Do plants follow a profit maximization approach during drought?

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Why does understanding plant response to drought matter?


nature climate change

LETTERS

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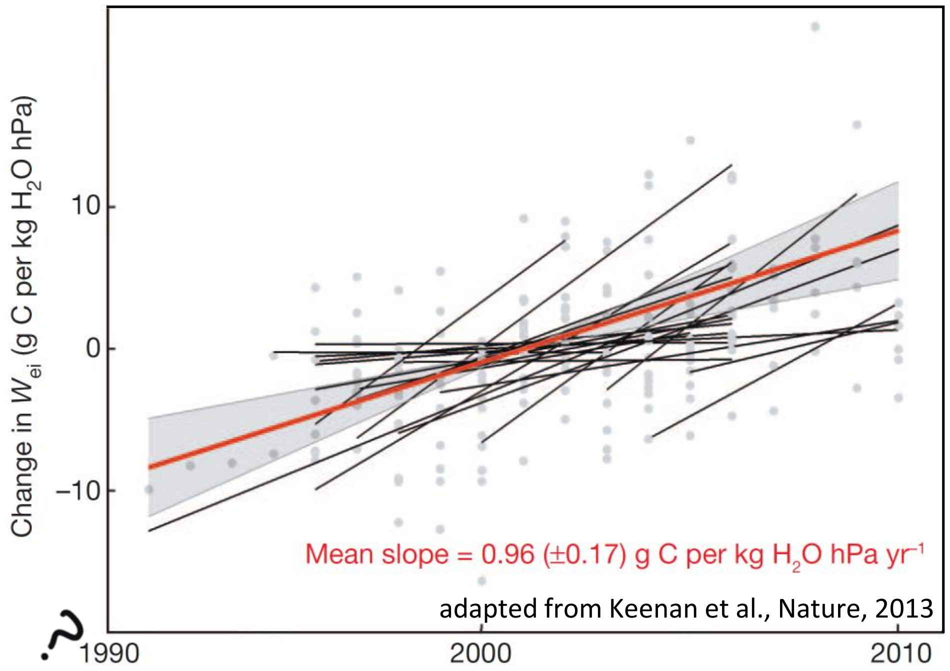
Darcy's law predicts widespread forest mortality under climate warming

Nathan G. McDowell[1]* and Craig D. Allen[2]

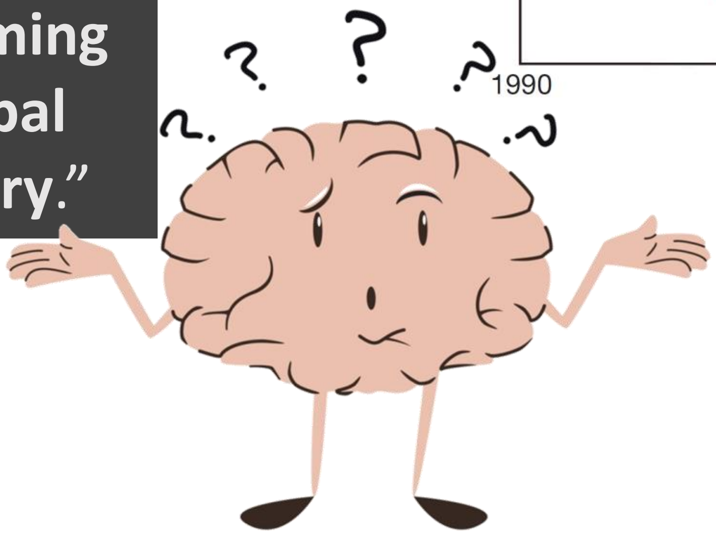
Drought and heat-induced tree mortality is accelerating in many forest biomes as a consequence of a warming climate, resulting in a threat to global forests unlike any in recorded

mechanisms, on canopy-scale water conductance G (mol m^{-2} leaf area s^{-1}):

"Drought and heat-induced tree mortality is accelerating in many forest biomes as a consequence of a warming climate, resulting in a threat to global forests unlike any in recorded history."

