Beyond the black box: A perspective on plant function for carbon cycle and land surface modelling

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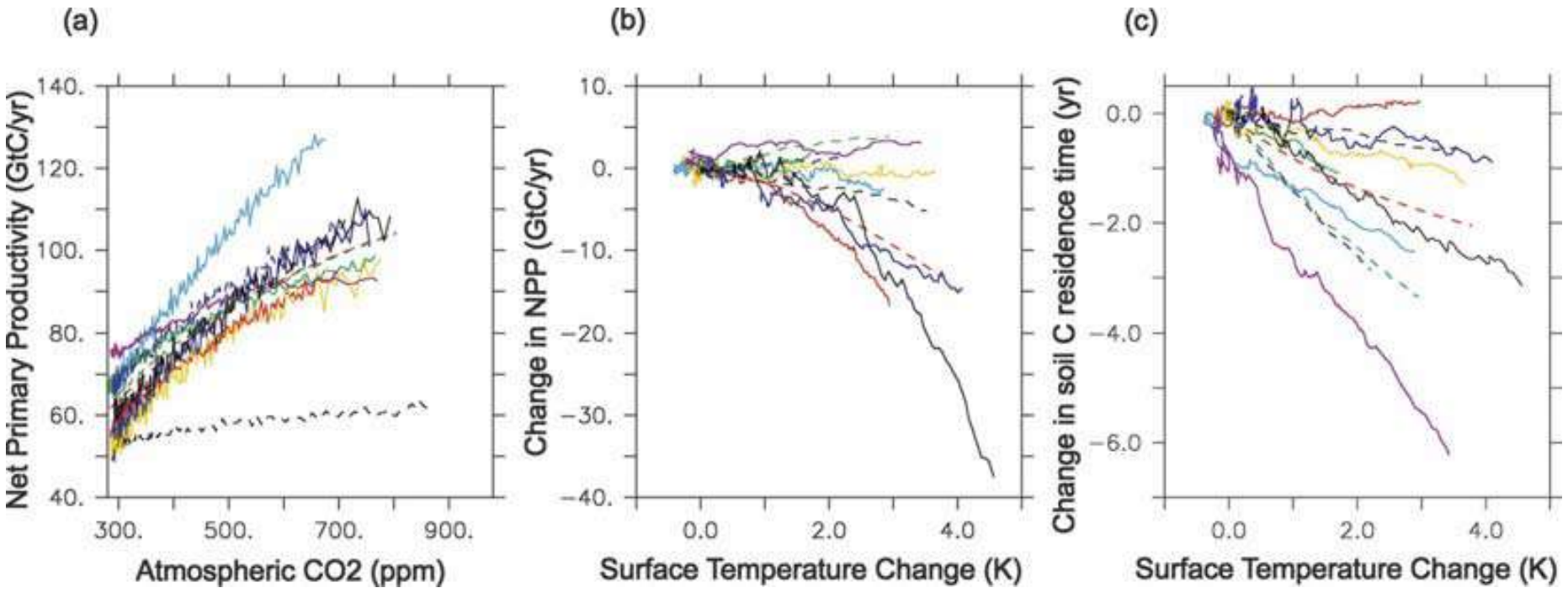
Topics

