Modeling the Stomatal Control from Plant Physiological Traits

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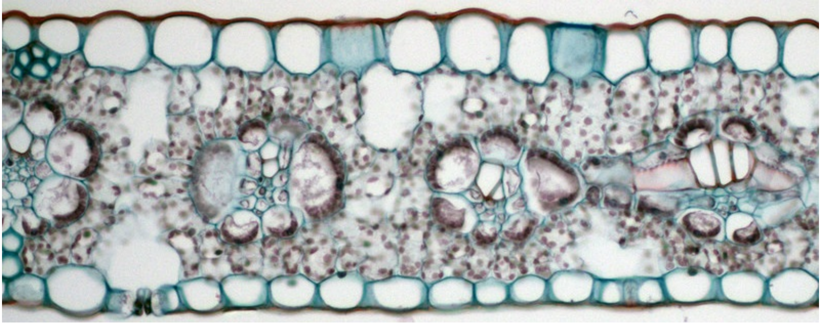
Why land plant use water

Why land plants need stomata

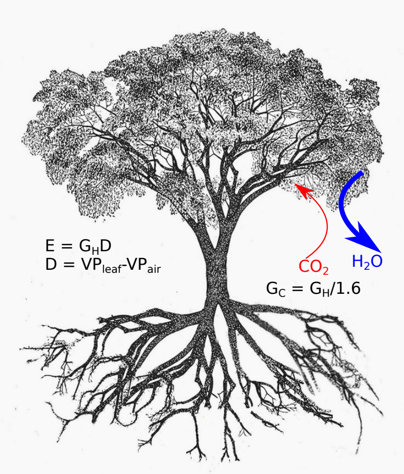


How trees use water

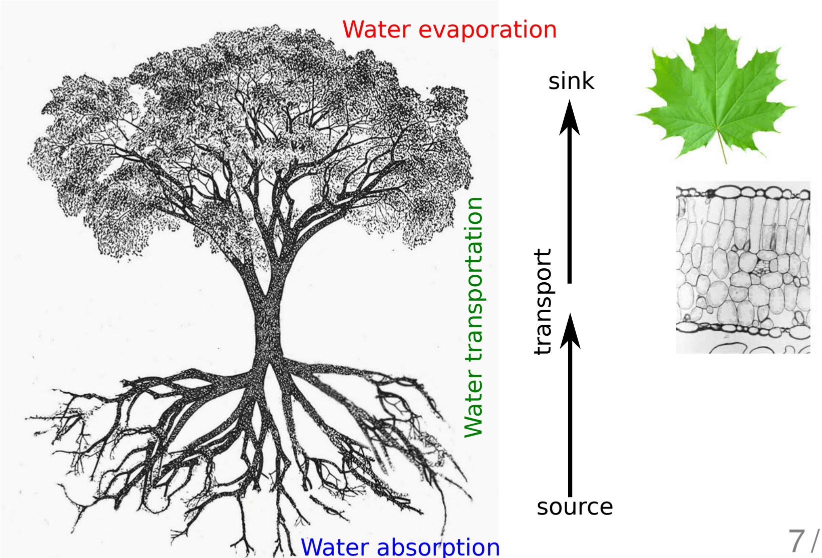
- Is there optimal water usage strategy?
- What is the standard of “optimal”?
- What is the optima?

How to optimize water usage?

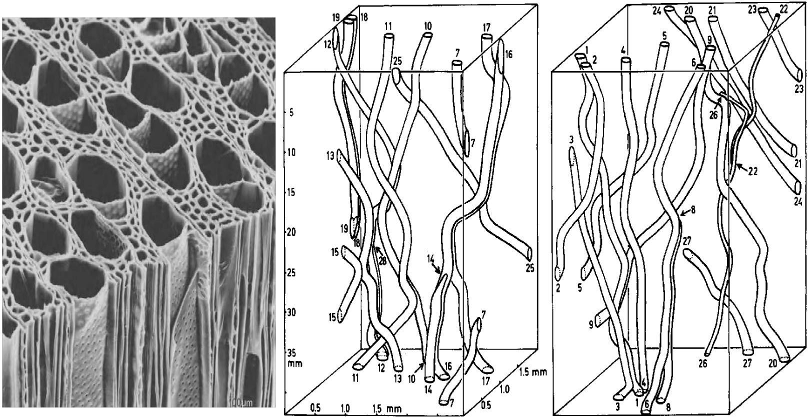
- Why do trees use water?