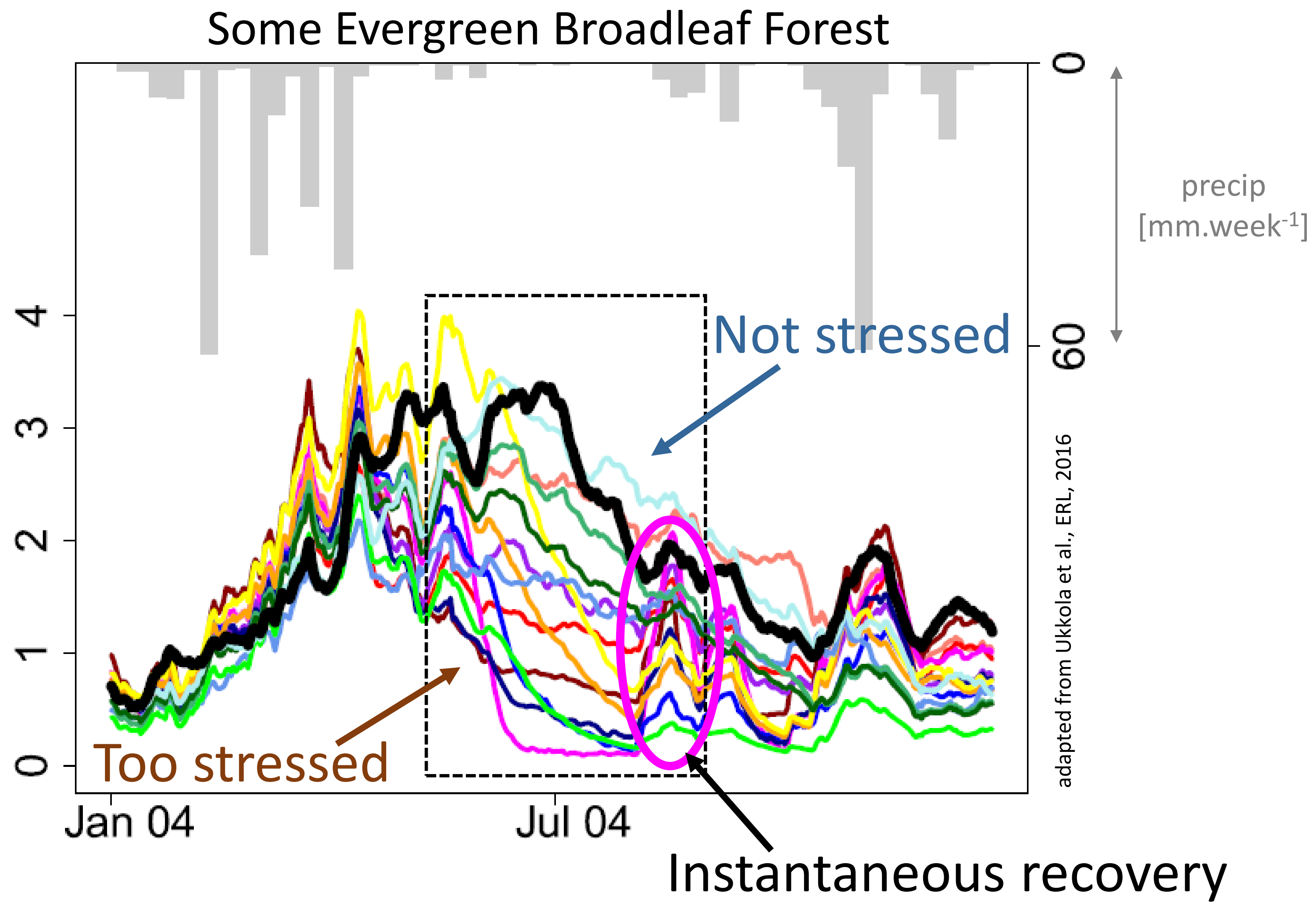


adapted from Keenan et al., Nature, 2013

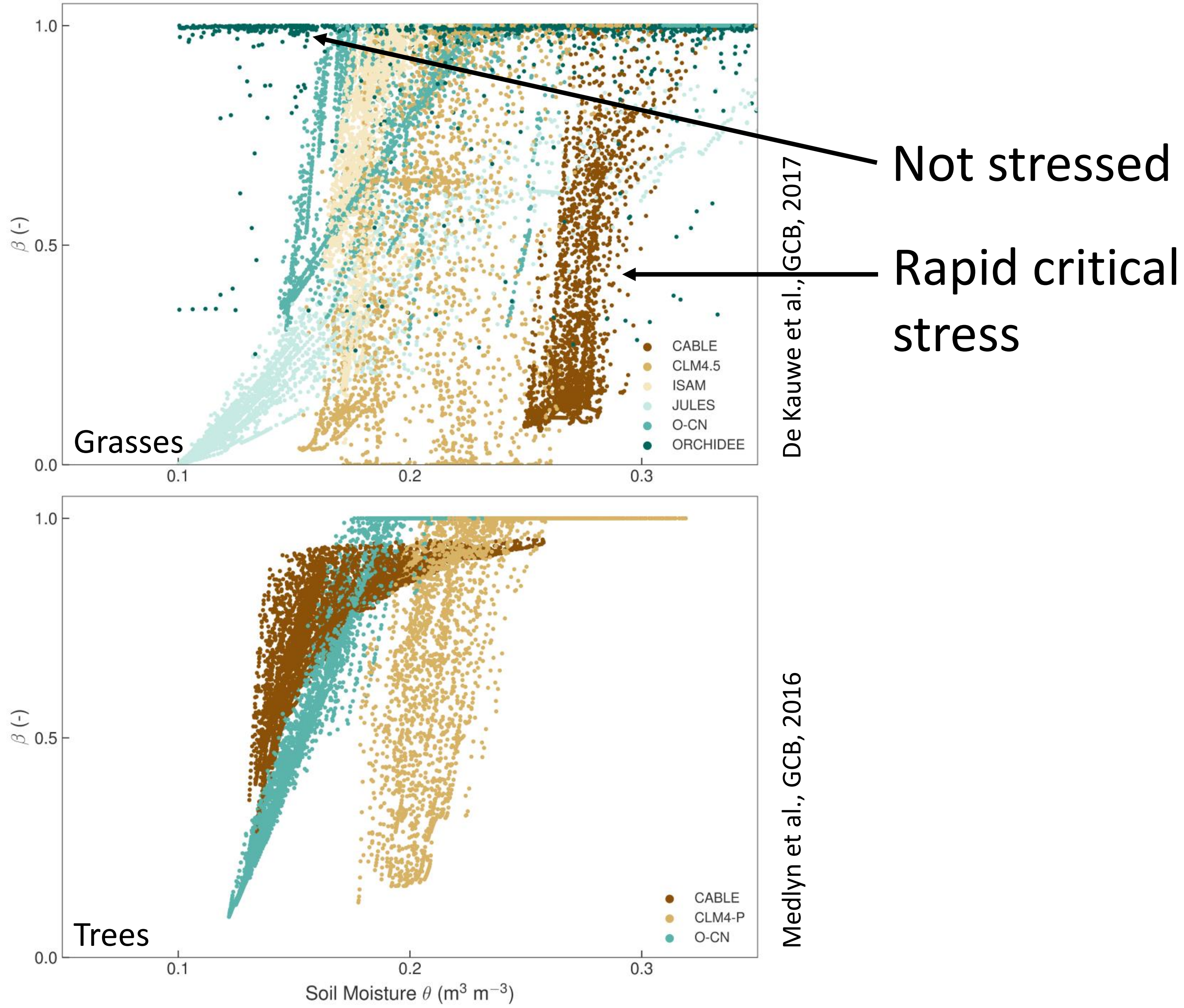


Representation of drought in LSMs

ET range
> 3 mm.day^{-1}



Soil moisture stress factor with scarce empirical support



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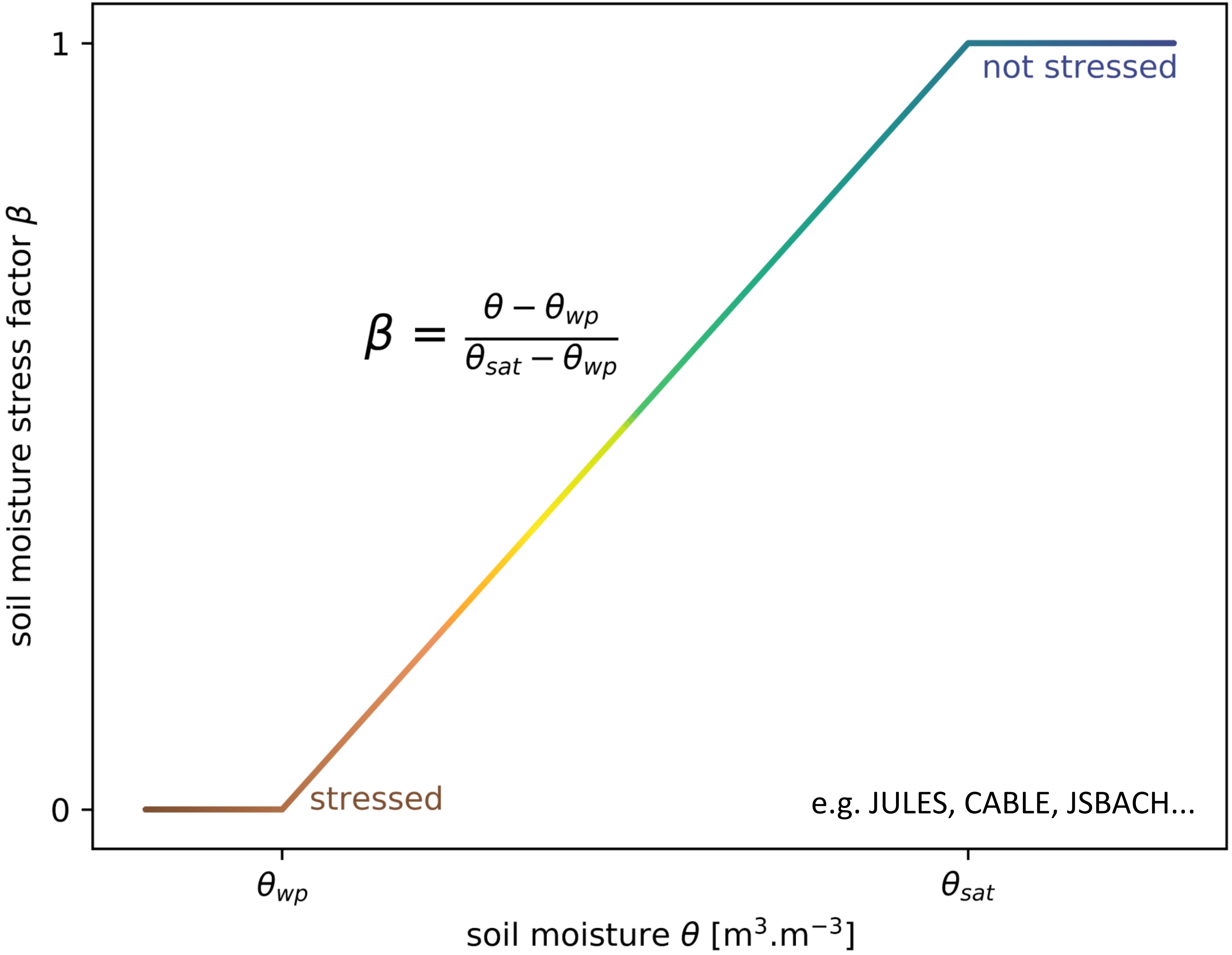
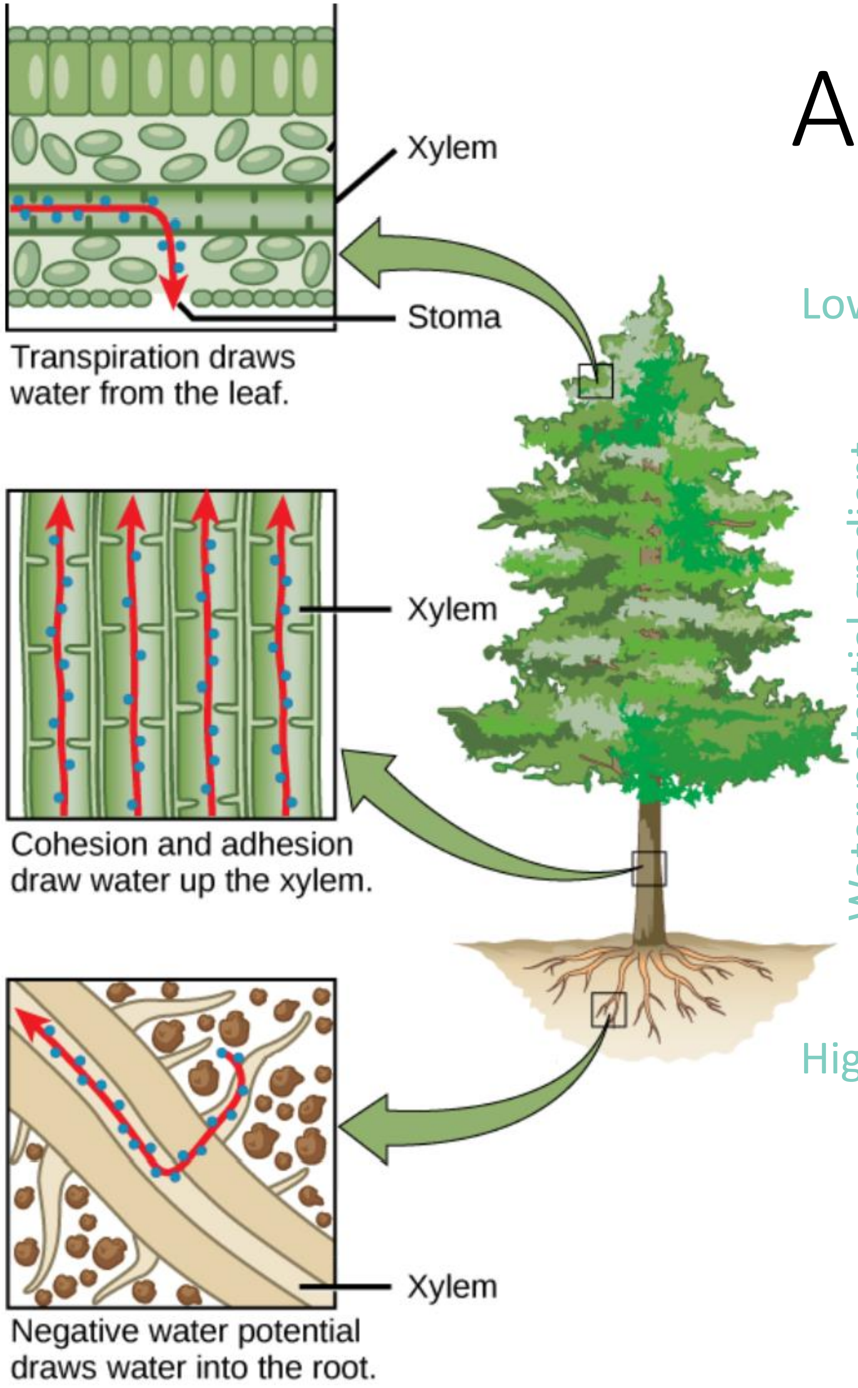


