Impacts of mesophyll diffusion on the long-term increase in global Carbon-13 discrimination and water use efficiency

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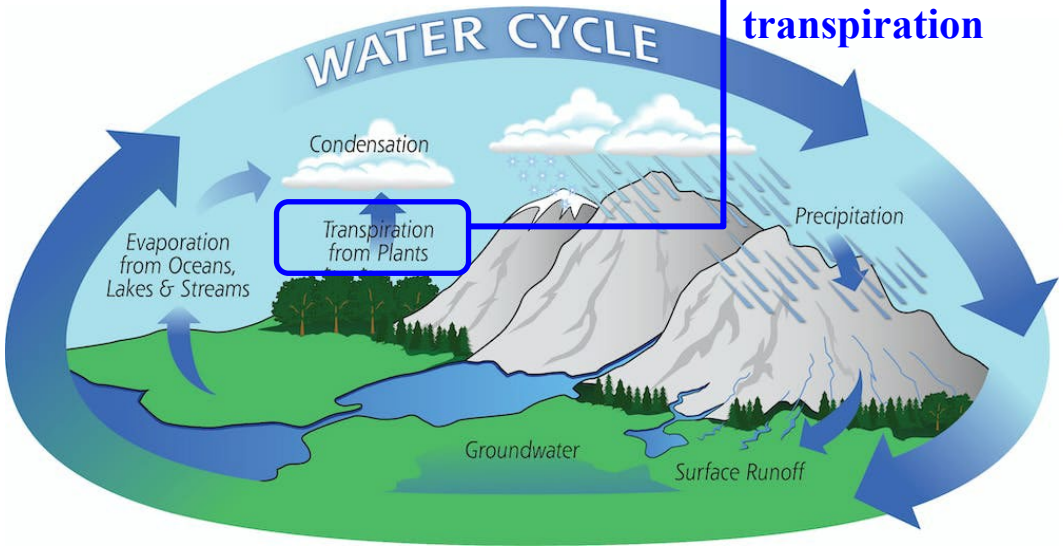
Coupling of terrestrial water and carbon cycles

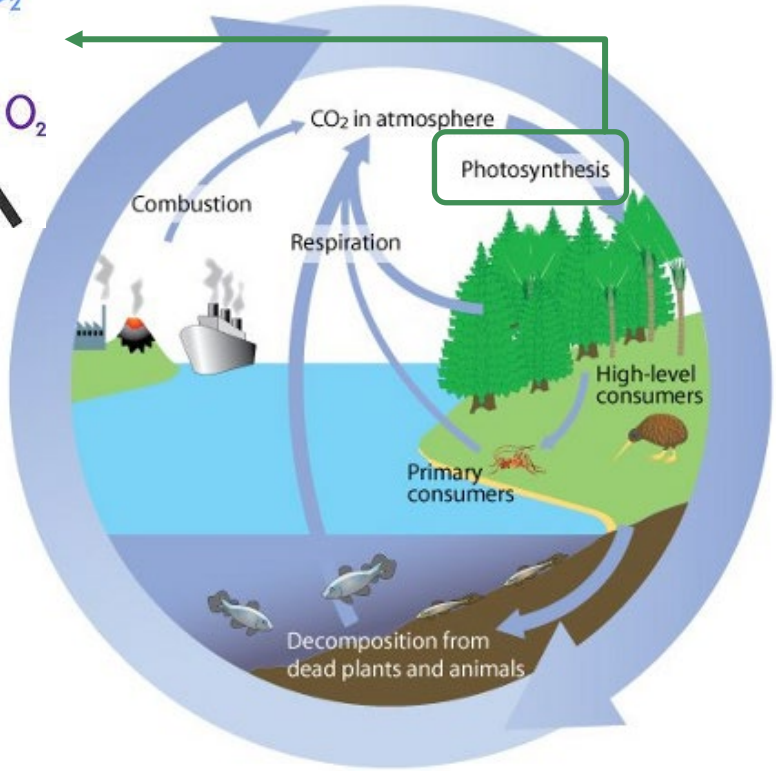
Joint stomatal control of carbon gain and water loss

