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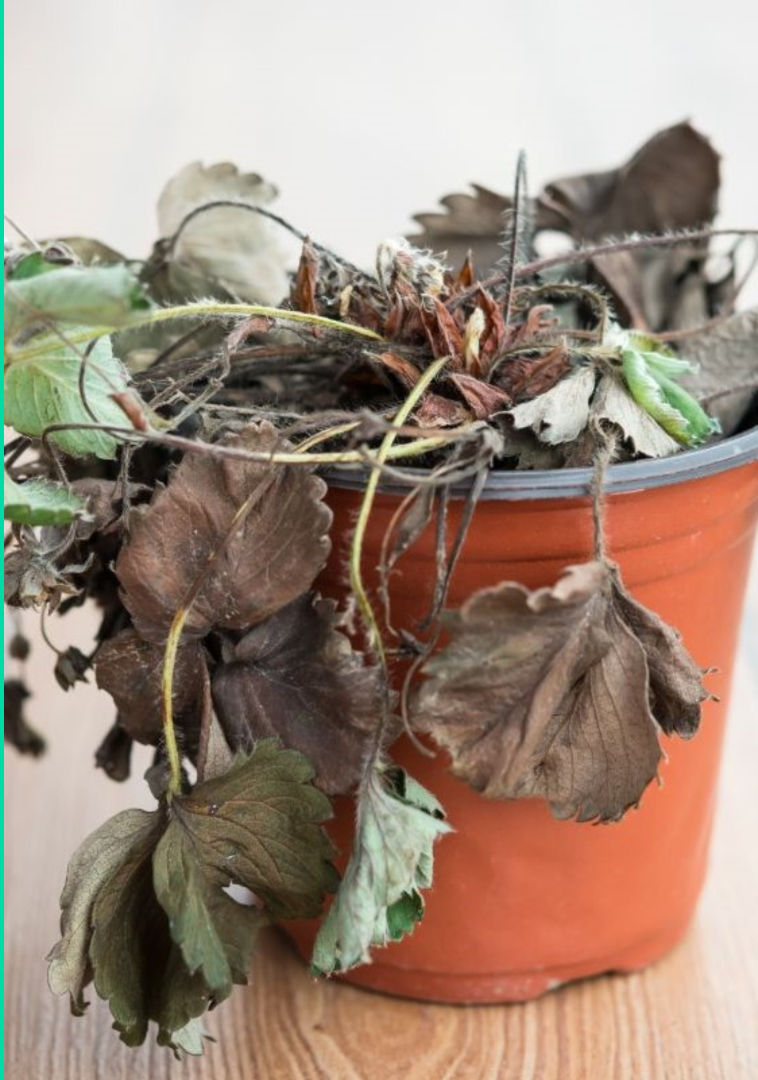
Modelling tree mortality during drought

Freek Engel, Simon Jones, Peter Cox



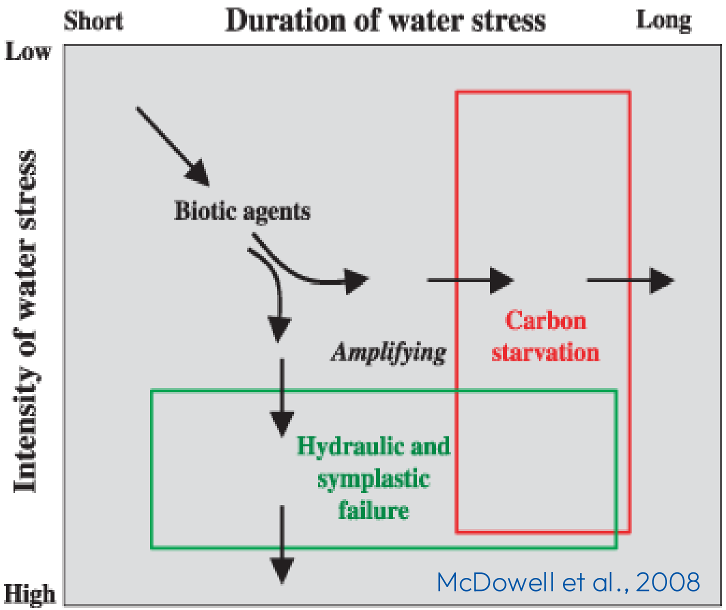
Tree mortality during drought

- Drought is a key driver of mortality across the globe.

