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 \( \lambda \) 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:
  • \( g_1 = f (\lambda, \Gamma^*, a) \)

• (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:
- \( g_1 = f (b, K, \Gamma^*, r_s, h, \rho_s, \eta, \Delta \Psi_{max}, k_s) \)
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 $\delta^{13}C$)

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 $\Rightarrow$ 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$_2$O, 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.
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