

Supporting Information for

**Comparing model representations of functional controls on transpiration at a semi-arid Ponderosa Pine site**

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**Introduction**

This supporting information file contains a text describing model updates (Text S1) and parameter sensitivity (Text S2), figures supporting the main text (S1 to S6).

### **Text S1. Updates made to the SPA model**

Following Ruehr et al., (2014), we increased soil evaporation in the SPA model by lowering the tortuosity from 2.5 to 1.0 which increased soil conductance to water vapor diffusion. We further increased the soil conductance to water vapor diffusion by scaling the porosity in the top soil layer from 0.37 to 0.9. Lastly, we reduced the soil roughness length from 0.13 to 0.01 times the canopy height (18m).

As in Reuhr et al., (2014) a sigmoid function was added to scale aboveground tree conductance ( $g_{plant}$ ) by soil water potential (SWP) (eq. S1). We increased the sensitivity of  $g_{plant}$  to SWP to improve model performance.

$$g_{plant} = g_{plant_0} \left( 0.2 + \frac{0.8}{(1 + \exp^{((SWP + 0.784)/0.163)})} \right) \quad (\text{eq. S1})$$

We also added an option to use site-specific soil water retention equations relating soil water content (SWC) to SWP in place of the widely used equations based on soil texture from Saxton et al., (1986). In this application, we used the following water retention relations from Ruehr et al., (2014):

$$SWP = -0.04 - \frac{1.6}{1 + \exp\left(\frac{SWC - 0.096}{0.0184}\right)} \quad (\text{eq. S2})$$

### **Text S2. Parameter sensitivity analysis**

For each model, 100 unique parameterizations were selected using a Latin hypercube sampling design (McKay et al., 1979). Two-year simulations were performed beginning January 1st, 2006 and ending December 31st, 2007 using each parameterization. The modeled transpiration (T) and gross primary productivity (GPP) were averaged over two growing seasons (May-July of 2006 and 2007) for each simulation (Figure S3). We performed a Fourier amplitude sensitivity test (FAST; Saltelli and Bolado, 1998) to quantify the contribution of each parameter to the total variance in

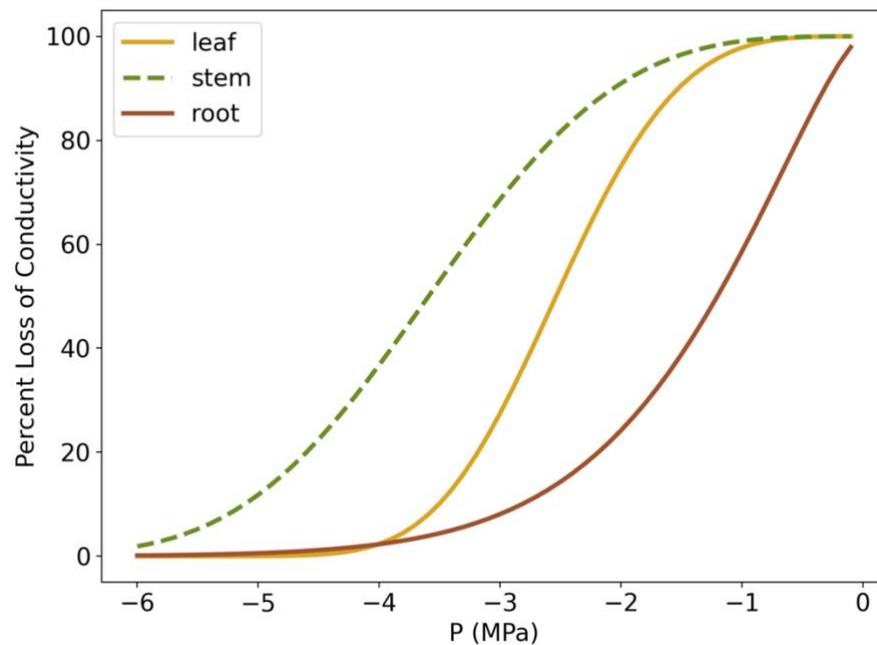
T across the perturbed parameter ensemble. For each parameter, the FAST quantifies the main effect as the ratio of an individual parameter's contribution to the total variance (Figure S4). Additionally, the proportion of variance contributed by interactions among parameters is quantified.

