

Quantifying the Influence of Stomatal Behavior on Photosynthesis in the Amazon

CESM Working Group Meeting | February 08, 2023

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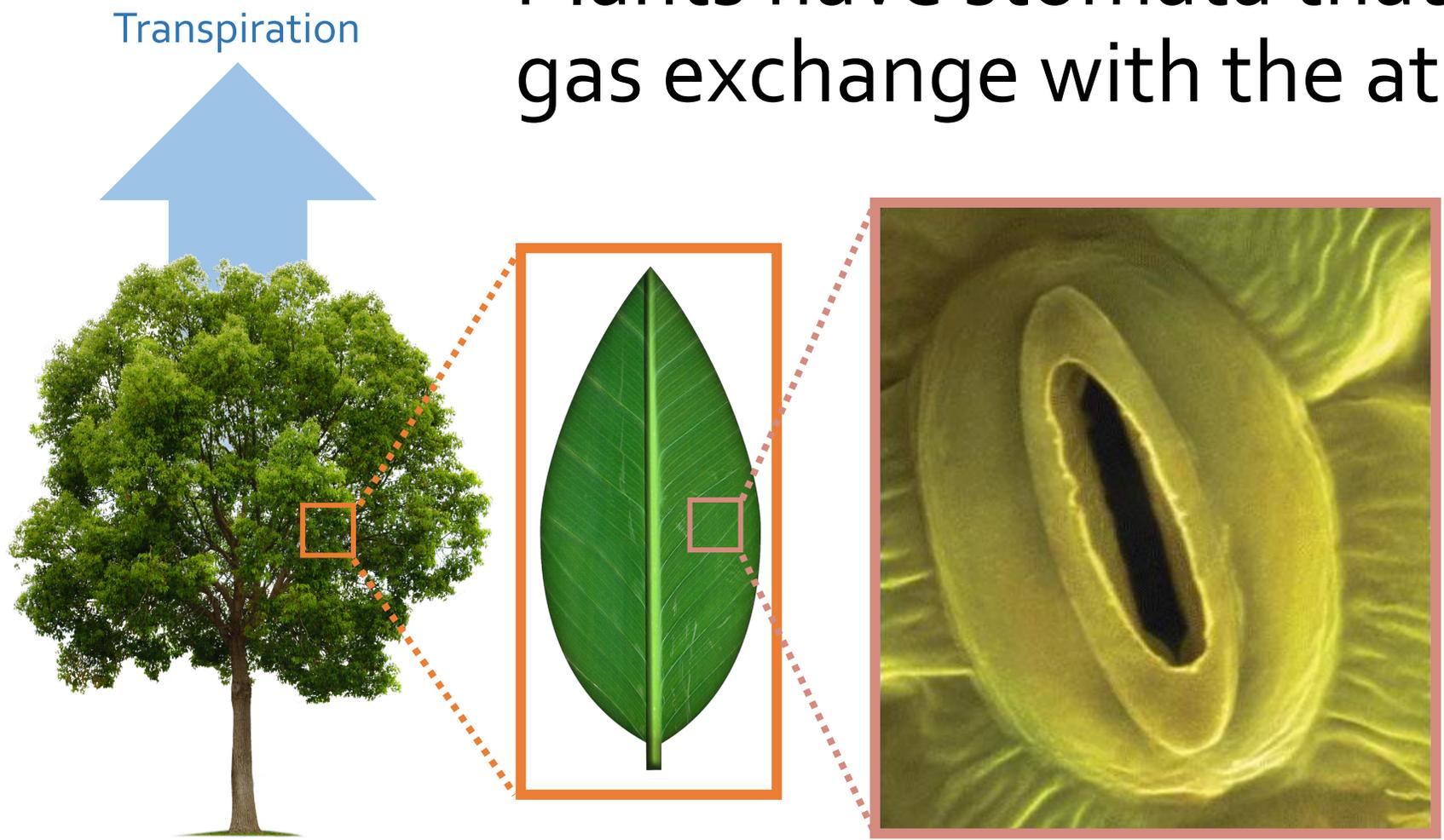
Collaborators: Gabriel Kooperman², Alana Cordak², Ashley Cornish², Christopher Still³, Linnia Hawkins^{4,5}, Jim Randerson⁶, Charles Koven⁷, Forrest Hoffman⁸

¹UW; ²UGA; ³OSU; ⁴CU; ⁵NCAR; ⁶UCI; ⁷LBL; ⁸ORNL

Funding from DOE and NSF

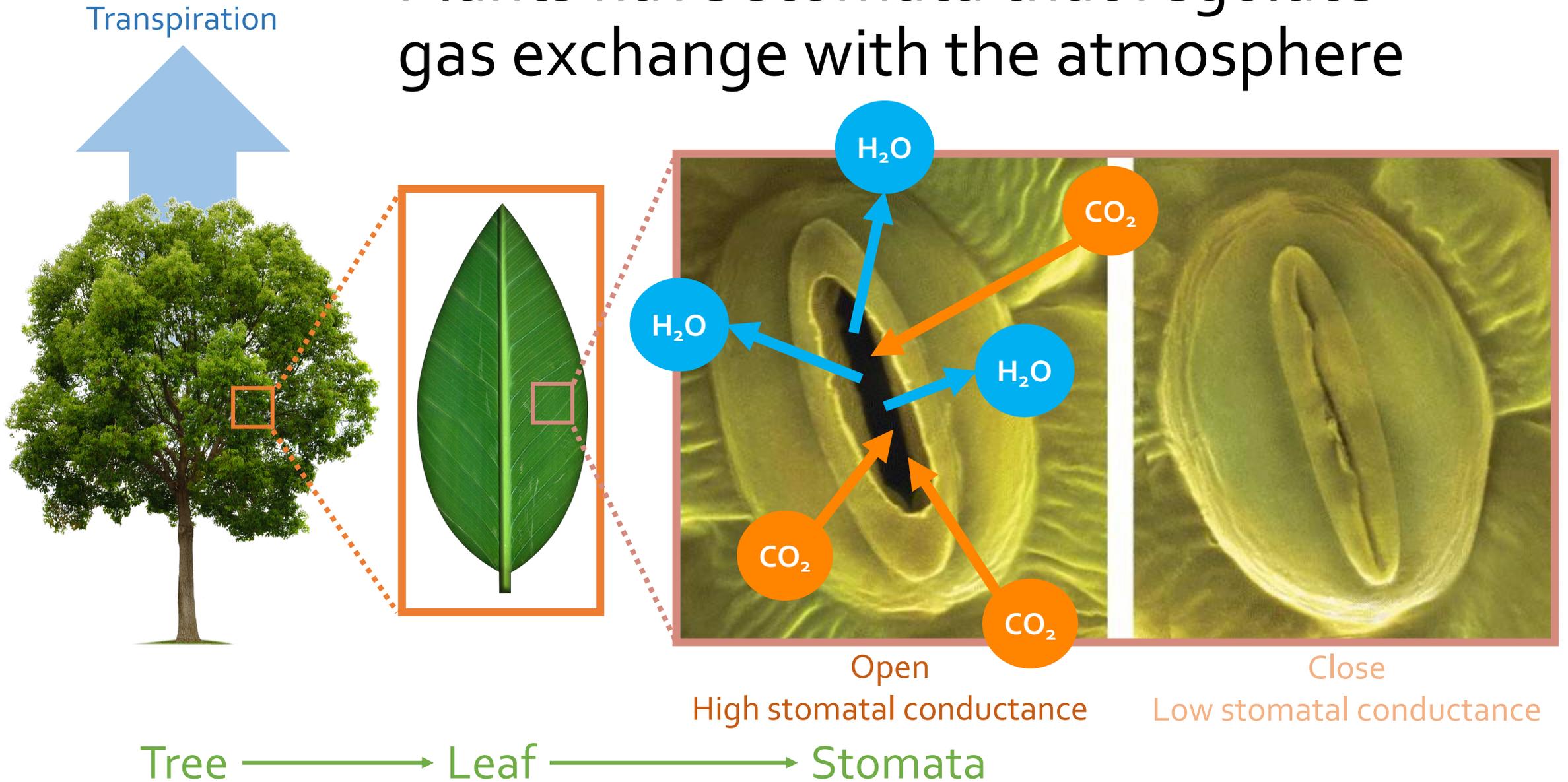


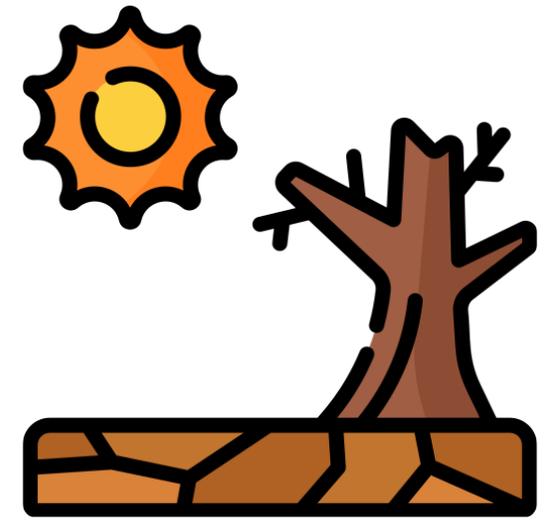
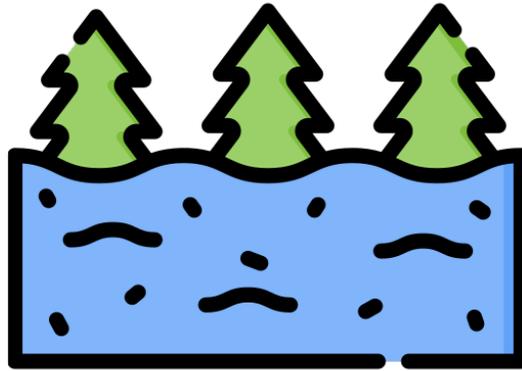
Plants have stomata that regulate gas exchange with the atmosphere



Tree → Leaf → Stomata

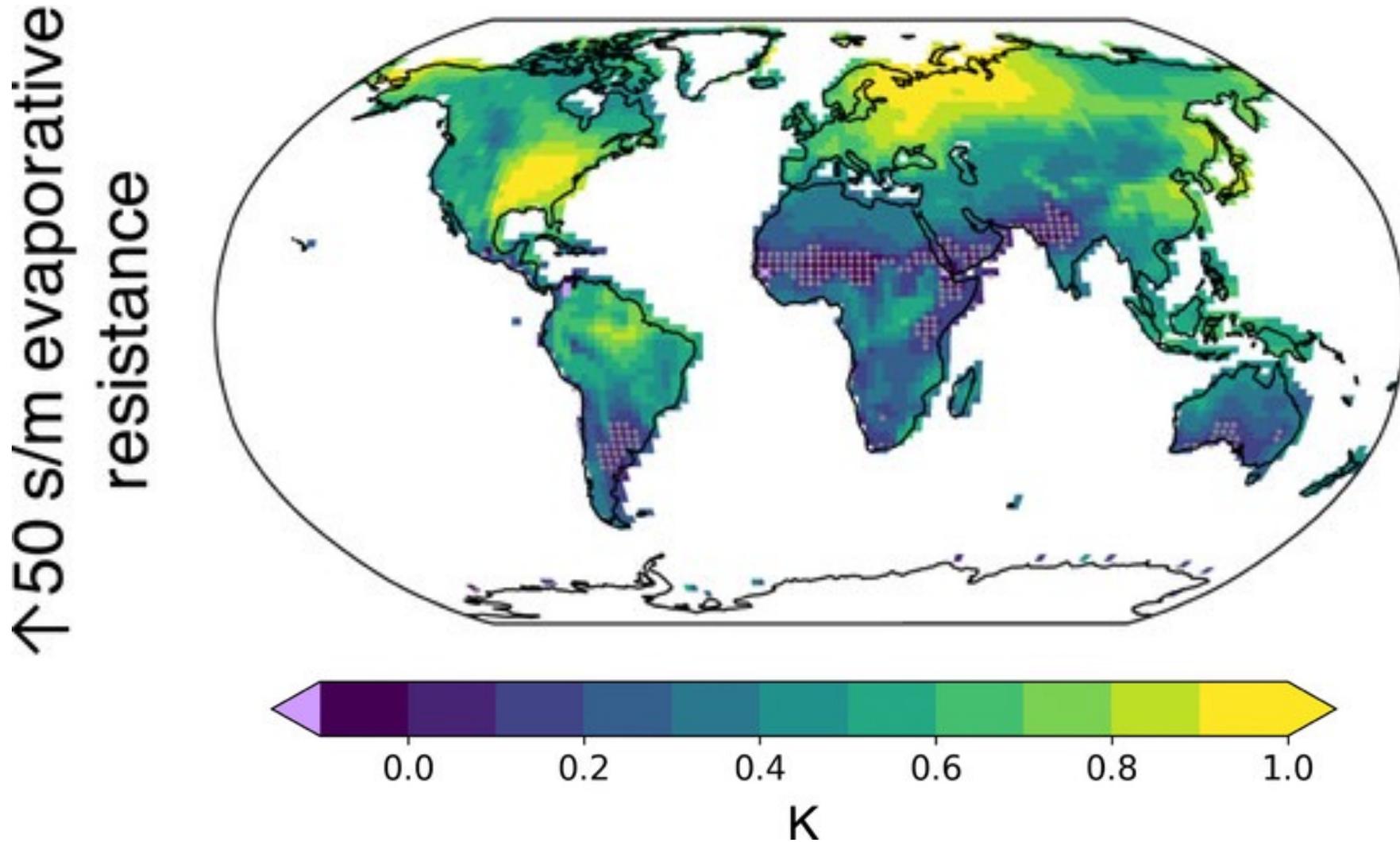
Plants have stomata that regulate gas exchange with the atmosphere





Changes in stomatal conductance drive changes in water flux, which impact the water cycle and affect water availability and the risk of extreme climate events like droughts, heatwaves, and floods.

