable manner along axes of variation in soil moisture, LAI, and [CO_2].

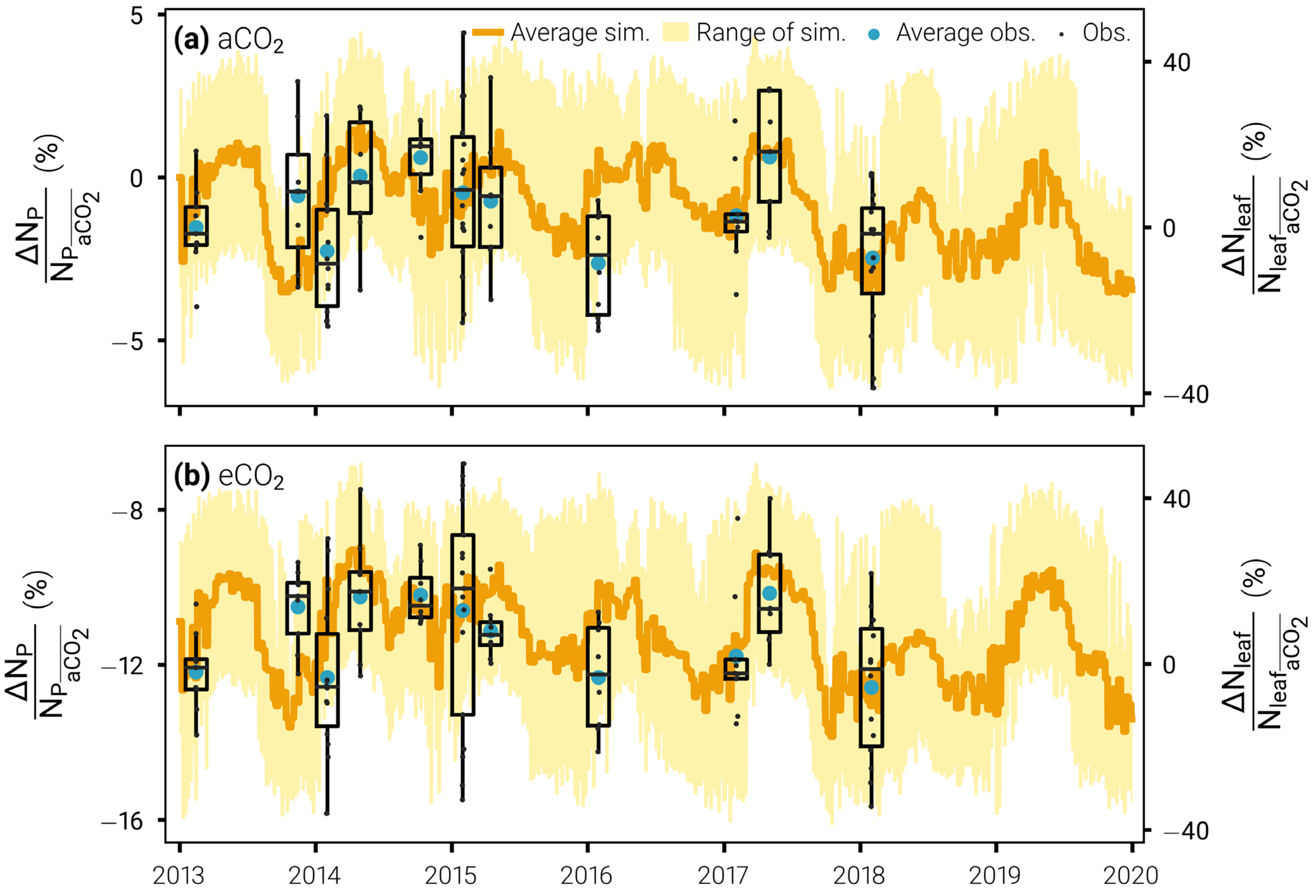
- Whether we could infer the timescales over which vegetation functions adjust to maximise resource investment and/or resilience.

