P-hydro: A new optimality-based first-principles theory unifying plant photosynthesis and hydraulics

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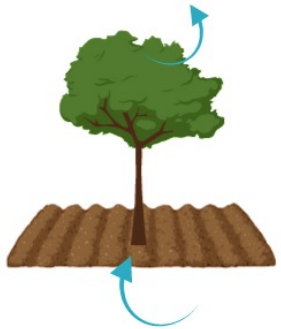
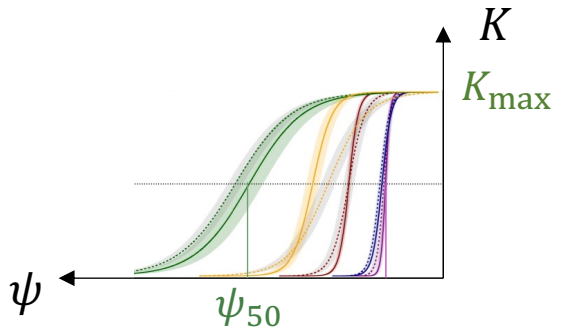
Need a theory to explain plant responses

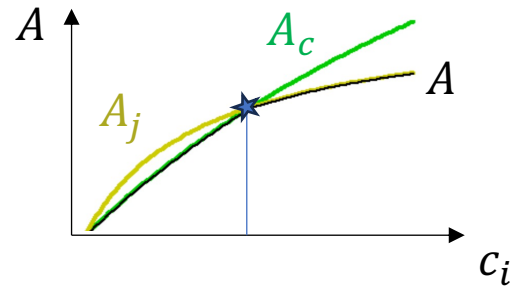
1. Decline of GPP and transpiration with decreasing soil moisture (Stocker et al, 2018)
2. Short term decline of V_{cmax} with soil moisture (Zhou et al 2013, 2014) and subsequent recovery (Zhou et al 2017)
3. Stomatal closure before substantial xylem embolism (Choat et al 2018)
4. Global convergence towards low hydraulic safety margins (Choat et al 2012)
5. Differential (trait-dependent) response of different species to soil moisture (Isohydric – Anisohydric spectrum)

P-hydro: a new first-principles theory of photosynthesis

1. **Variable conductivity:** Plant conductivity declines with decreasing water potential
2. **Water balance:** Water supply from stem equals atmospheric demand from leaves
3. **Photosynthetic coordination**: leaves operate at the point where photosynthesis is co-limited by carboxylation capacity and light
4. **Profit Maximization:** Plants adjust photosynthetic capacity ($J_{\max}$) and soil-leaf water potential difference ($\Delta\psi$) to maximise net assimilation