Implications for the future

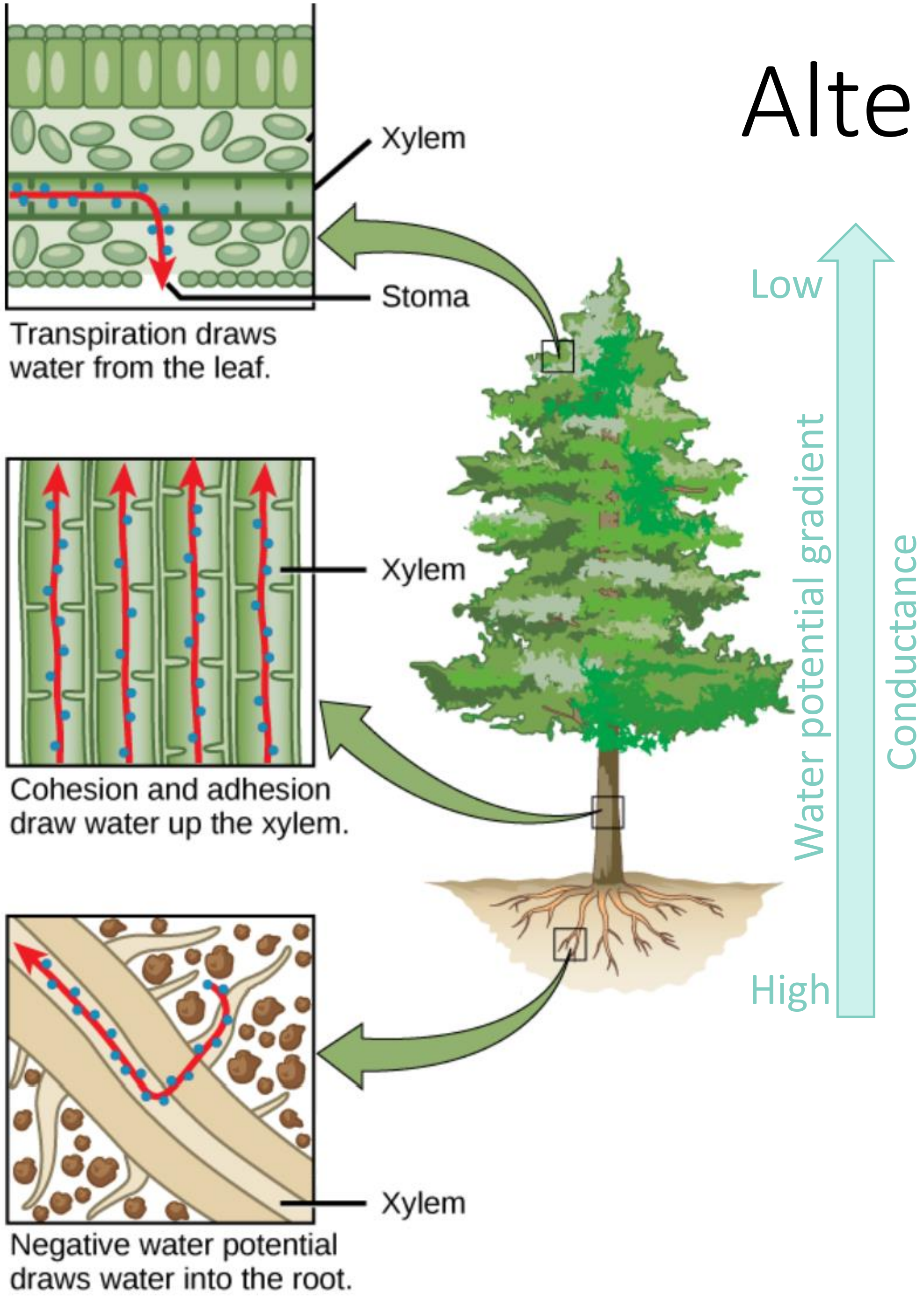
Land surface models cannot reliably predict...

- the impact of drought on vegetation
- plant mortality
- vegetation feedback on the atmosphere
- the sign of future drought

Alternative approaches



Alternative approaches

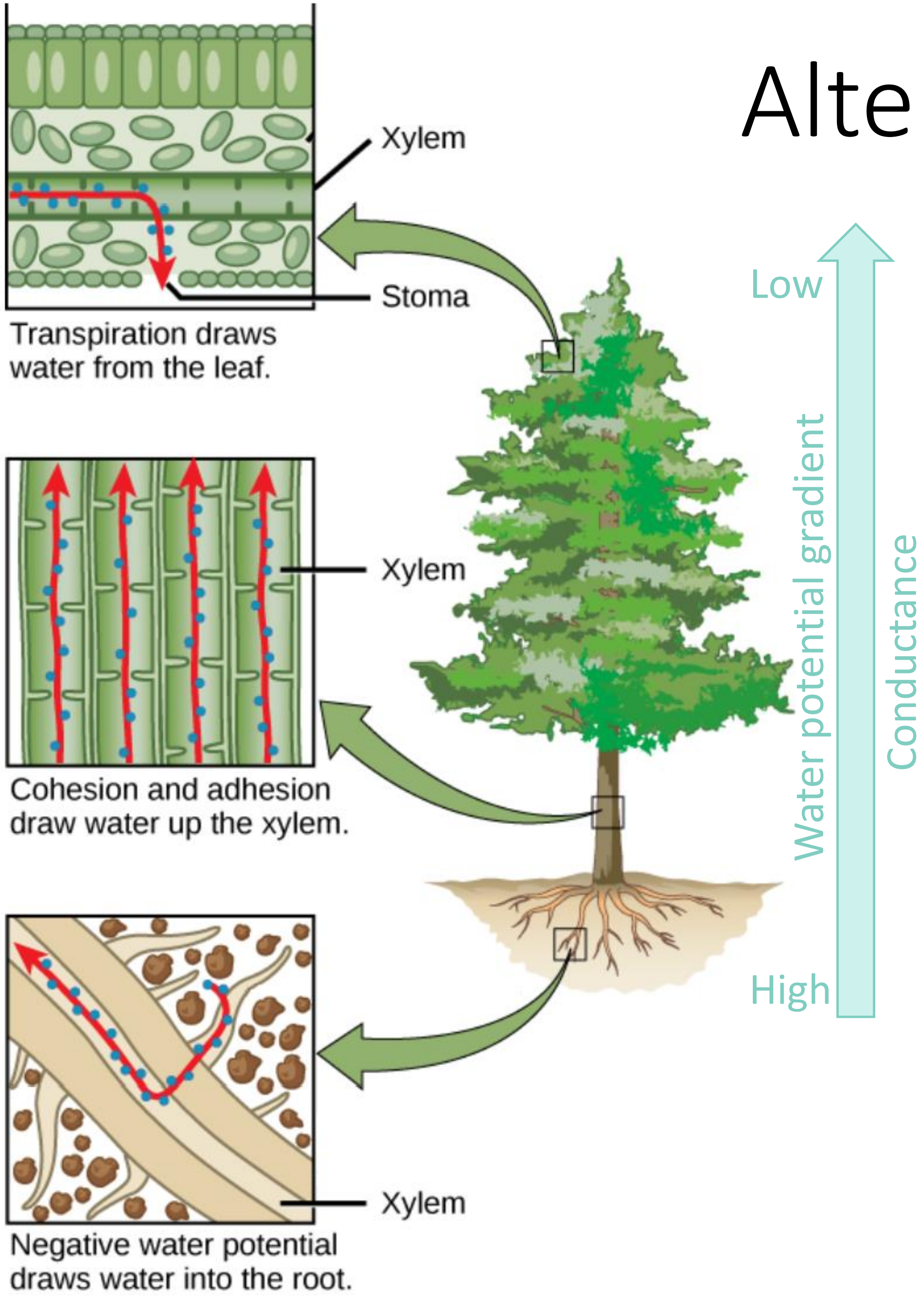


Classic Water Use Efficiency Hypothesis (WUEH):