- JULES does not represent explicit mortality from drought

$$\gamma = \gamma_{background} + \gamma_{fire} + \gamma_{drought}$$

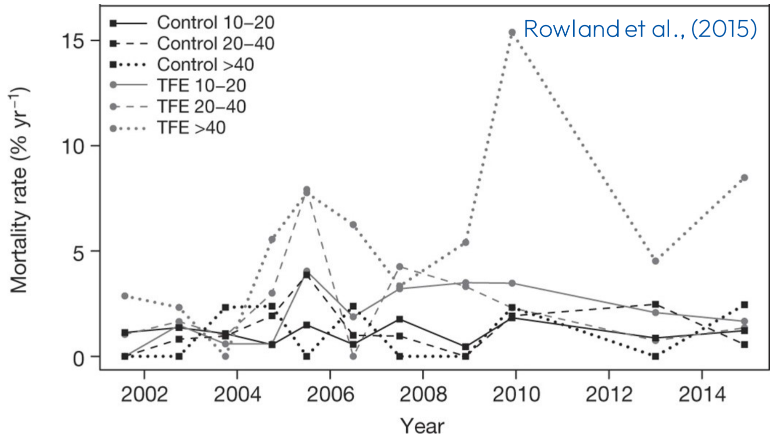
- The drivers of mortality during drought are uncertain.

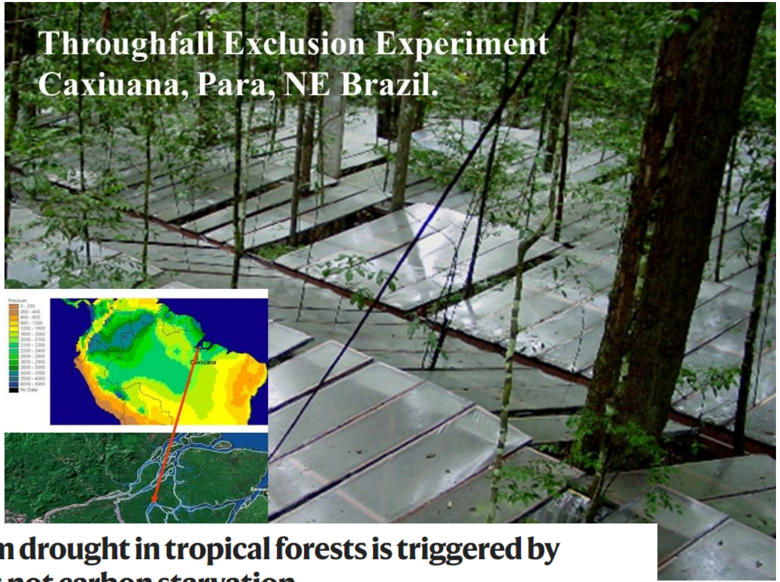


McDowell et al., 2008

The Caxiuanã drought experiment

- Throughfall Exclusion Experiment (TFE)
  - approx. 50% of rainfall is intercepted above the forest floor.
  - >20 years of artificial drought.
- Significant mortality events observed in the TFE plot.
- Due to hydraulic failure*.





Death from drought in tropical forests is triggered by hydraulics not carbon starvation

L. Rowland, A. C. L. da Costa, D. R. Galbraith, R. S. Oliveira, O. J. Binks, A. A. R. Oliveira, A. M. Pullen, C. E. Doughty, D. B. Metcalfe, S. S. Vasconcelos, L. V. Ferreira, Y. Malhi, J. Grace, M. Mencuccini & P. Meir

