Optimal Stomatal Conductance under rising CO_2

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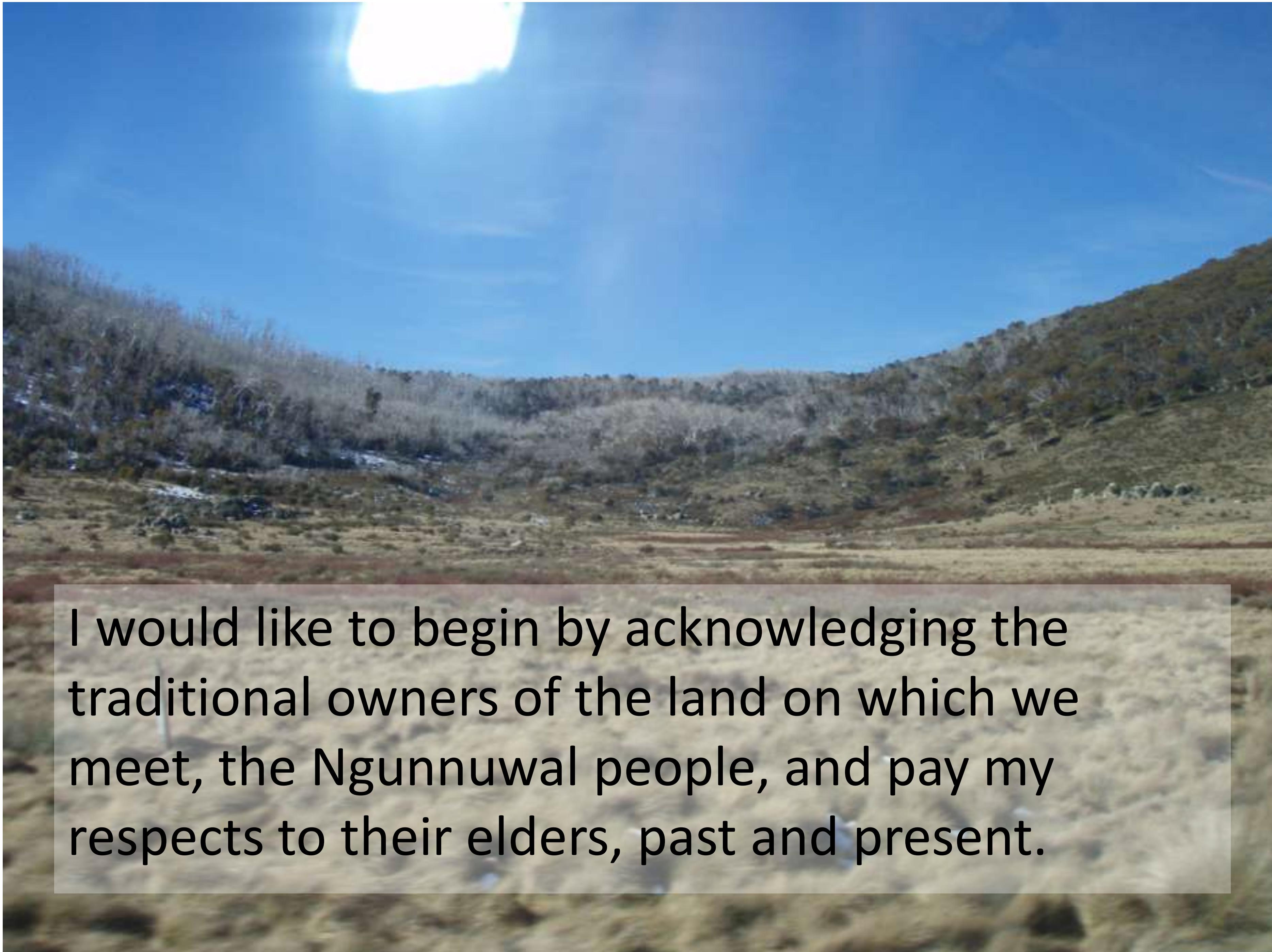

I would like to begin by acknowledging the traditional owners of the land on which we meet, the Ngunnuwal people, and pay my respects to their elders, past and present.

And also to the "traditional owners" of the optimal stomatal model ..

- Cowan & Farquhar (1978)
- Hari, Mäkelä et al. (1986)
- Lloyd (1991), Lloyd & Farquhar (1994)
- Arneth, Lloyd et al. (2002)
- Katul et al. (2009) ..

.. I pay my respects!