Changes in evaporative resistance affects surface temperature



The Medlyn model represents stomatal conductance in CLM

The diagram illustrates the Medlyn model equation for stomatal conductance, g_s . The equation is $g_s = g_0 + 1.6 \left(1 + \frac{g_{1M}}{\sqrt{D_s}} \frac{A_n}{c_s} \right)$. Labels with arrows point to various parts of the equation: g_s is labeled 'Stomatal conductance'; g_0 is labeled 'Medlyn intercept'; g_{1M} is labeled 'Medlyn (stomatal) slope'; $\sqrt{D_s}$ is labeled 'Vapor pressure deficit'; A_n is labeled 'Photosynthesis'; and c_s is labeled 'CO₂ concentration'.

$$g_s = g_0 + 1.6 \left(1 + \frac{g_{1M}}{\sqrt{D_s}} \frac{A_n}{c_s} \right)$$

Stomatal conductance

Medlyn intercept

Medlyn (stomatal) slope

Vapor pressure deficit

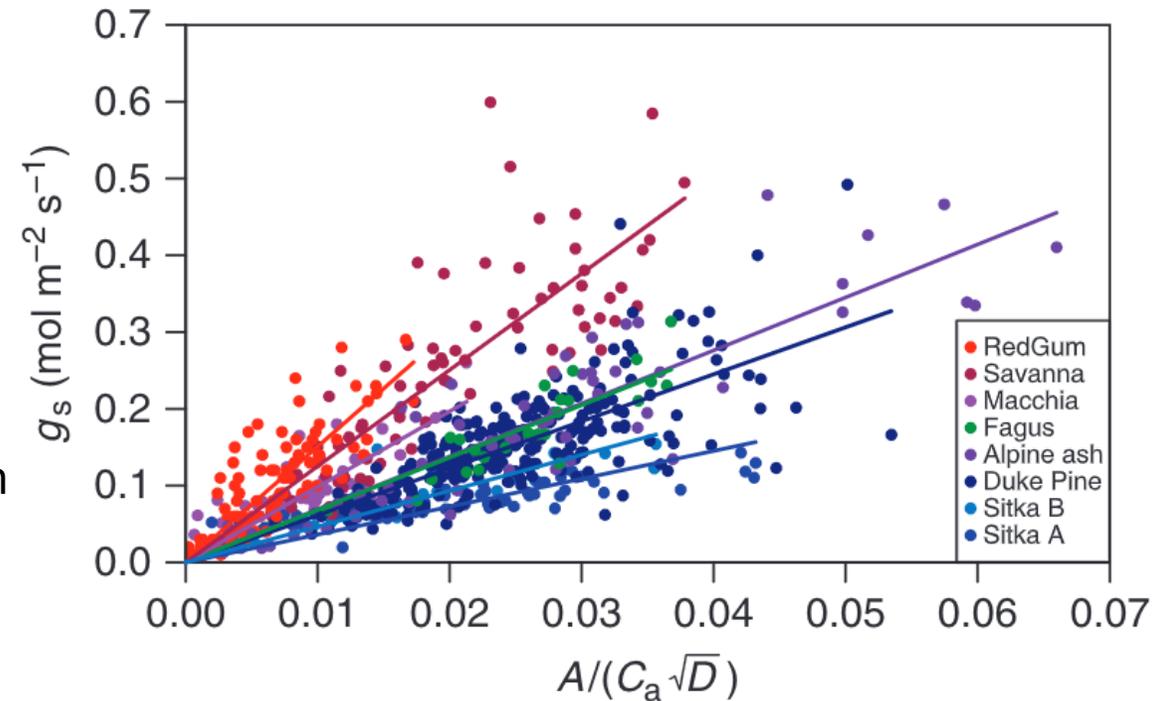
Photosynthesis

CO₂ concentration

The Medlyn slope is a fitted parameter based on observations

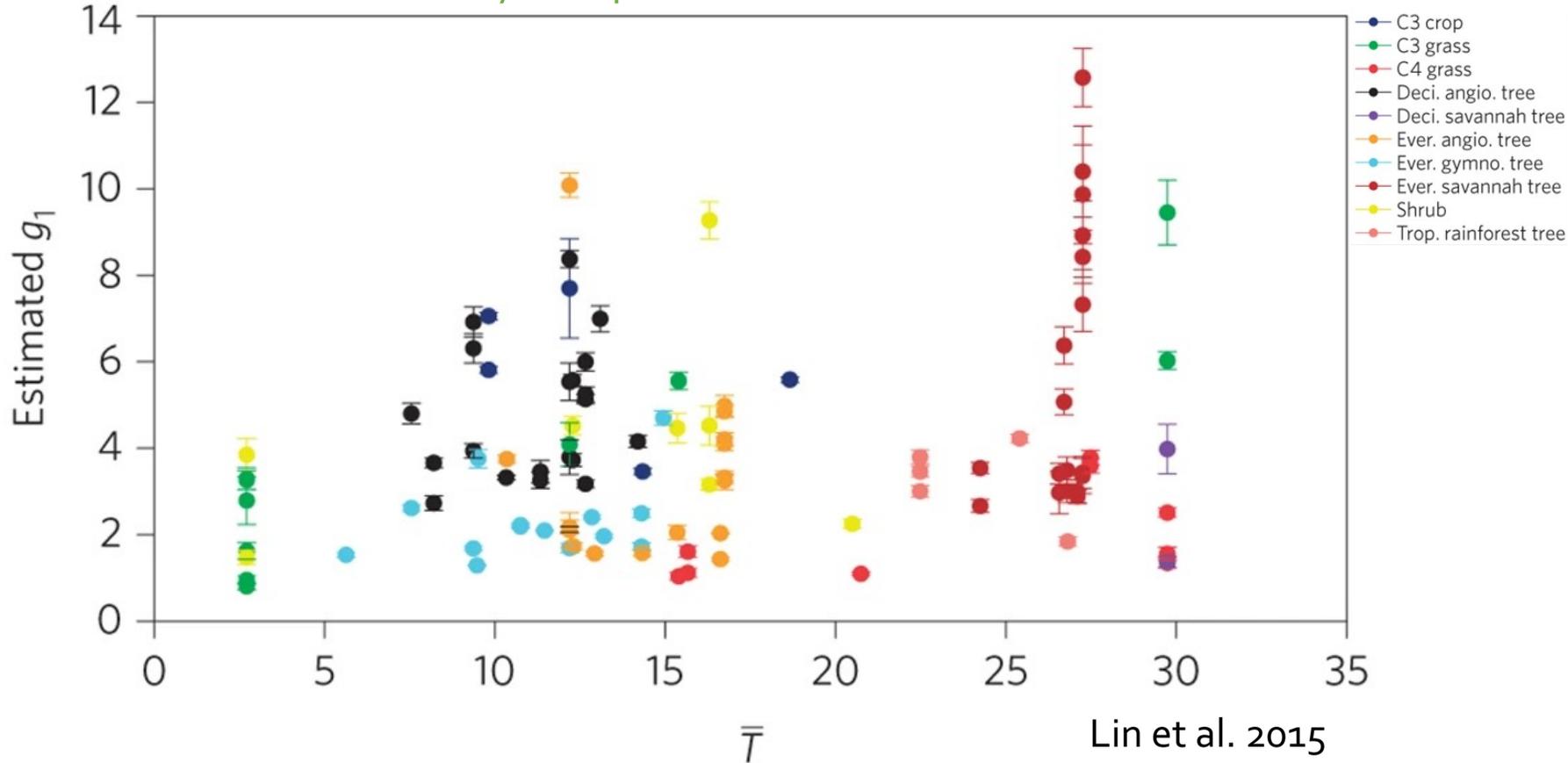
$$g_s = g_0 + 1.6 \left(1 + \frac{g_{1M}}{\sqrt{D_s}} \frac{A_n}{c_s} \right)$$

Stomatal conductance g_s is equal to the Medlyn intercept g_0 plus 1.6 times the sum of 1 and the Medlyn (stomatal) slope g_{1M} divided by the square root of the vapor pressure deficit $\sqrt{D_s}$, multiplied by the ratio of photosynthesis A_n to CO₂ concentration c_s .



There is variability across + within plant types

Estimated Medlyn Slope based on Field Observations

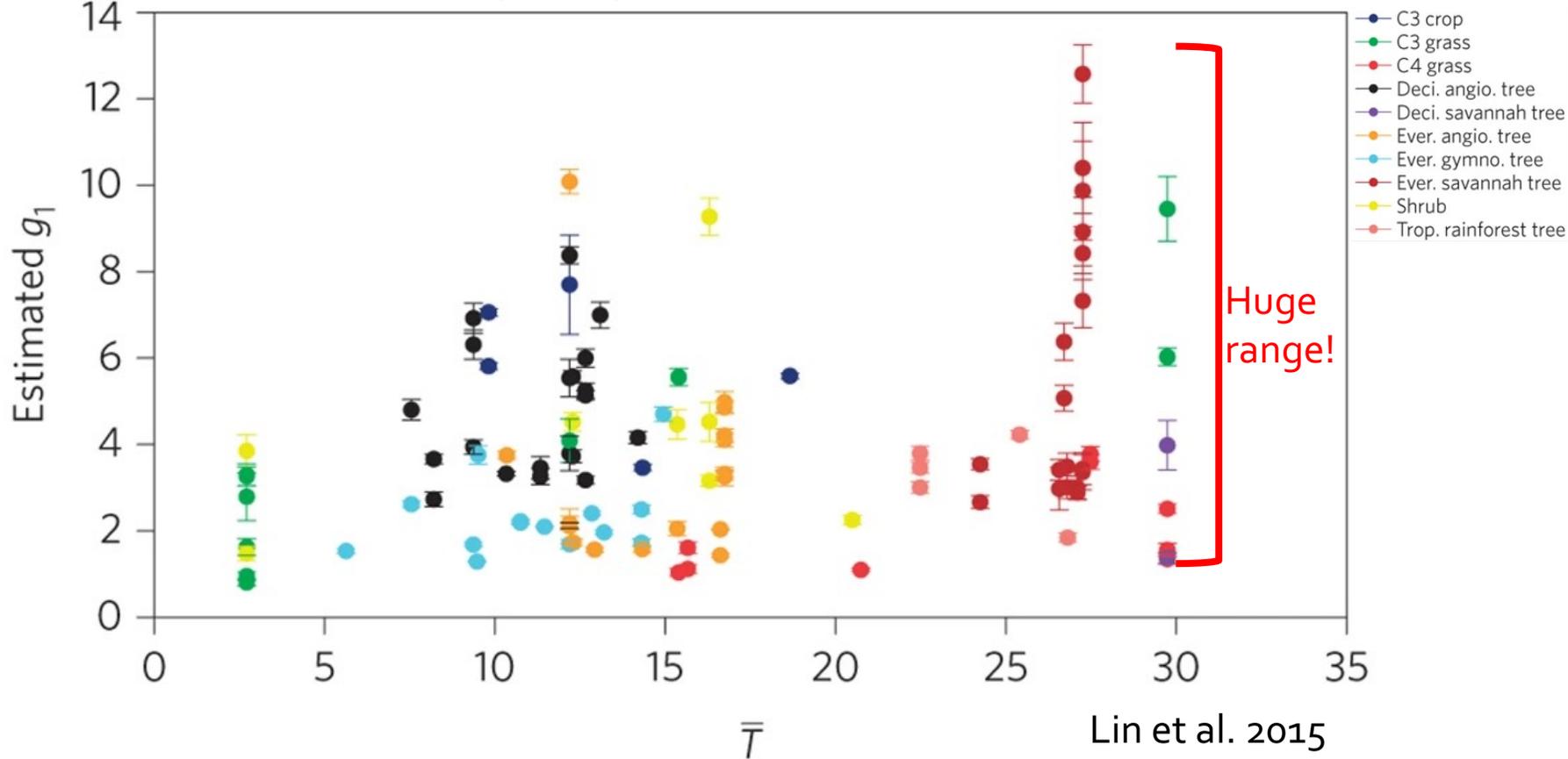


$$g_s = g_0 + 1.6 \left(1 + \frac{g_{1M}}{\sqrt{D_s}} \frac{A_n}{c_s} \right)$$

Medlyn slope
↓
g_{1M}

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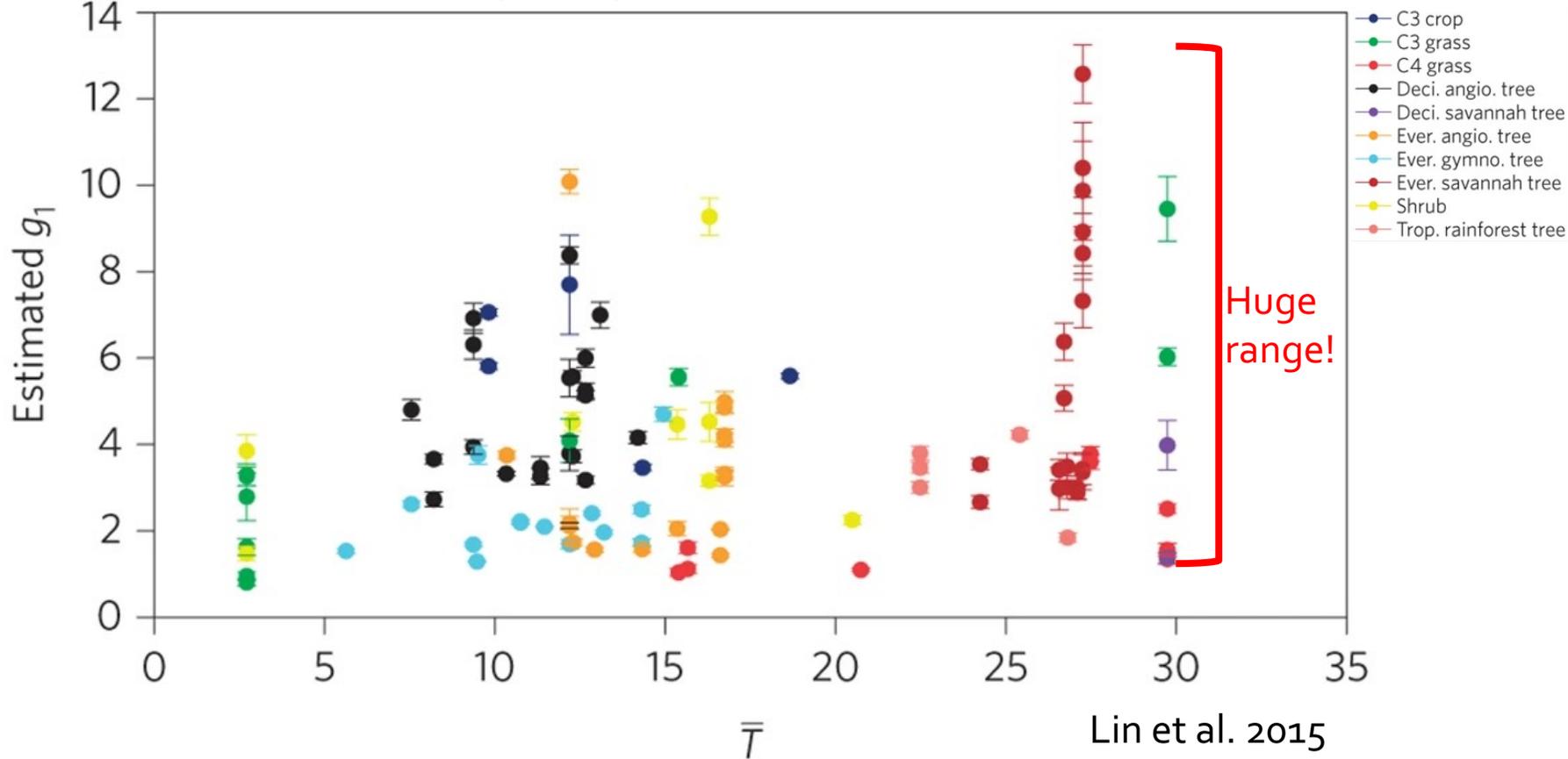