lose water via transpiration

uptake CO2 via photosynthesis



Water cycle

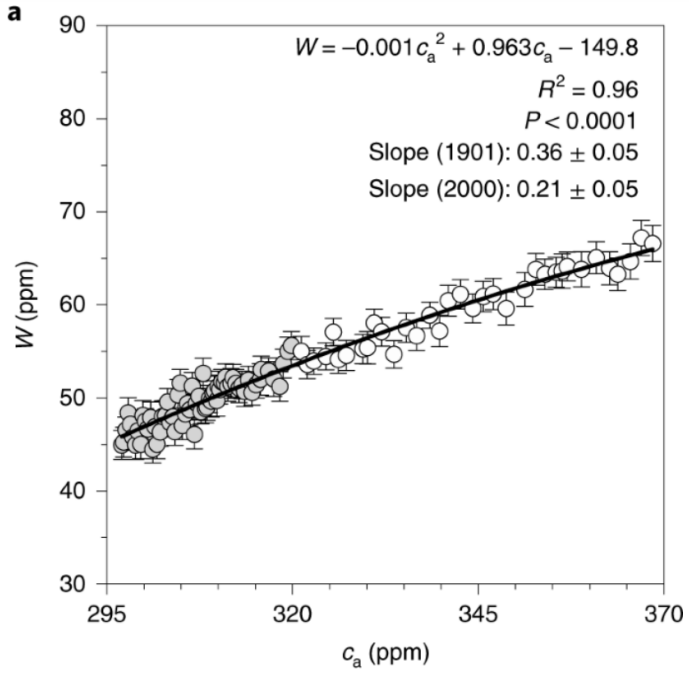


Carbon cycle

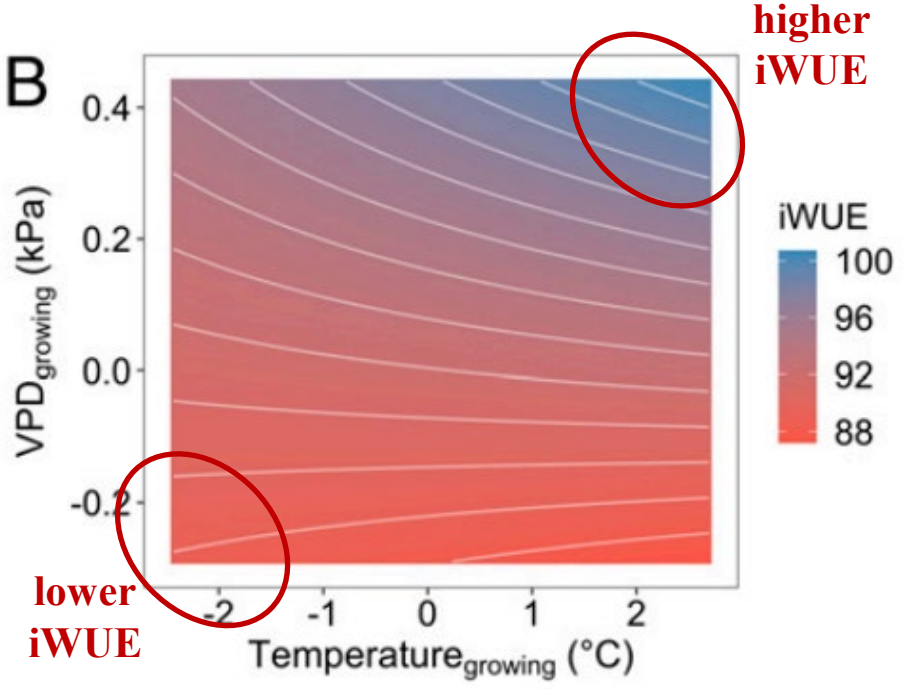
Water use efficiency (WUE) varies with environment

- Higher leaf-level WUE under higher CO2 concentration
- Higher leaf-level WUE under water/heat stresses

$$\text{WUE} = \frac{\text{carbon gain}}{\text{water loss}}$$



Adams et al., 2020
(based on tree-ring data)



Mathias and Thomas, 2020
(based on tree-ring data)

Understanding WUE response to environmental changes

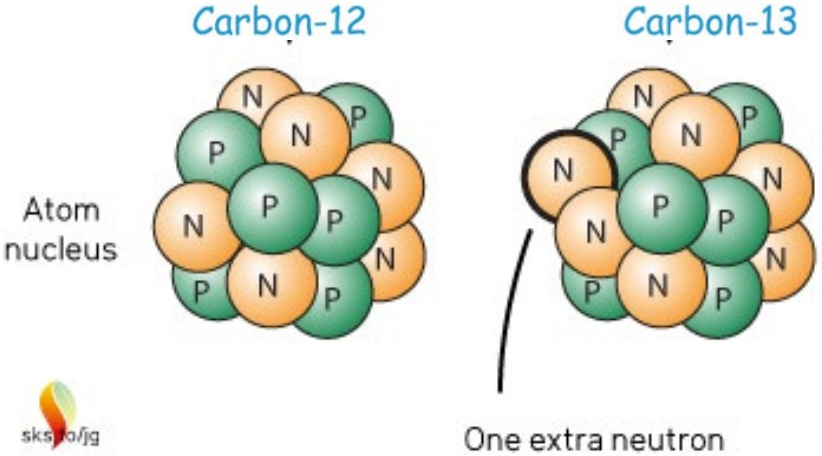
Satellite product

Flux measurement

Free-Air CO2 Enrichment Experiments (FACE)