How trees use water

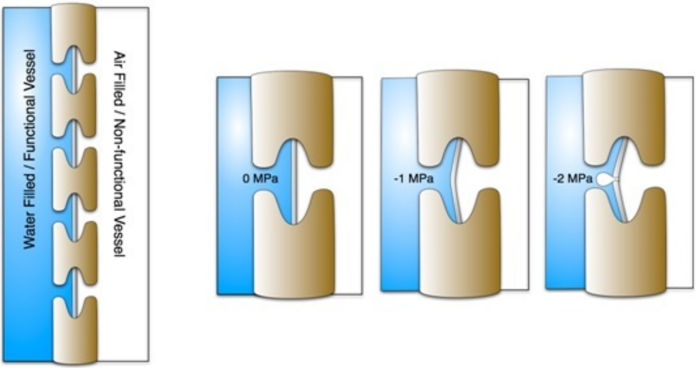


Water transportation — vessel network[1]

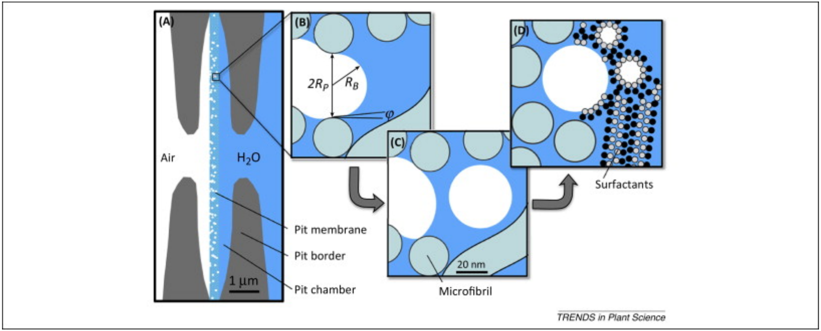


[1] Tyree and Zimmermann, 2002.