$$A - \alpha J_{\max} - \gamma \Delta\psi^2 = \max$$

Cost parameters: α, γ

Traits: $K_{\max}$, ψ_{50}

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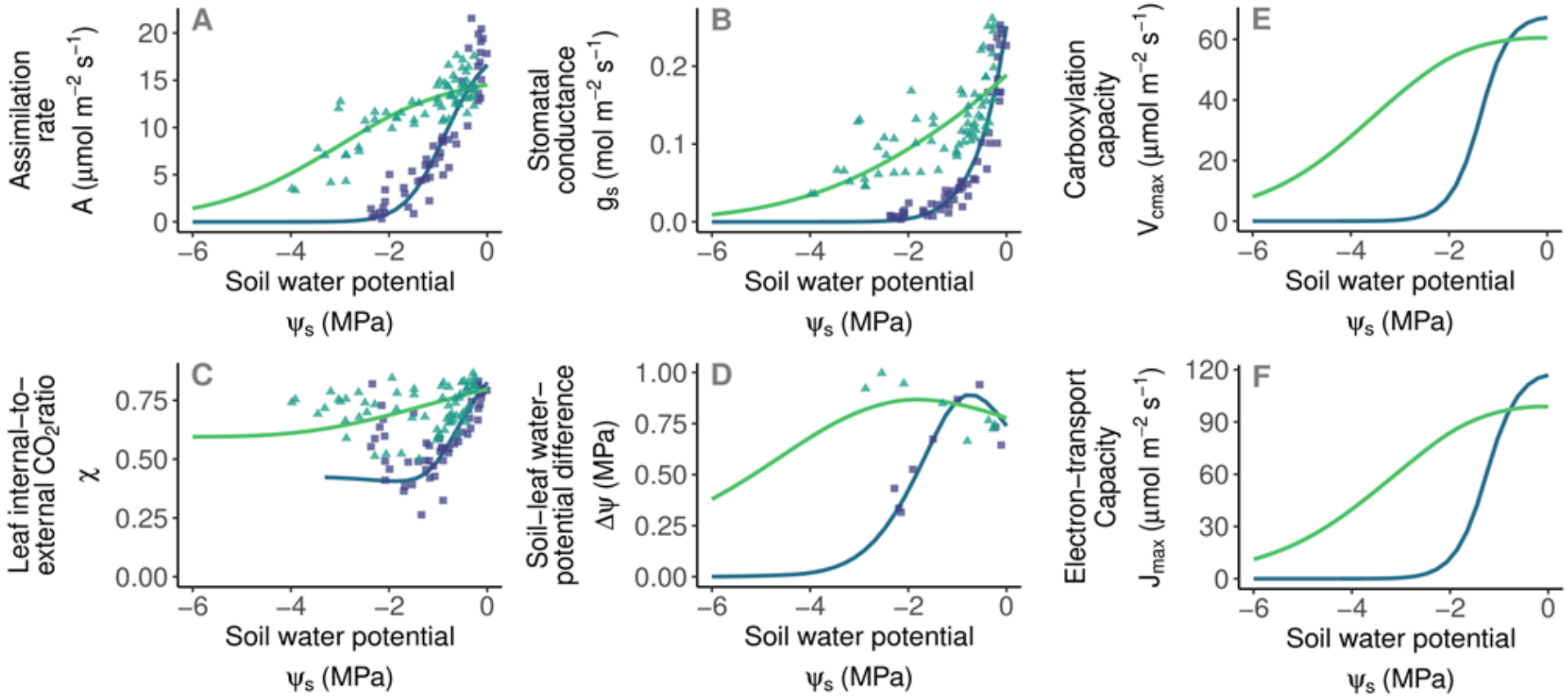
Predicting plant responses in drydown experiments

- Drydown response data from species spanning diverse plant functional types (Zhou et al 2013)
  - Gymnosperms 2
  - Malacophyll angiosperms 3
  - Schlerophyll angiosperms 9
  - Shrubs 2
  - Herbs 2
- Progressive soil drydown under otherwise natural conditions (in glasshouses)
- Report triplets of Assimilation rate (A), stomatal conductance (g_s), predawn leaf water potential (ψ_s); sometimes also soil-leaf water potential difference ($\Delta\psi$)

Drought response of two contrasting *Eucalyptus* species

Eucalyptus populnea $K = 0.94,\quad \psi_{50} = -1.75,\quad \gamma = 1.97,\quad \alpha = 0.1,\quad b = 1$

Eucalyptus pilularis $K = 1.71,\quad \psi_{50} = -0.36,\quad \gamma = 1.13,\quad \alpha = 0.1,\quad b = 1$