We identified the parameters most influential on the growing season mean transpiration for each model. The WUEi and WUE models were sensitive to the plant conductivity ( $g_{\text{plant}}$ ), which represents 39% and 22% of variance in seasonal mean T respectively (Figure S4). The minimum leaf water potential ( $_{\text{min}}\text{LWP}$ ) was also influential, representing 45% of variance in the WUEi model and 26% of variance in the WUE model. The WUE model was more sensitive to the stomatal efficiency parameter than the WUEi model (33% and 9% respectively). The  $\iota$  parameter determines the plant water use strategy; low values of  $\iota$  allow plants to use water liberally in the mornings which can lead to water depletion and stomatal closure in the afternoons. High values of  $\iota$  represent a more conservative water strategy, but often lead to lower total daily carbon gains.

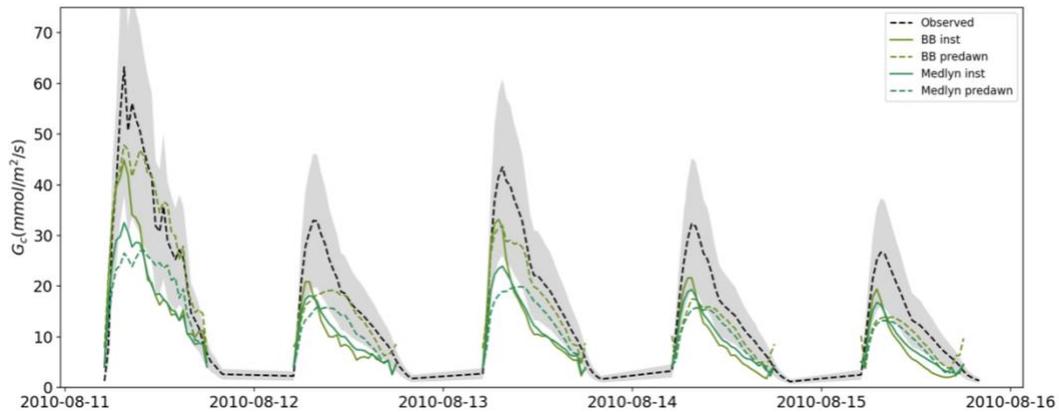
In the Ball-Berry and Medlyn models the  $g_1$  parameter is the dominant source of variability (Figure S4). The parameters influencing hydraulic limitations on stomatal conductance (eq. 6:  $b$  and  $c$ ) have less impact on the variance in seasonal mean T. This is because hydraulic limitations only constrain the simulated T when soil water potential is low during the late summer (July-August). Transpiration rates during the early growing season are much higher and likely dominate the seasonal mean T. The range of values for the  $g_1$  parameter is much larger (and thus much more influential on T) than the degree to which hydraulic limitation modifies  $g_1$  for the latter half of the summer.

In the Sperry model, the maximum whole plant conductance parameter ( $K_{\text{max}}$ ) is most influential on growing season mean T, followed by the  $b$  parameter in the leaf hydraulic vulnerability curve (eq. 7; *Weibull<sub>b</sub>*). The  $K_{\text{max}}$  parameter determines the unstressed rate of T, but this parameter can be constrained with measurements (e.g., Love et al., 2018).