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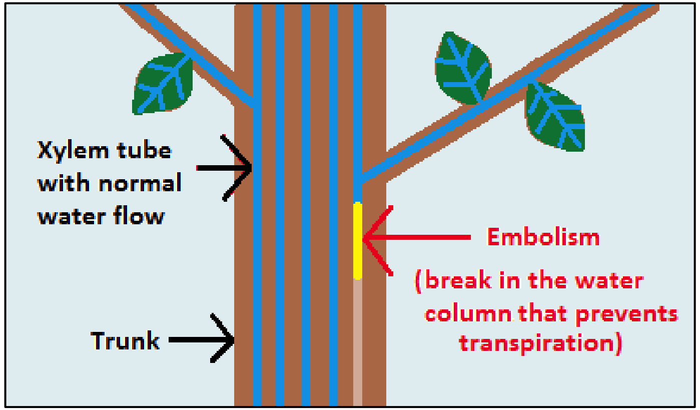
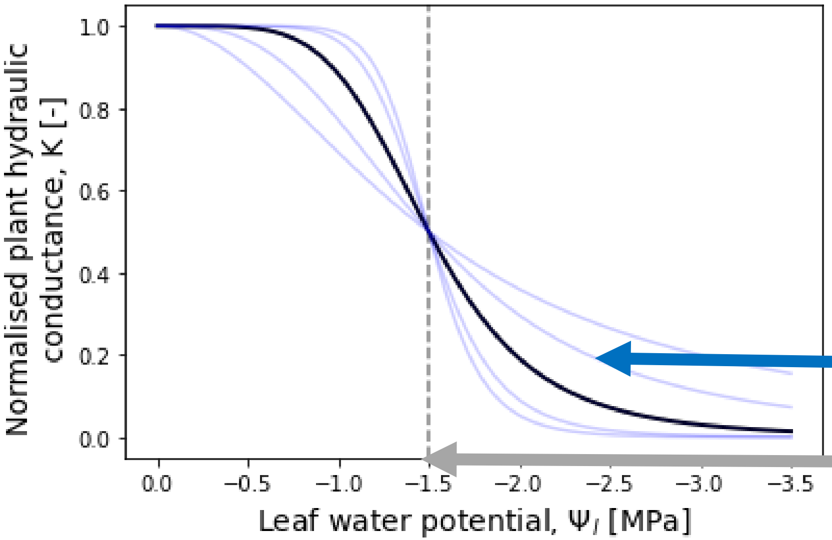
Hydraulic failure

- Excessive xylem embolism can lead to mortality.
- The vulnerability curve describes the percentage loss of hydraulic conductance.





Vulnerability curve

$$\hat{K} = \frac{1}{1 + \left(\frac{\psi_l}{\psi_{50}}\right)^a}$$

K = Hydraulic conductance

ψ_l = leaf water potential

Theory – The vulnerability curve

Vulnerability curve

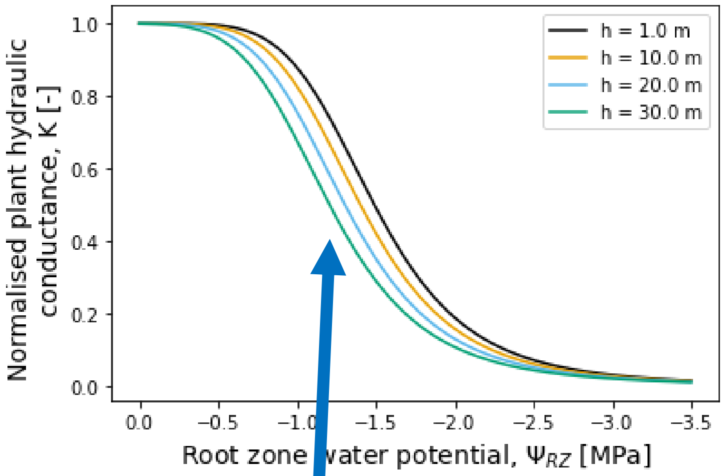
$$\hat{K} = \frac{1}{1 + \left(\frac{\psi_l}{\psi_{50}}\right)^a} = \frac{1}{1 + \left(\frac{\psi_{RZ} - \rho g h}{\psi_{50}}\right)^a}$$

≈ Soil moisture availability

Gravity effect

ψ_{RZ} = Root zone water potential, ρ = density of water, g = acceleration due to gravity, h = plant height

This is made possible by RED!