Across model configurations, more frequent adjustments to function typically increased model performance.

⇒ WHAT DID THE SIMULATED ADJUSTMENTS TO FUNCTION LOOK LIKE?

PREDICTED ADJUSTMENTS TO FUNCTION

(Best model configuration)



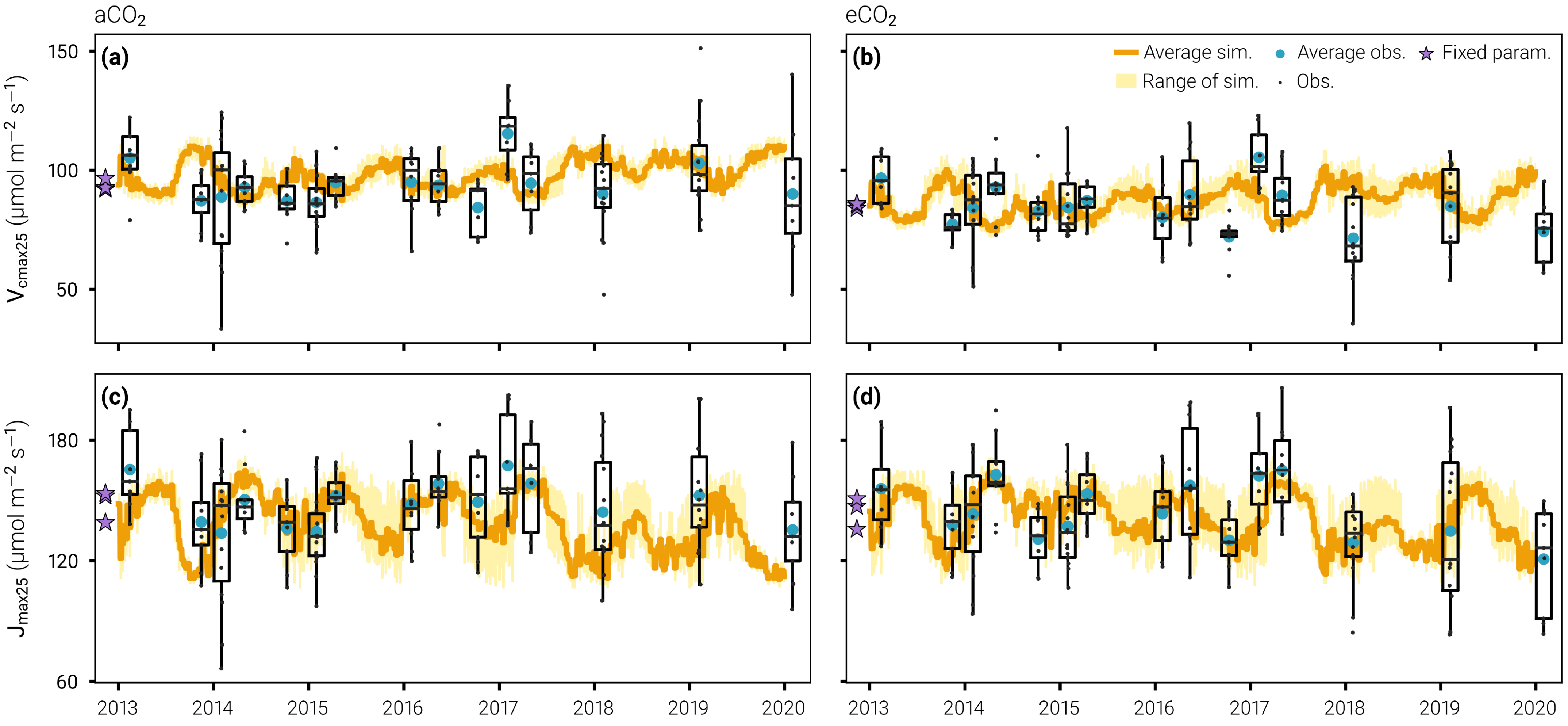
- Good agreement between the dynamics of the simulated leaf nitrogen directly involved in photosynthesis (N_P) and those of the observed total leaf nitrogen (N_{leaf}).