Relatively short time records

Stable carbon isotope C13



selectively uptake C-12

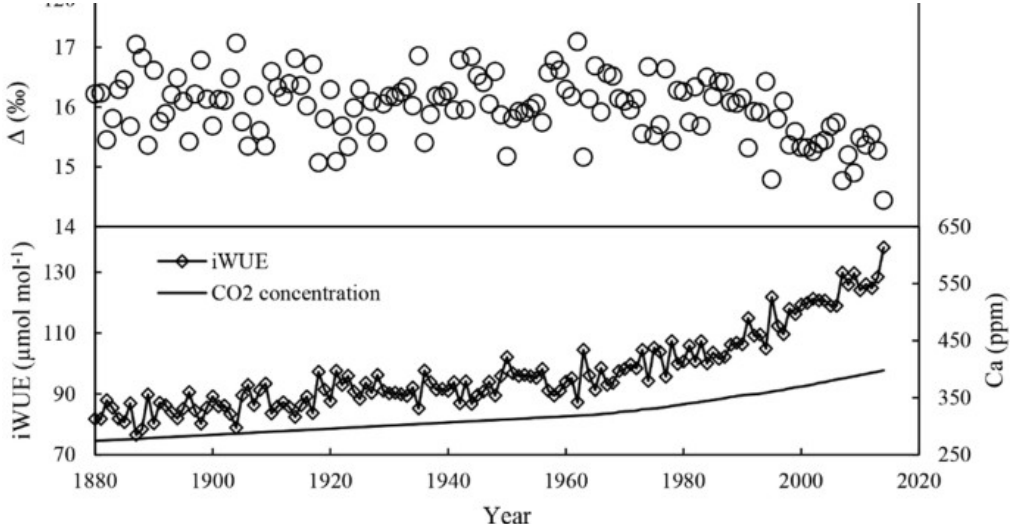
discriminate against C-13

Carbon isotopic discrimination (Δ13)

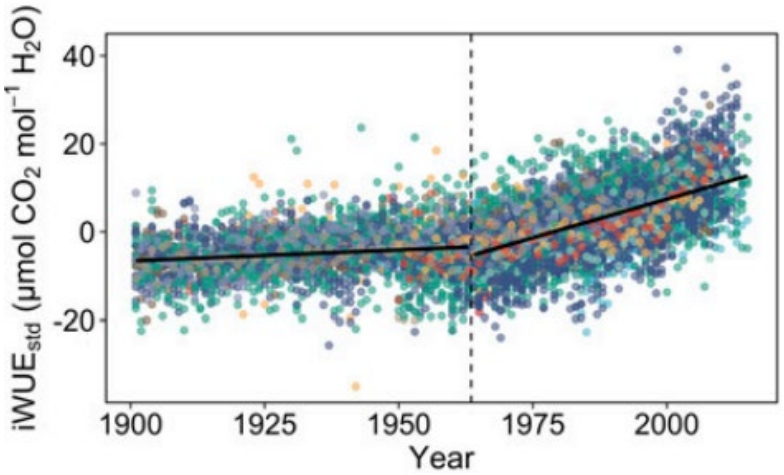
Long time series data available

C13:C12 ratio ($\delta^{13}C$) from plant materials

- Tree-ring records of δ13C used to infer the historical change of Δ13 and leaf-level WUE