CO_2 Response

Optimal stomatal theory:

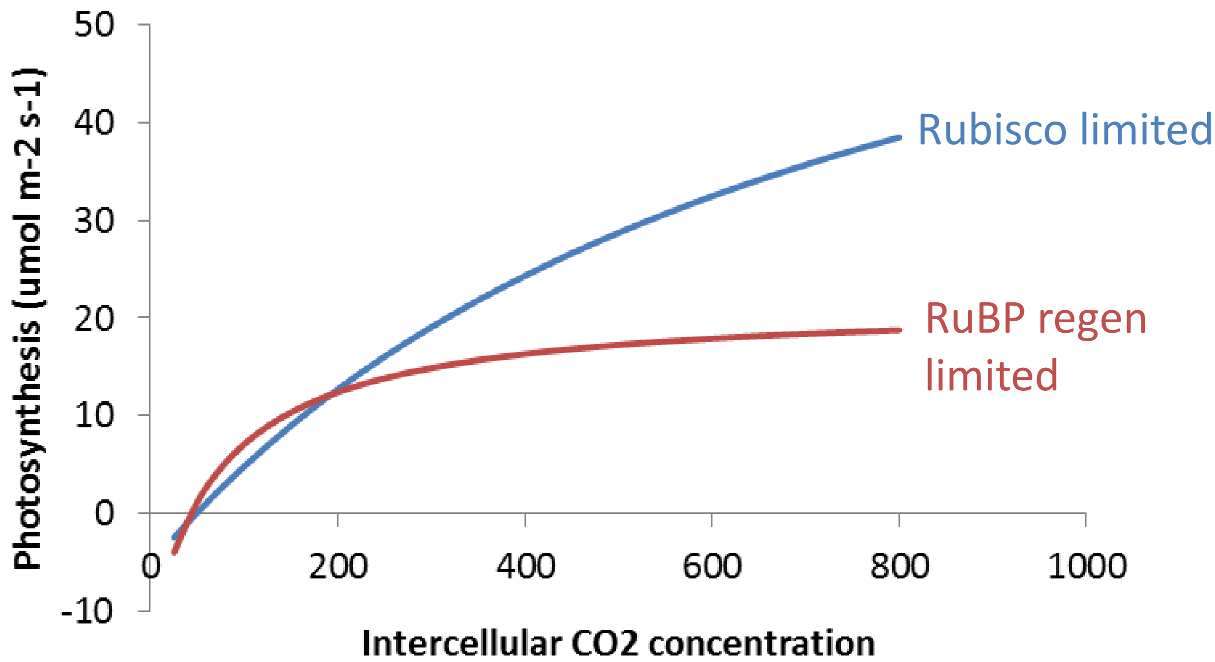
maximise $A - \lambda E$

λ (mol C mol^{-1} H_2O) is marginal cost of water

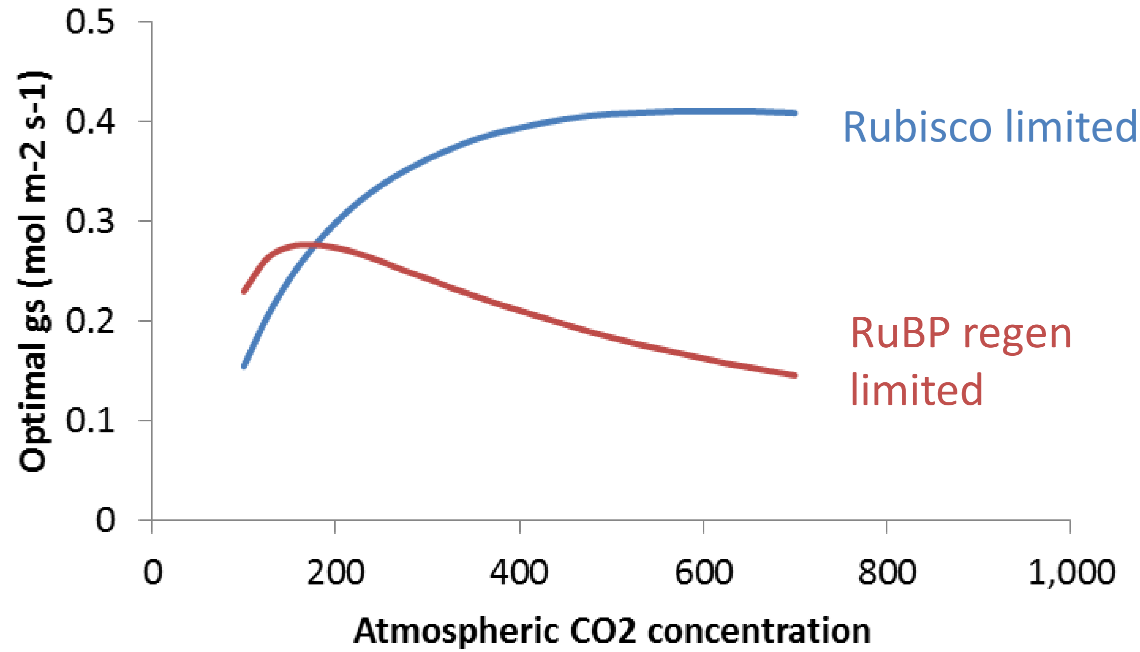
What happens as CO_2 increases?