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Medlyn slope

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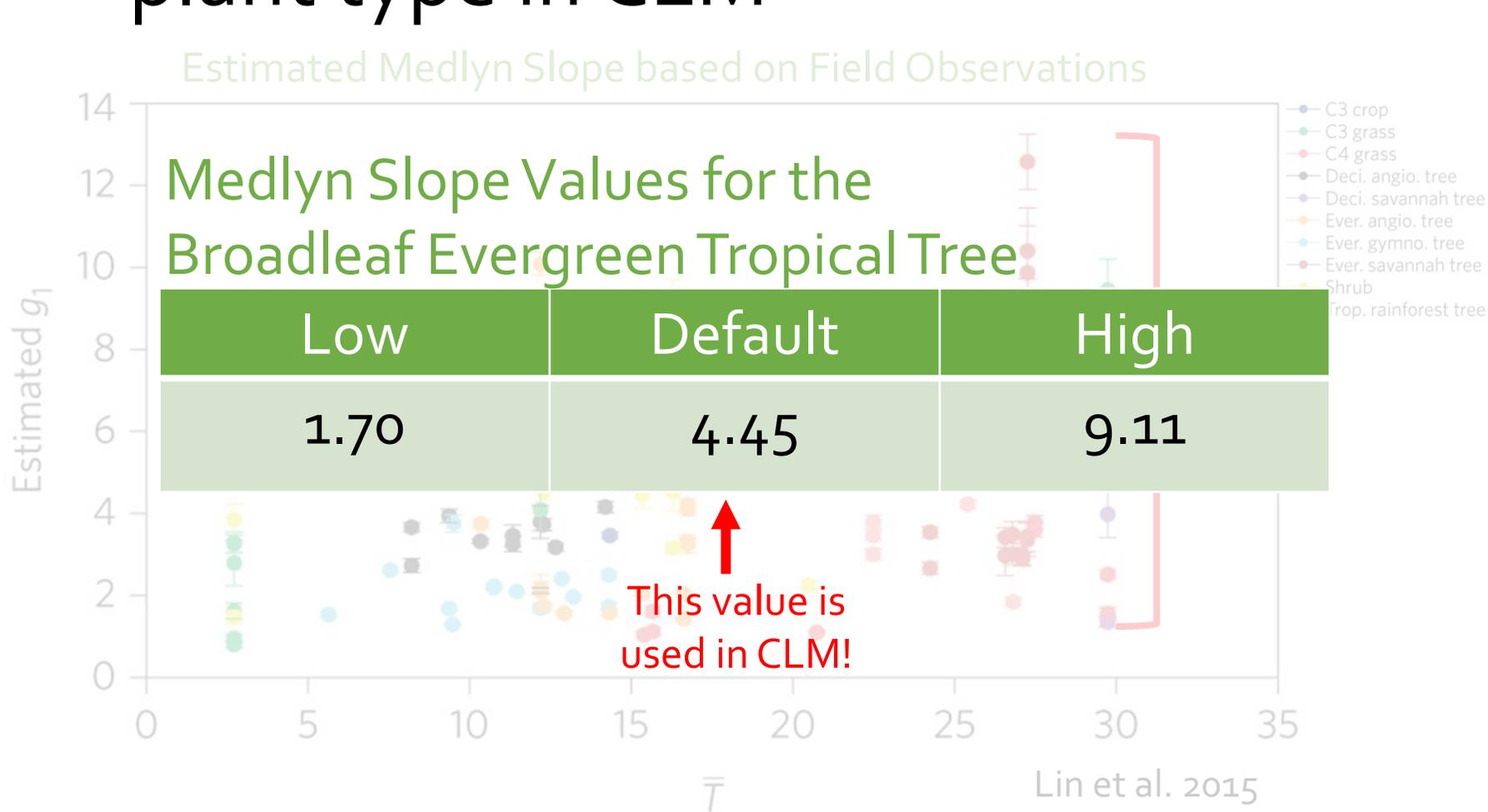


$$g_s = g_0 + 1.6 \left(1 + \frac{g_{1M}}{\sqrt{D_s}} \frac{A_n}{c_s} \right)$$

Medlyn slope

... leading to large variance for plant related processes.

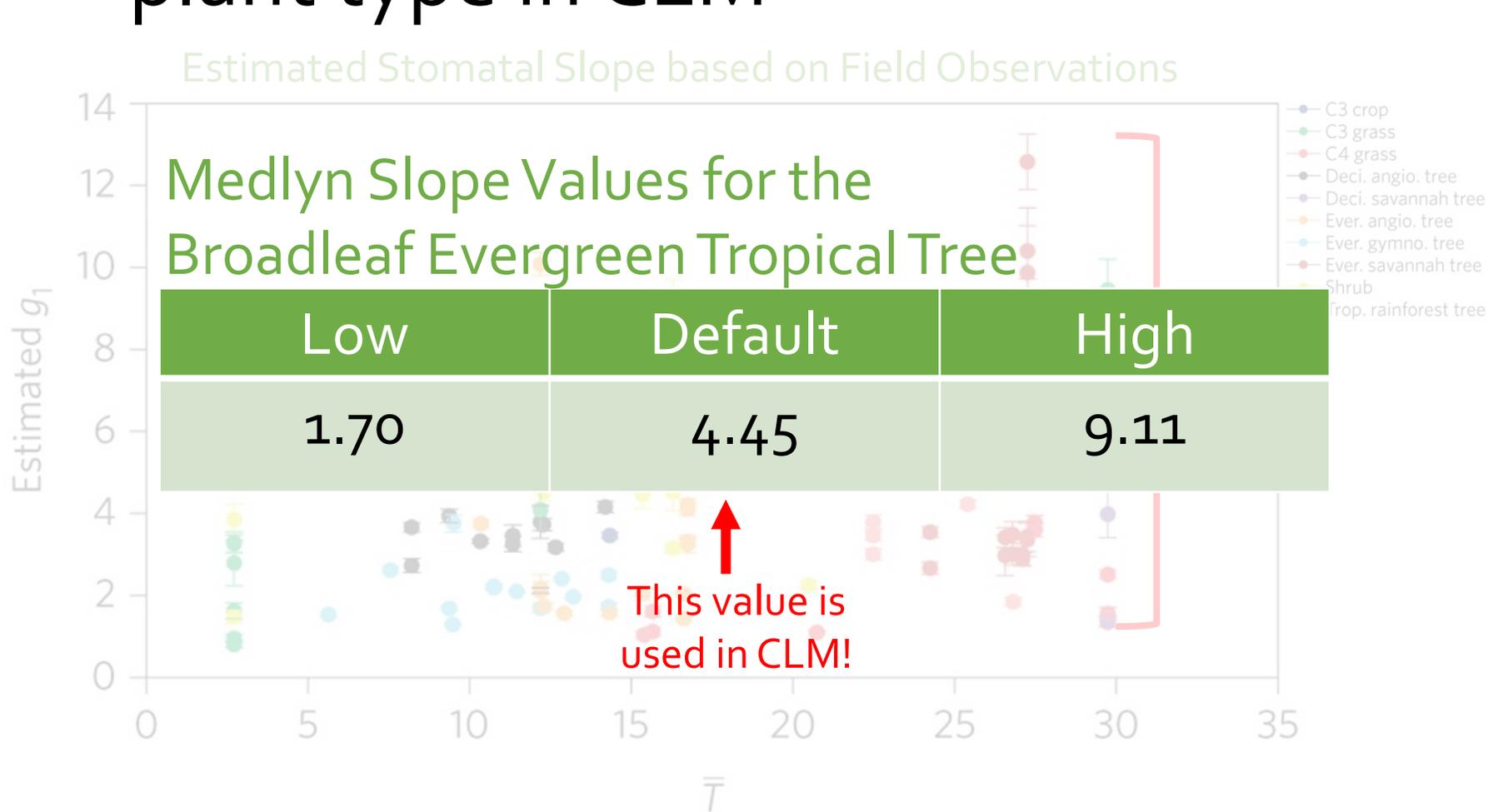
One Medlyn slope value is used to represent each plant type in CLM



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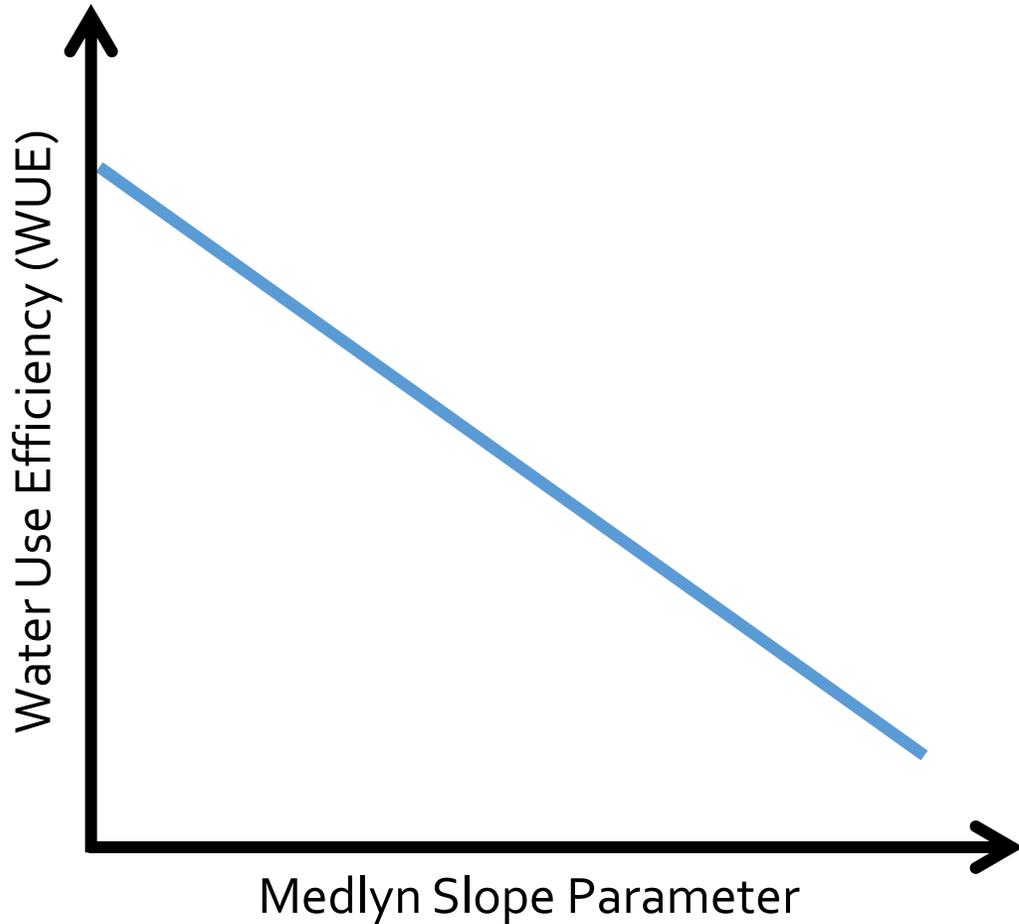
Medlyn slope
↓
g_{1M}

What happens if we use a different Medlyn slope value?

Focusing on the Medlyn slope parameter (g_{1M})

$$g_s = g_0 + 1.6 \left(1 + \frac{g_{1M}}{\sqrt{D_s}} \frac{A_n}{c_s} \right)$$
$$WUE = \frac{A_n}{\text{Transpiration}} \propto \frac{A_n}{\sqrt{D_s}}$$

Focusing on the Medlyn slope parameter (g_{1M})