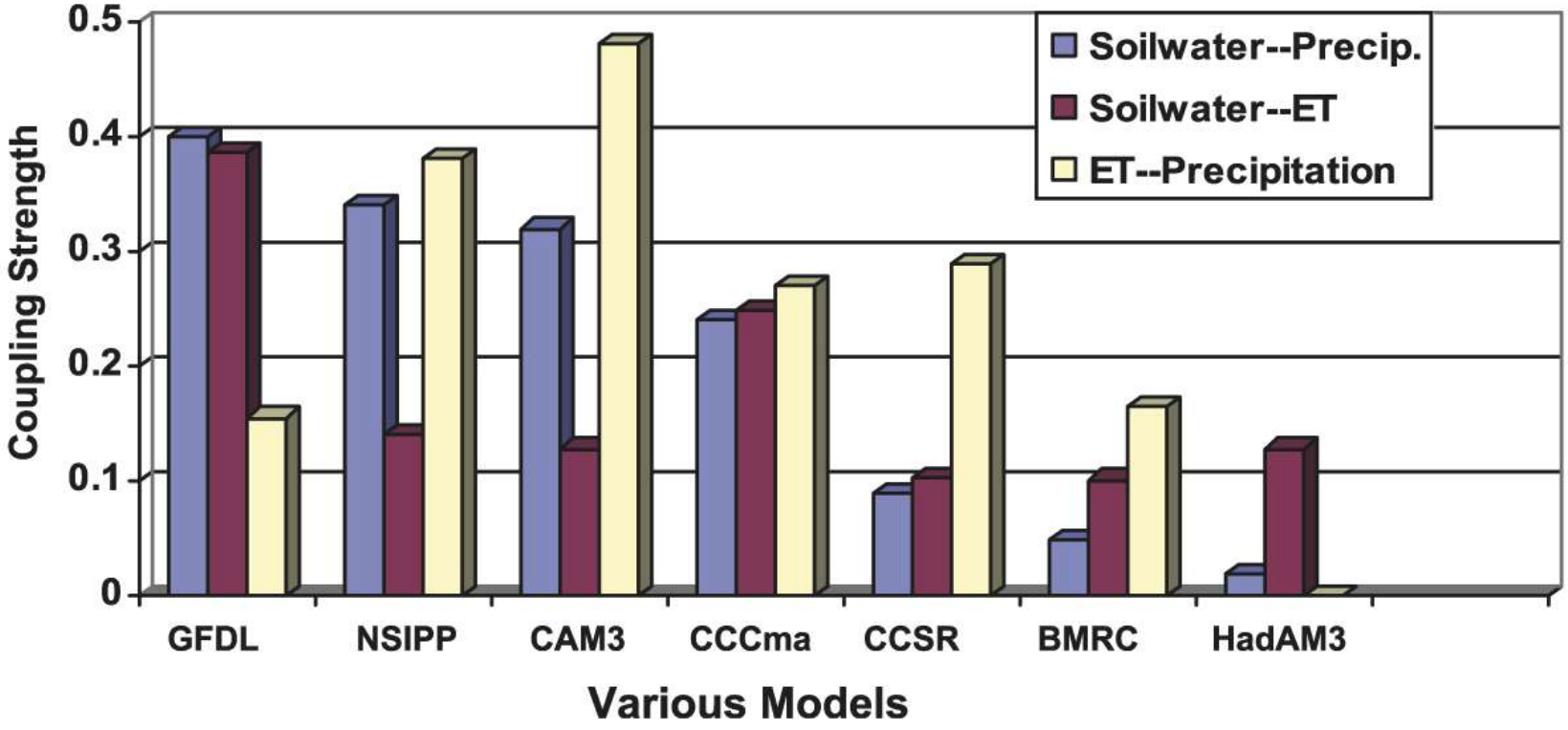
- 2 scandalous findings from IPCC 2007 (we can't model the carbon cycle; we can't model the hydrological cycle)
- What's missing?
- 2 examples why biology can be simpler than physics (because of natural selection)
- Includes yet another spin on optimal stomatal conductance
- A brief manifesto for the 'next-generation DGVM'

“Uncertainty” in C cycle feedbacks



Friedlingstein *et al.* (2006) *J. Climate*

“Uncertainty” in hydrological cycle feedbacks

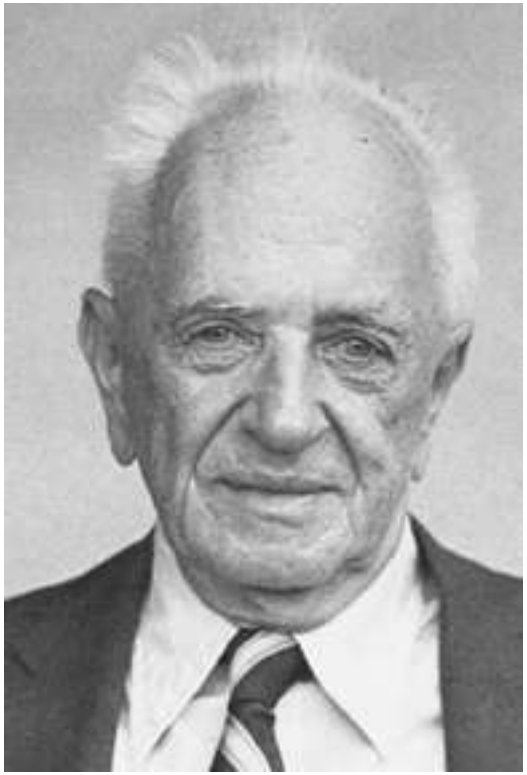


What is missing?