$$\frac{\partial A_n}{\partial g_s} = \lambda \frac{\partial E}{\partial g_s}$$

e.g. CABLE, CLM5

Alternative approaches



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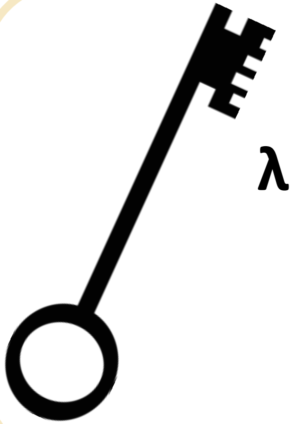
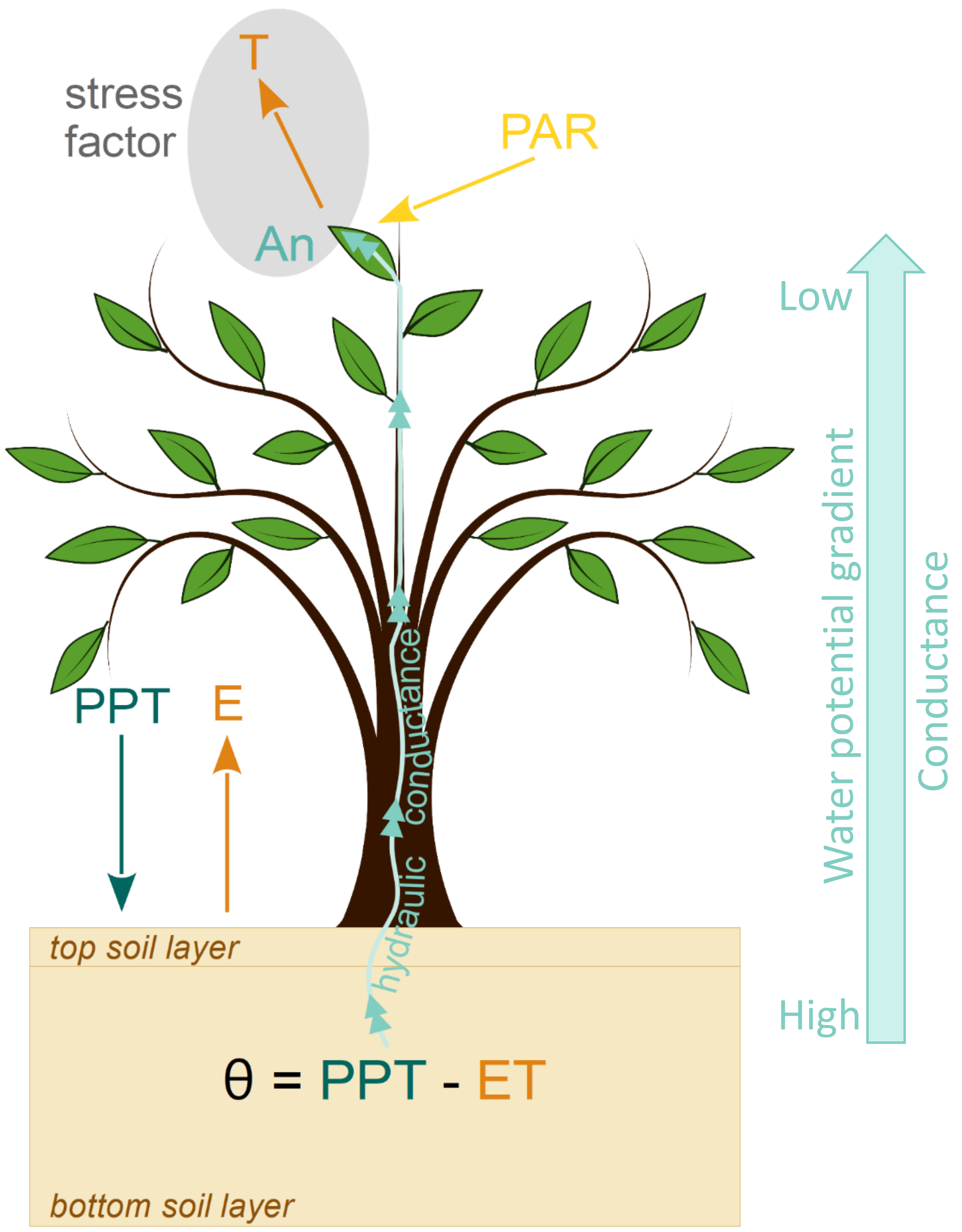


λ increases instantaneously with H_2O stress

- Wolf et al., PNAS, 2016
- Sperry et al., PCE, 2017

Experimental modelling framework



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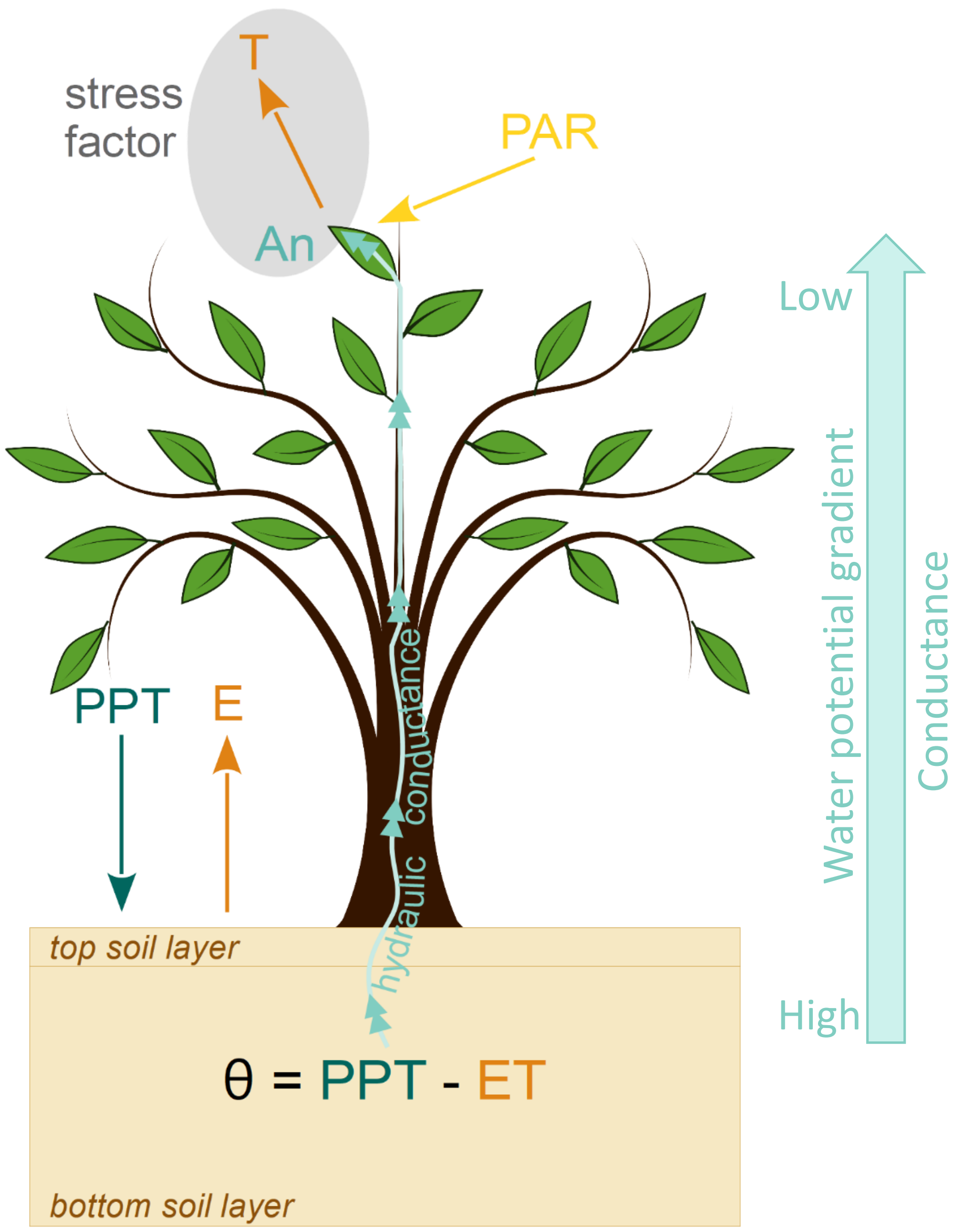
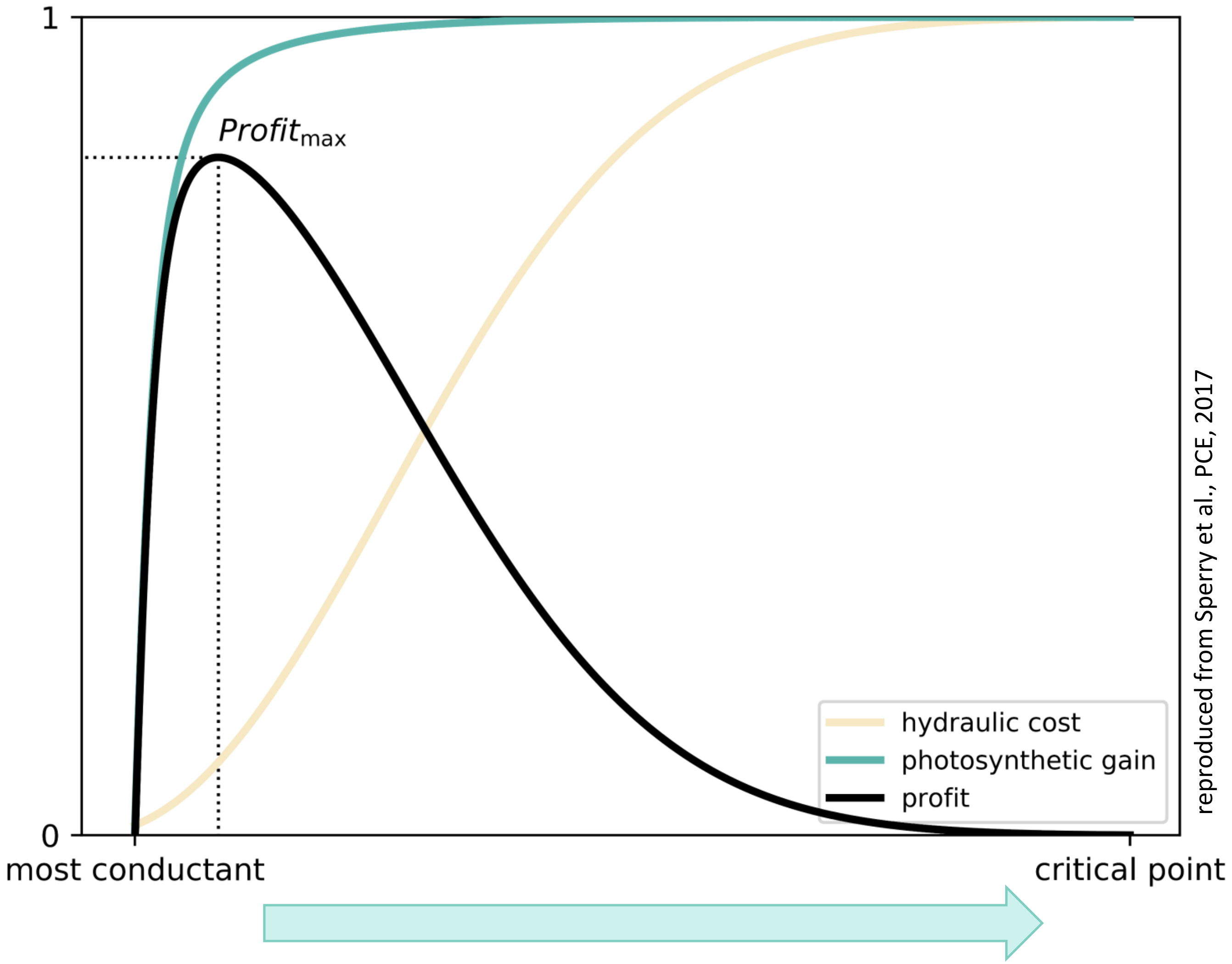