Increasing Dryness

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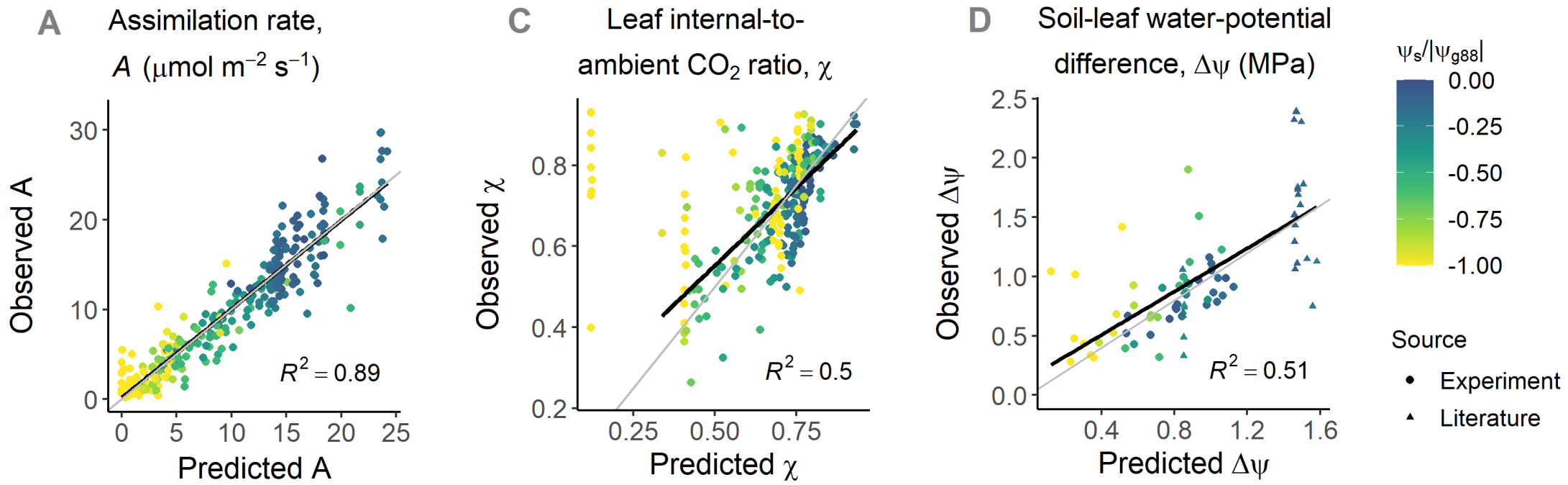
Predictions match observations across 18 species from diverse biomes