ΔN_P: difference between the time-varying N_P and the average N_P from across the aCO_2 plots at the onset of the simulations ($N_{P_{\overline{aCO_2}}}$).

ΔN_{leaf}: difference between the time-varying N_{leaf} and the average N_{leaf} at the aCO_2 rings during the first measurement campaign in 2013 ($N_{leaf_{\overline{aCO_2}}}$).

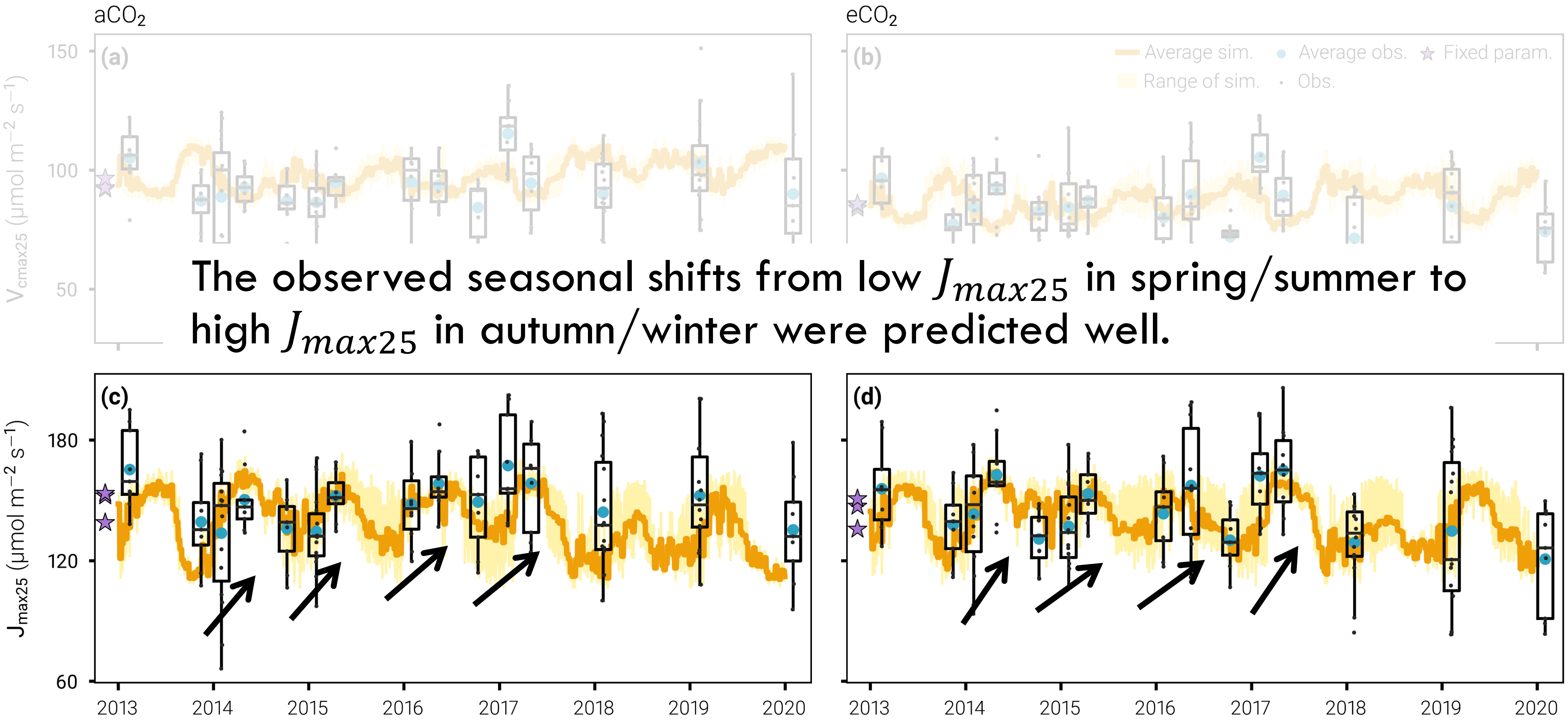
PREDICTED ADJUSTMENTS TO FUNCTION

(Best model configuration)