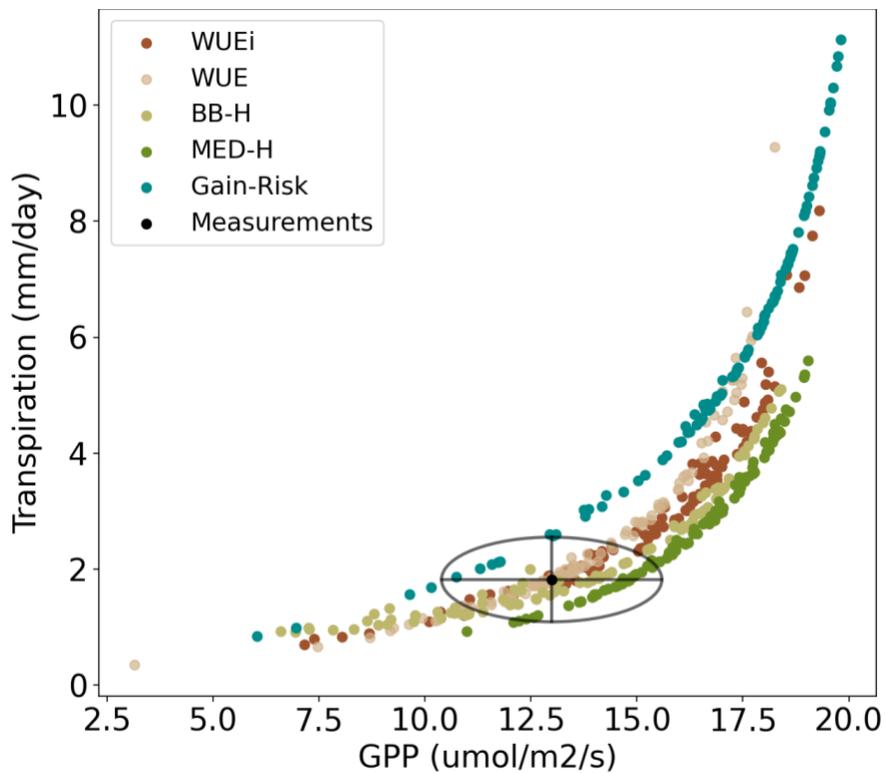
Given the functional form of the hydraulic vulnerability curve (eq. 7), the  $Weibull_b$  parameter determines the point at which hydraulic conductivity falls to 50%, whereas the  $Weibull_c$  parameter determines the steepness of the curve, i.e., how gradually the hydraulic conductivity falls to 50% of maximum conductivity. Given this relationship it is expected that perturbations to the  $Weibull_b$  parameter are more influential on growing season mean T since it effectively determines how early in the summer T begins to be constrained by water availability. The leaf specific conductivity parameter ( $LSC$ ) was not influential on growing season mean T (Figure S4).



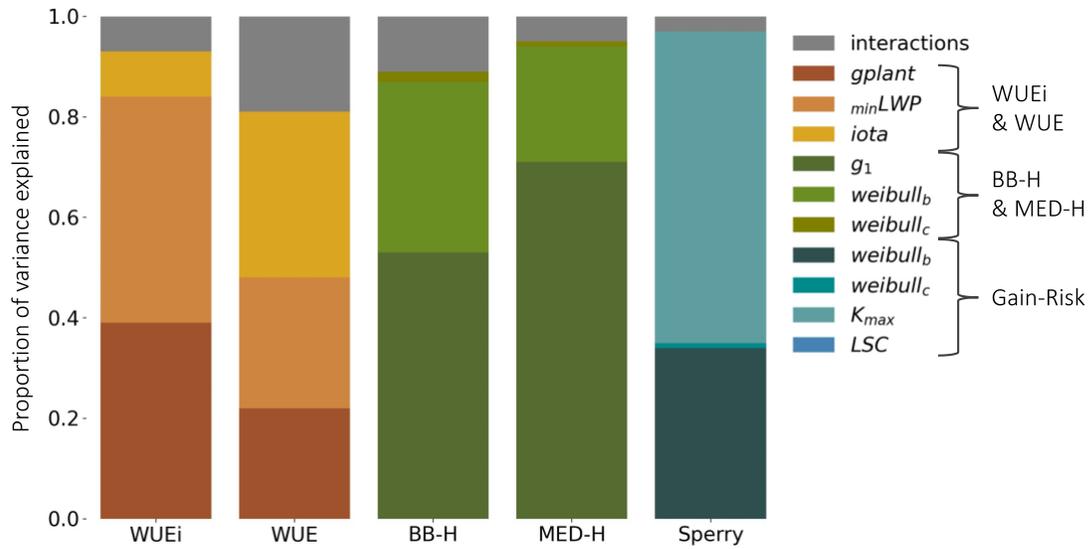
**Figure S1.** Hydraulic vulnerability curves (VC's) for leaves, stem, and roots used in the gain-risk model. The leaf VC is fit to ponderosa pine data from Johnson et al., (2009) as used in Sperry et al., (2019). The stem VC was measured at the US-Me2 site and agrees well with curves fit to data in Sperry et al., (2019). The root VC was fit to measurements from Stout & Sala, 2003, Domec et al., 2004, and Koepke & Kolb, (2013) as used in Sperry et al., (2019). The same leaf VC was used in the MED-H and BB-H models.