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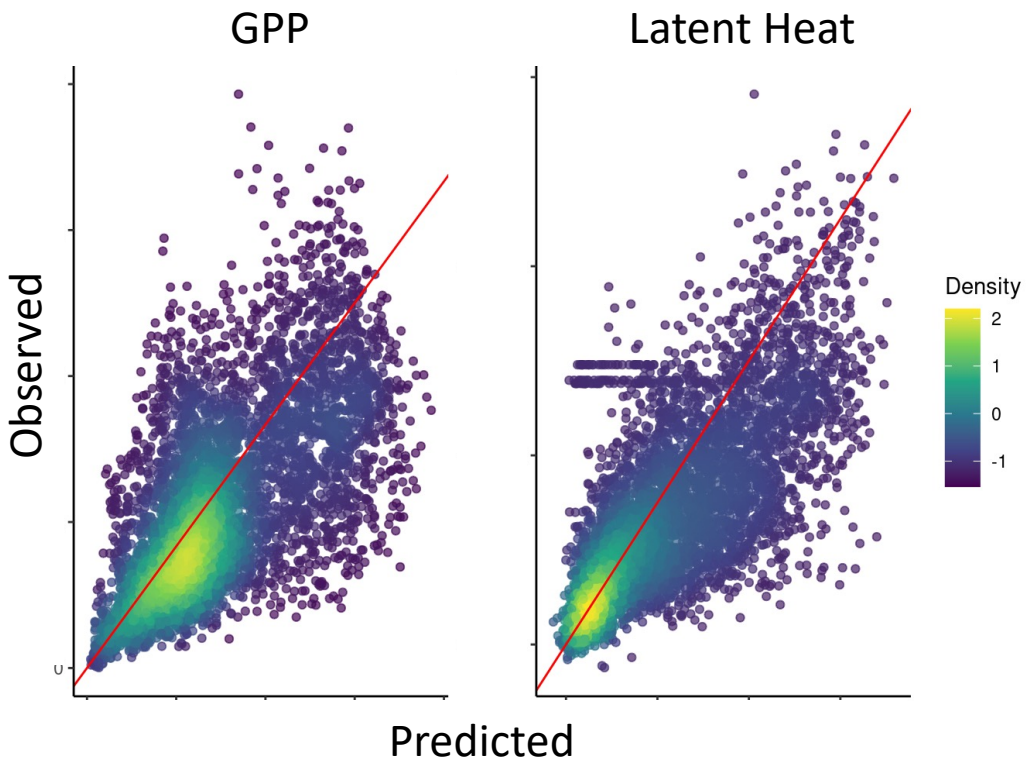
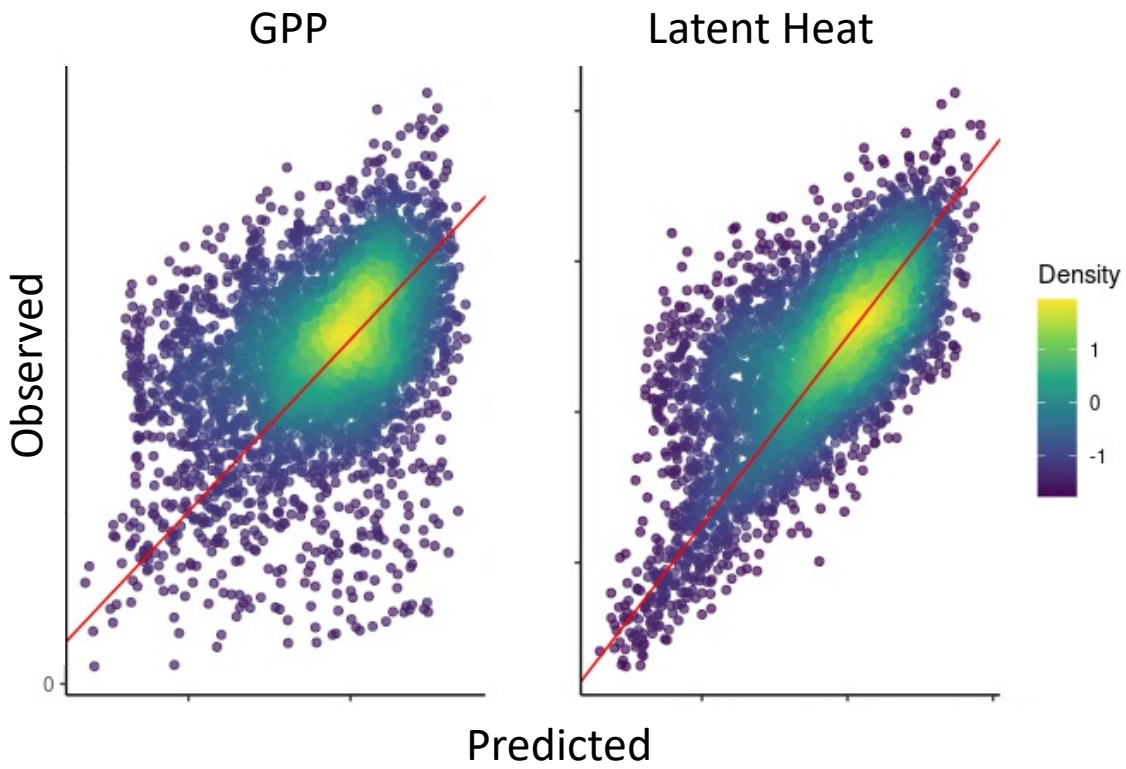
Predicting fluxes at the global scale (Fluxnet sites)

Plant | P-hydro ⟷ SPLASH | Soil + Bayesian parameter estimation

Puechabon, France (Seasonal temperate)