PREDICTED ADJUSTMENTS TO FUNCTION

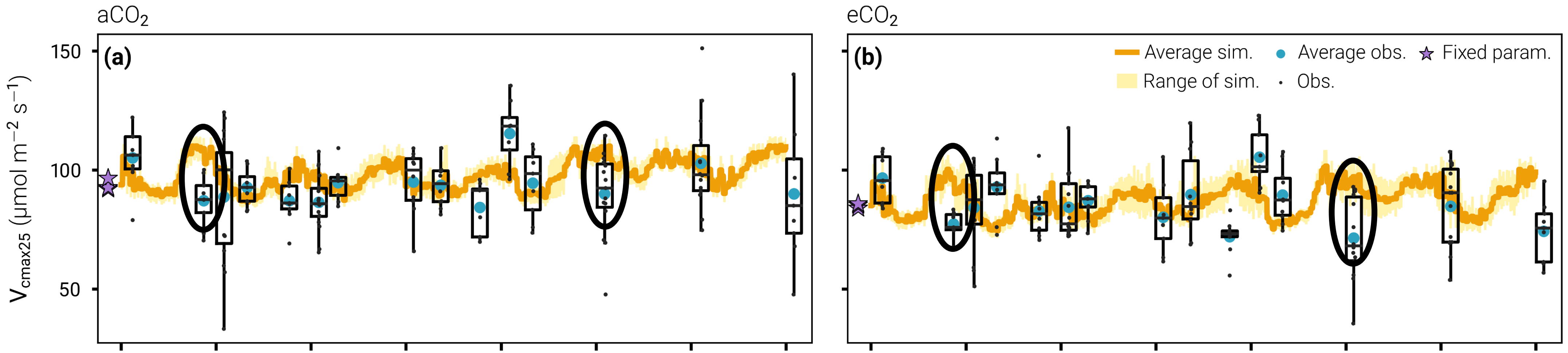
(Best model configuration)



The observed seasonal shifts from low J_{max25} in spring/summer to high J_{max25} in autumn/winter were predicted well.

PREDICTED ADJUSTMENTS TO FUNCTION

(Best model configuration)