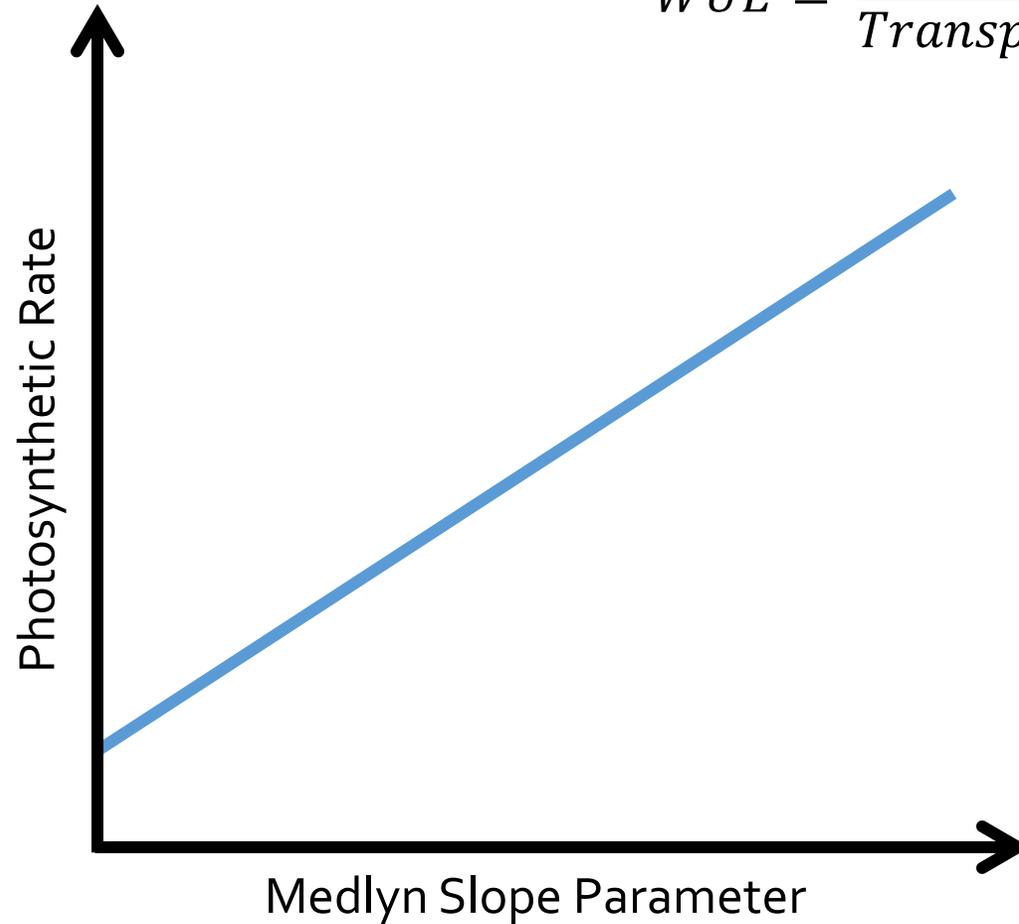
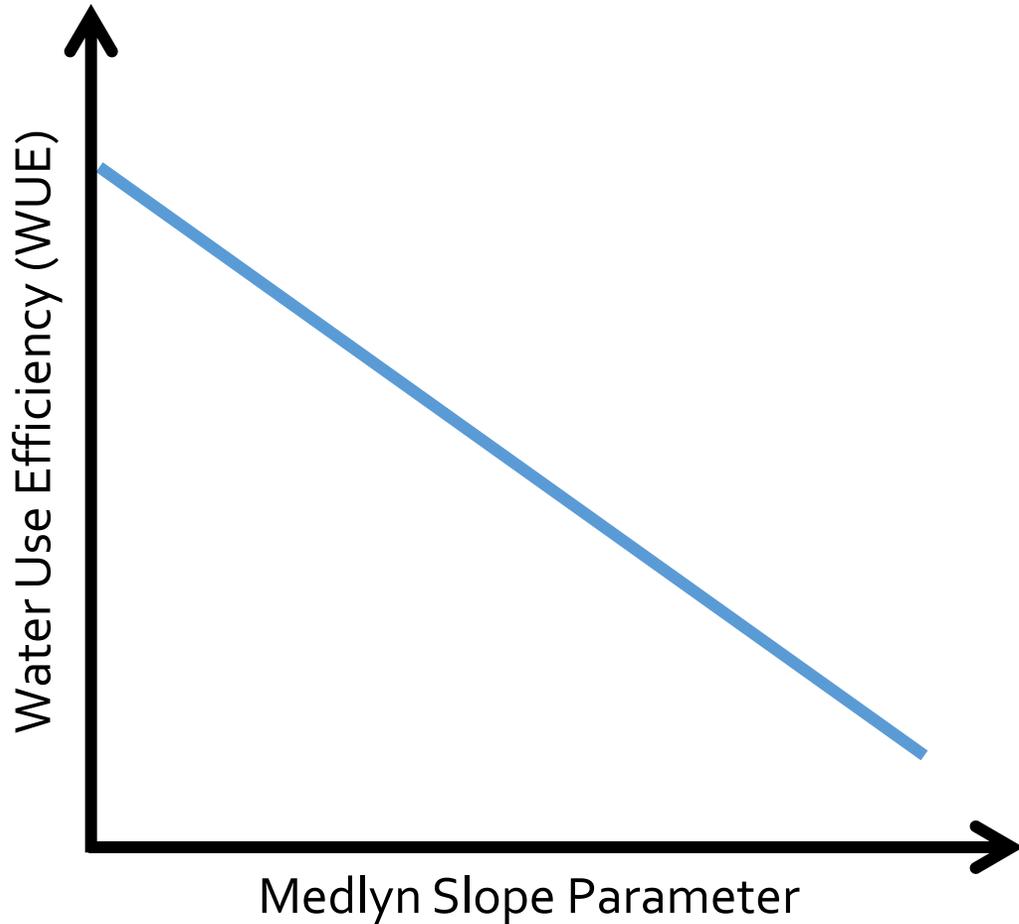


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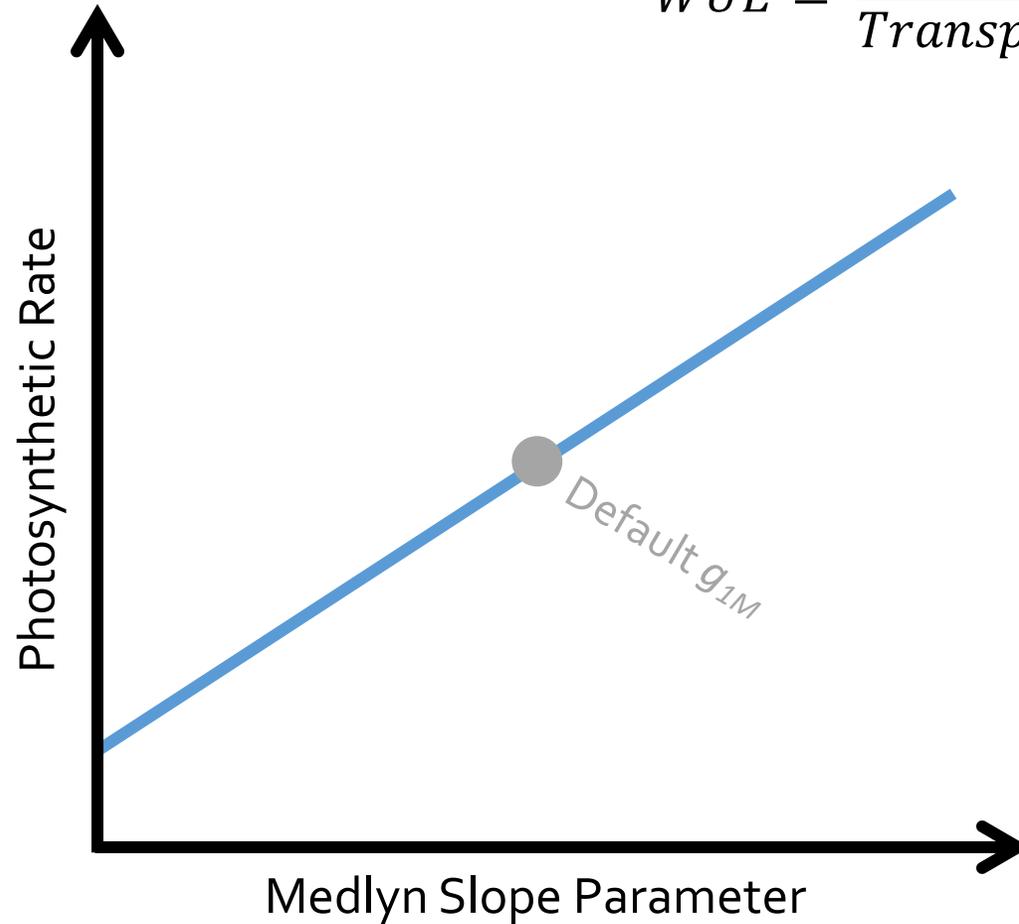
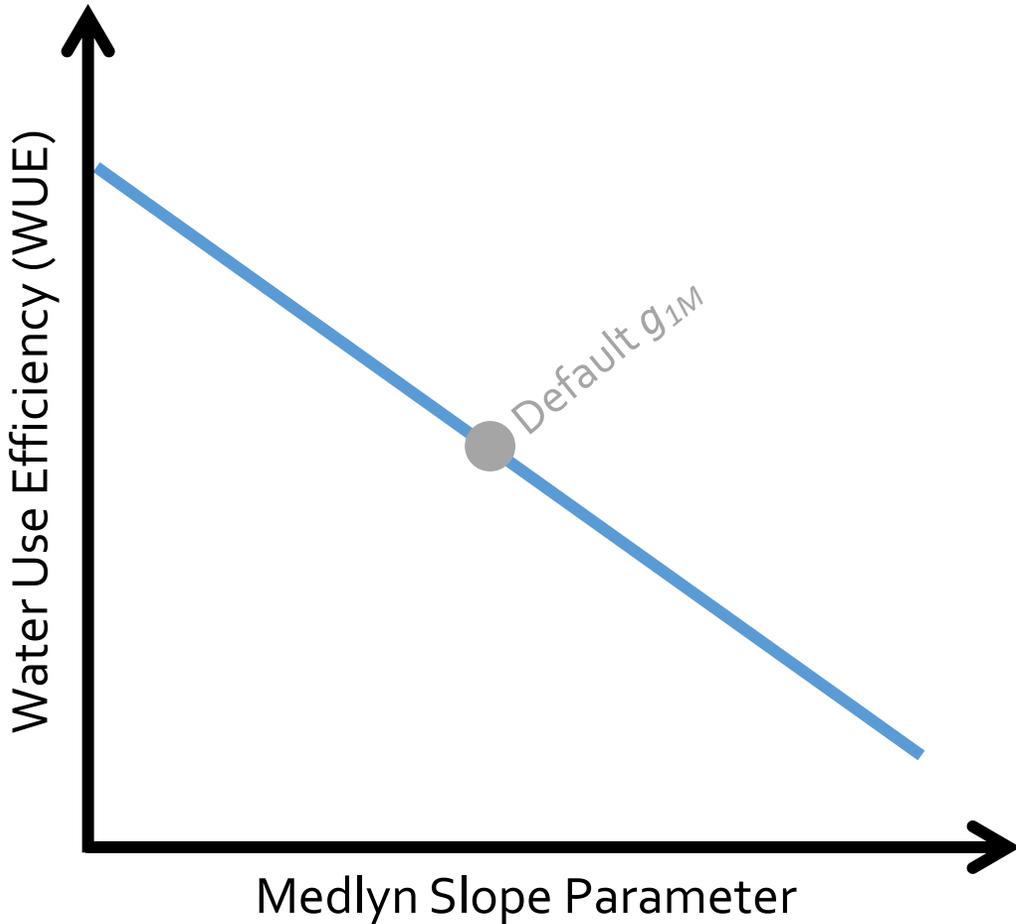


Focusing on the Medlyn slope parameter (g_{1M})

We vary this

$$g_s = g_0 + 1.6 \left(1 + \frac{g_{1M}}{\sqrt{D_s}} \frac{A_n}{c_s} \right)$$

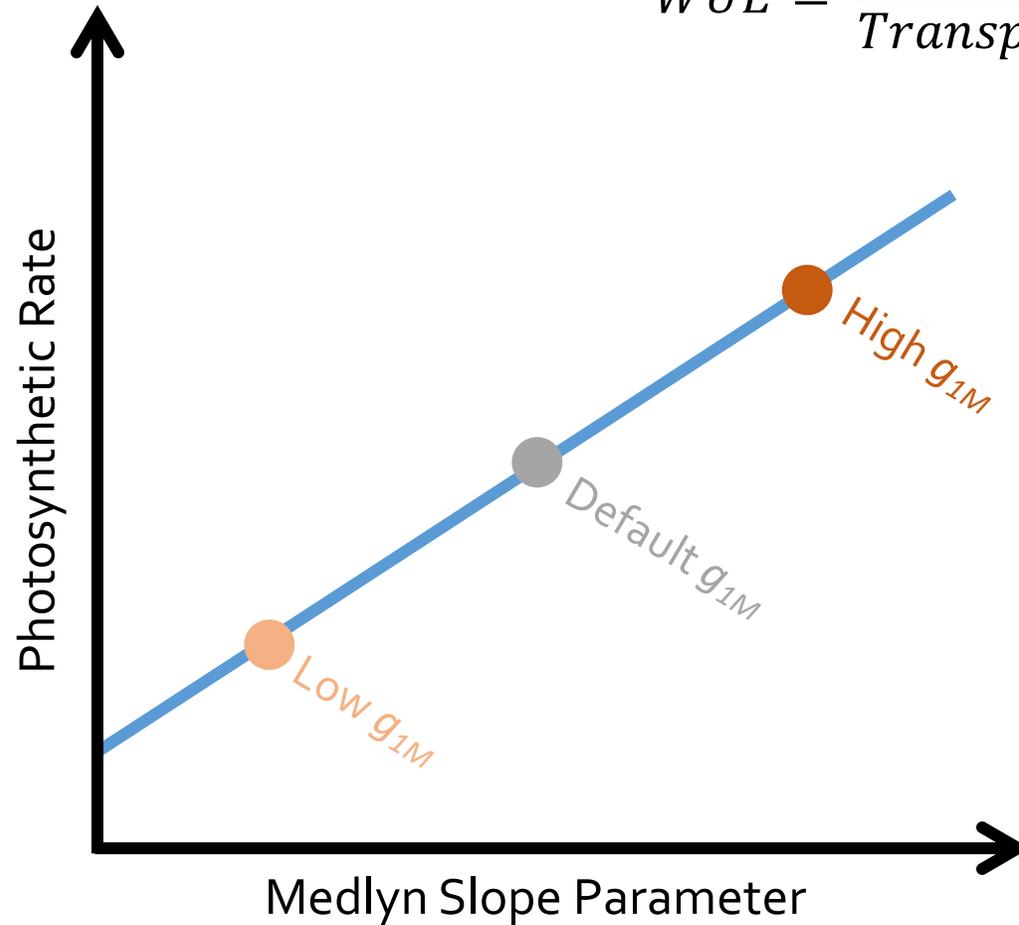
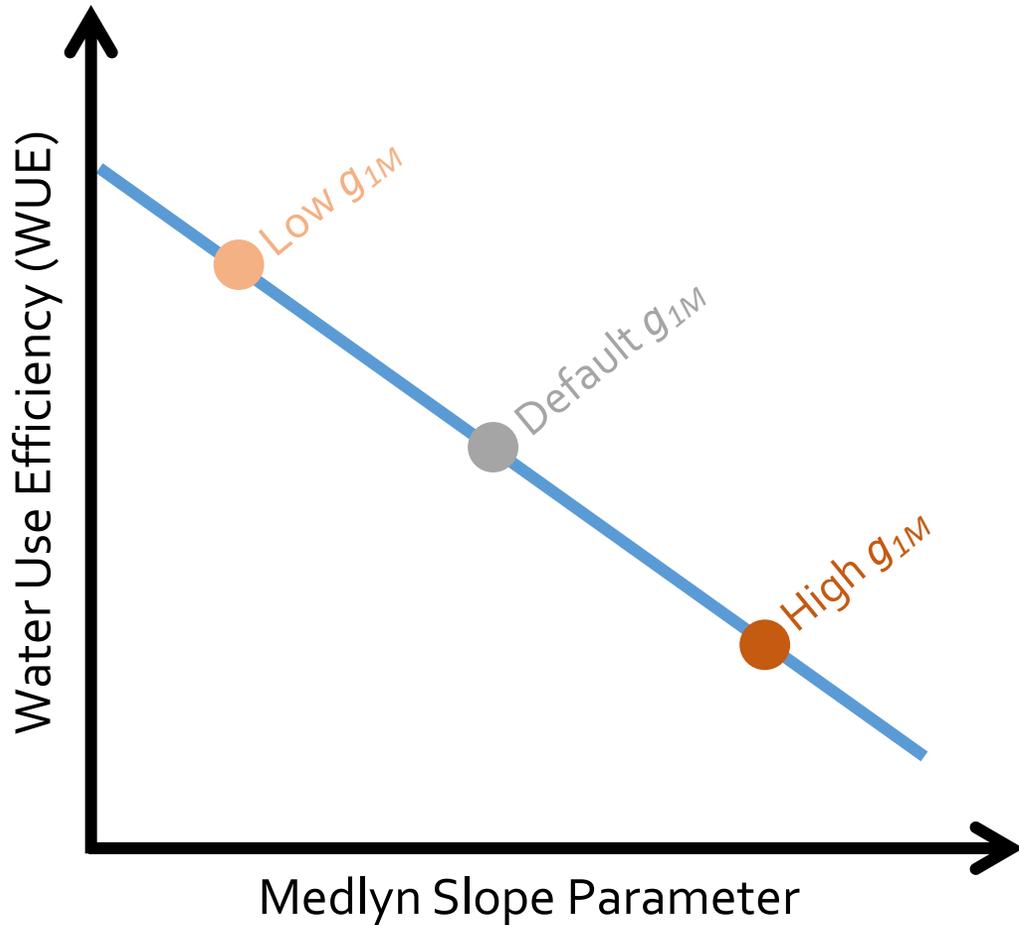
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Focusing on the Medlyn slope parameter (g_{1M})