- Benchmarking (both carbon and water metrics)…. necessary, but not sufficient
- Data assimilation…. valuable, but not “the answer”
- Clear thinking…. explicit, tested or testable hypotheses
- Transparency in models
- Synergy between modelling and experimental work
- Optimization: the “missing law” of biology (and thus biophysics and biogeochemistry)

Dobzhansky's dictum

"Nothing in biology makes sense except in the light of evolution"



What is optimized?

- Cowan & Farquhar (1977): maximize assimilation, minus cost of transpiration
- maximize $\{A - \lambda E\}$ where λ is the “carbon cost of water”
- Solution by Medlyn *et al.* (2011) under light limitation
- $c_i/c_a \approx g_1/(g_1 + \sqrt{D})$, where D is vpd and:
- $g_1 = \mathrm{f}(\lambda, \Gamma_*, a)$

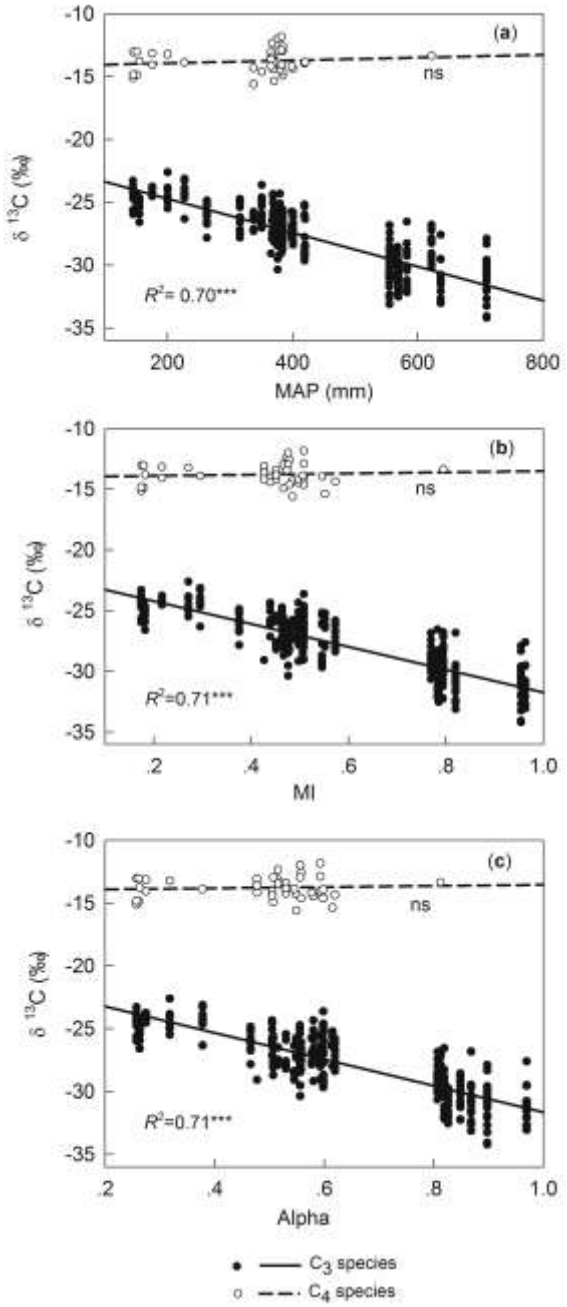
- (NB the devil in the details)

What is optimized?

- Wright *et al.* (2003 *Am. Nat.*): minimize the *sum* of the unit costs of transpiration and photosynthesis
- minimize $\{aE/A + bV_{cmax}/A\}$
- Solution by Prentice *et al.* (in prep.) under Rubisco limitation
- $c_i/c_a \approx g_1/(g_1 + \sqrt{D})$, where D is vpd and:
- g_1 = f (b, K, Γ_*, r_s, h, ρ_s, η, $\Delta\Psi_{max}$, k_s)