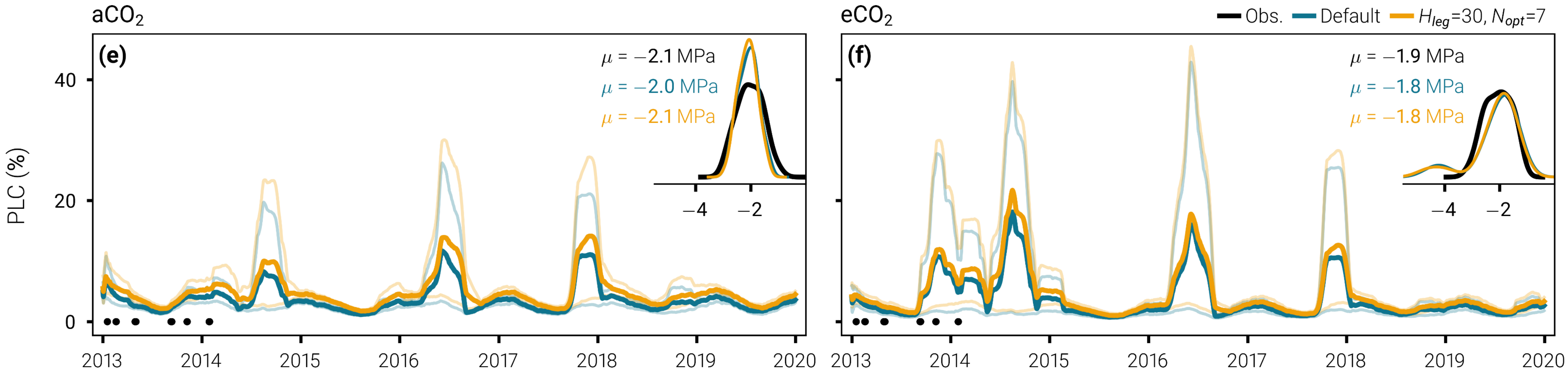


The observed increase in J_{max25}:V_{cmax25} between summer and autumn was also predicted well.

However, the model exaggerated the decline in J_{max25}:V_{cmax25} between autumn and spring because it overestimated V_{cmax25} in spring/early summer when LAI was very low.

PREDICTED ADJUSTMENTS TO FUNCTION

(Best model configuration)