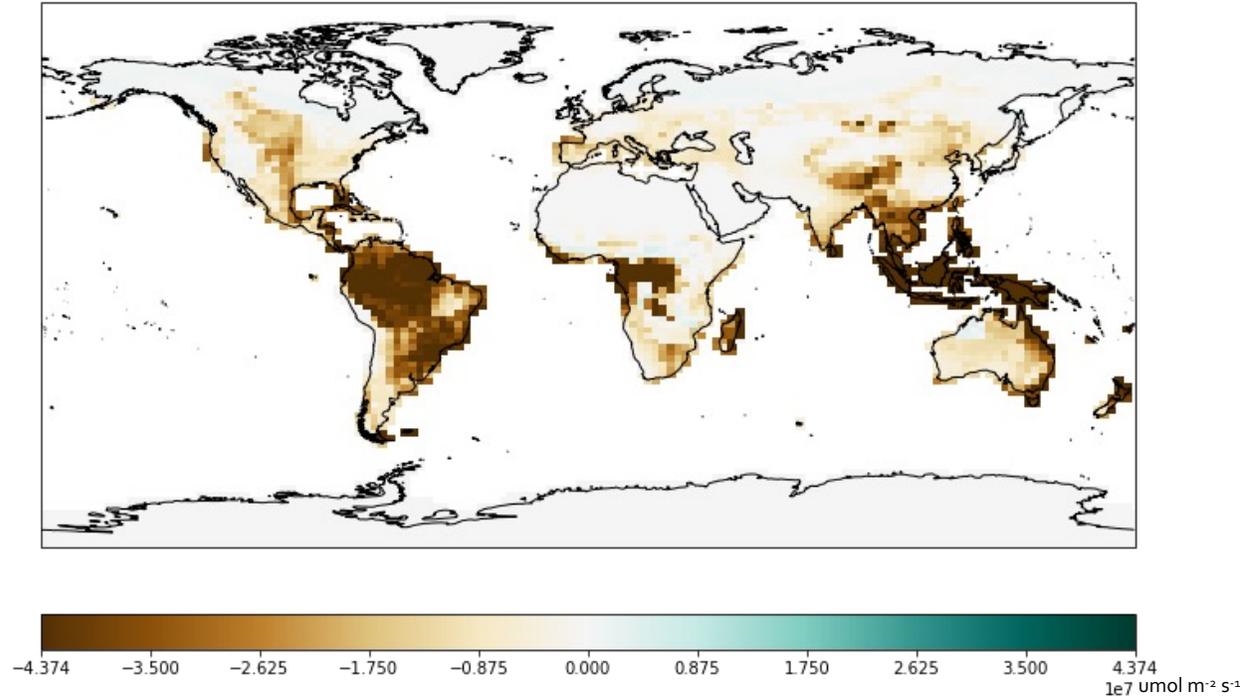
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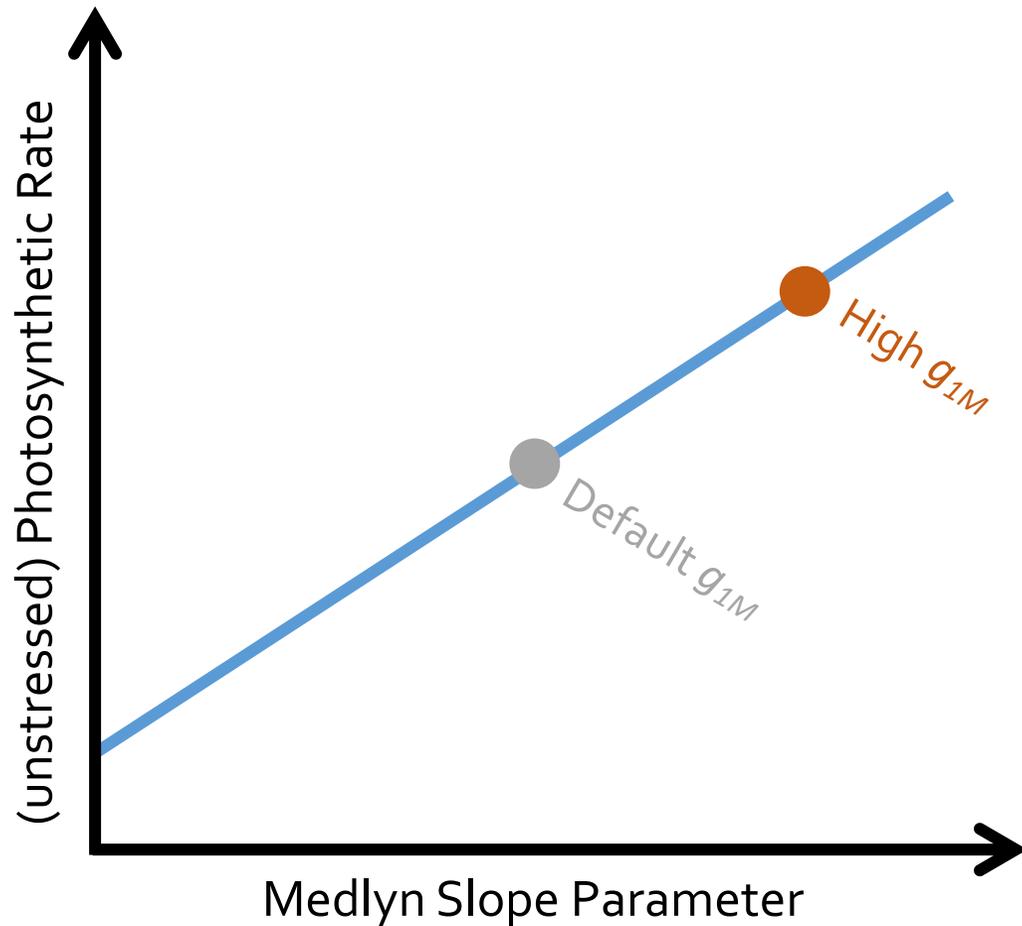


Decreases in photosynthesis for the high Medlyn slope case is consistent globally

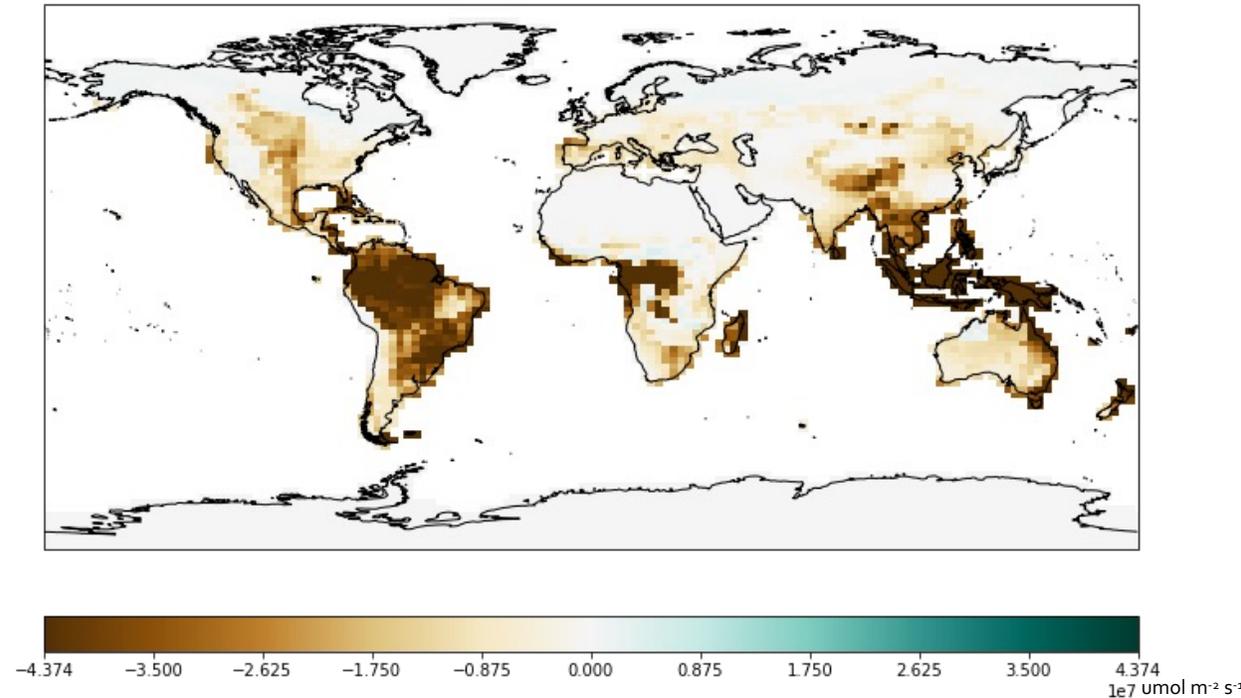
Photosynthesis **High** – Default g_{1M}



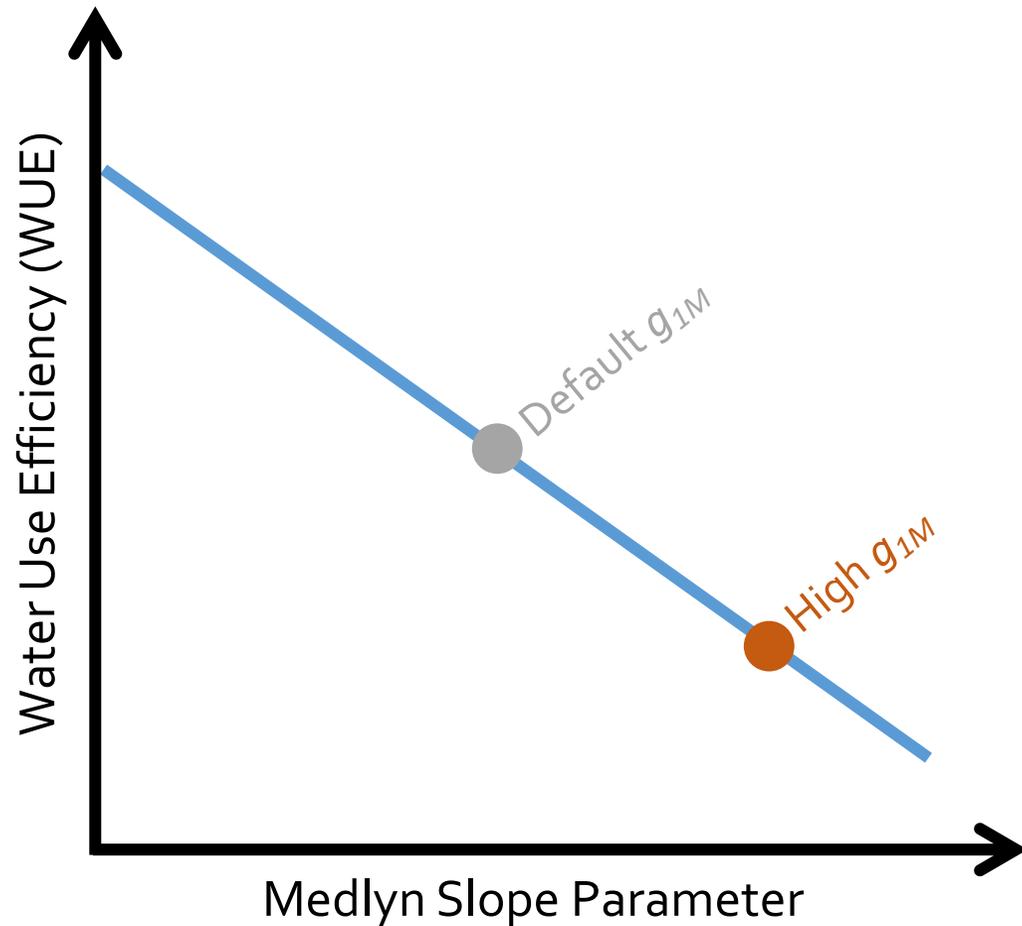
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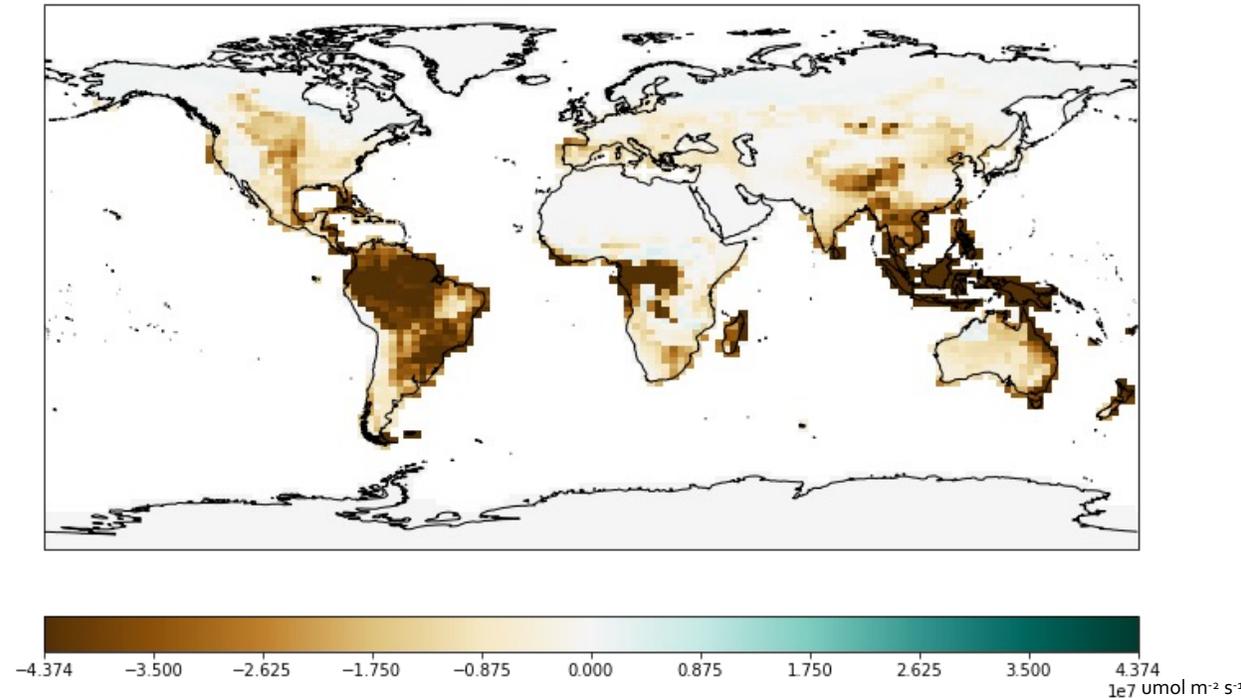
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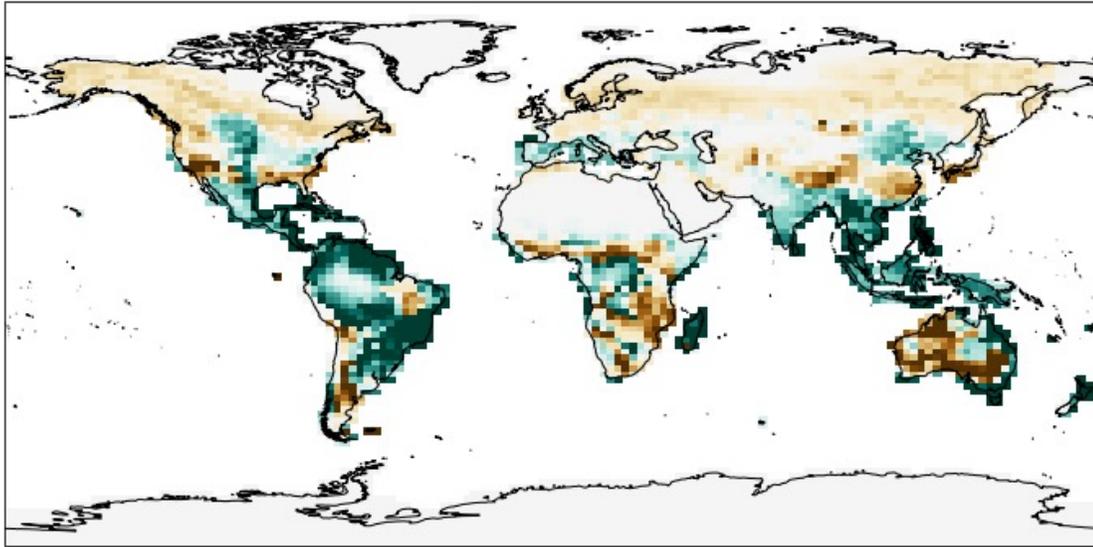