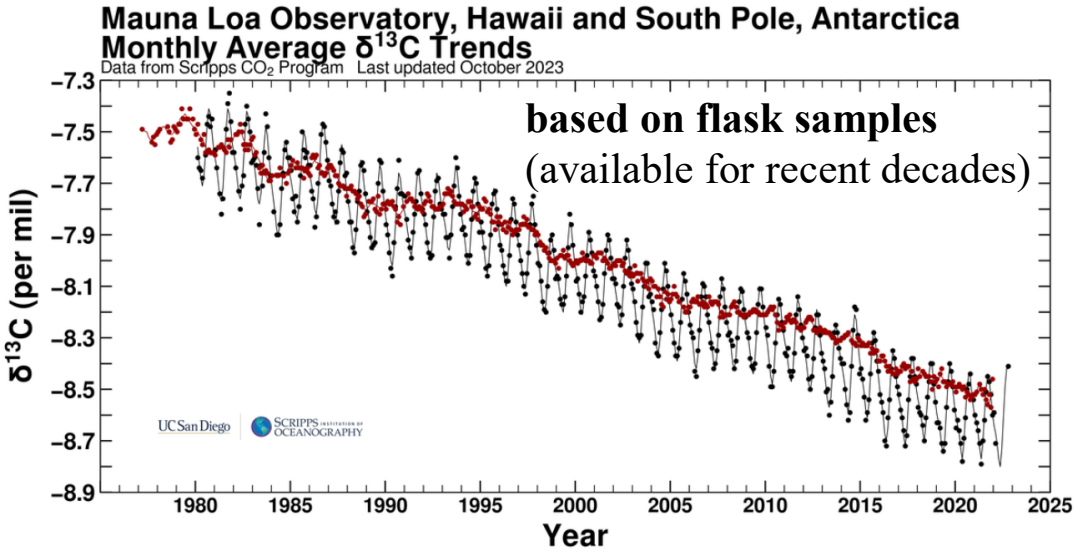
Lu et al., 2018



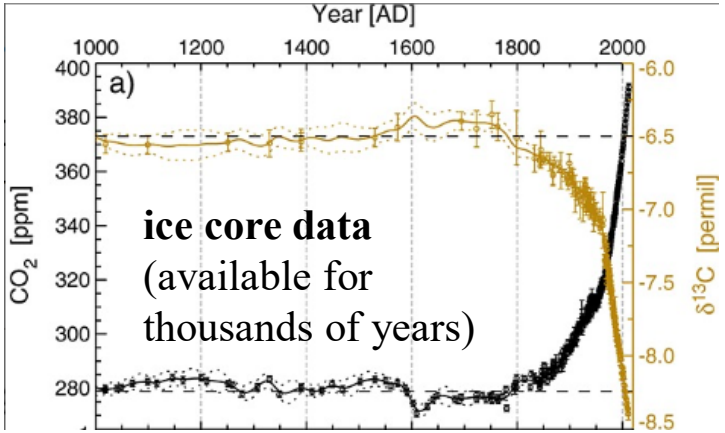
Mathias and Thomas, 2020

C13:C12 ratio ($\delta^{13}C$) in atmosphere

- Tree-ring records of δ13C used to infer the historical change of Δ13 and leaf-level WUE
- Atmospheric δ13C used to diagnose the long-term change of Δ13