Tall trees are drought stressed sooner!

Xylem hydraulic status to mortality

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Key assumption

- Mortality rate is linearly proportional to the percentage loss of conductance $(1 - K)$

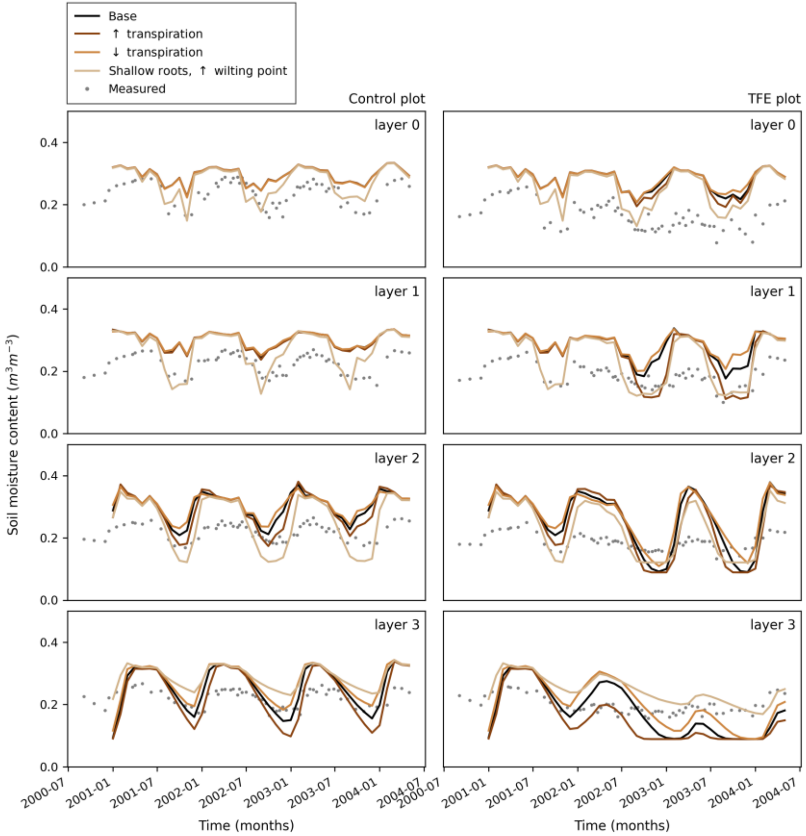
$1.0\ yr^{-1}$

$$\gamma_{drought} = \gamma_{d_{max}}(1 - K)$$

Tuneable parameters: a = shape parameter, ψ_{50} = water potential at 50% conductance loss, $\gamma_{d_{max}}$ = drought mortality at 100% conductance loss