Photosynthesis High – Default g_{1M}

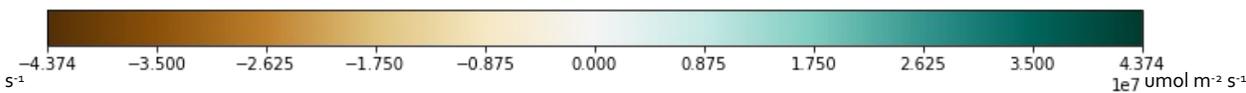
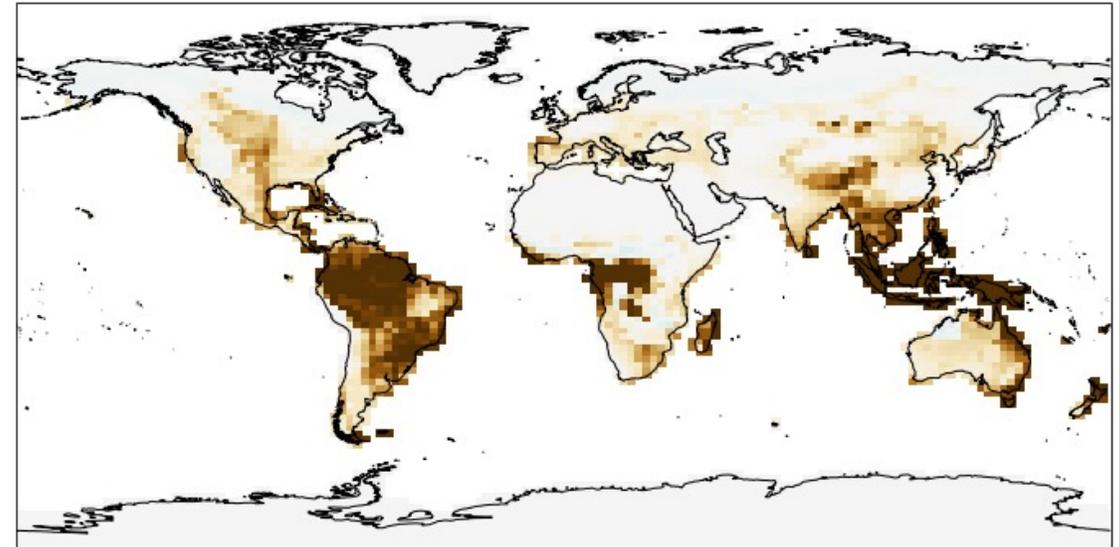


The low Medlyn slope case shows response is regionally dependent

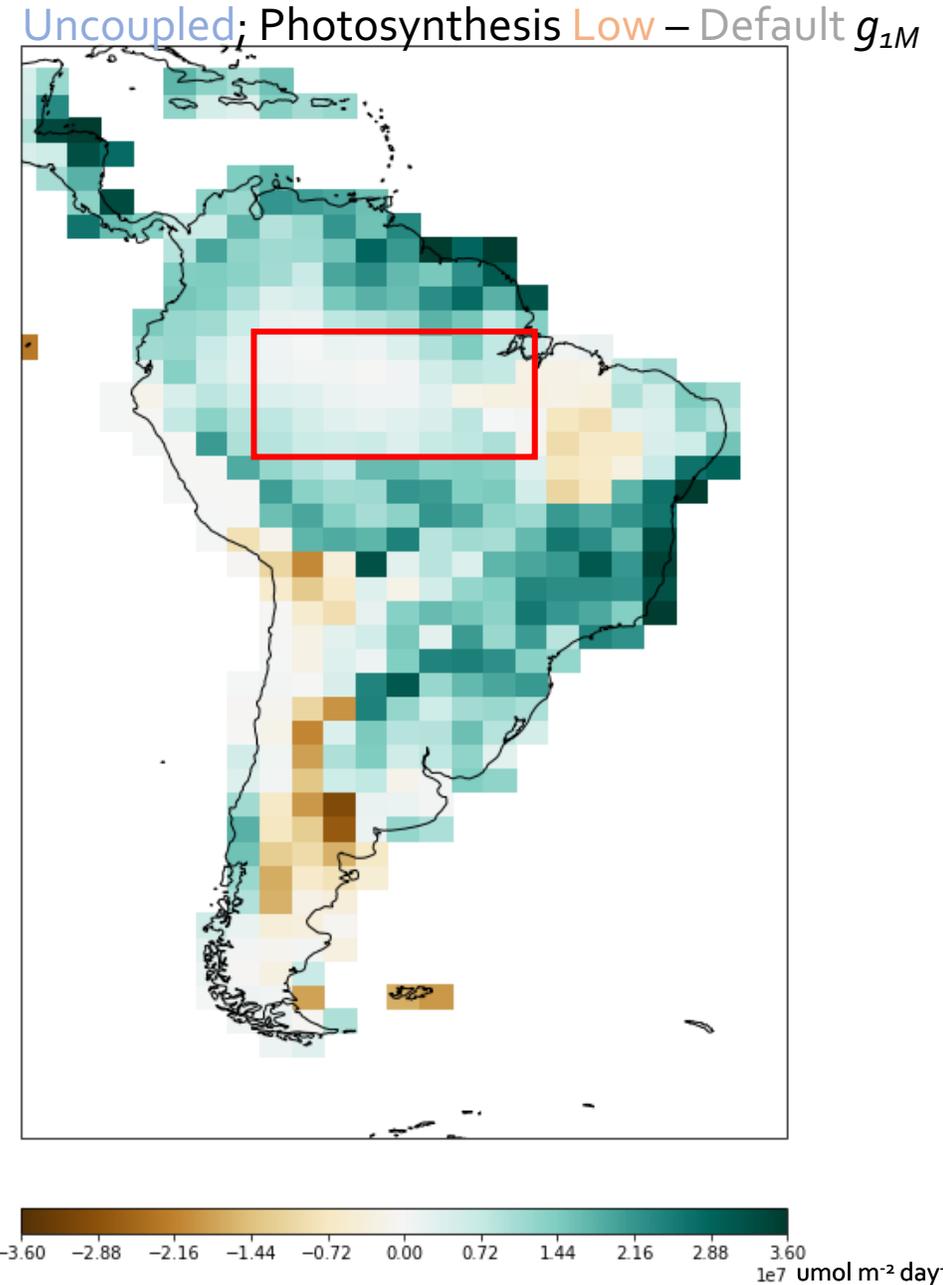
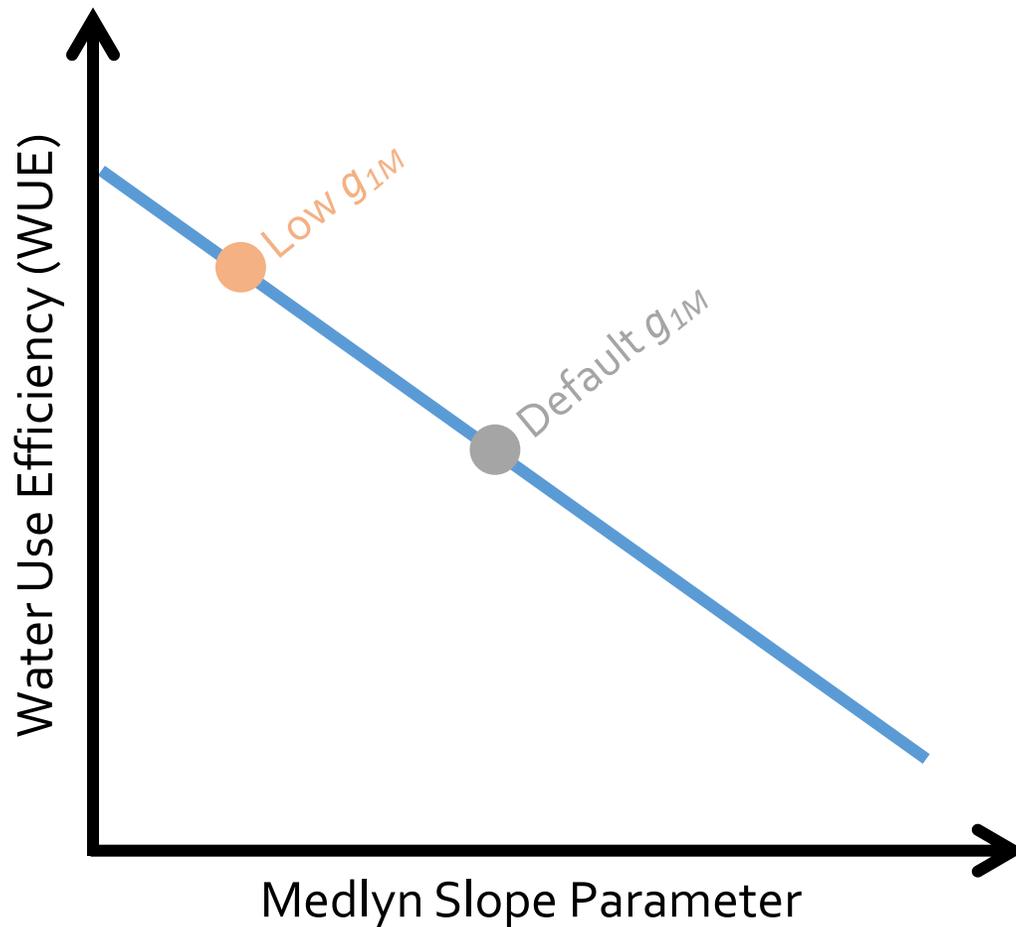
Photosynthesis **Low** – Default g_{1M}



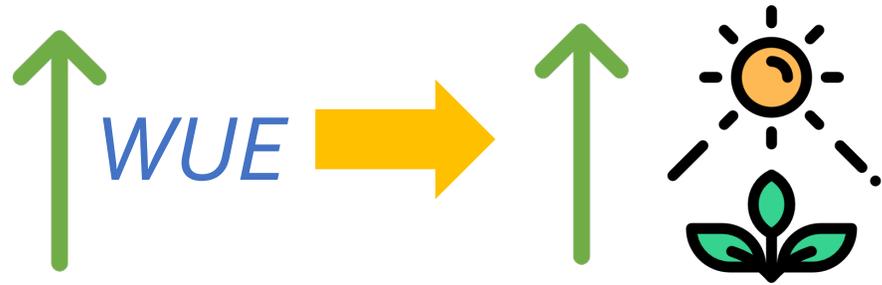
Photosynthesis **High** – Default g_{1M}