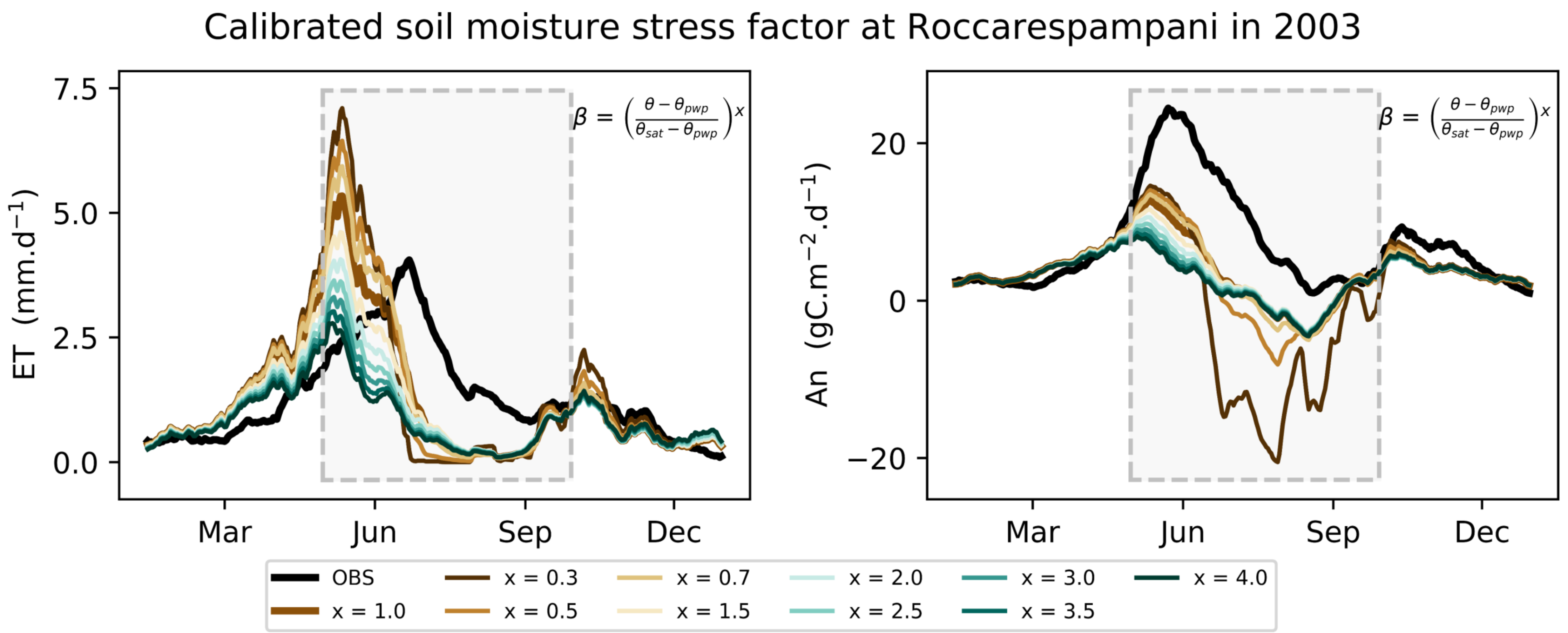


Droughted forested fluxnet sites

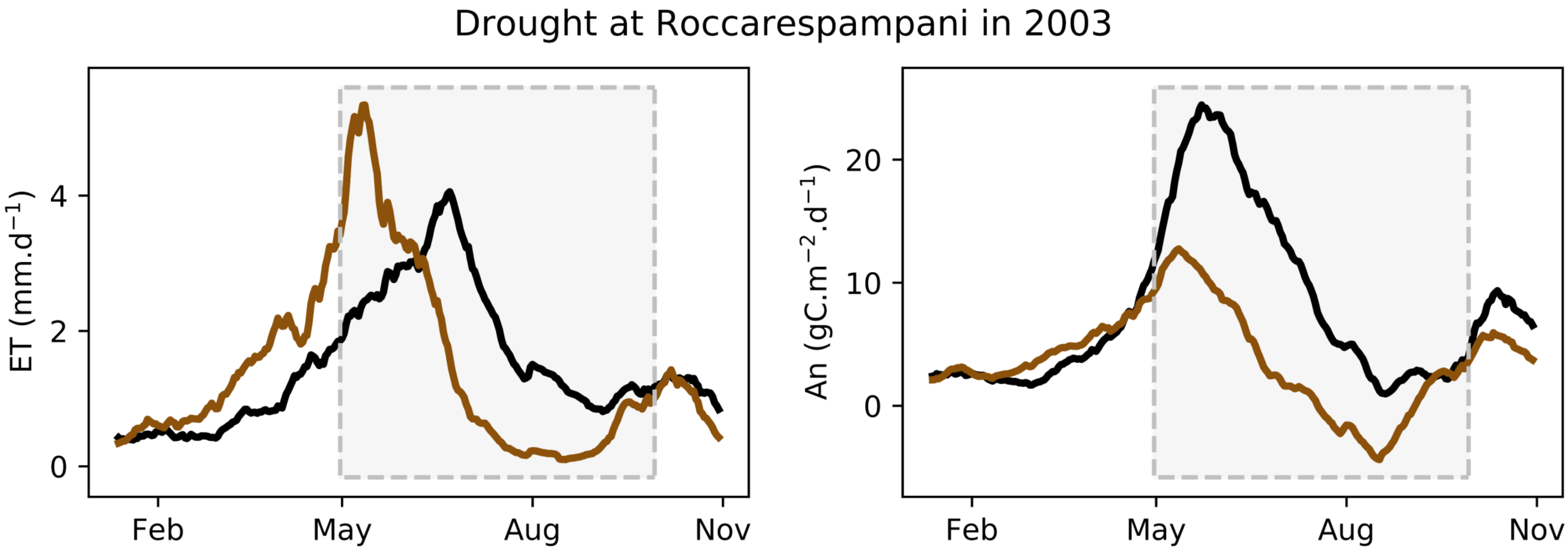
Espirra
Eucalyptus Globulus
Evergreen Broadleaf