- depends on how A is assumed to increase with CO_2
- If A increases steeply with CO_2, stomata should OPEN, because the increase in A outweighs the increase in E
- If A increases shallowly with CO_2, stomata should CLOSE, because the increase in E outweighs the increase in A

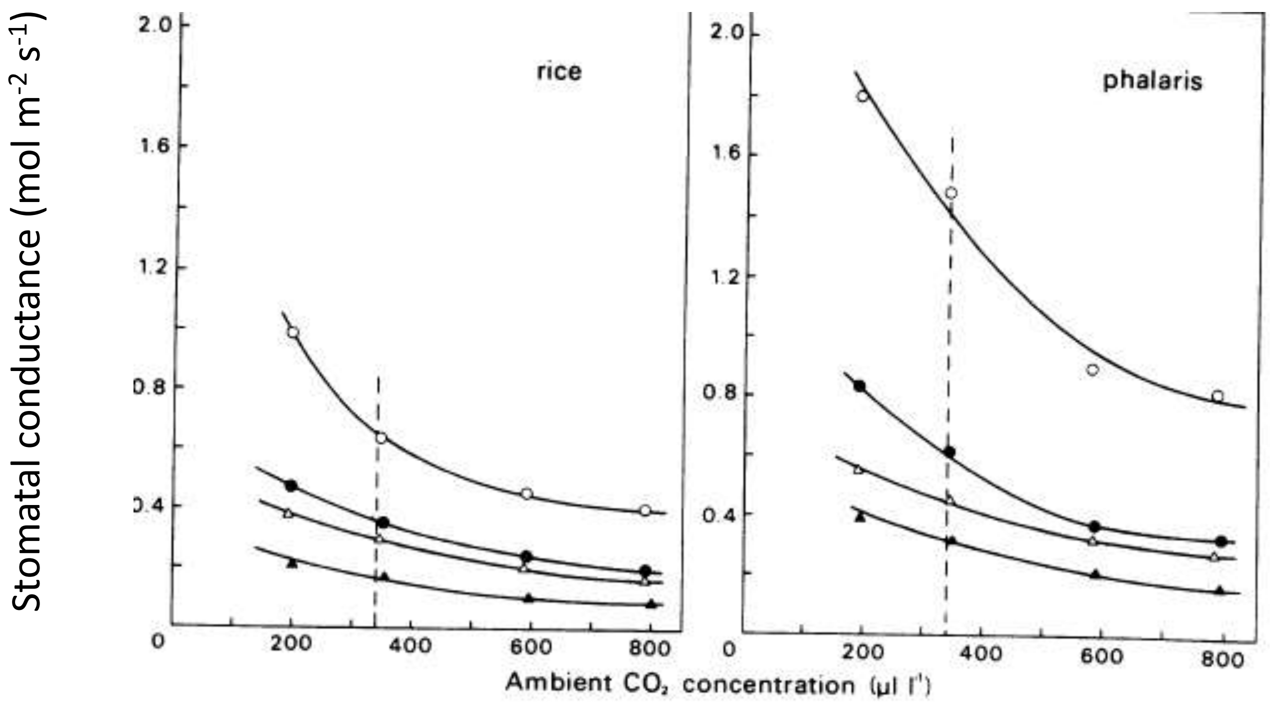
A-C_i Curve



Optimal g_s



What Stomata Actually Do



Morison & Gifford (1983)

Conclusion: Stomata are optimising for the electron-transport limited rate of photosynthesis

Approximate Solution

$$g_s^* \approx g_0 + \left(1 + \frac{g_1}{\sqrt{D}}\right)\frac{A}{C_a}$$

Where

$$g_1 \sim \sqrt{\frac{\Gamma^*}{\lambda}}$$

Γ^* = CO_2 compensation point, weak T dependence
λ = marginal carbon cost of water

- Very similar to widely-used empirical models ..
- But now we can interpret the parameters – and make predictions about them

Medlyn et al. (2011, Global Change Biol)