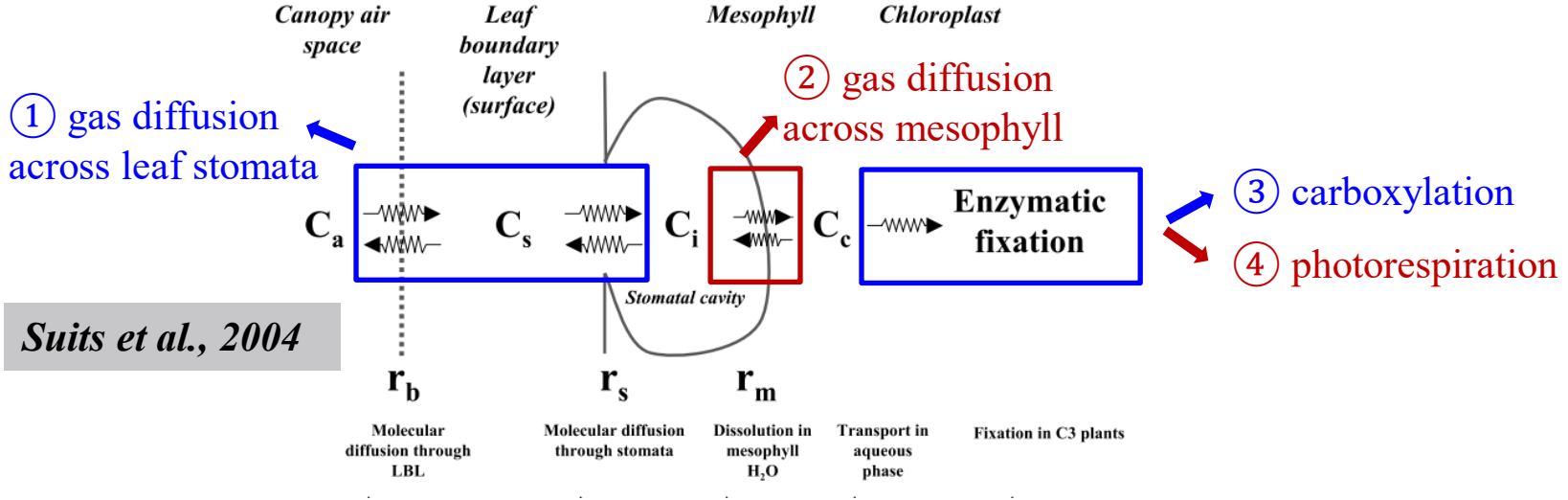


From https://scrippsco2.ucsd.edu/



Rubino et al., 2013

Carbon isotopic discrimination (Δ13) in models



Suits et al., 2004

$$\Delta^{13} = a + (b-a)(C_i/C_a) - (b-a_m)(A/C_a)/g_m - f\Gamma^*/C_a$$

① ③ ② ④

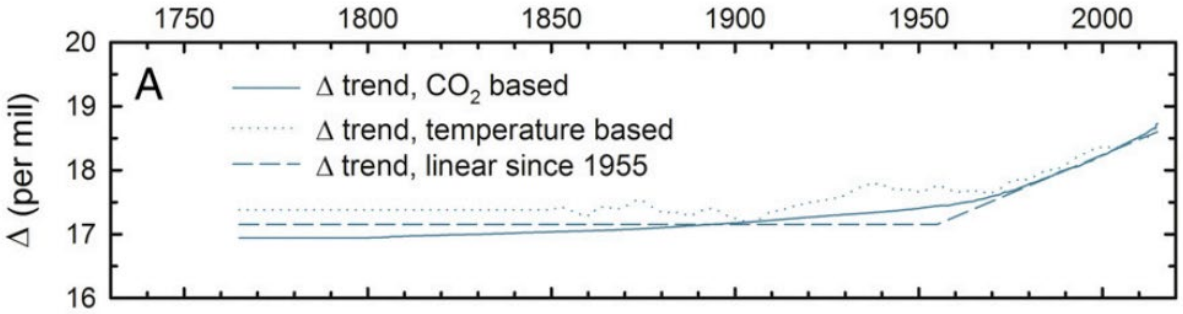
Keeling et al., 2017

Simplified equation adopted in most models

Mesophyll and photorespiration effects not considered

a = 4.4‰
b = 30 ‰ (or 27 ‰)
a_m = 1.8 ‰
f = 12 ‰

Large contribution from mesophyll and photorespiration



Keeling et al., 2017

together explain ~70% of the secular increase in Δ13

mesophyll

photorespiration

$$\Delta^{13} = a + (b - a)(C_i/C_a) - (b - a_m)(A/C_a)/g_m - f\Gamma^*/C_a$$

Limitation a) Used representative values of g_m and Γ^* assumed constant over space and time

Limitation b) Ignored C4 plants with lower Δ13 (Δ13 for C4: ~4‰; Δ13 for C3: ~18 ‰)

Science questions

Challenge: The effect from spatiotemporally dynamic g_m and Γ*, and that from C4 expansion on Δ13 patterns remain unclear.