Roccarespampani
Quercus Cerris
Deciduous Broadleaf

Calibrating β is not a viable solution



C-H_2O optimisation as an alternative



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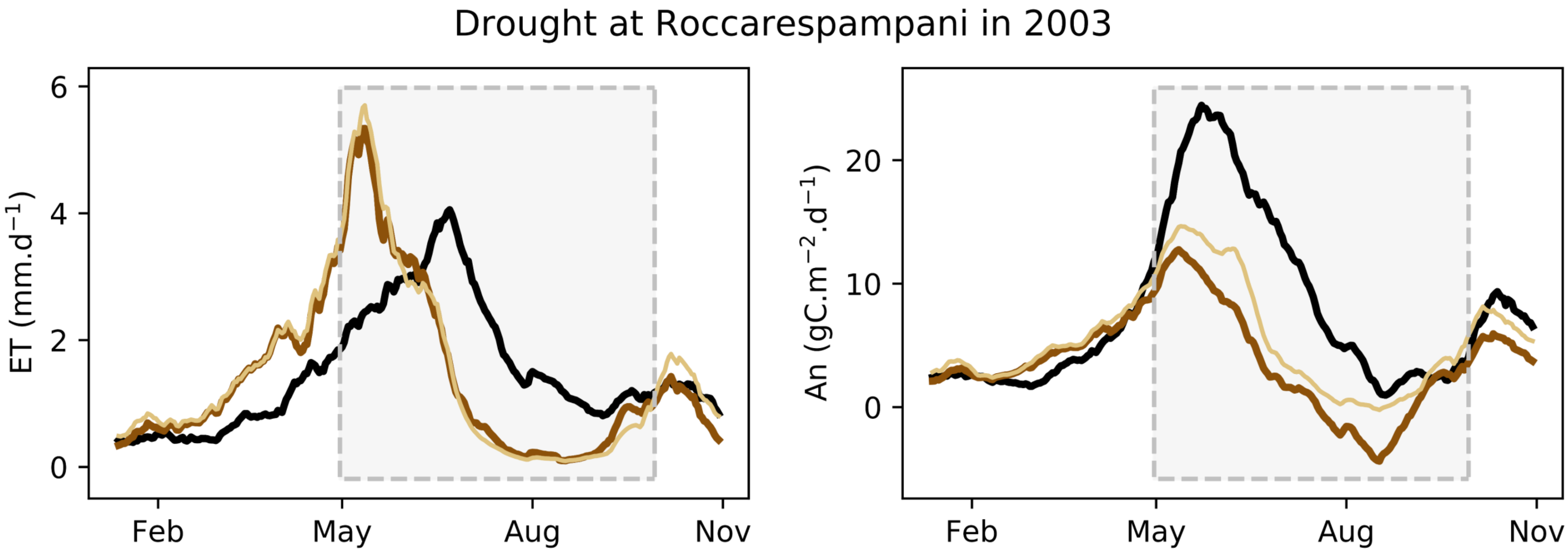

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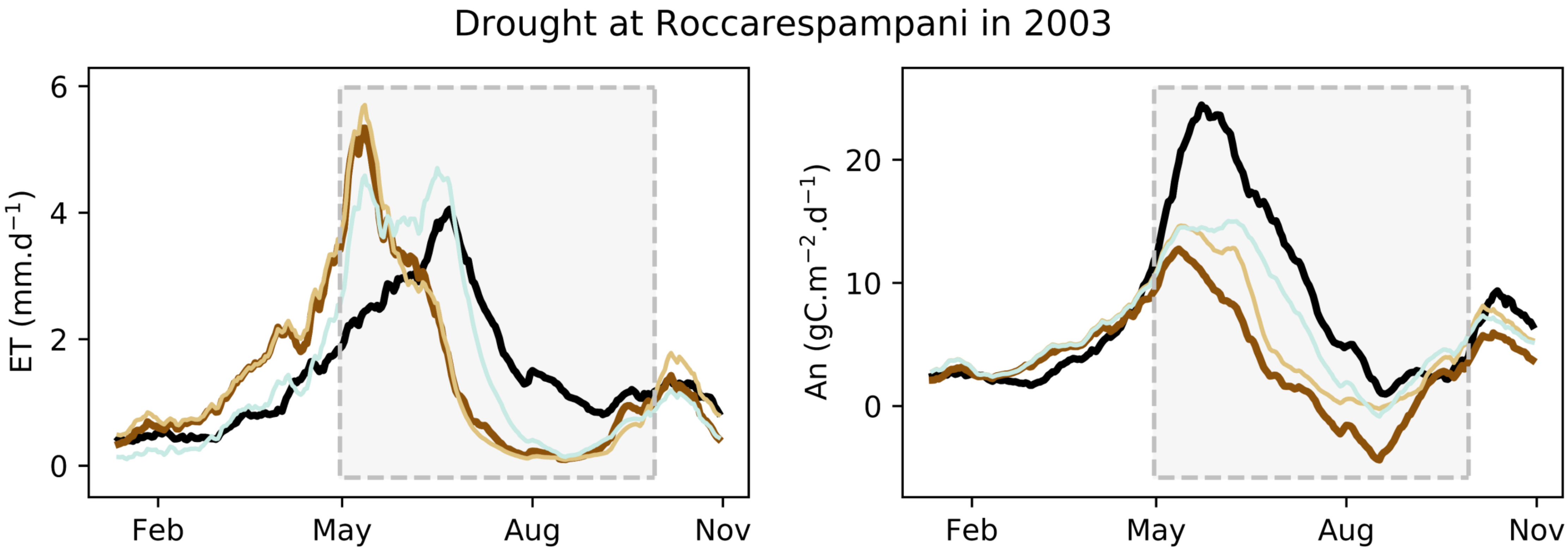

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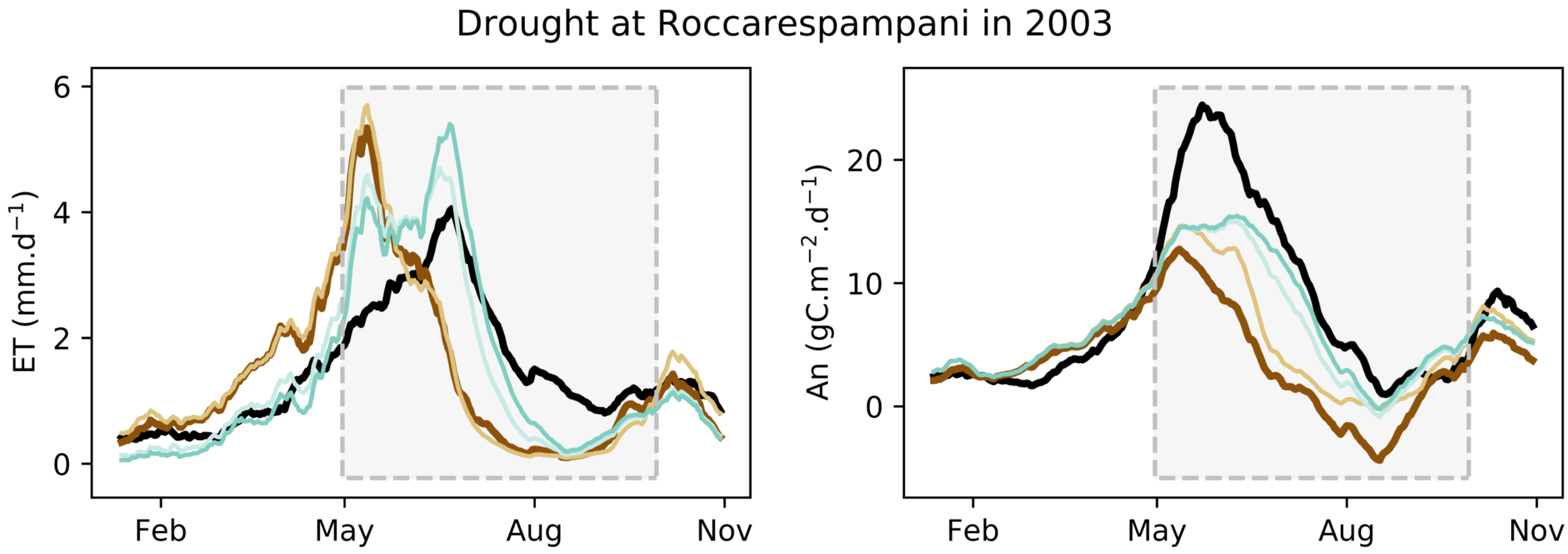
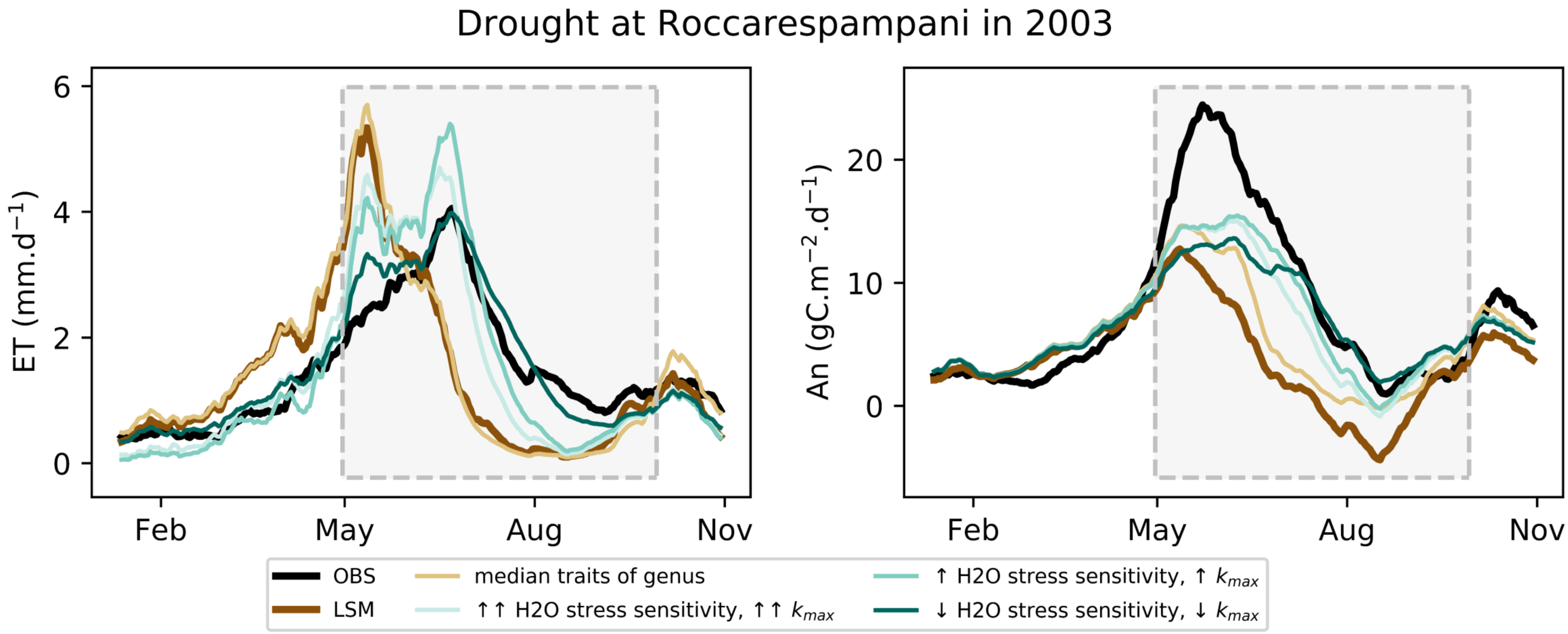