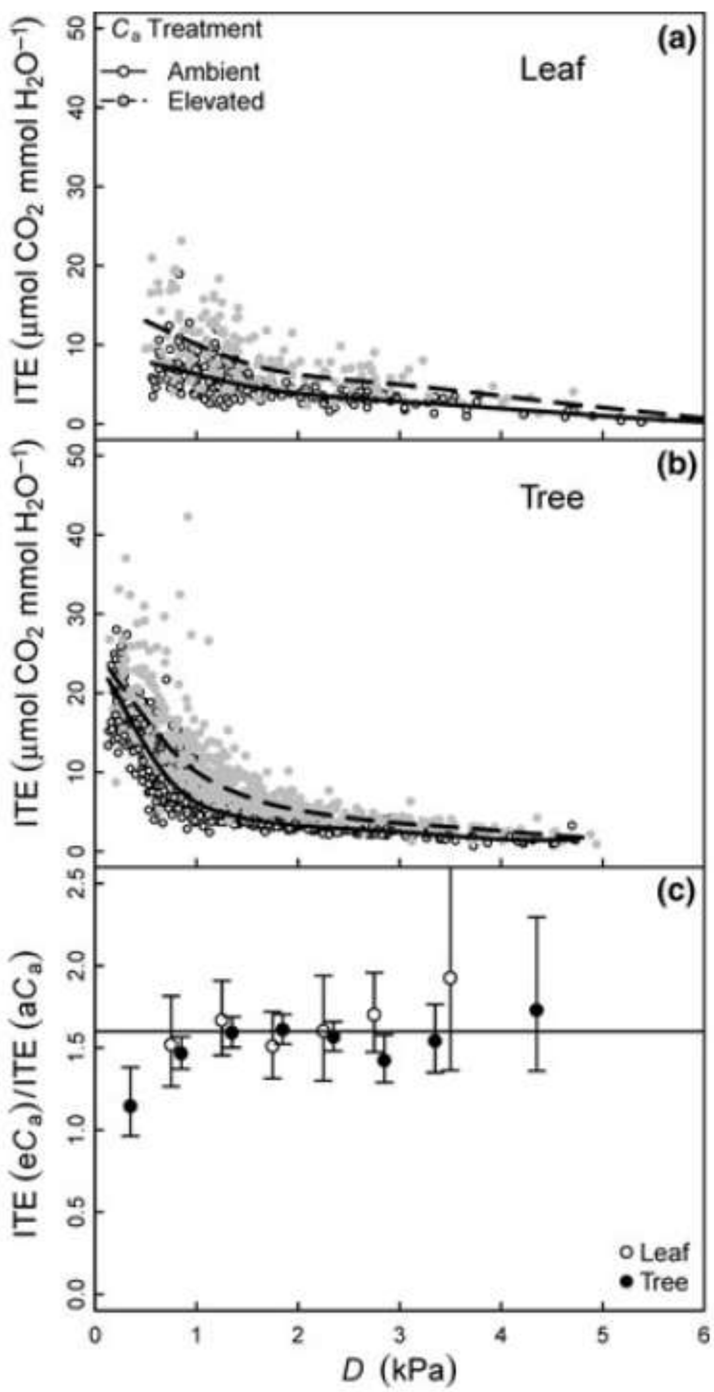
Water Use Efficiency

The equation for g_s can be re-arranged to give an expression for water use efficiency:

$$\frac{A}{E} = \frac{C_a}{g_1\sqrt{D} + D}\left(1 - \frac{g_0}{g_s}\right)$$

WUE

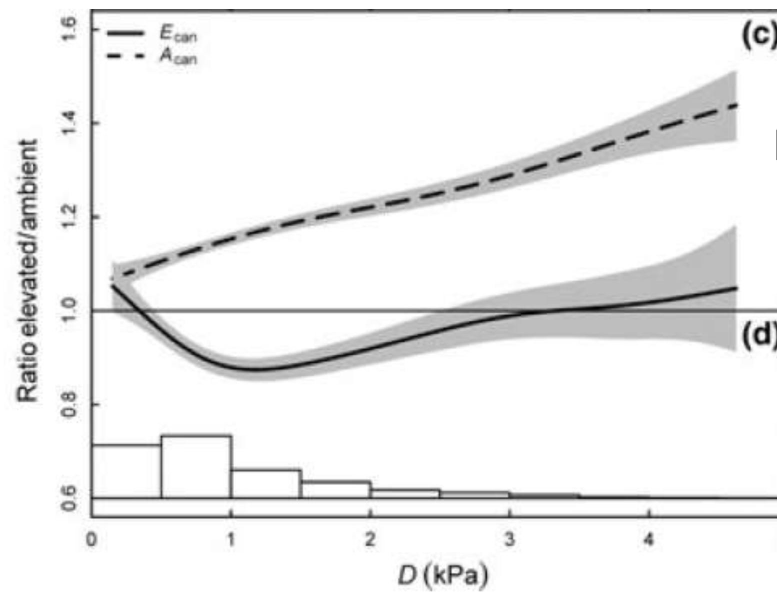
- Has a square-root dependence on VPD (D)
- Is (largely) independent of PAR and leaf N
- Is proportional to atmospheric CO_2 (C_a) WHEN VPD IS CONSTANT



Works for Eucalypts

Whole-tree chambers at UWS showed:

- WUE is the same at leaf and canopy scales
- WUE is proportional to CO_2

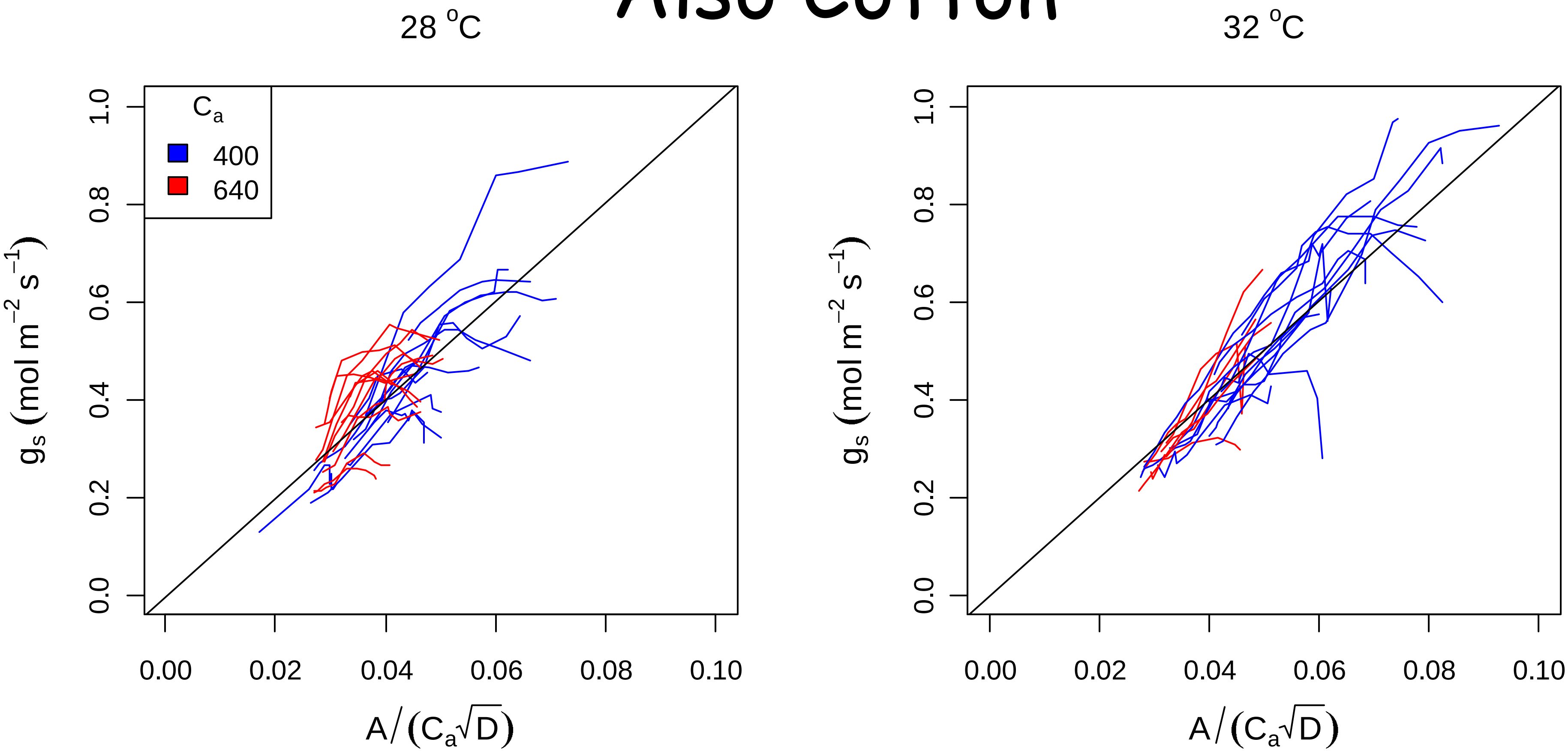


CO_2 effect on photosynthesis

CO_2 effect on transpiration

(Barton et al. 2011 Global Change Biol)