Evaluating the model - Methods

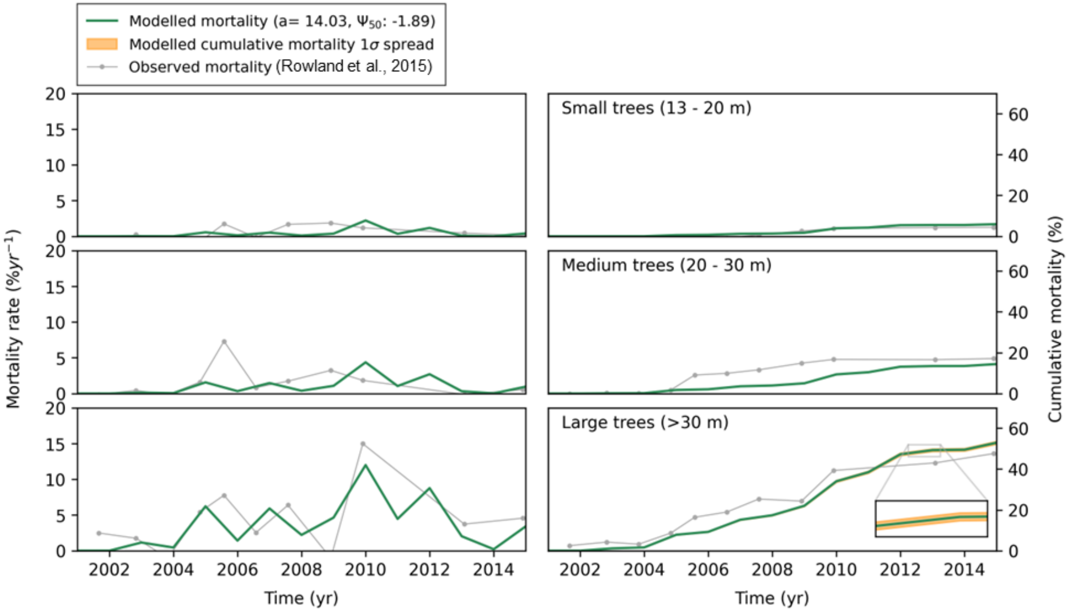
- Run JULES vn7.4 at Caxiuanã under control and drought conditions.
- Drive the mortality model using simulated soil moisture from JULES
- Validate the model using excess mortality observed in the TFE plot for three different tree height categories. Data from Rowland et al., (2015). (We assume that excess mortality in the TFE plot is due to hydraulic failure*).



*big assumption!

Results

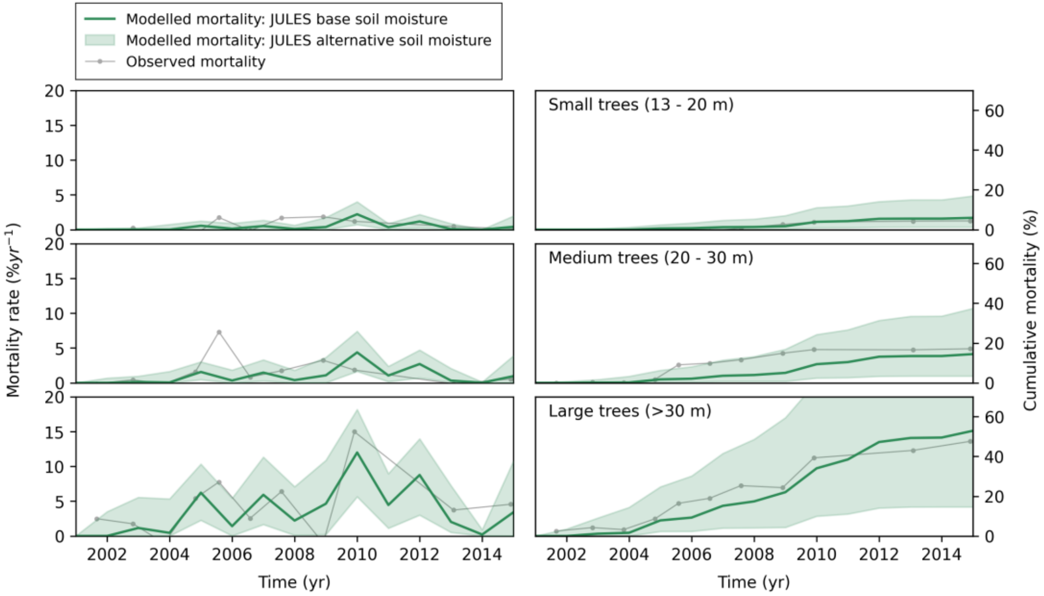
- The model accurately captures observed mortality rates in the TFE plot.
- The model correctly captures the difference between small, medium and large trees.
- MCMC analysis suggests there are small uncertainty bounds on the two parameter values.
  - $\Psi_{50} = 1.89 \pm 0.00476$ [-MPa]
  - $a = 14.03 \pm 0.19$ [unitless]



Results

- The model is very sensitive to the input soil moisture.

- Accounting for the spread in the simulated soil moisture across different JULES configurations:
    - ➢ the model uncertainty increases!