Testable hypotheses

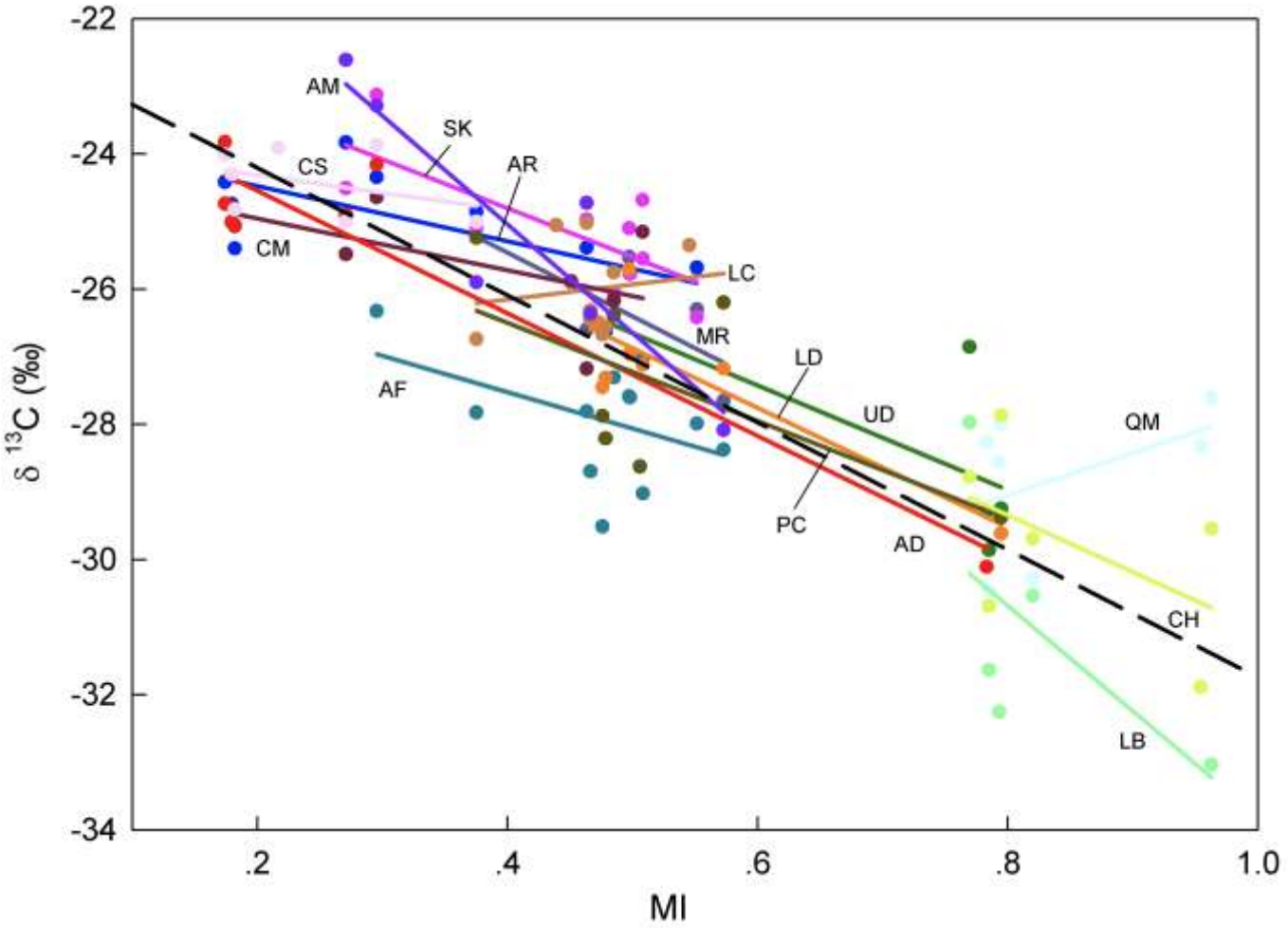
- Does c_i/c_a vary with D in the way predicted?
- How does g_1 vary with soil moisture?
- Does this variation explain the effects of drought on assimilation?
- How do these relationships differ among different types of plants?