$$\Delta^{13} = a + (b - a)(C_i/C_a) - (b - a_m)(A/C_a)/g_m - f\Gamma^*/C_a$$

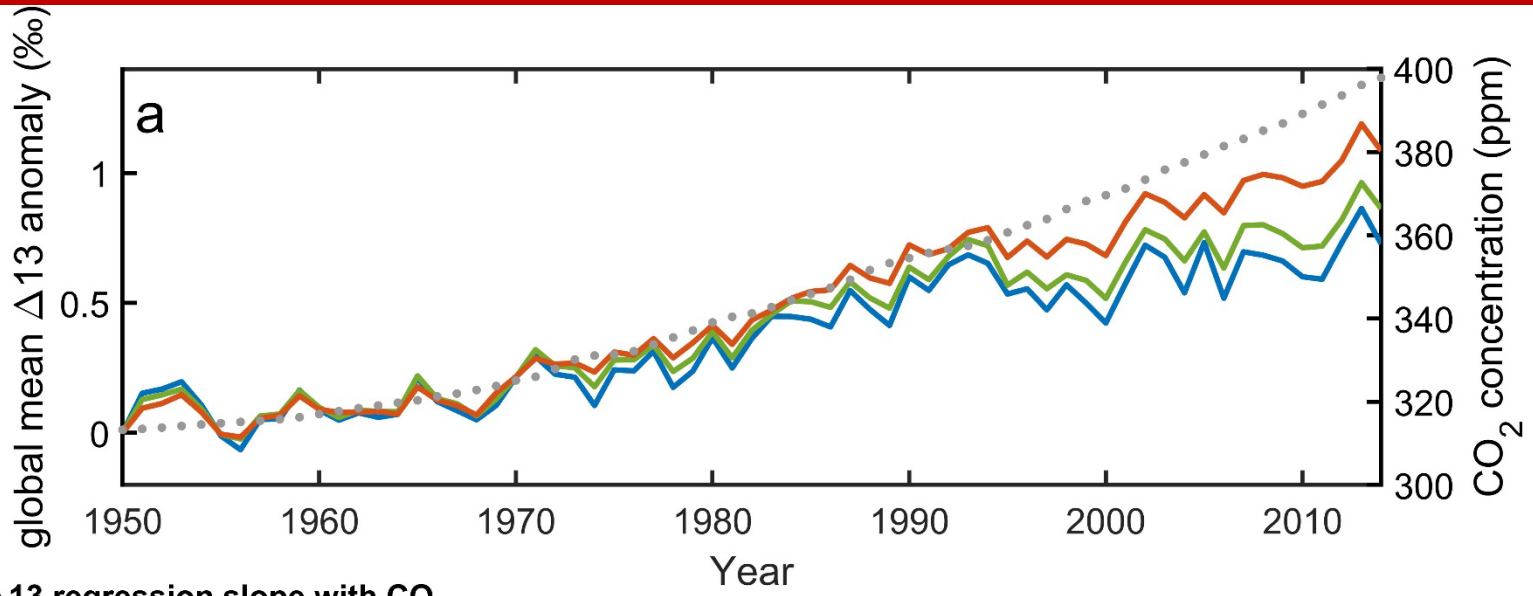
Original equation in CLM5

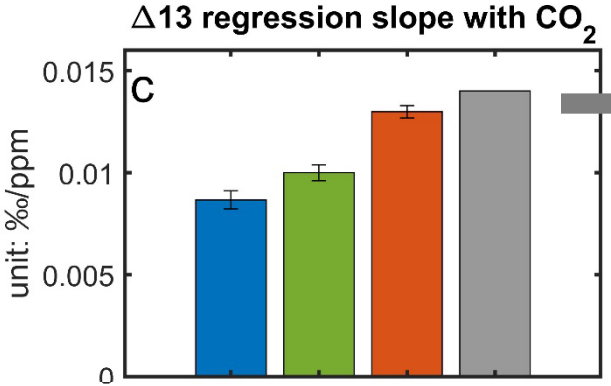
from a process-based model (Sun et al., 2014)

Science question a): what are the relative contribution of C4 expansion, g_m and Γ* to the observed growth in land photosynthesis discrimination across different biomes.

Science question b): how explicit g_m affects the response of WUE to CO2 increase and heat/drought stress.