Also Cotton

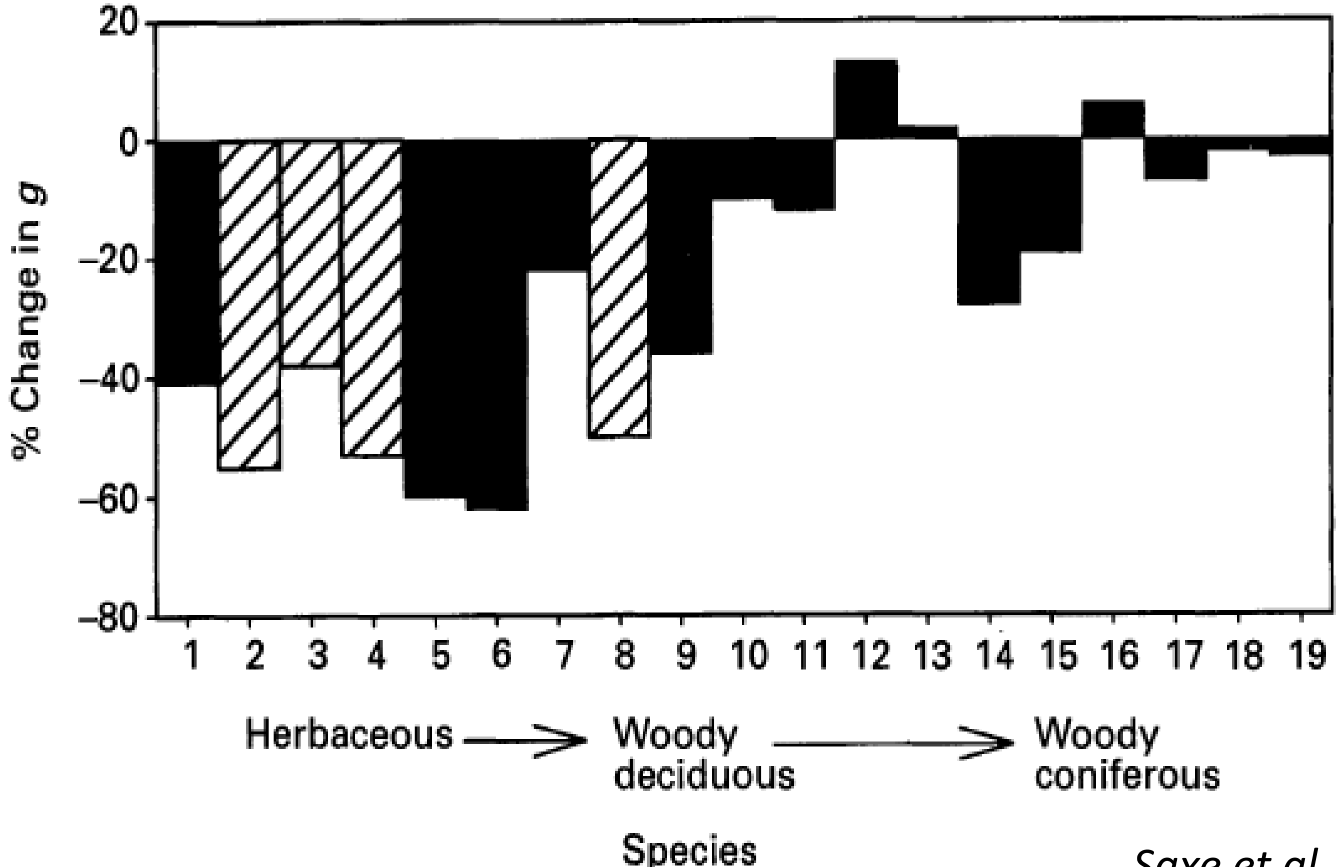


VPD response curves from cotton plants grown at a range of CO_2 concentrations and temperatures

G_1 = 10, not sig. diff. between treatments

Duursma et al. (submitted)

What About Conifers?



Saxe et al. 1997

Stomata of conifers are less responsive to elevated CO_2

Hypotheses

Model predicts $A/g_s \propto CO_2$

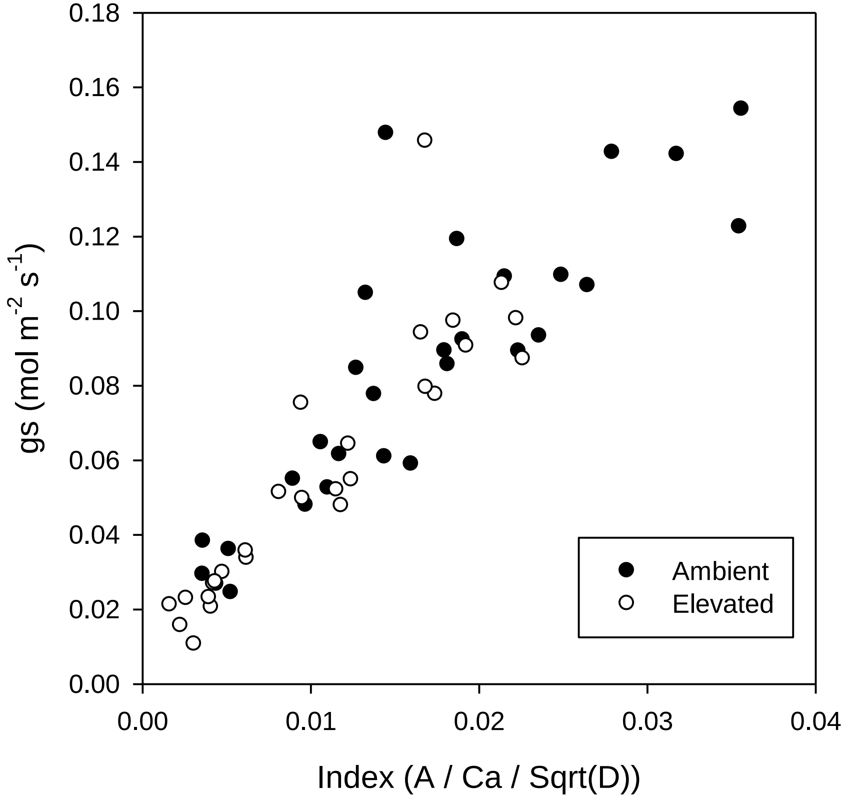
If g_s changes less => A must change more