North East China Transect

Prentice IC, T Meng, H Wang,
SP Harrison, J Ni, G Wang (2011) *NP*

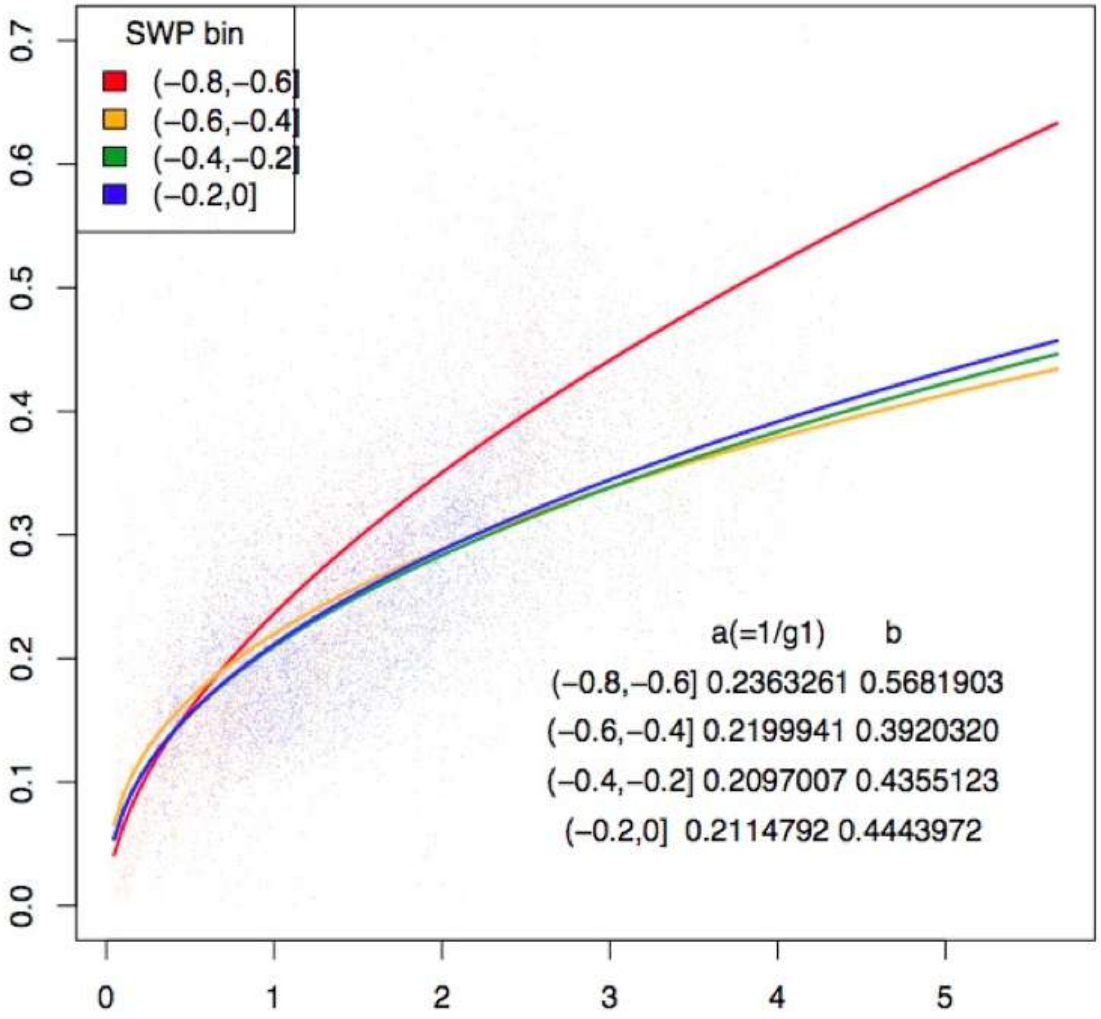
Highly consistent response of c_i/c_a to aridity in C_3 plants (indexed by leaf $\delta^{13}C$)