Plants can follow a profit maximization approach!



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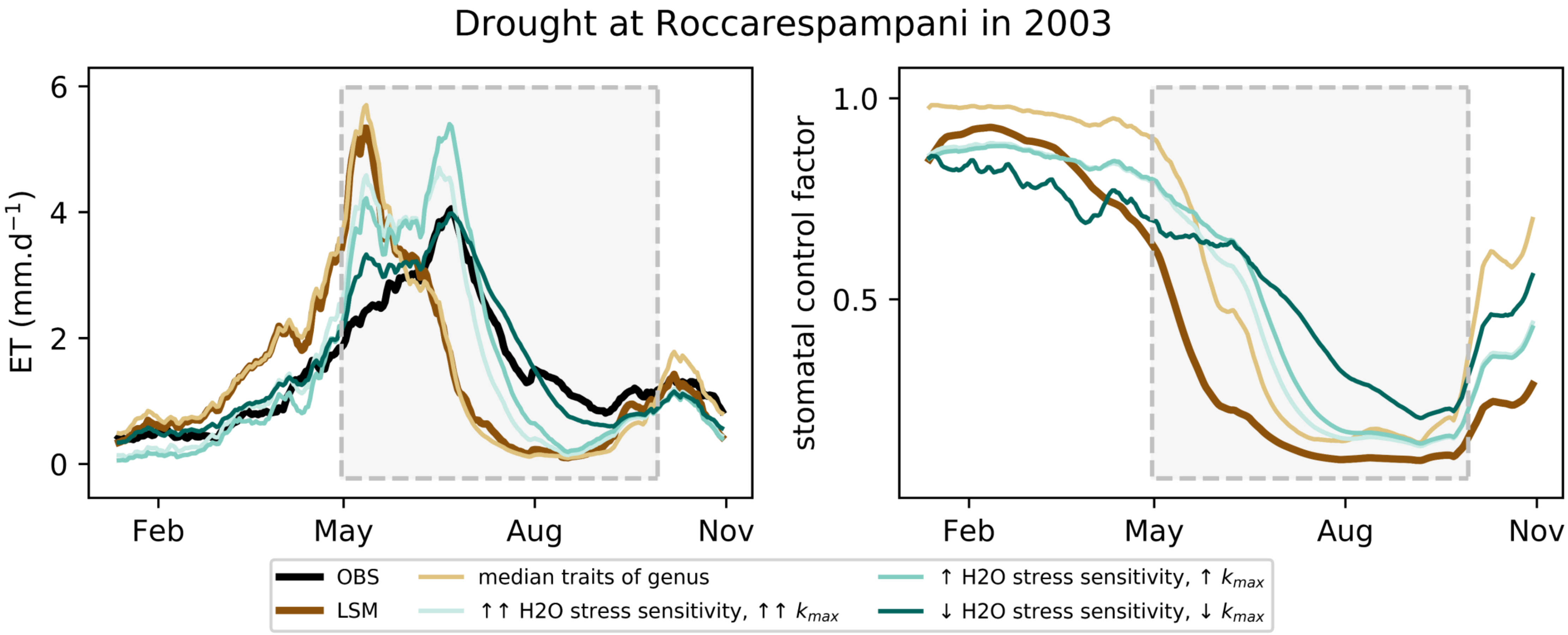
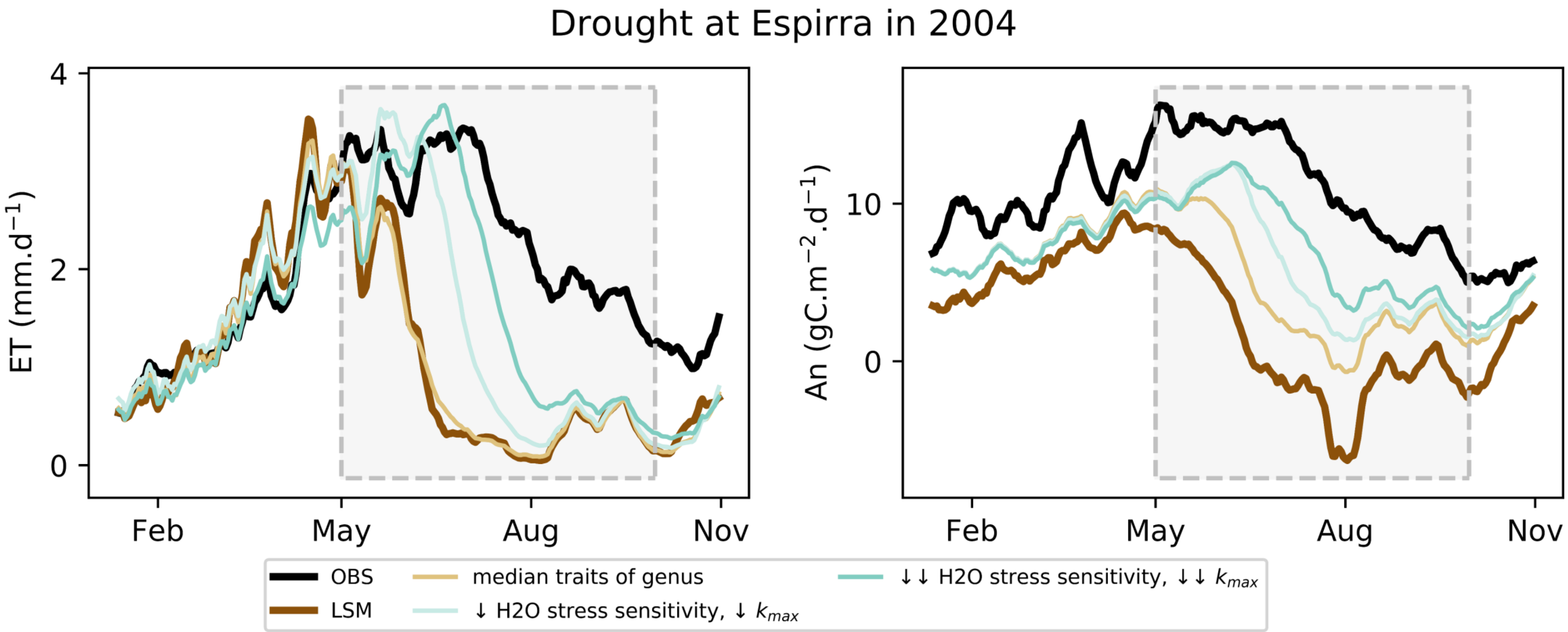


But it might not be sufficient…



Future directions

- Can we capture the response of wet ecosystems to drought?
- What about grasses and their recovery?
- Can carbon gain be invested in rooting depth and/or dynamic LAI?
- Can hydraulic cost be used to infer plant mortality?