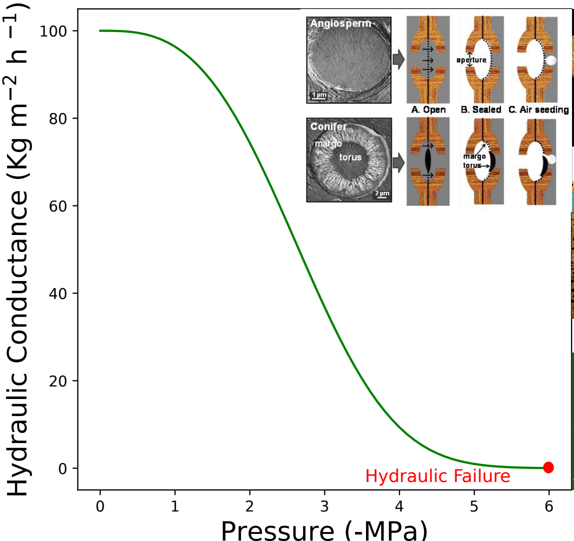
Air seeding and cavitation

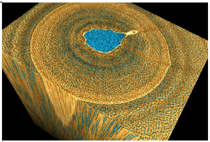


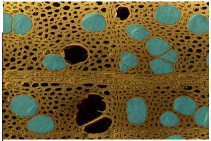
Air seeding and cavitation



How trees use water — water transportation



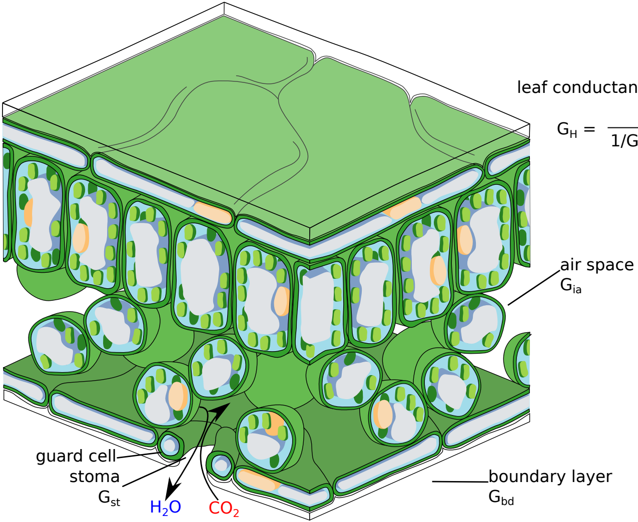




How trees use water — gas exchange

leaf conductance to water vapor

$$G_H = \frac{1}{1/G_{ia}+1/G_{st}+1/G_{bd}}$$



How could tree optimize water usage

- Via the root water absorption;
- Via the water transportation pathway;
- Via the gas exchange.

How do stoma regulate the pore size?

Feedback control

- VPD;
- Soil water potential;

Active control

- ABA;
- Light.

How stoma regulates pore size

stoma

Higher $[CO_2]$
Lower Humidity
Drier Soil

Save water

Lower $[CO_2]$
Higher Humidity
Wetter Soil

Gain carbon

How to model stomatal control?

Summarize?

“Guess”?

Empirical Model

Ball, Woodrow and Berry (1987)

$$g_{sw} = k \cdot A \cdot \frac{h_s}{c_s} \tag{1}$$

Ball, Berry and Leuning

$$G_H = G_0 + \frac{a \cdot A}{(C_a - \Gamma)(1 + D_L/D_0)} \tag{2}$$

G_0, a, and D_0 are fitted parameters.

Photosynthesis Optimization Model

Cowan and Farquhar (1977)

$$\frac{\delta E}{\delta A} = \lambda \tag{3}$$

The disadvantage is the definition of λ, and there is no details of what λ should be.

(Dis-)Advantages

Advantages

- Small time complexity;
- Easy to model;

Disadvantages

- No response to [CO_2] or soil moisture;
- Rely on dataset to obtain the empirical parameters;
- Lack interface to physiological traits;

We need better models!

Why do trees regulate stomata?

To reproduce?

To grow?

Profit should be optimized[2].

[2] Wolf et al. PNAS

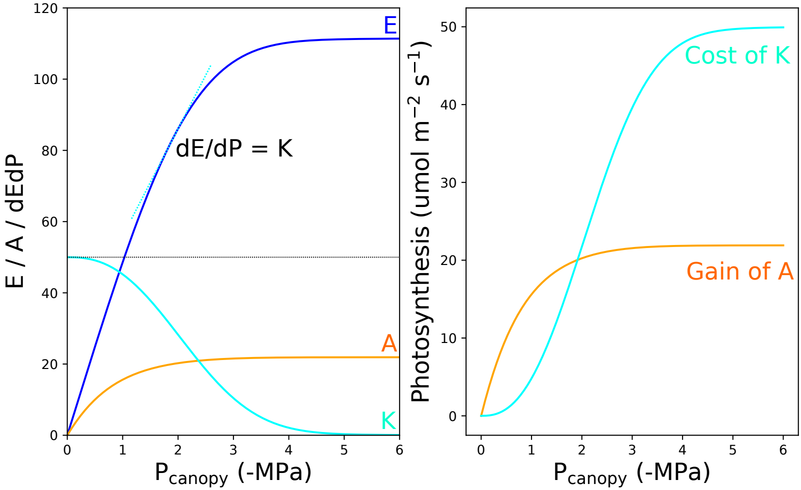
Gain?

Photosynthesis

Cost?

Water?
Hydraulics?
Future?

Cost — Hydraulic impairment



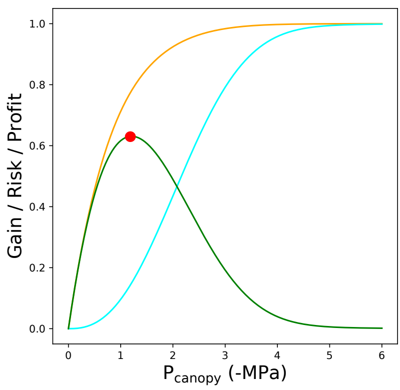
Relative photosynthesis vs. hydraulics trade-off