Contribution from g_m and Γ*





Inferred from observation: 0.014 ‰/ppm

CLM5 original equation: 0.009 ‰/ppm

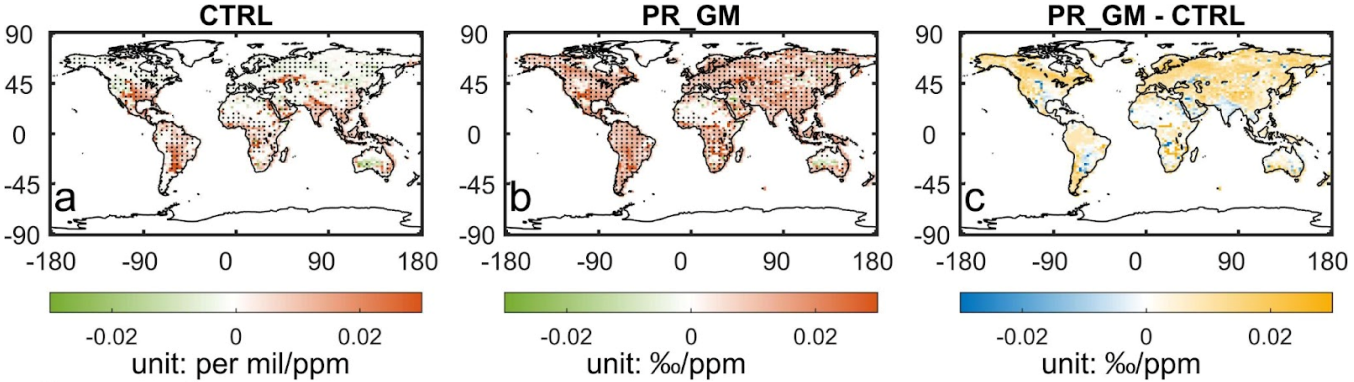
With Γ* added: 0.010 ‰/ppm

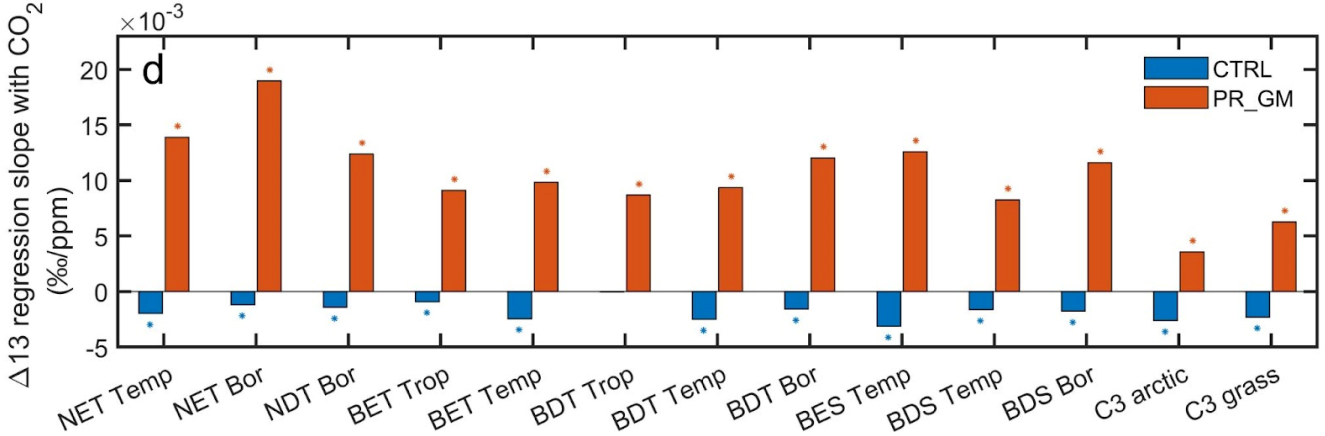
With g_m and Γ* added: 0.013 ‰/ppm

Keeling et al., 2017

Contribution from g_m and Γ* over natural vegetated lands

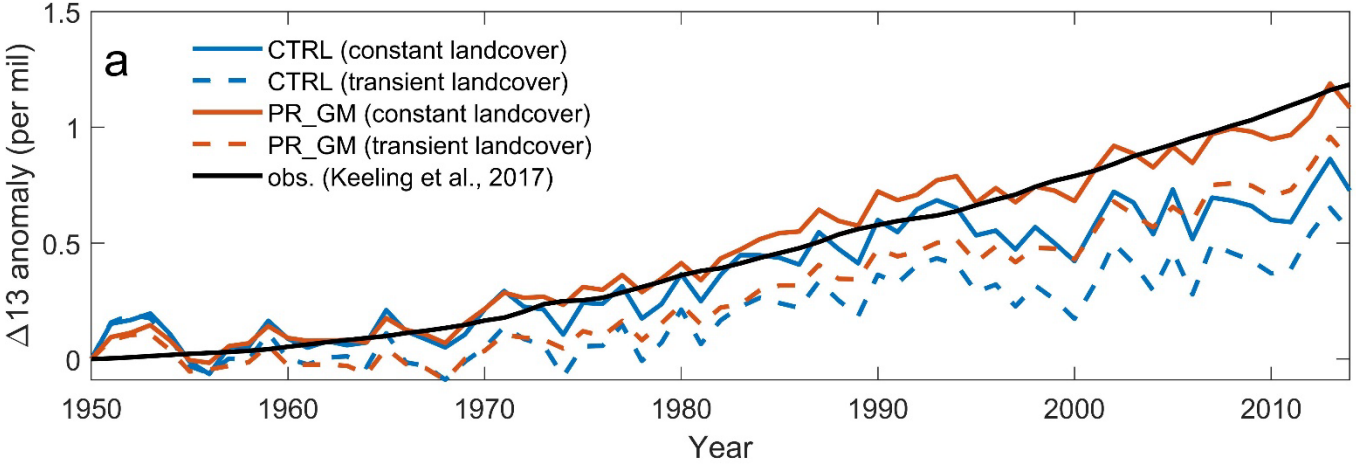
CTRL: original CLM5 equation PR_GM: with g_m and Γ* added PR_GM – CTRL: their difference