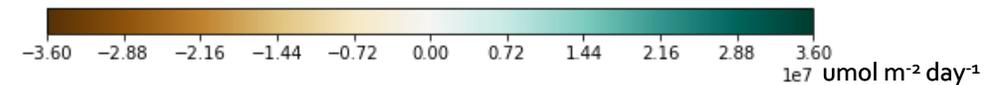
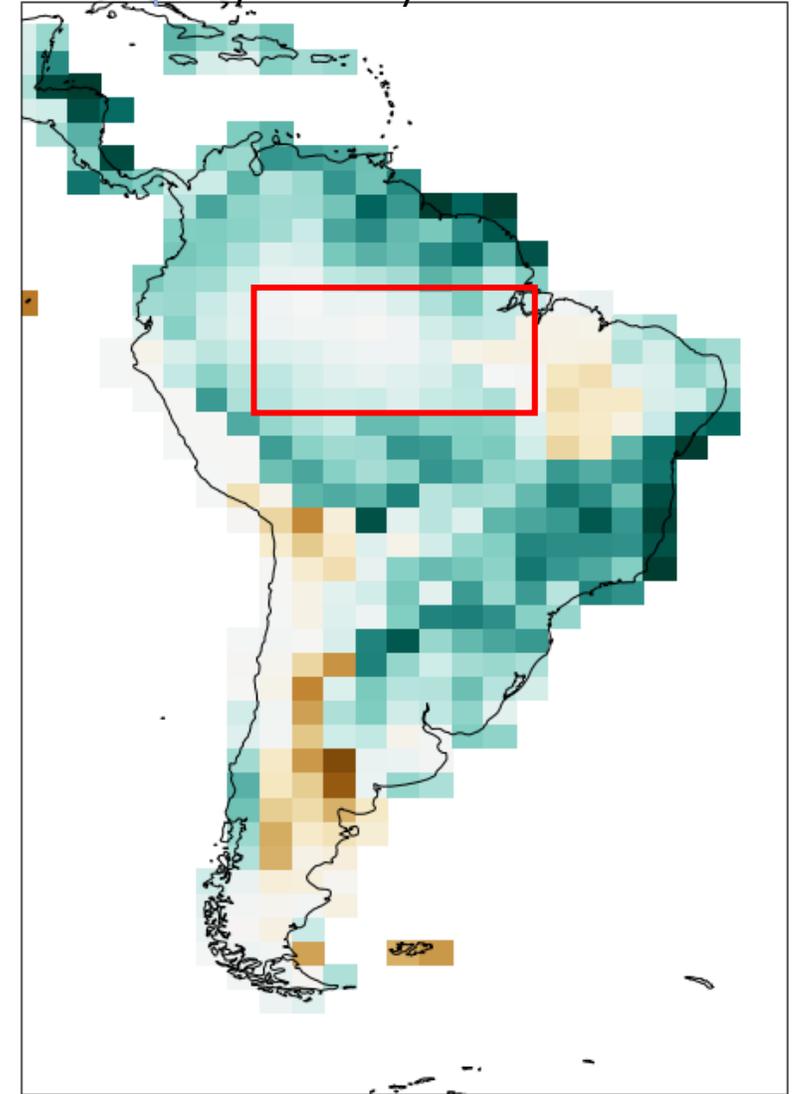
Photosynthesis **increases** in the Amazon with low Medlyn slope



Photosynthesis **increases** in the Amazon with low Medlyn slope



Uncoupled; Photosynthesis **Low** – Default g_{1M}

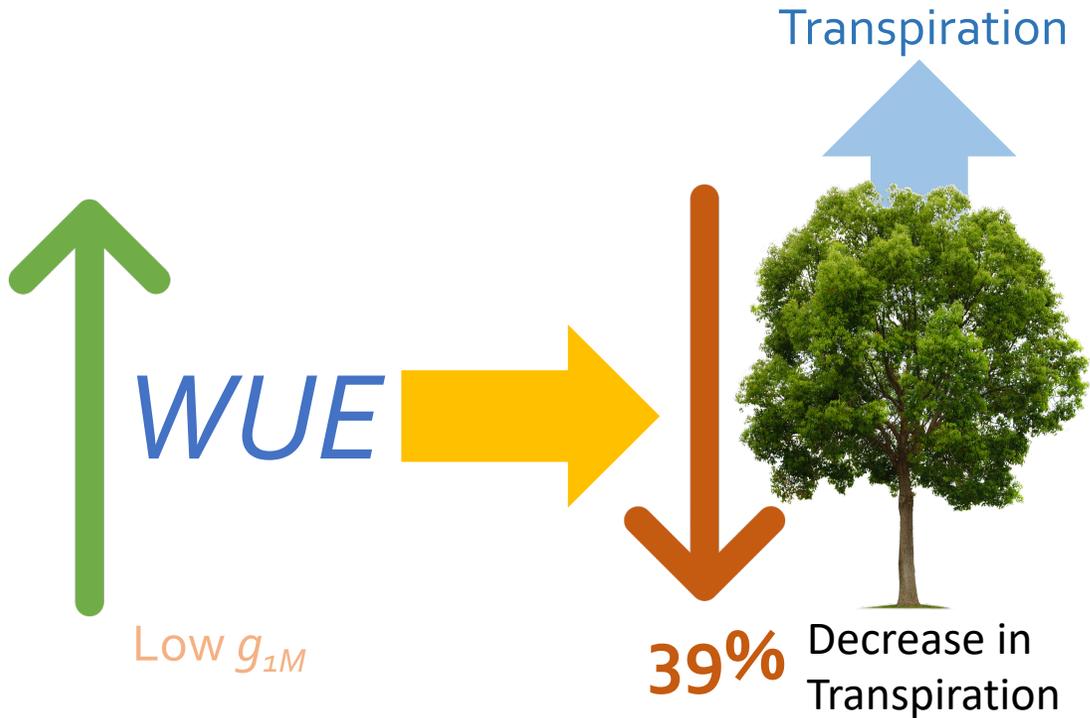


There is an increase in WUE and an increase in photosynthesis



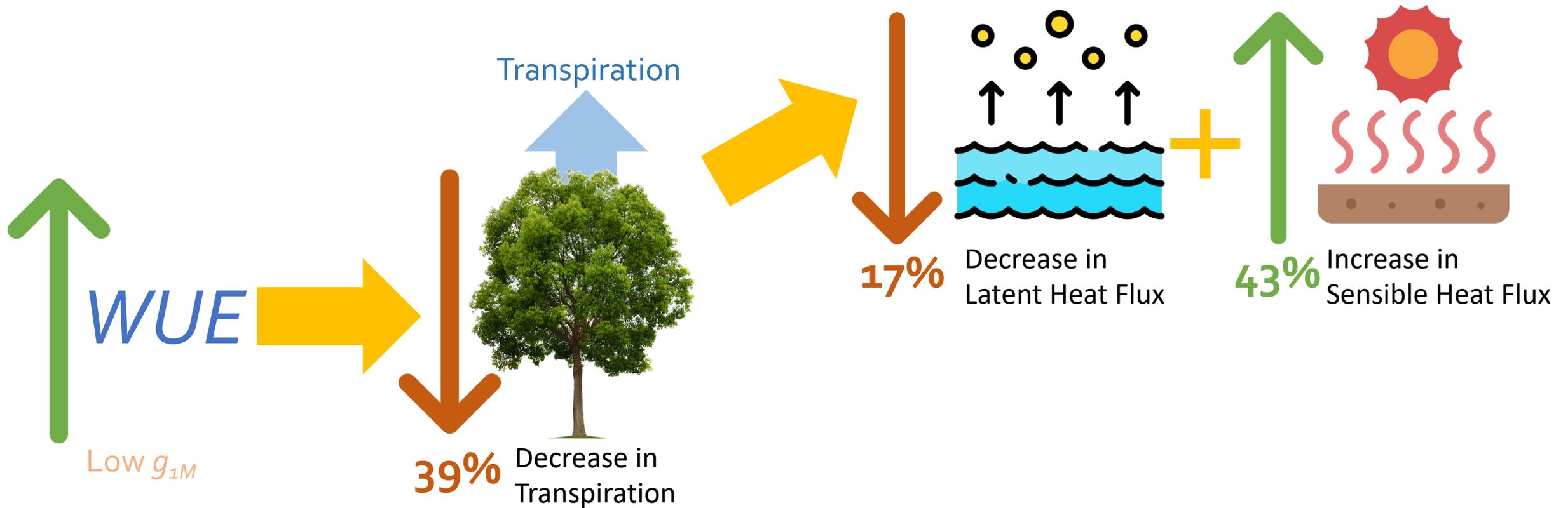
2% Increase in photosynthesis

Transpiration decreases as expected with increase in WUE



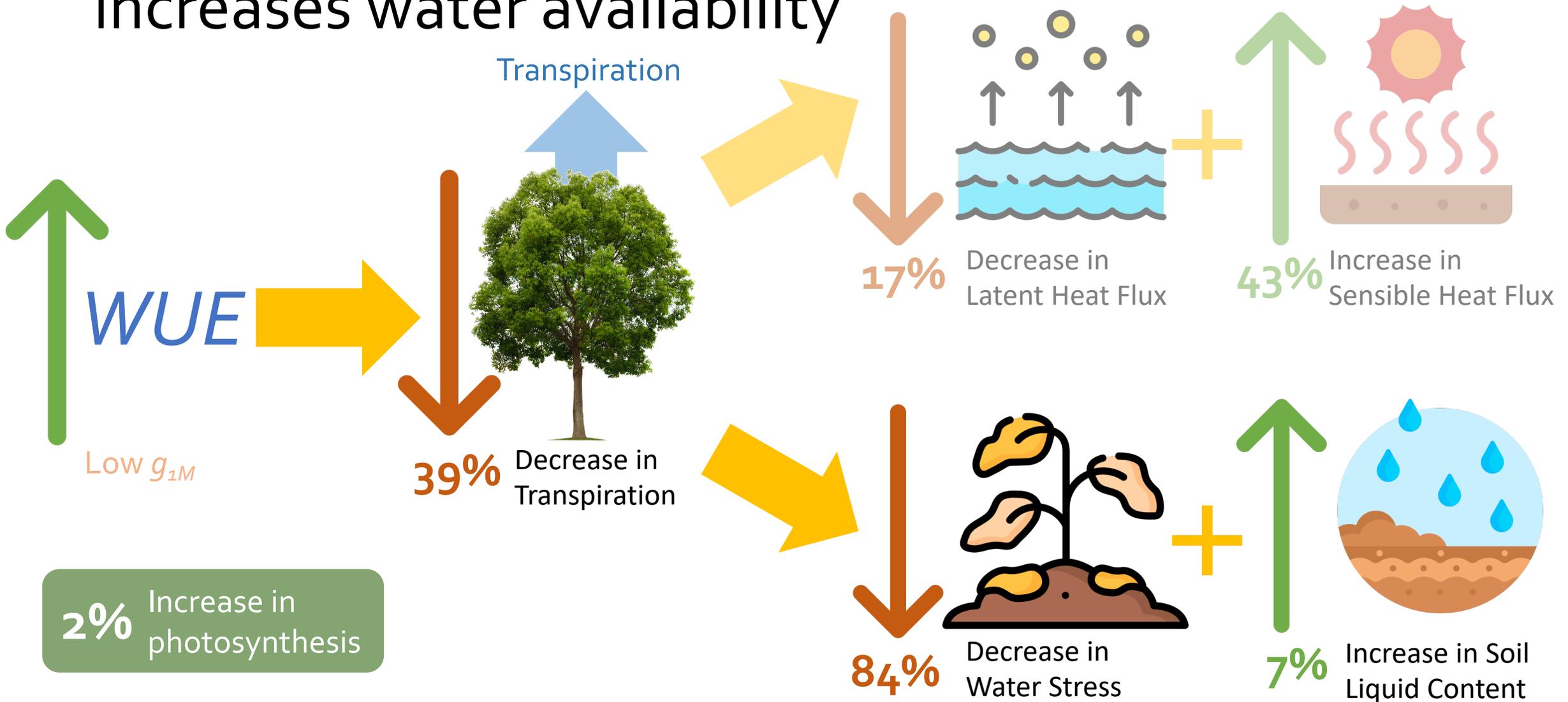
2% Increase in photosynthesis

The heat fluxes also change as expected

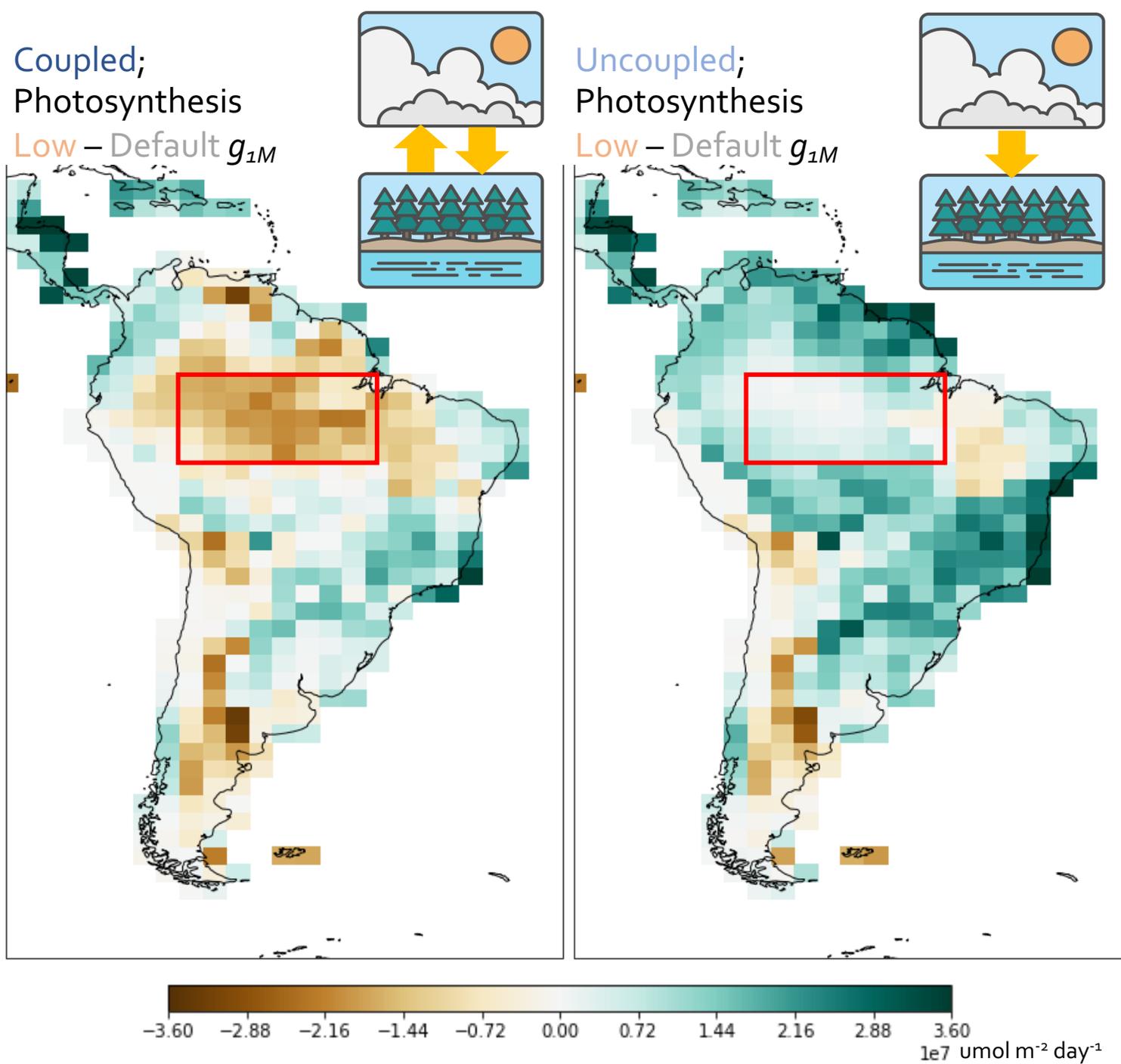
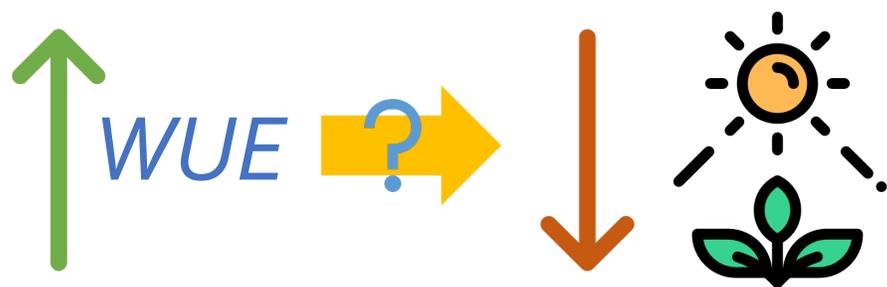