Conclusions and next steps

- Drought mortality is an important process missing from JULES.
- We have developed a simple model of hydraulic failure induced mortality.
- The model can capture observed tree mortality at the Caxiuanã drought experiment.

Next steps:

- What is the regional impact of the model across the Amazon?
- What about other plant functional types / biomes?

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Thank you for listening

JPEG proposal:
"Vegetation disturbance and recovery"
Email: s.r.g.jones@exeter.ac.uk

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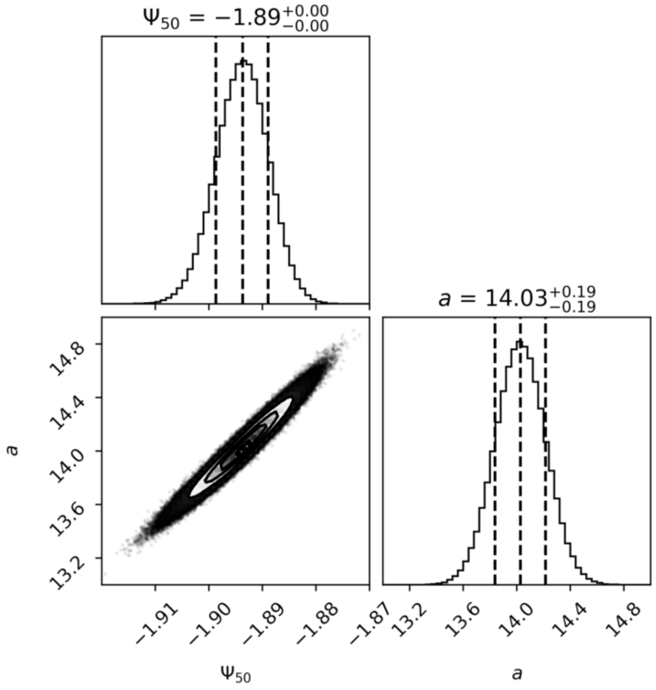
Additional slides

MCMC

- Markov-Chain Monte Carlo sampling estimates small uncertainty bounds on ψ_{50} and a parameters.



Why is our $\boldsymbol{a}$ value so large?

- There is an additional evaporative effect in the calculation of ψ_l.
- Originally we assumed this could be ignored as stomatal conductance (g_s) goes to zero during drought.
- BUT stomatal conductance does NOT go to zero during drought
  - Evaporative effect should not be ignored
  - Tall trees experience higher VPD than small trees
  - But this is difficult to capture since JULES does not currently have a microclimate.

Vulnerability curve

$$\hat{K} = \frac{1}{1+\left(\frac{\psi_l}{\psi_{50}}\right)^a} = \frac{1}{1+\left(\frac{\psi_{RZ}-\rho g h - r_p g_s D}{\psi_{50}}\right)^a}$$

Evaporative effect

Root-zone water potential

- Root-zone water potential is not the same as soil water potential
- Calculating $\boldsymbol{\psi_{RZ}}$ is not trivial

$$\psi_{rz} = R_{rz} \sum_i \frac{\psi_{s_i}}{R_i} \quad \text{where} \quad R_{rz} = \sum_i \frac{1}{R_{s_i}}$$

<u>Brooks-Corey</u>

$$\psi_s = \psi_{sat} \left(\frac{\theta}{\theta_{sat}} \right)^{-b}$$

$$K_s = K_{sat} \left(\frac{\theta}{\theta_{sat}} \right)^{2b+3}$$

<u>van Genuchten</u>

$$\frac{\theta - \theta_r}{\theta_s - \theta_r} = \frac{1}{[1 + (a_v \psi_s)^n]^m}$$

$$K_s = K_{sat} S^{\xi} \left[1 - \left(1 - S^{\frac{1}{m}} \right)^m \right]^2$$

$$m = 1/n \text{ , } S = \frac{\theta - \theta_r}{\theta_s - \theta_r}, \ \xi = 0.5$$

<u>Resistances</u>

$$R_i = \frac{-\ln\left(r\sqrt{N_i}\right)}{2\pi d z_i K_{s_i} N_i} + \frac{R_p}{froot_i}$$