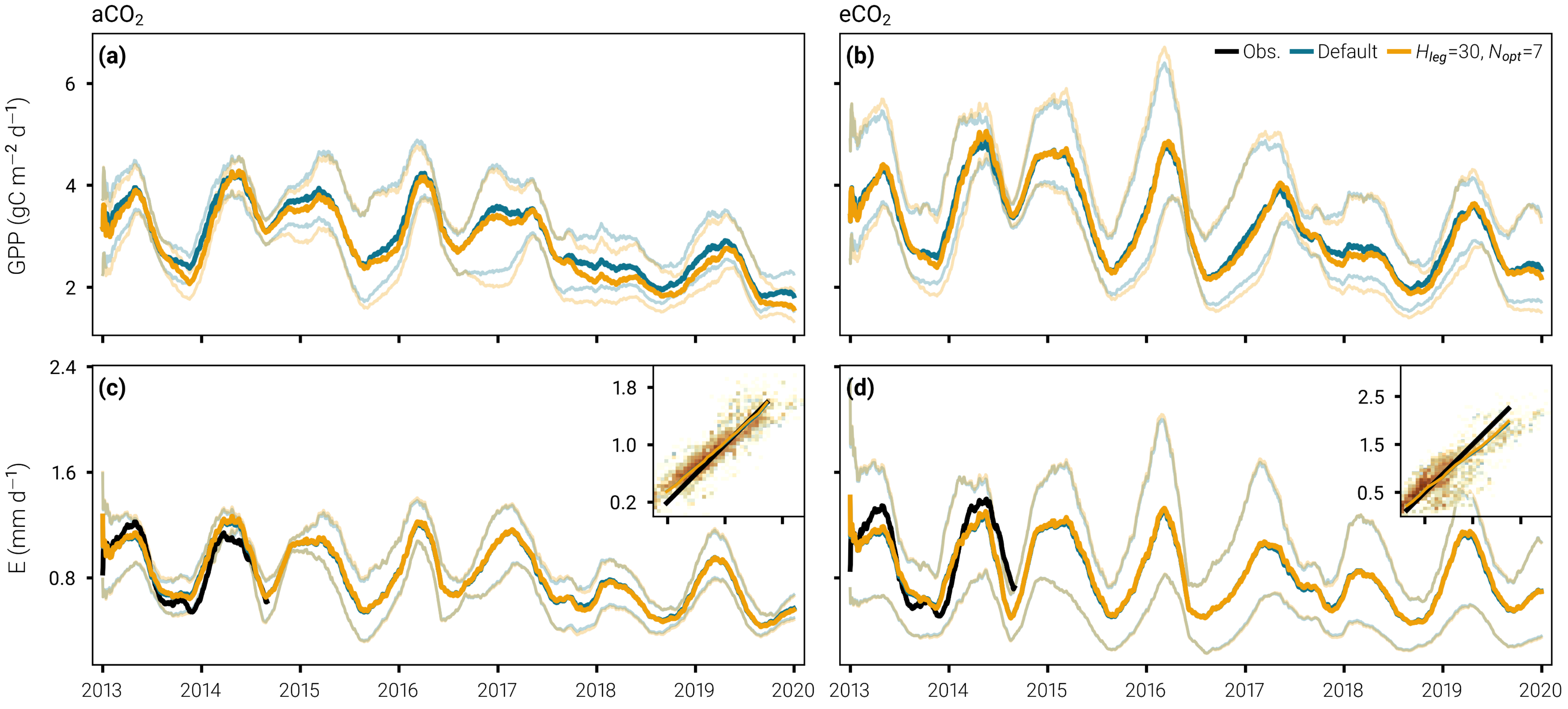


Leaf water potential was fairly well captured (inset density plots), for the dates at which observations were collected in 2013/2014 (marking dots along the x- axis).

Significant percentage losses of hydraulic conductivity (PLC) but small hydraulic legacy effect (<15% extra PLC in the best model configuration compared to the default, lasting no more than 2 months).

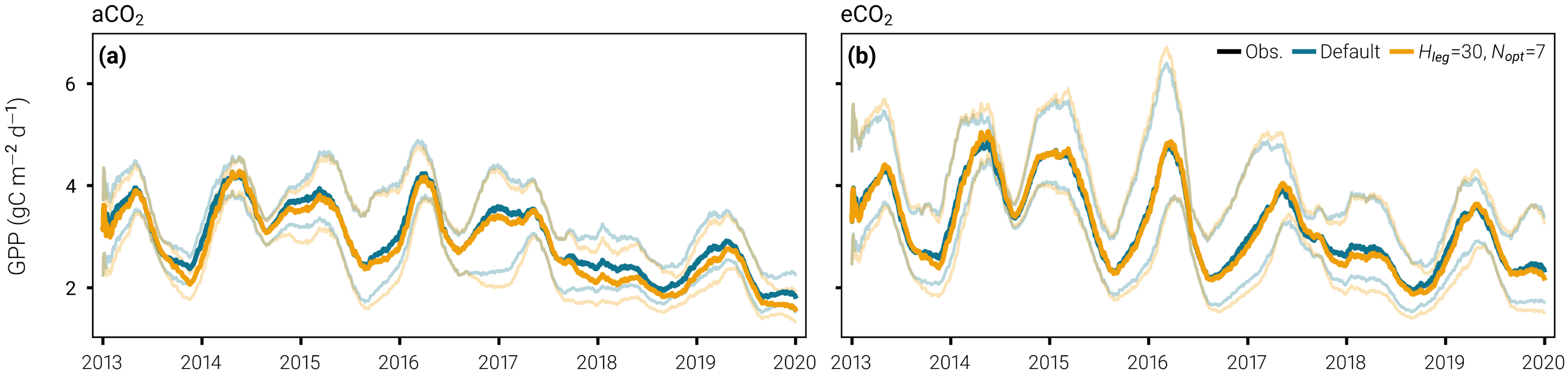
PREDICTED ADJUSTMENTS TO FUNCTION

(Best model configuration)



PREDICTED ADJUSTMENTS TO FUNCTION

(Best model configuration)