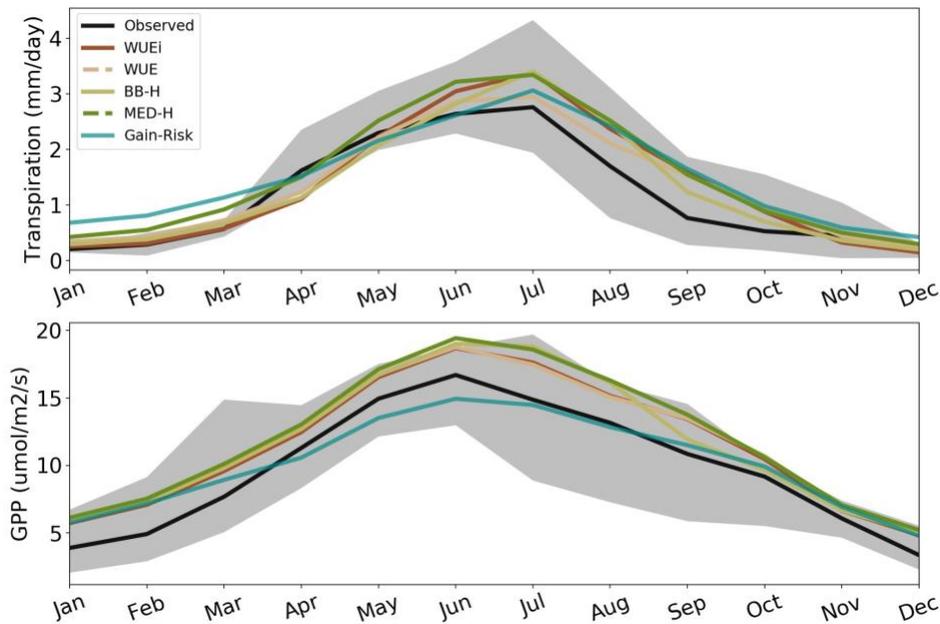
**Figure S2.** Simulated canopy conductance using the Ball-Berry and Medlyn models with hydraulic limitations based on instantaneous leaf water potential (solid) or predawn leaf water potential (dashed).