Either (1) Photosynthesis of conifers responds more strongly to CO_2

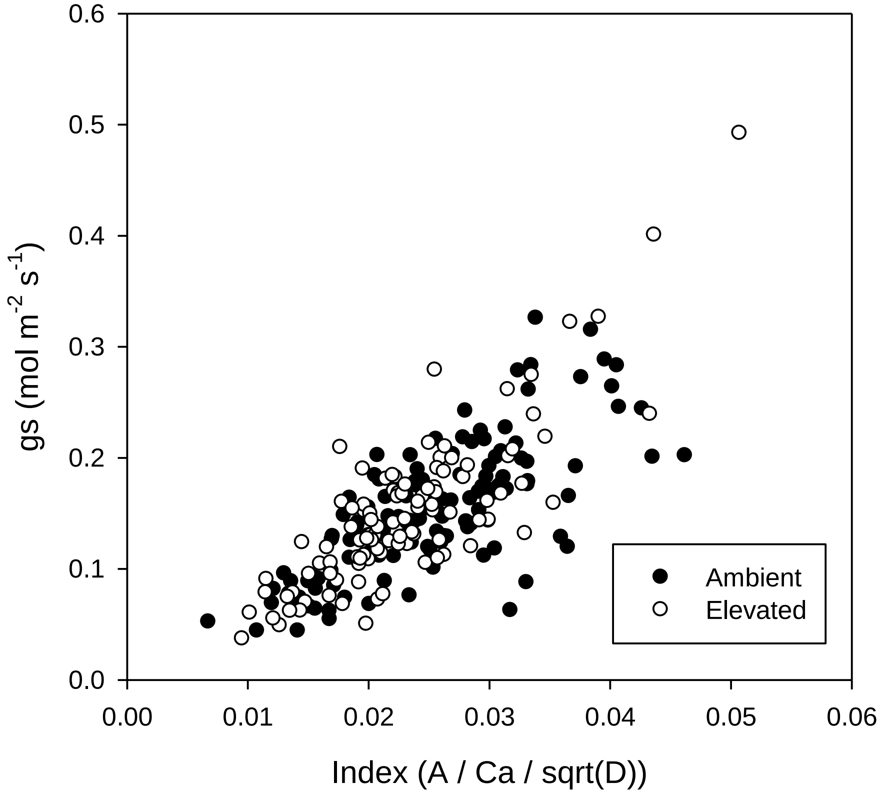
- Lower mesophyll conductance?
- Lower g_1? i.e. lower C_i:C_a?

Or (2) Conifers do not follow optimal stomatal model

Data do follow optimal model



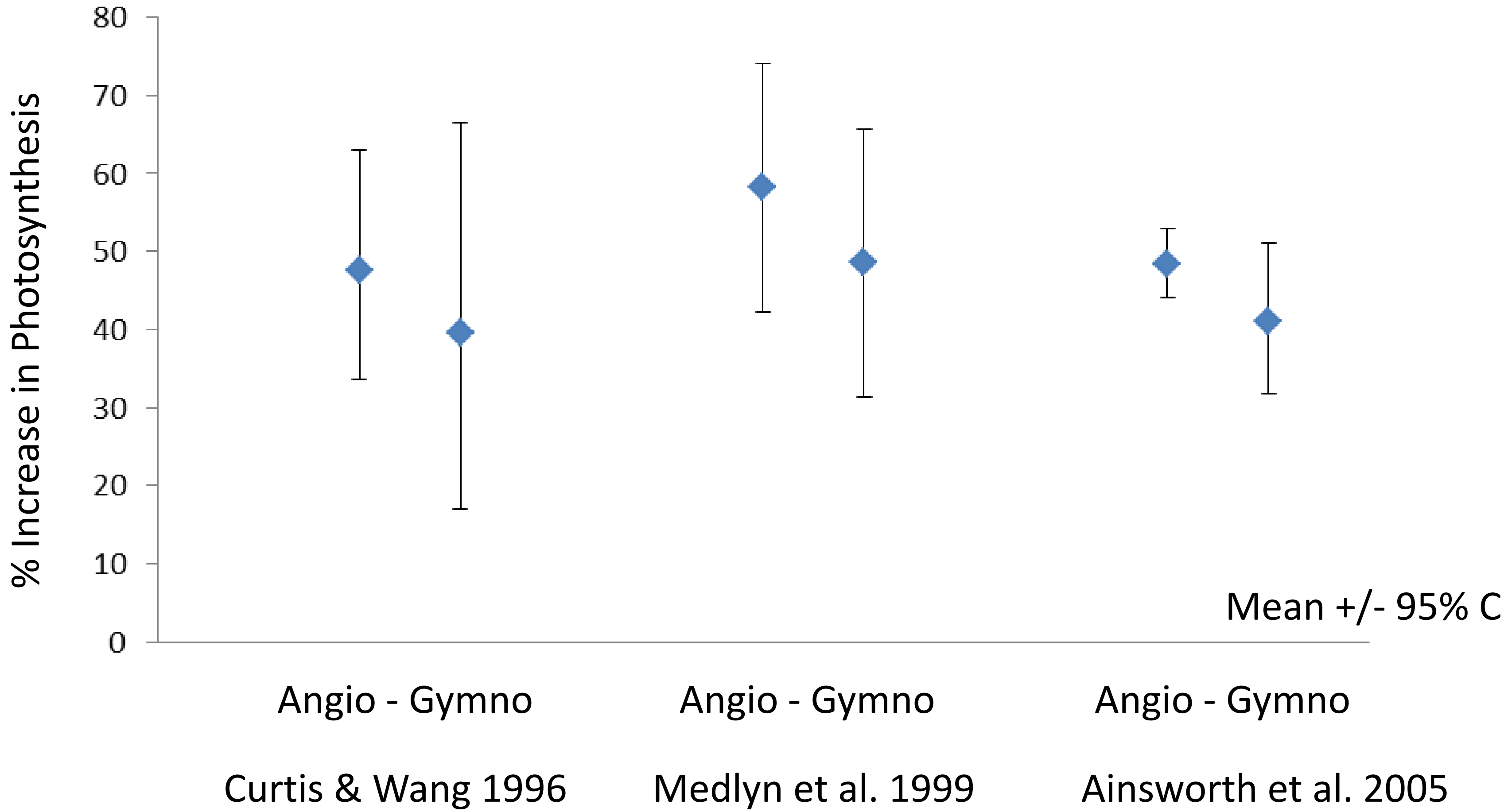
Sitka spruce (*Barton & Jarvis 1999*)