Prentice IC, T Meng, H Wang, SP Harrison, J Ni, G Wang (2011) *NP*

Within species response similar to between species response

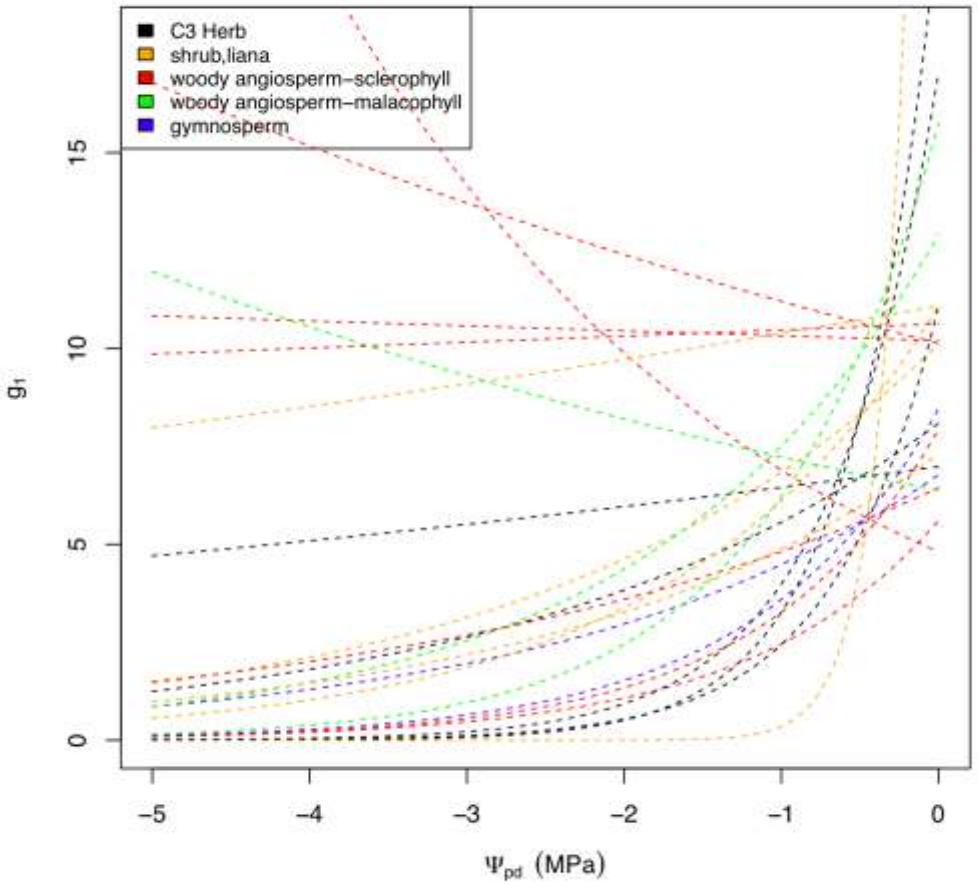
Measured response of $A/(g_s c_a - A)$ to D



S Zhou, R Duursma, B Medlyn, IC Prentice *et al.* (in prep.)

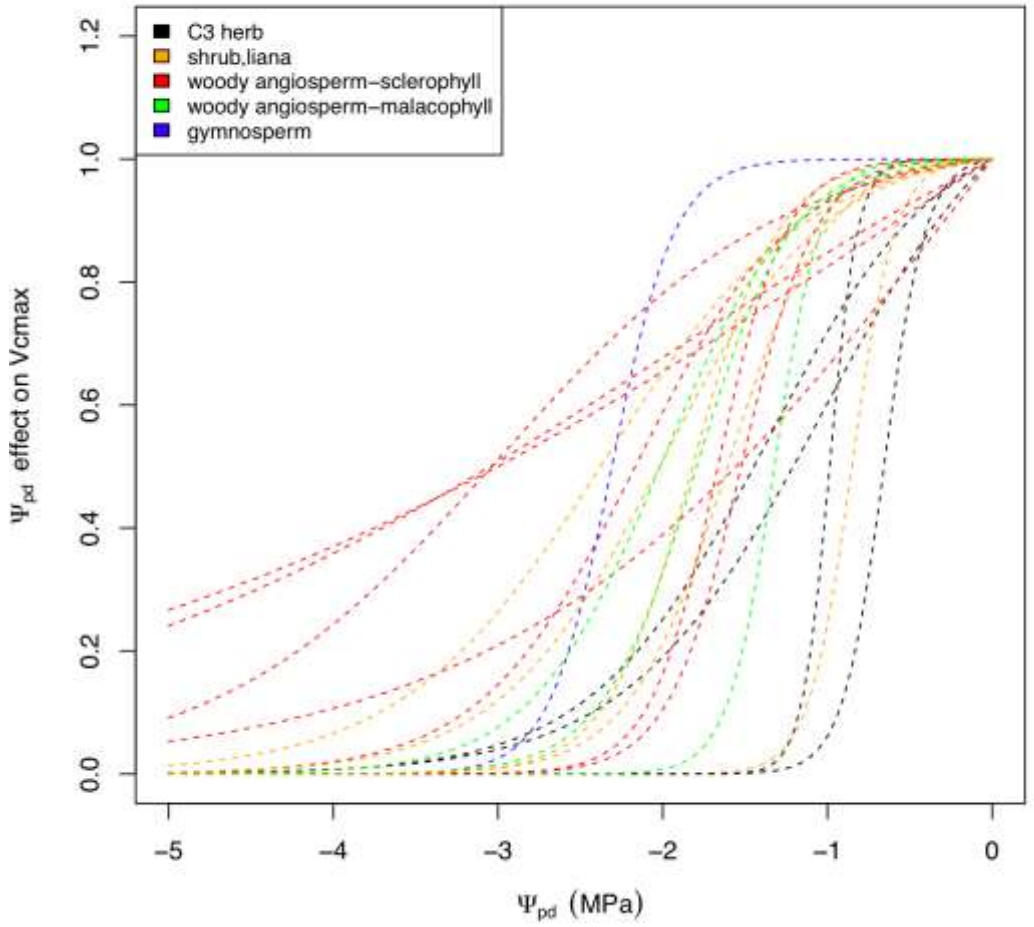
Fagus sylvatica data: Op de Beeck *et al.* 2010 *AFM*