Natural ecosystems

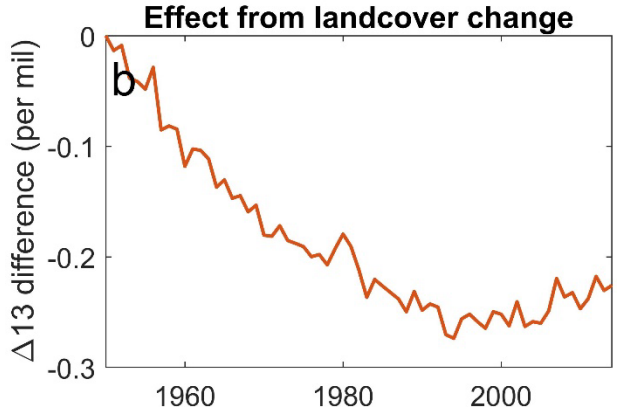
Large contribution from C4 expansion

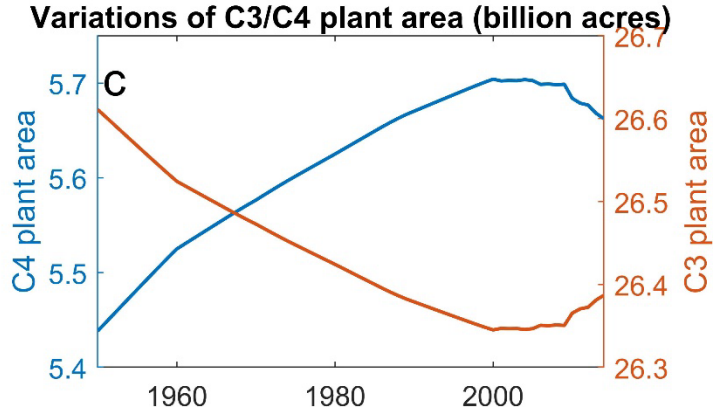


Reduced Δ13 trend if considering land cover changes

reduced by 18%

reduced by 31%

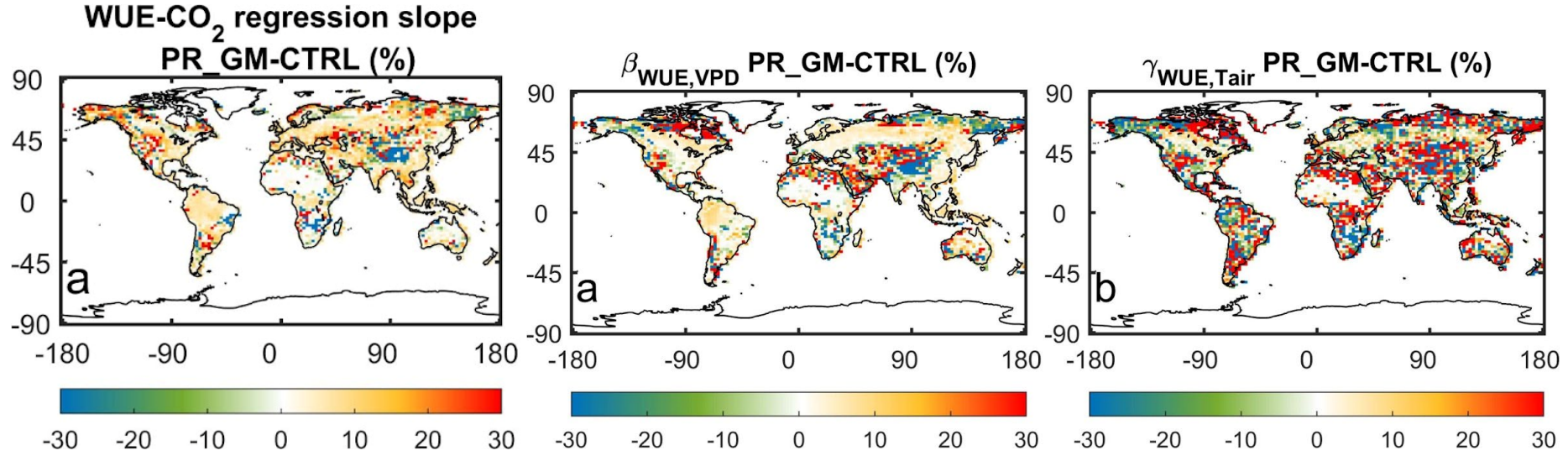




Fast C4 expansion particularly in the 20th century

Effect of g_m on WUE

Current models lacking an explicit consideration of g_m is likely to **underestimate** the response of WUE to CO2 enhancement, and to heat/drought stress.



weaker response to CO2 | stronger response to CO2 | weaker response to VPD | stronger response to VPD | weaker response to temperature | stronger response to temperature

… with explicit g_m

Thanks for listening!

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Acknowledge:

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