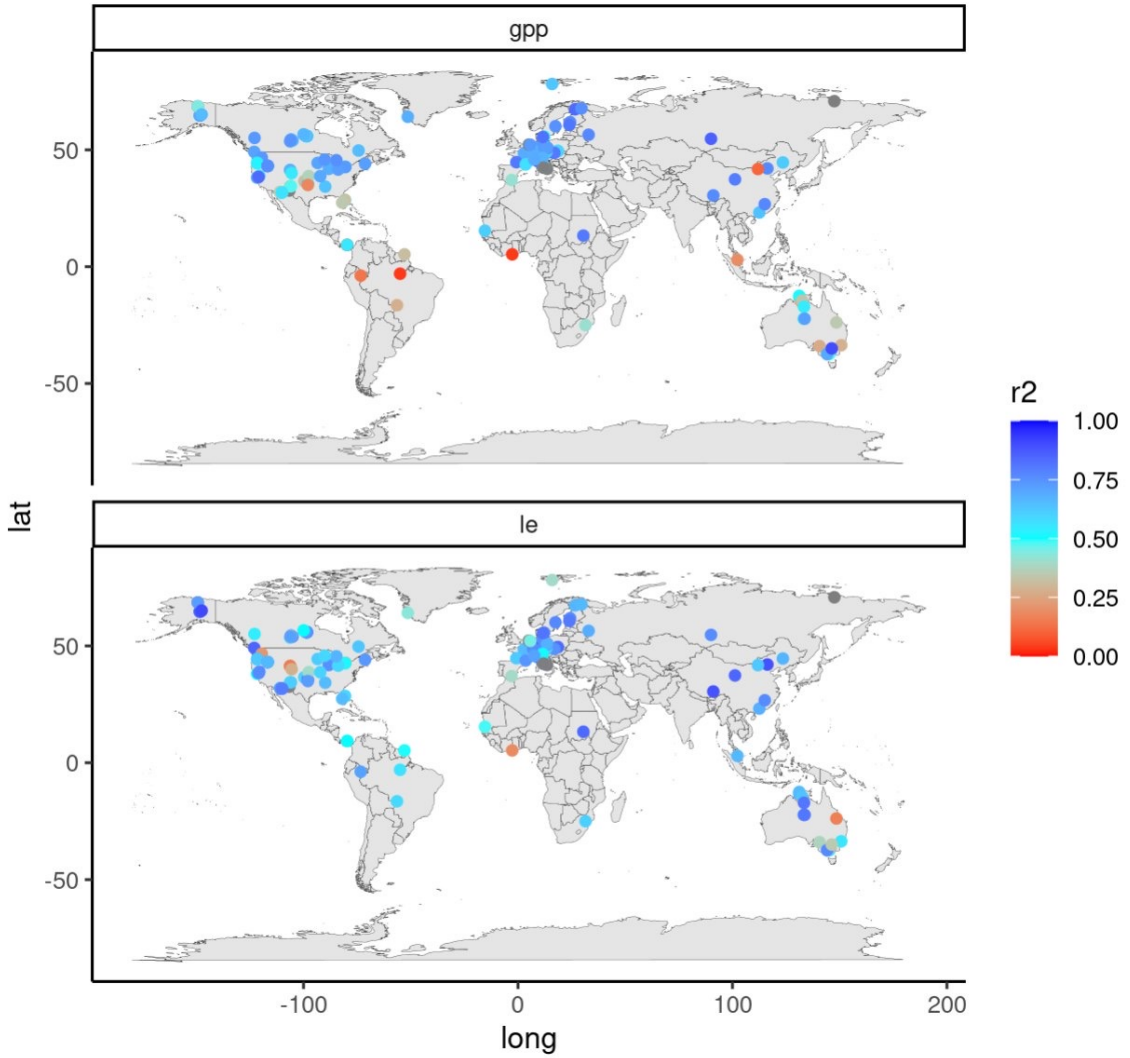


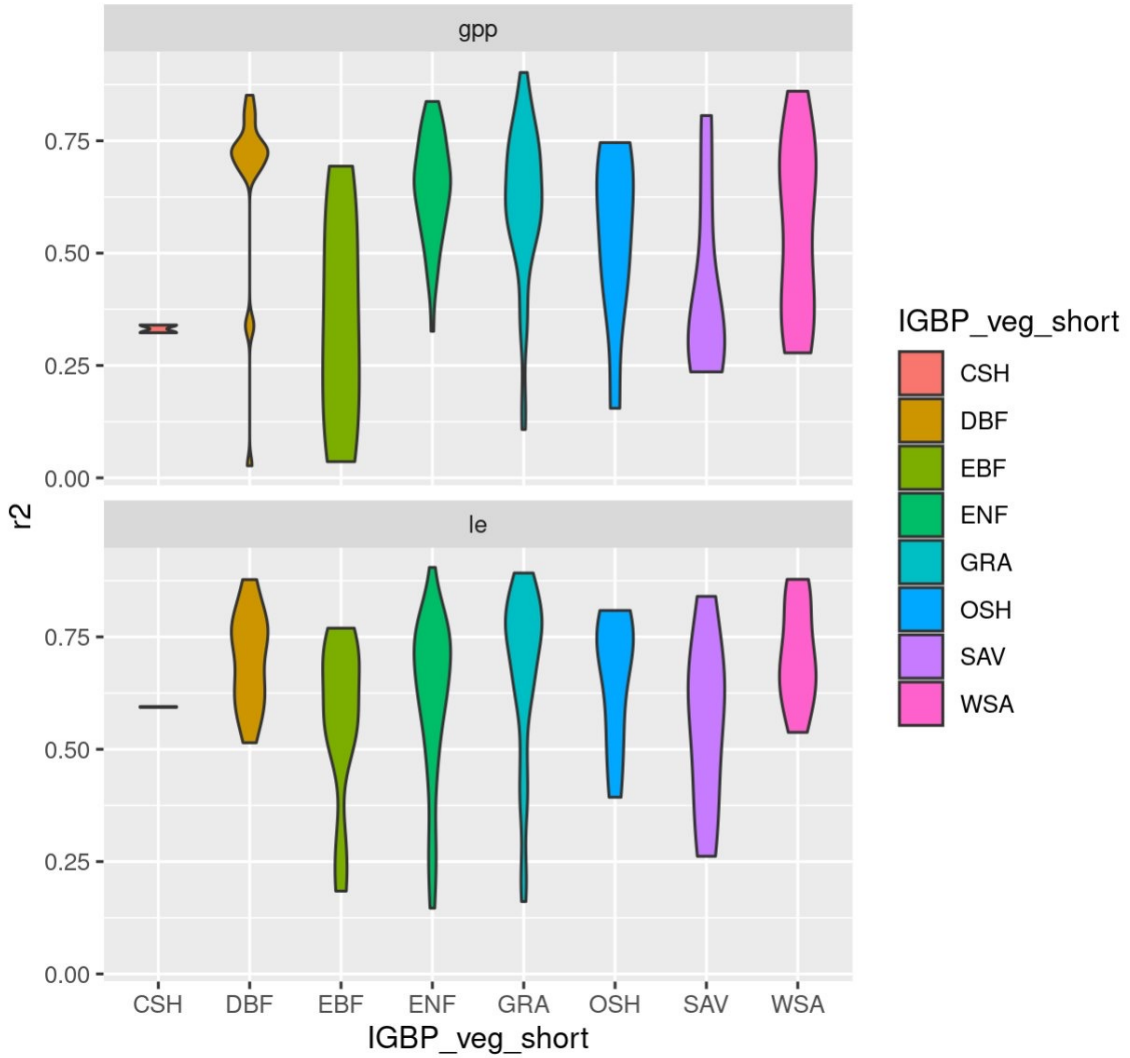
Guyaflux, French Guiana (aseasonal tropical)



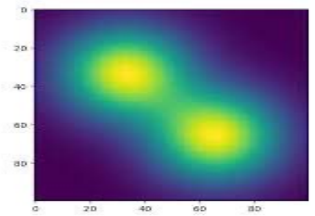
Joshi & Stocker. *in prep*.

Phydro delivers good fits across PFTs and geographies



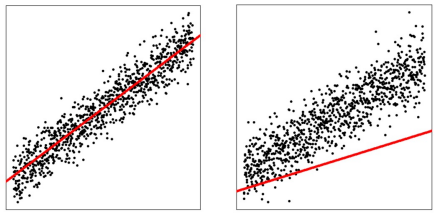


Challenges and solutions



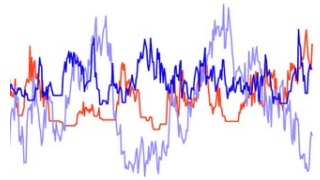
Equifinality

Multiple hydraulic parameters give same output.



Indirect observations

Available proxies (e.g. VOD) of water potential are mere correlates, so need more parameters to assimilate them.