Experimental responses of g_1 to pre-dawn water potential



S Zhou, R Duursma, B Medlyn, IC Prentice (unpubl.)

Experimental responses of V_{cmax} to pre-dawn water potential



S Zhou, R Duursma, B Medlyn, IC Prentice (unpubl.)

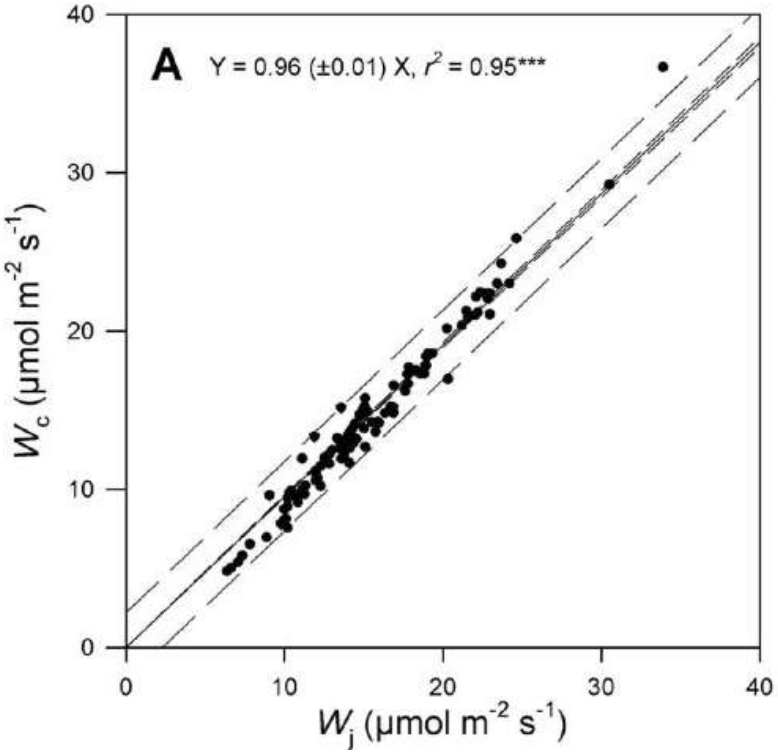
What else is optimized?

- Haxeltine and Prentice (1996), Dewar (1996): leaf-level optimization of leaf carbon gain => optimal V_{cmax} (for well-watered conditions)
- Predicts:
  - A single optimal value of V_{cmax} and leaf N
  - The light use efficiency model
  - Vertical gradients of leaf N and V_{cmax}
  - Declining leaf N with temperature
  - “Acclimation” of leaf N and V_{cmax} to $[CO_2]$
- Inhabits: LPJ, LPX
- Implies: Leaf N is determined by V_{cmax}
- Systematic testing: very little