Sperry et al. (2016)

$$gain = \frac{A}{A_{max}} \qquad (4)$$

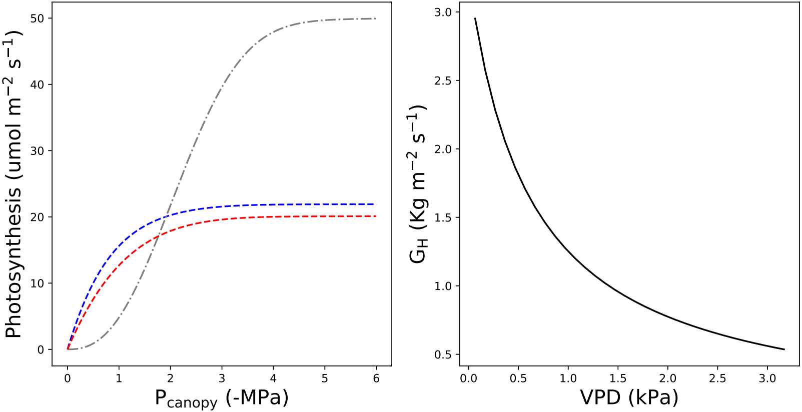
$$risk = 1 - \frac{dE/dP}{dE/dP_{max}} \qquad (5)$$

$$profit = gain - risk \qquad (6)$$

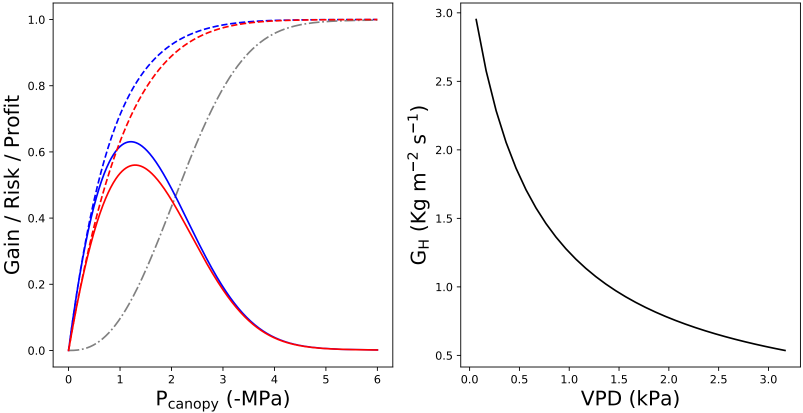


How does the trade-off model behave?