Pinus taeda (*Ellsworth et al. 2011*)

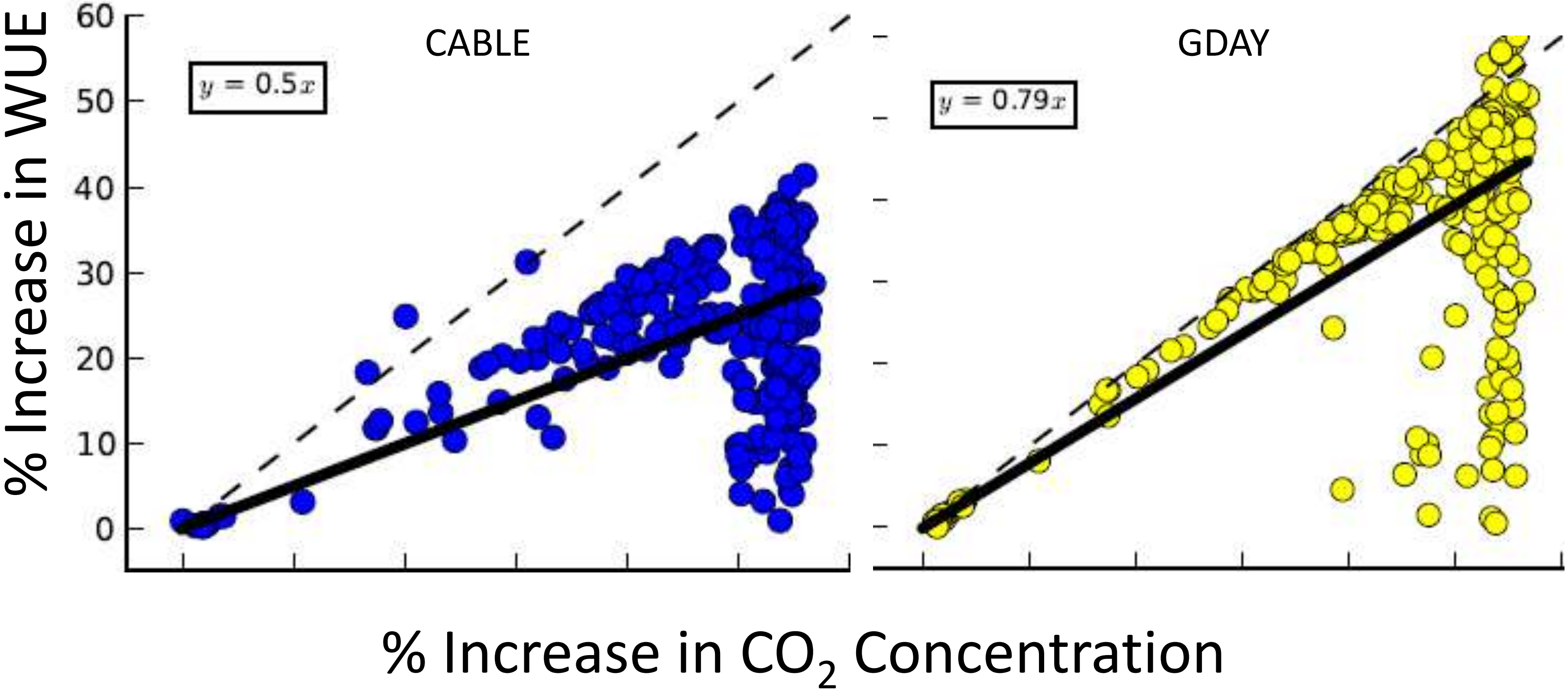
Slopes do not differ significantly between treatments

But no evidence for higher A response?!



Consequences at Larger Scales

- Daily WUE is no longer exactly proportional to CO_2



- Nonetheless, GPP & transpiration are strongly coupled
- CO_2 effect on transpiration DEPENDS on effect on GPP

De Kauwe et al incl. Wang YP (in prep)

Key Points

1) Optimal stomatal theory predicts stomatal closure with rising CO_2
2) Strongly supported by data – when changes in VPD are controlled for
3) Implies that CO_2 effect on transpiration depends on CO_2 effect on GPP

Thanks!

Macquarie: Colin Prentice, Martin de Kauwe

HIE: Craig Barton, David Ellsworth, David Tissue

+ many other kind people who have given their data to the cause!

Coming soon:

Stomatal Behaviour Synthesis Project