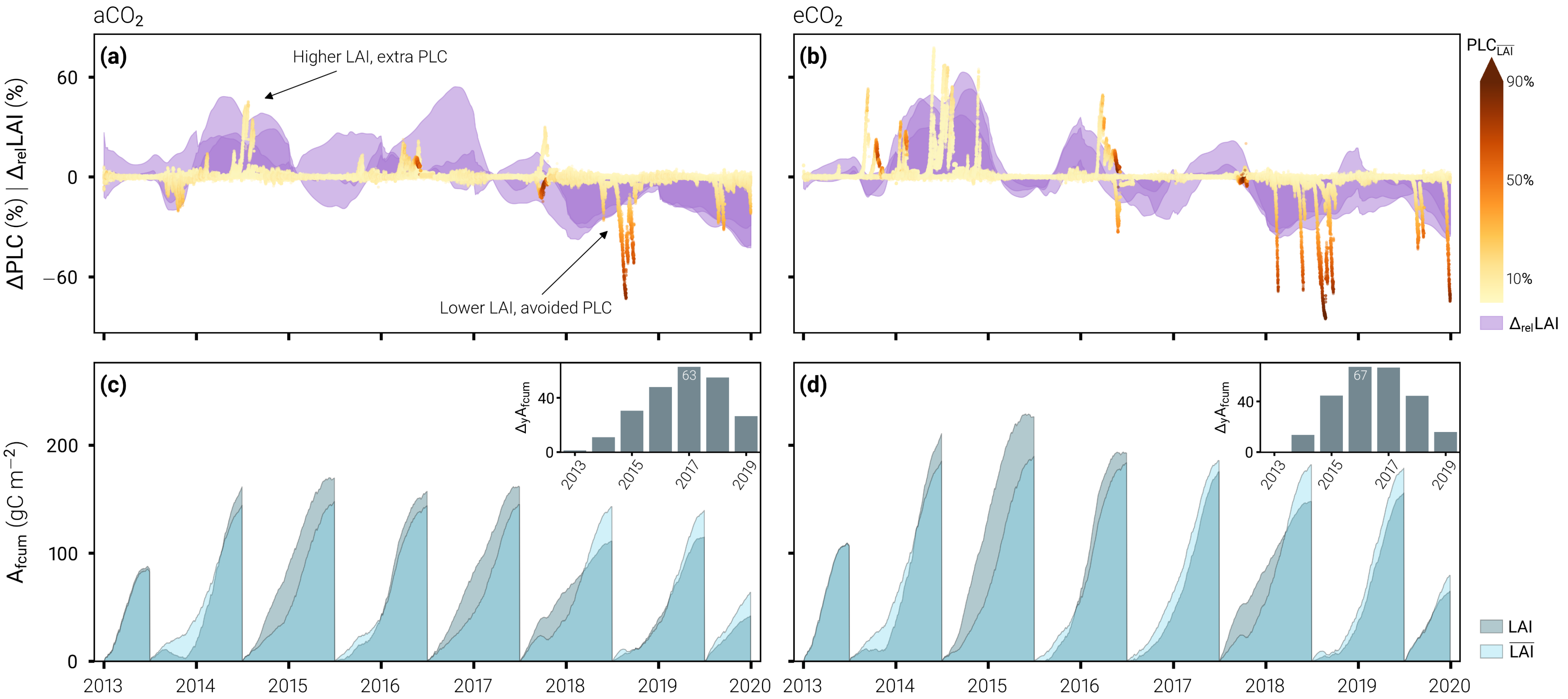
Limited impacts on the canopy fluxes, although the GPP simulated by the best model configuration could be >10% lower than the default's in spring/summer/dry years.

Departure from the default model configuration more pronounced at the aCO_2 than at the eCO_2 plots: greater CO_2 fertilisation effect simulated by accounting for N_{opt} and H_{leg} (+13.1% GPP between aCO_2 and eCO_2 in the best model vs. +9.6% in the default).

UNDERSTANDING THE LACK OF SIMULATED HYDRAULIC LEGACY: FOLIAGE RESPONSE TO DROUGHT

(Best model configuration)

Simulations driven by the actual LAI minus simulations driven by an average phenology of the observed LAI ($\overline{LAI}$).