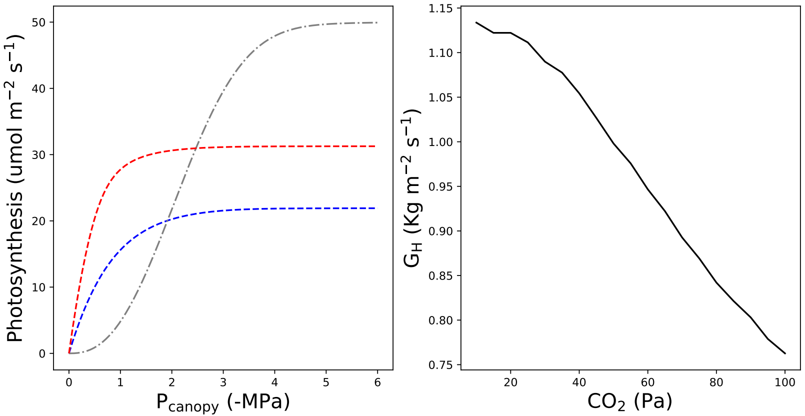
Response to VPD



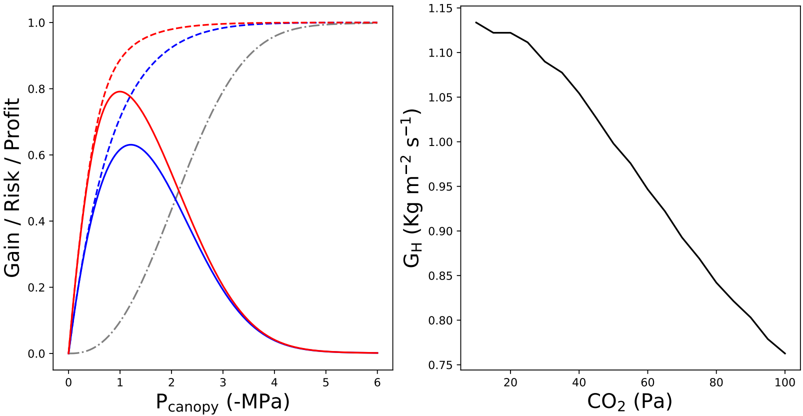
Response to VPD



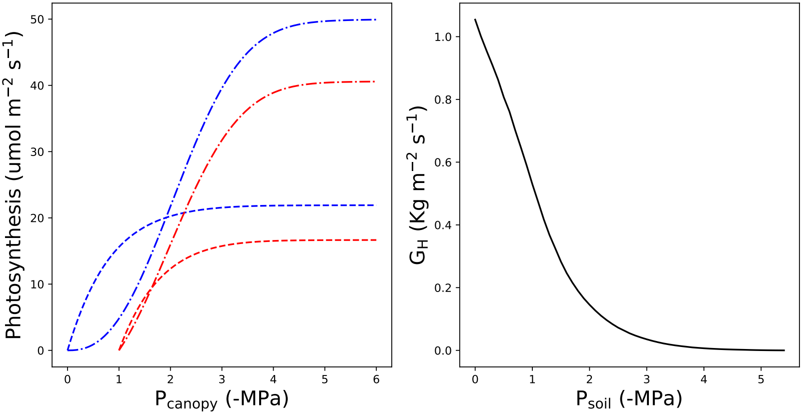
Response to CO_2



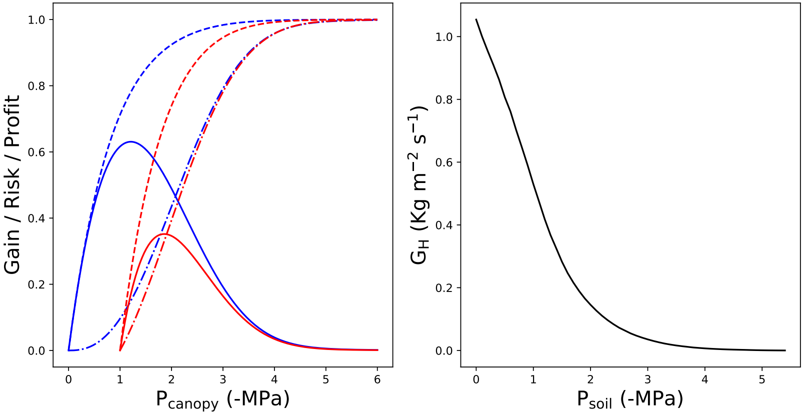
Response to CO_2



Response to P_{soil}



Response to P_{soil}



Plant, Cell & Environment

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Original Article

Predicting stomatal responses to the environment from the optimization of photosynthetic gain and hydraulic cost

John S. Sperry[1], Martin D. Venturas[1], William R. L. Anderegg[1], Maurizio Mencuccini[2,3], D. Scott Mackay[4], Yujie Wang[1] & David M. Love[1]

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ABSTRACT

Stomatal regulation presumably evolved to optimize CO_2 for H_2O exchange in response to changing conditions. If the optimization criterion can be readily measured or calculated, then stomatal responses can be efficiently modelled without recourse to empirical models or underlying mechanism. Previous efforts have been challenged by the lack of a transparent index for the cost of losing water. Yet it is accepted that stomata control water loss to avoid excessive loss of hydraulic conductance from cavitation and soil drying. Proximity to hydraulic failure and desiccation can represent the cost of water loss. If at any given instant, the stomatal aperture adjusts to maximize the instantaneous difference between photosynthetic gain and hydraulic cost, then a model can predict the trajectory of stomatal responses to changes in environment across time. Results of this optimization model are consistent with the widely used Ball–Berry–Leuning empirical model ($r^2 > 0.99$) across a wide

1987). The trade-off has seemingly resulted in tight coordination between capacity to supply and transpire water (hydraulic conductance, k, and diffusive conductance to water vapour, G_w) and the maximum capacity for photosynthesis (carboxylation rate, V_{max}, and electron transport rate, J_{max}; Brodribb *et al.* 2002). If the fulcrum on which this trade-off balances could be identified, it would greatly simplify the difficult problem of predicting how plant gas exchange responds to environmental cues (Prentice *et al.* 2014). In this paper, we describe such a balancing point, explain how it can be readily quantified from measurable plant traits and processes, and evaluate the resulting patterns in stomatal regulation of gas exchange and xylem pressure.