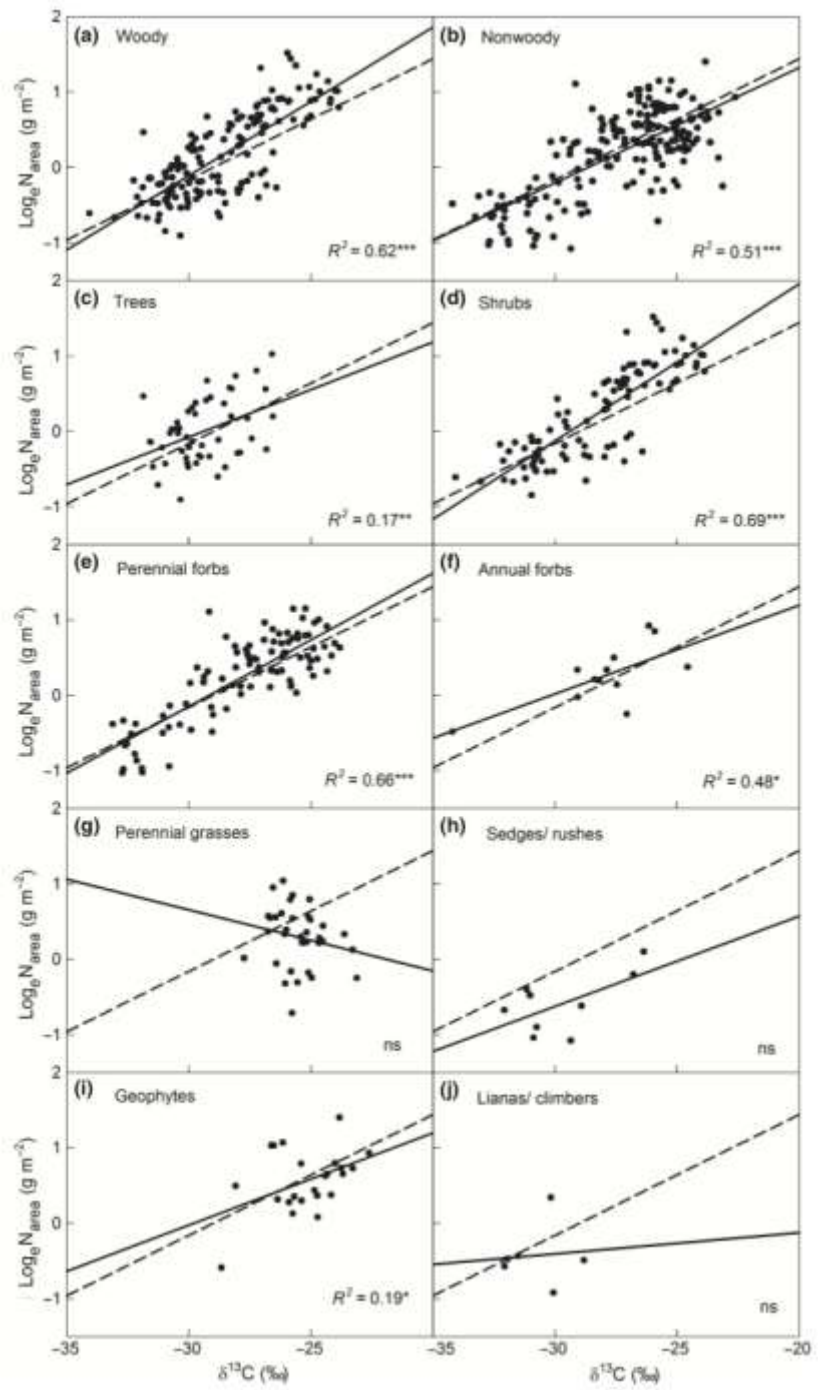
A more general form: conditional optimization

- “Co-ordination hypothesis”: Rubisco- and light-limited photosynthetic rates are equal under normal field conditions (Maire *et al.* 2012 *PLOS One*)
- **Not** a new idea, but little investigated
- Relevant time scale for large-scale modelling

Test of the co-ordination hypothesis



Maire *et al.*
(2012) PLOS One



North East China Transect

As c_i/c_a declines, leaf N increases

Does leaf N acclimate to long-term drying?

Towards the next-generation DGVM

- Much DGVM work focuses on “additional processes” (e.g. fire, CH_4, N_2O, land-use effects in LPX)
- Ill-directed frenzy of modelling C-N cycle coupling
- Little work on the “dynamical core”…. We need:

(1) A model structure based on testable hypotheses.

(2) Explicit relationships of model parameters to field-measurable traits.

(3) Close connection of model development to experiments.

Thanks

- Especially: Remko Duursma, Belinda Medlyn, Shuangxi Zhou, Ni Jian, Meng Tingting, Wang Han, Jean-François Soussana…
- …and Ray Leuning!