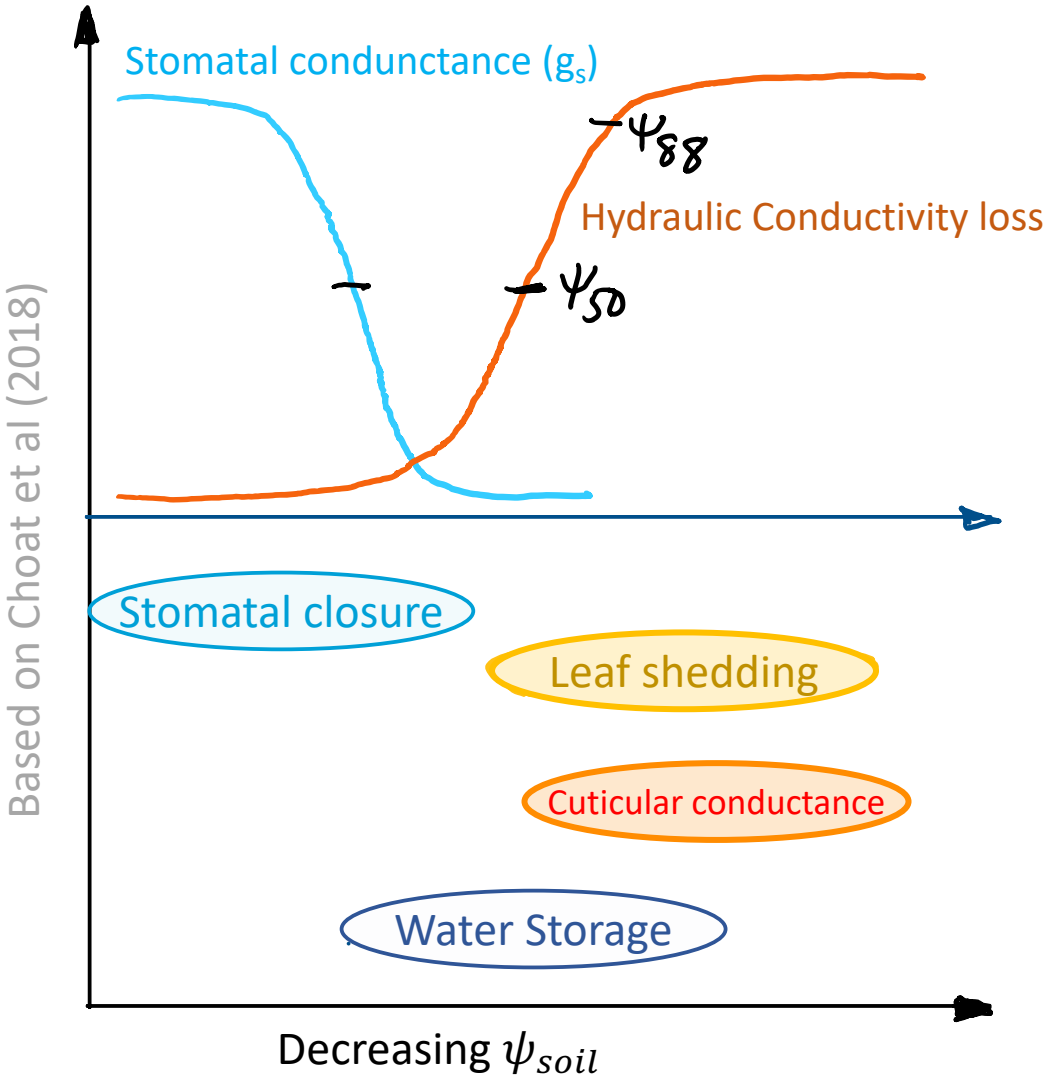


Slow convergence

Equifinality traps MCMC chains in parts of the posterior, leading to slow convergence

Solution: need measurements of water potential to constrain posteriors

Next steps: Predict plant-level properties by optimality



Variable (Regulating process)	Time scale
$g_s, c_i/c_a$ (Stomatal regulation)	Seconds - hours
Jmax, Vcmax (Biochemical acclimation)	Weeks
Leaf area acclimation	Months
Trait adaptation	Years

Questions?

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