The utility of a stomatal optimization framework has long been recognized, but uncertainty in the optimization criteria and its relation to true fitness costs and benefits has limited its potential for understanding and modelling stomatal behaviour,

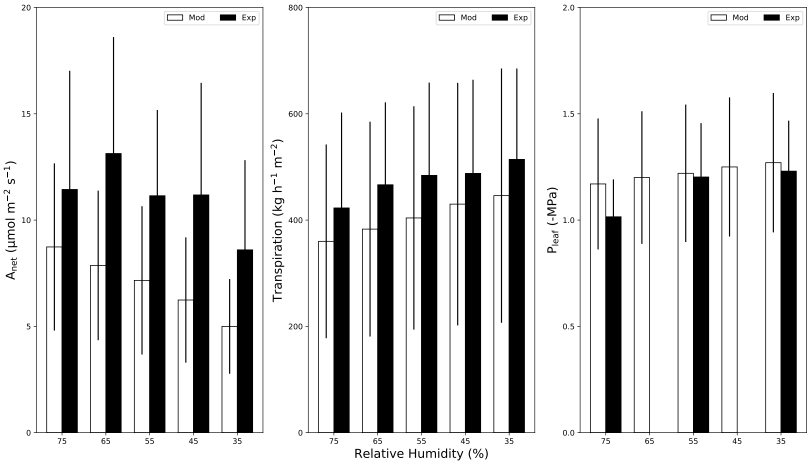
How does the model perform?

Test the model in growth chamber

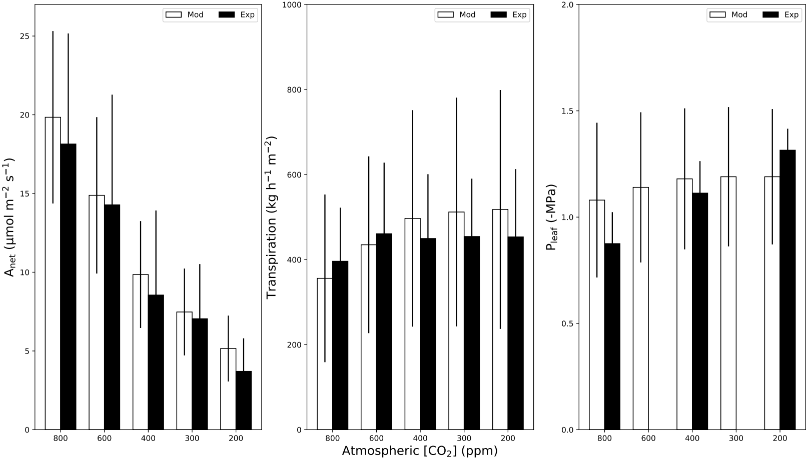
Why growth chamber?

- Stable environment;
- The responses are in plant-level.