Thank you

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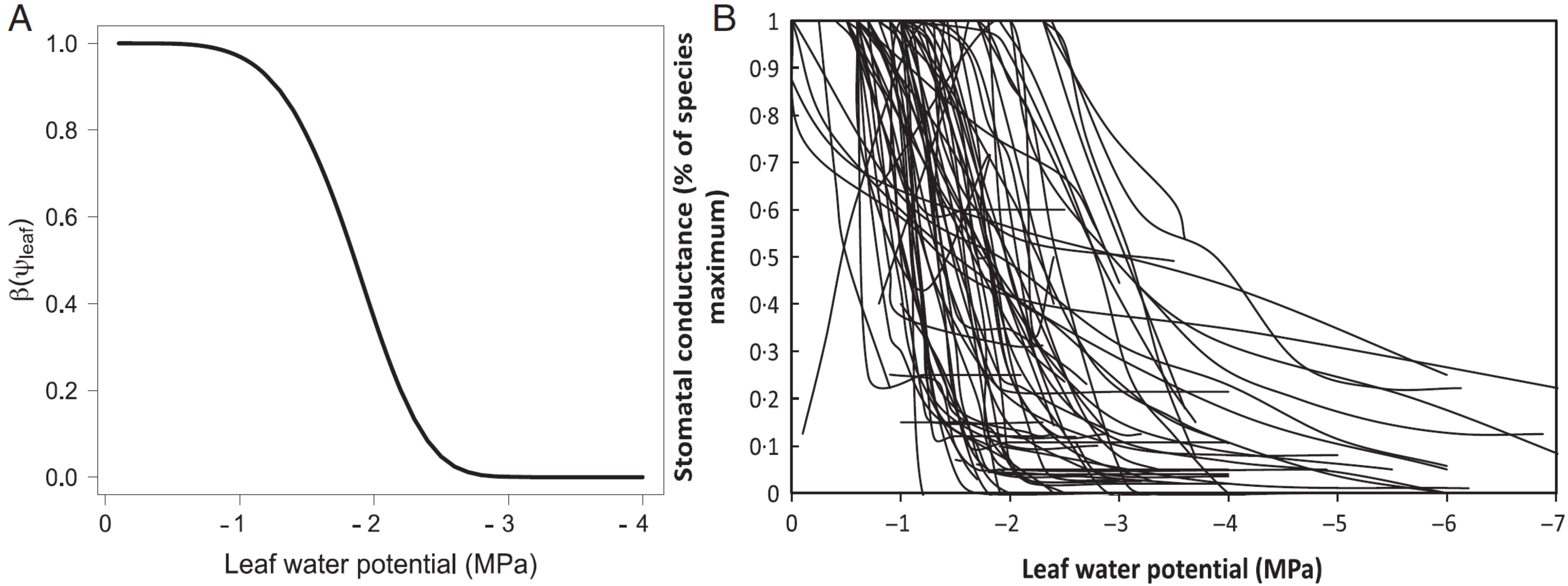
Vulnerability curves



Wolf et al., PNAS, 2016

Fig. 1. (*A*) Stomatal conductance response as a function of leaf water potential [$\beta(\psi_{\text{leaf}})$] with a Weibull-like functional form. (*B*) Observed stomatal conductance response (normalized to species-level maximum) as a function of leaf water potential (MPa) from 70 woody plant species from around the globe Reprinted with permission from ref. 82.

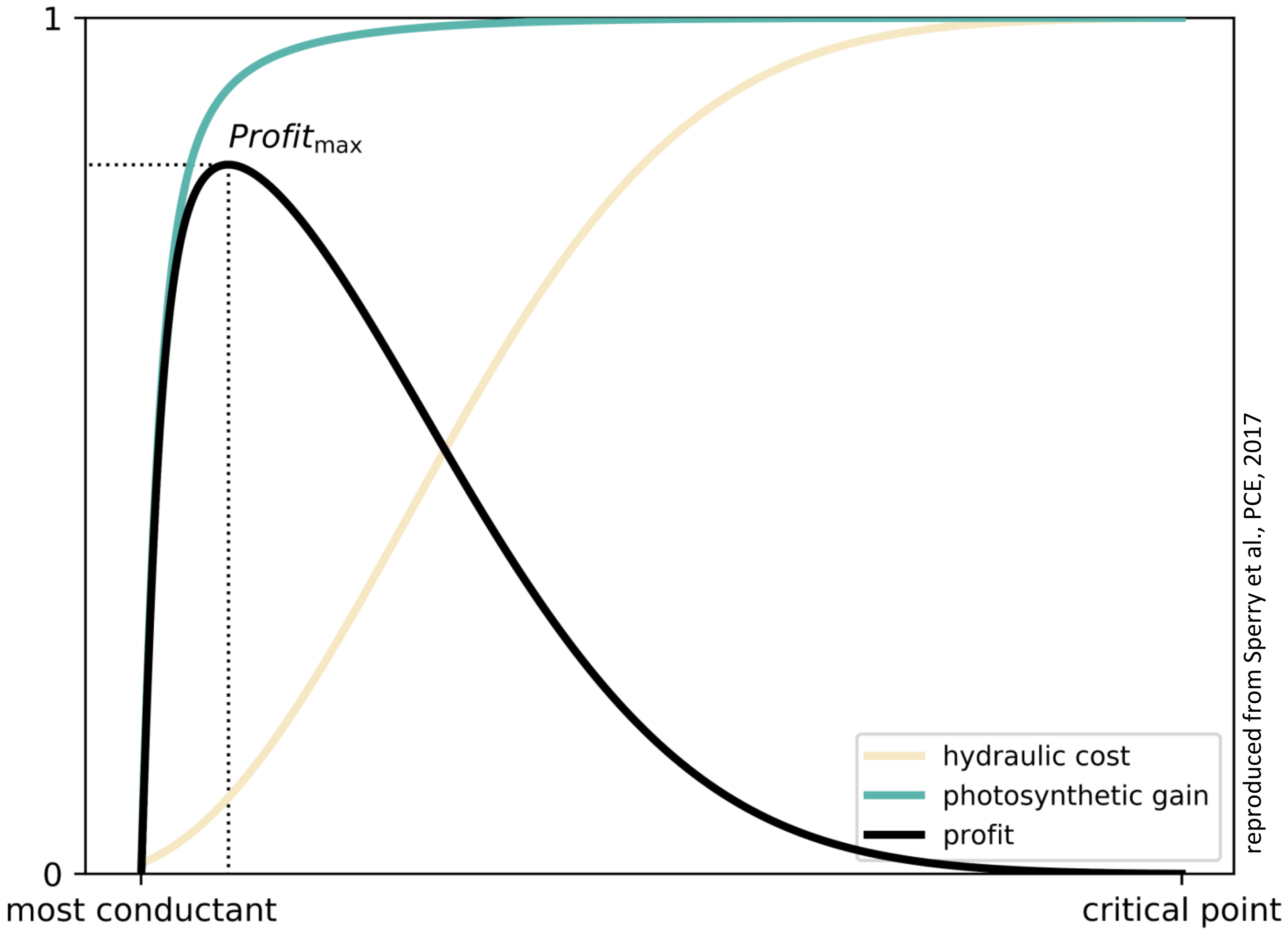
C-H_2O optimization

- Hydraulic cost:

$$\frac{kmax - k}{kmax - kcrit}$$

- Photosynthetic gain:

$$\frac{A}{Amax}$$



reproduced from Sperry et al., PCE, 2017

References

- Allen, C. D., et al. (2015). On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene. *Ecosphere*, *6*(8), 1-55.
- Choat, B., et al. (2012). Global convergence in the vulnerability of forests to drought. *Nature*, *491*(7426), 752.
- De Kauwe, M. G., et al. (2017). Challenging terrestrial biosphere models with data from the long-term multifactor Prairie Heating and CO2 Enrichment experiment. *Global change biology*, *23*(9), 3623-3645.
- Kattge, J., et al. (2011). TRY–a global database of plant traits. *Global change biology*, *17*(9), 2905-2935.
- Keenan, T. F, et al. (2013). Increase in forest water-use efficiency as atmospheric carbon dioxide concentrations rise. *Nature*, *499*(7458), 324.
- McDowell, N. G., & Allen, C. D. (2015). Darcy's law predicts widespread forest mortality under climate warming. *Nature Climate Change*, *5*(7), 669.
- Medlyn, B. E., et al. (2016). Using models to guide field experiments: a priori predictions for the CO2 response of a nutrient-and water-limited native Eucalypt woodland. *Global change biology*, *22*(8), 2834-2851.
- Sperry, J. S., et al. (2017). Predicting stomatal responses to the environment from the optimization of photosynthetic gain and hydraulic cost. *Plant, cell & environment*, *40*(6), 816-830.
- Ukkola, A. M., et al. (2016). Land surface models systematically overestimate the intensity, duration and magnitude of seasonal-scale evaporative droughts. *Environmental Research Letters*, *11*(10), 104012.
- Wolf, A., et al. (2016). Optimal stomatal behavior with competition for water and risk of hydraulic impairment. *Proceedings of the National Academy of Sciences*, *113*(46), E7222-E7230.
- Zhao, T., & Dai, A. (2017). Uncertainties in historical changes and future projections of drought. Part II: model-simulated historical and future drought changes. *Climatic Change*, *144*(3), 535-548.