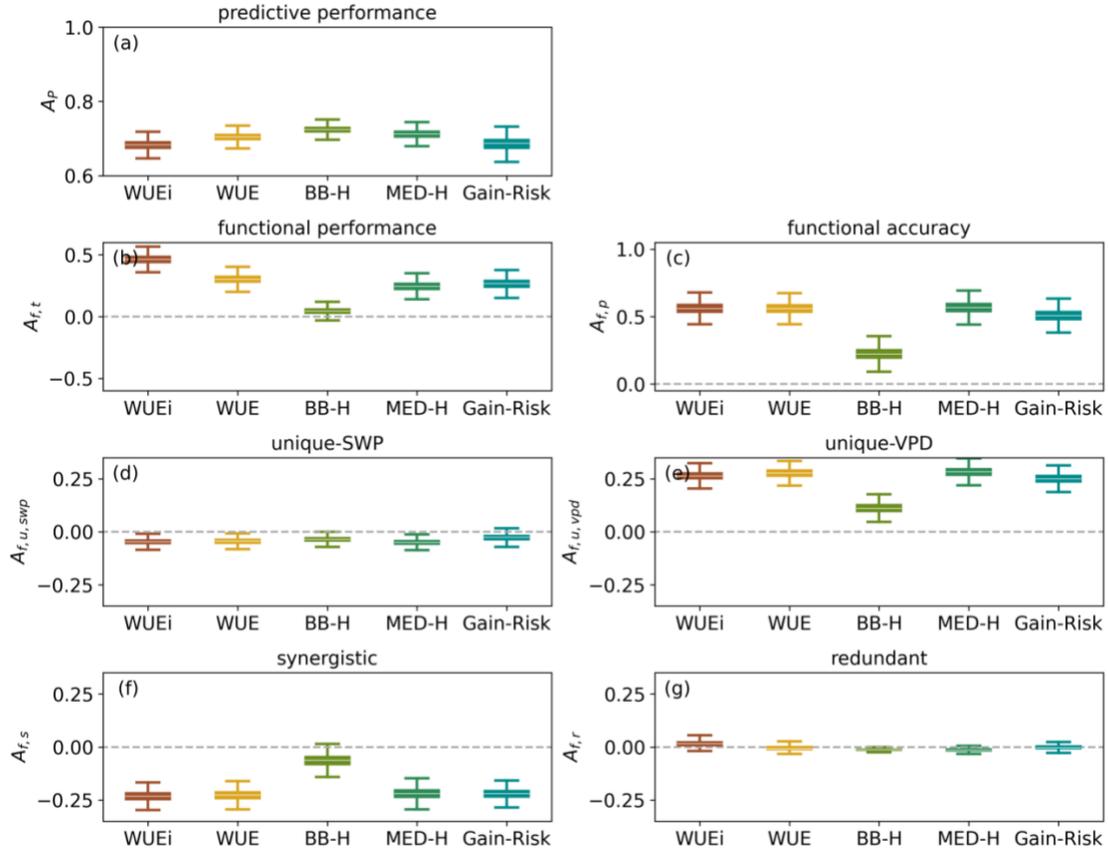
**Figure S3.** Model-simulated GPP ( $\mu\text{mol}/\text{m}^2/\text{s}$ ) and transpiration ( $\text{mm}/\text{day}$ ) during daytime averaged over the growing season (May-July) in 2006 and 2007 using 100 unique parameterizations. Observed GPP and T are shown in black with an oval representing measurement uncertainty. The non-linear relationship suggests that Rubisco limits GPP when transpiration rates are high, as opposed to stomatal limitation.



**Figure S4.** Proportion of the total emulated variance (total=1) in the 2006/2007 growing season mean transpiration contributed from perturbations of individual parameters, estimated with the Fourier Amplitude Sensitivity Test (FAST), and parsed into main effects (colors) and interaction terms among parameters (grey) for each model. Parameter sensitivity in the gain-risk model agrees well with previous studies (Venturas et al., 2018).



**Figure S5.** Mean annual cycle (2006–2018) of measured (black) and modeled (color) daytime (8am–4pm) transpiration (top; mm/day) derived from sapflow measurements and gross primary productivity (bottom; umol/m<sup>2</sup>/s) from eddy-covariance measurements. Grey shading represents the range of observed monthly mean values from 2006–2018.



**Figure S6.** Evaluation of model predictive performance and information partitioning of daily transpiration (T) during growing season (May-August) of 2006 through 2018 when soil water potential (SWP) was above the 75th percentile (i.e., low soil water stress). (a) Predictive performance ( $A_p$ , bits bit<sup>-1</sup>) quantifies the relative fraction of information missing in the model about T compared to observations (a perfect model would have zero missing information). Boxes represent the interquartile range of bootstrapped samples; whiskers represent 5th and 95th percentiles; and white lines represent medians. (b) Functional performance; the relative difference between observed and modeled total multi-variate mutual information from SWP and VPD about T ( $A_{f,T}$ , bits bit<sup>-1</sup>). (c) Functional accuracy; the sum of multi-variate mutual information from SWP and VPD about T ( $A_{f,p} = |A_{f,swp}| + |A_{f,vpd}| + |A_{f,s}| + |A_{f,r}|$ , bits bit<sup>-1</sup>). The components of functional accuracy are partitioned into (d) unique from soil water potential ( $A_{f,swp}$ , bits bit<sup>-1</sup>), (e) unique from VPD ( $A_{f,vpd}$ , bits bit<sup>-1</sup>), (f) synergistic ( $A_{f,s}$ , bits bit<sup>-1</sup>), and (g) redundant ( $A_{f,r}$ , bits bit<sup>-1</sup>) information.