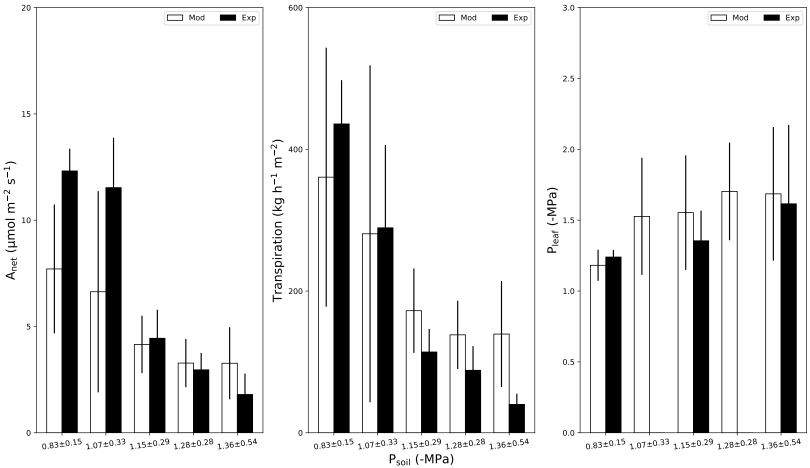
Response to VPD



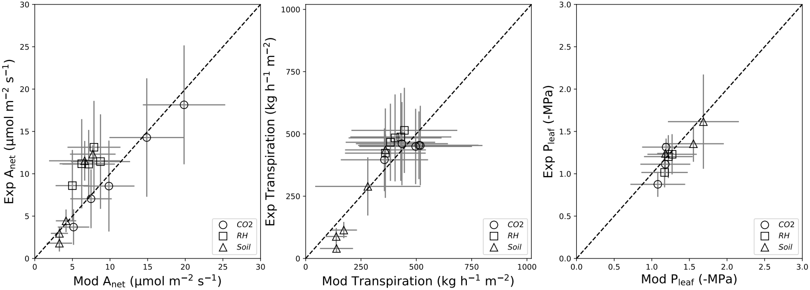
Response to CO_2



Response to soil moisture



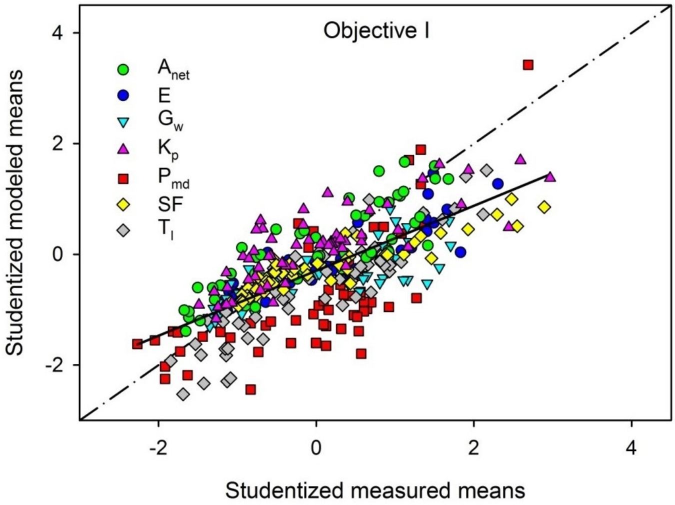
General response



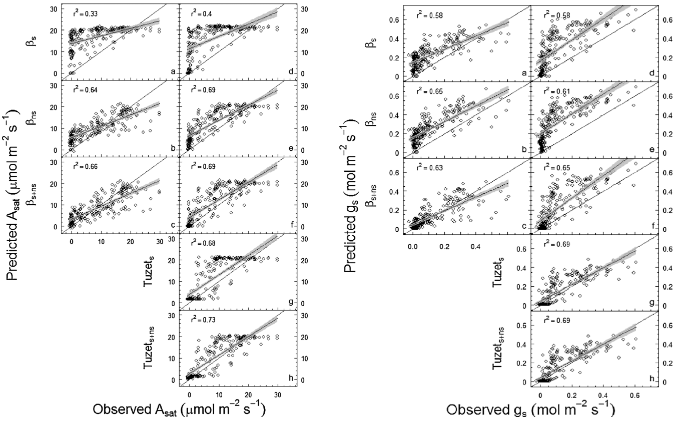
Test the model in open garden[3]

[3] Venturas et al. (minor revision)

Model performance in open garden

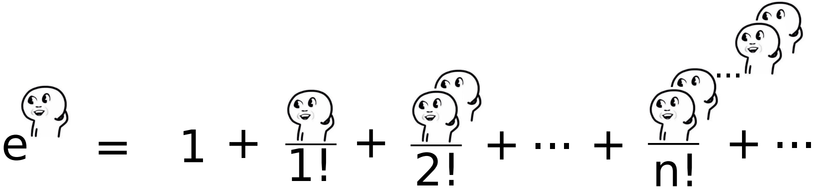


Empirical models[4]



[4]Drake et al. 2017

Acknowledgments


e = 1 + 1! + 2! + ⋯ + n! + ⋯