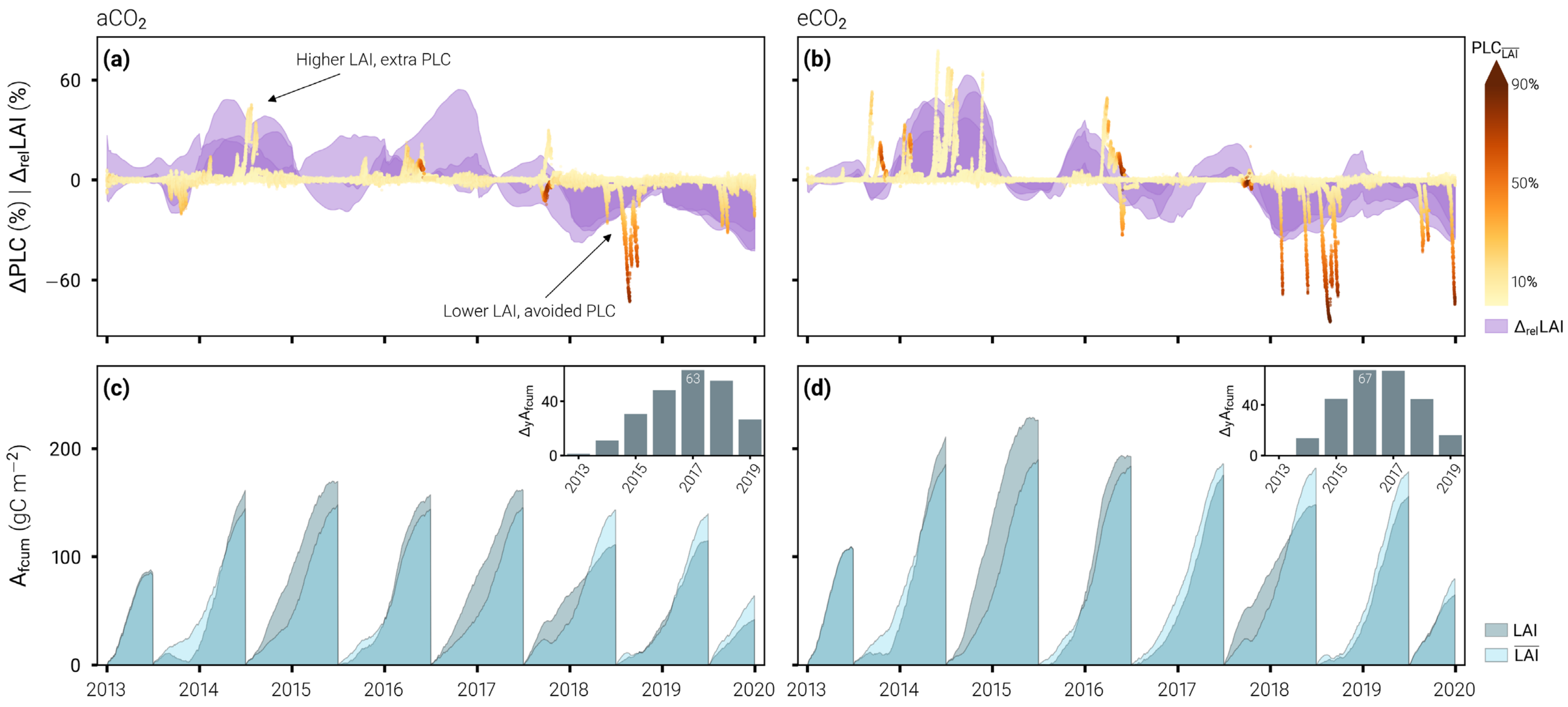


UNDERSTANDING THE LACK OF SIMULATED HYDRAULIC LEGACY: FOLIAGE RESPONSE TO DROUGHT

(Best model configuration)

Higher than average LAI (wet years) led to extra PLC, and to increasing carbon storage (A_{fcum}) until c. 2016 (eCO_2) or c. 2017 (aCO_2).

After those years (dry years), the trend was reversed.



⇒ Drought legacy effects were accounted for through LAI dynamics that prevented hydraulic damage.

TAKEAWAY

Competing optimisation approaches affected model simulations in a predictive manner, via interactive physiological adjustments that could also be interpreted theoretically.

Significant canopy PLC, but no sustained hydraulic damage thanks to LAI dynamics that averted hydraulic conductivity loss.

How to capture LAI dynamics during drought is a key research frontier for predictions of canopy dieback and/or plant mortality.

Don't hesitate to get in touch :)
m.e.b.sabot@gmail.com