2% Increase in photosynthesis

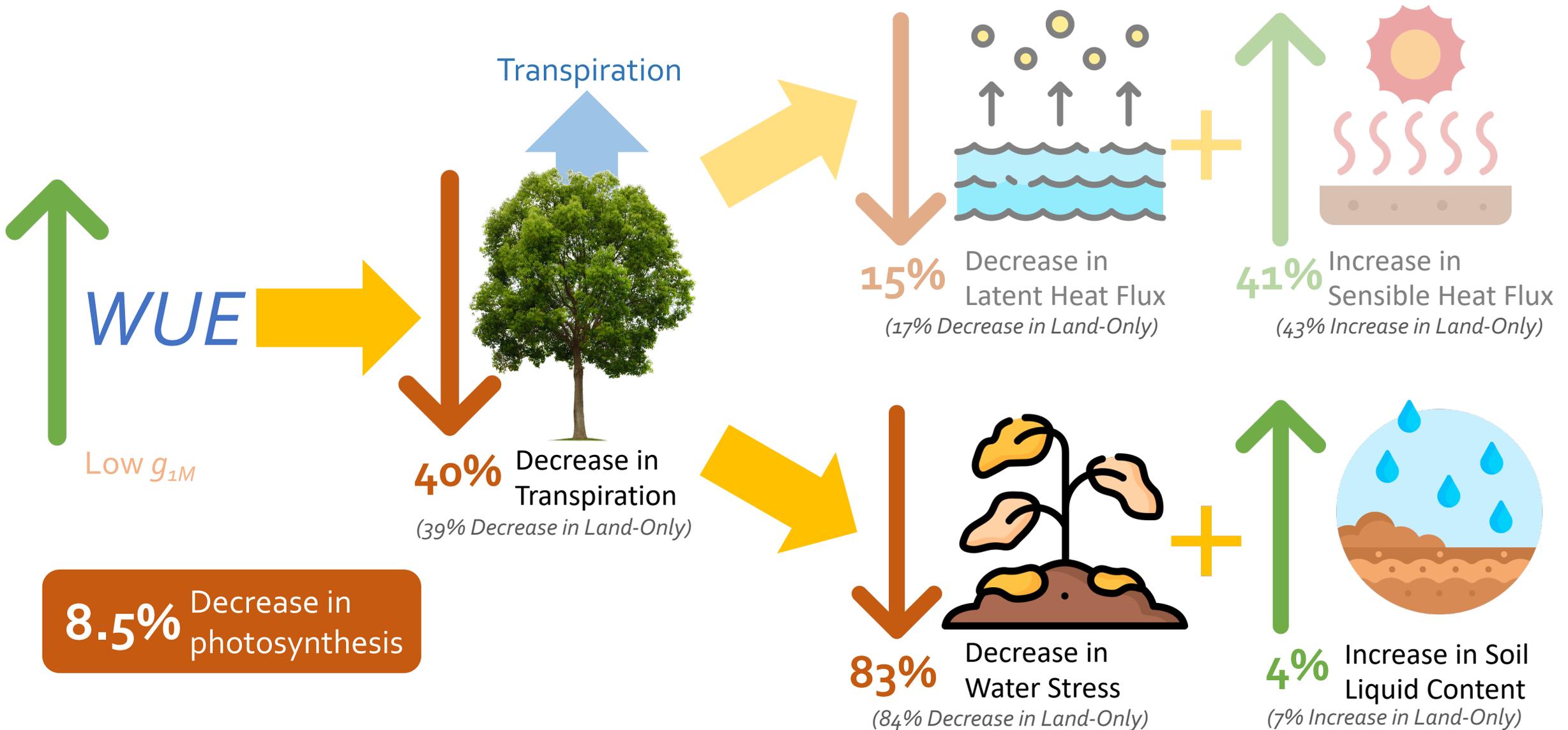
Increase in WUE decreases water stress and increases water availability



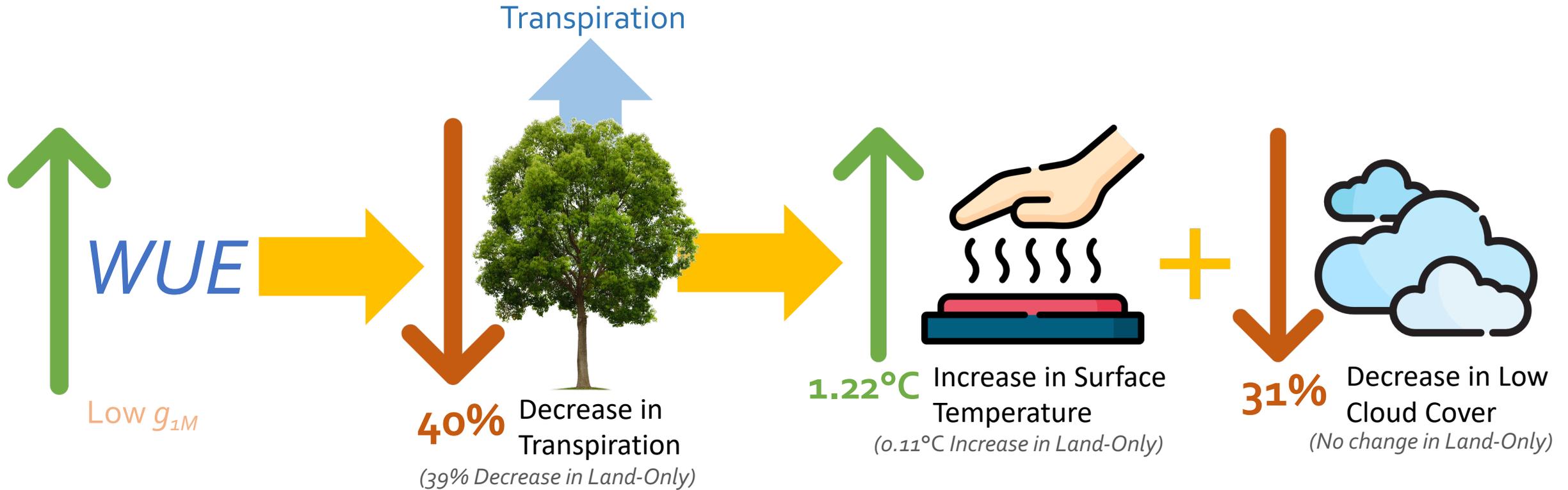
With a coupled atmosphere, photosynthesis **decreases** in the Amazon



Impacts on water are similar in both cases



Increase in temperature decreases photosynthesis



8.5% Decrease in photosynthesis

Multiple factors can affect stomatal conductance

Land-Atmosphere
Coupling

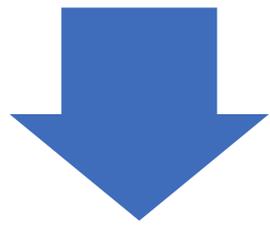
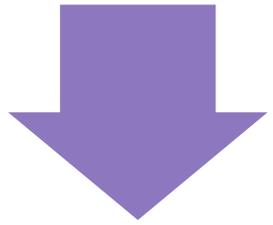
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graph TD; A[Land-Atmosphere Coupling] --> B[atmospheric feedbacks modify temperature and precipitation impacts of land surface change];
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atmospheric
feedbacks modify
temperature and
precipitation
impacts of land
surface change

Multiple factors can affect stomatal conductance

2x Pre-Industrial
CO₂

Land-Atmosphere
Coupling



higher CO₂
changes the
relationship
between carbon
and water fluxes

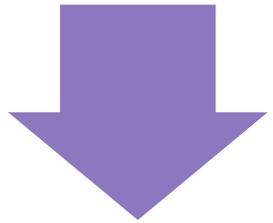
atmospheric
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Multiple factors can affect stomatal conductance

2x Pre-Industrial
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Land-Atmosphere
Coupling

Dynamic Leaf Area



higher CO₂
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atmospheric
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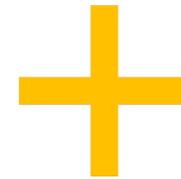
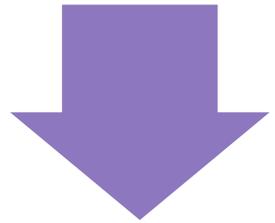
leaf area changes
the relationship
between WUE
and total fluxes of
carbon and water

Multiple factors can affect stomatal conductance

2x Pre-Industrial
CO₂

Land-Atmosphere
Coupling

Dynamic Leaf Area



Low and high vs
default Medlyn
slope

higher CO₂
changes the
relationship
between carbon
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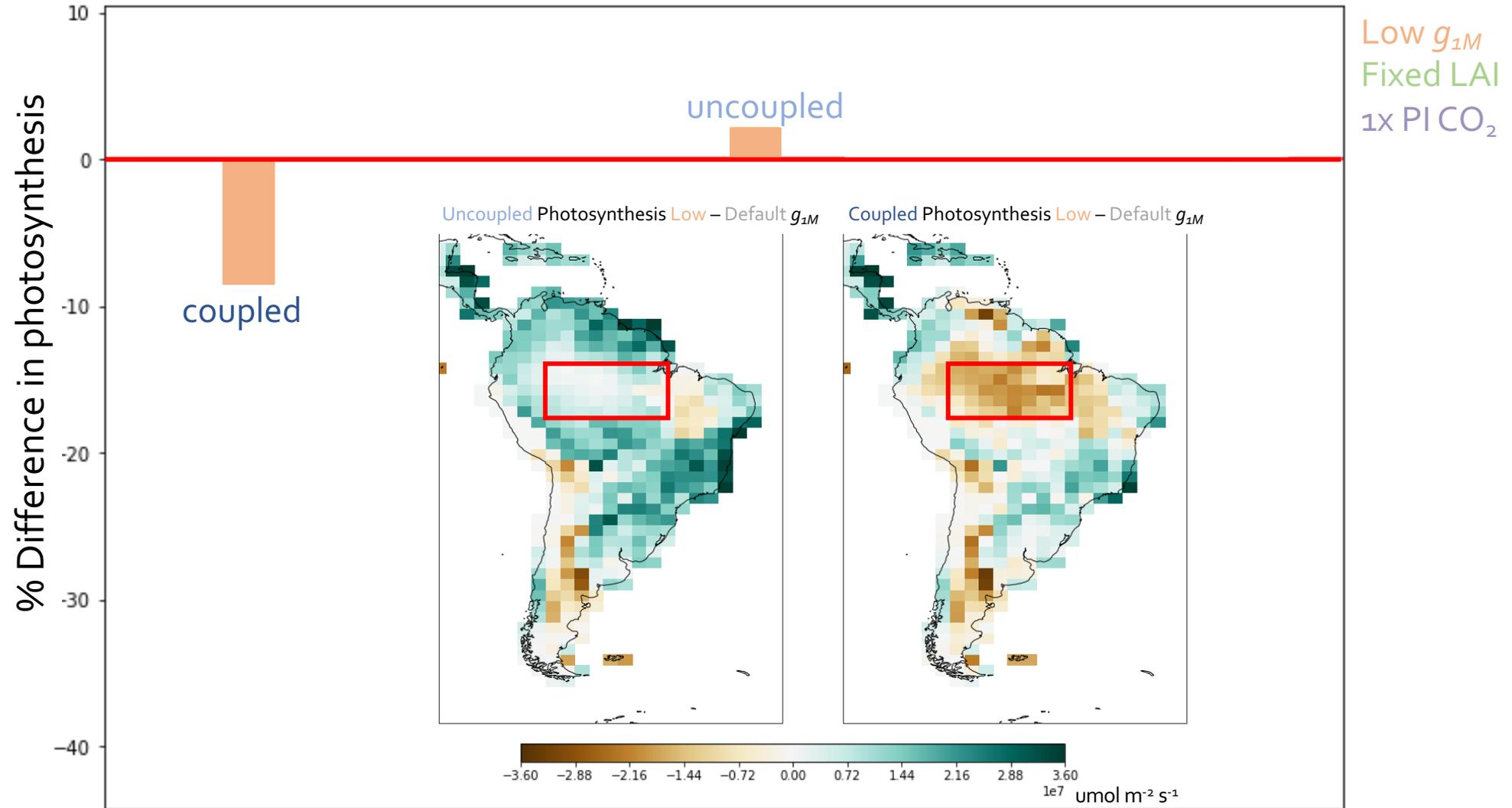
Summary of all runs

| | | | | |
|--|---------------------------|-------------------|---------------------------------------|---------|
| 1x Pre-Industrial Land CO ₂ | Land-Atmosphere (coupled) | Dynamic Leaf Area | 1x Pre-Industrial Atm CO ₂ | Low |
| | | Fixed Leaf Area | 1x Pre-Industrial Atm CO ₂ | Default |
| | Land Only (uncoupled) | Dynamic Leaf Area | 1x Pre-Industrial Atm CO ₂ | High |
| | | Fixed Leaf Area | 1x Pre-Industrial Atm CO ₂ | Low |
| | Land-Atmosphere (coupled) | Dynamic Leaf Area | 1x Pre-Industrial Atm CO ₂ | Default |
| | | Fixed Leaf Area | 1x Pre-Industrial Atm CO ₂ | High |
| 2x Pre-Industrial Land CO ₂ | Land-Atmosphere (coupled) | Dynamic Leaf Area | 2x Pre-Industrial Atm CO ₂ | Low |
| | | Fixed Leaf Area | 2x Pre-Industrial Atm CO ₂ | Default |
| | Land Only (uncoupled) | Dynamic Leaf Area | 1x Pre-Industrial Atm CO ₂ | High |
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| | | Fixed Leaf Area | 2x Pre-Industrial Atm CO ₂ | High |

Summary of all runs

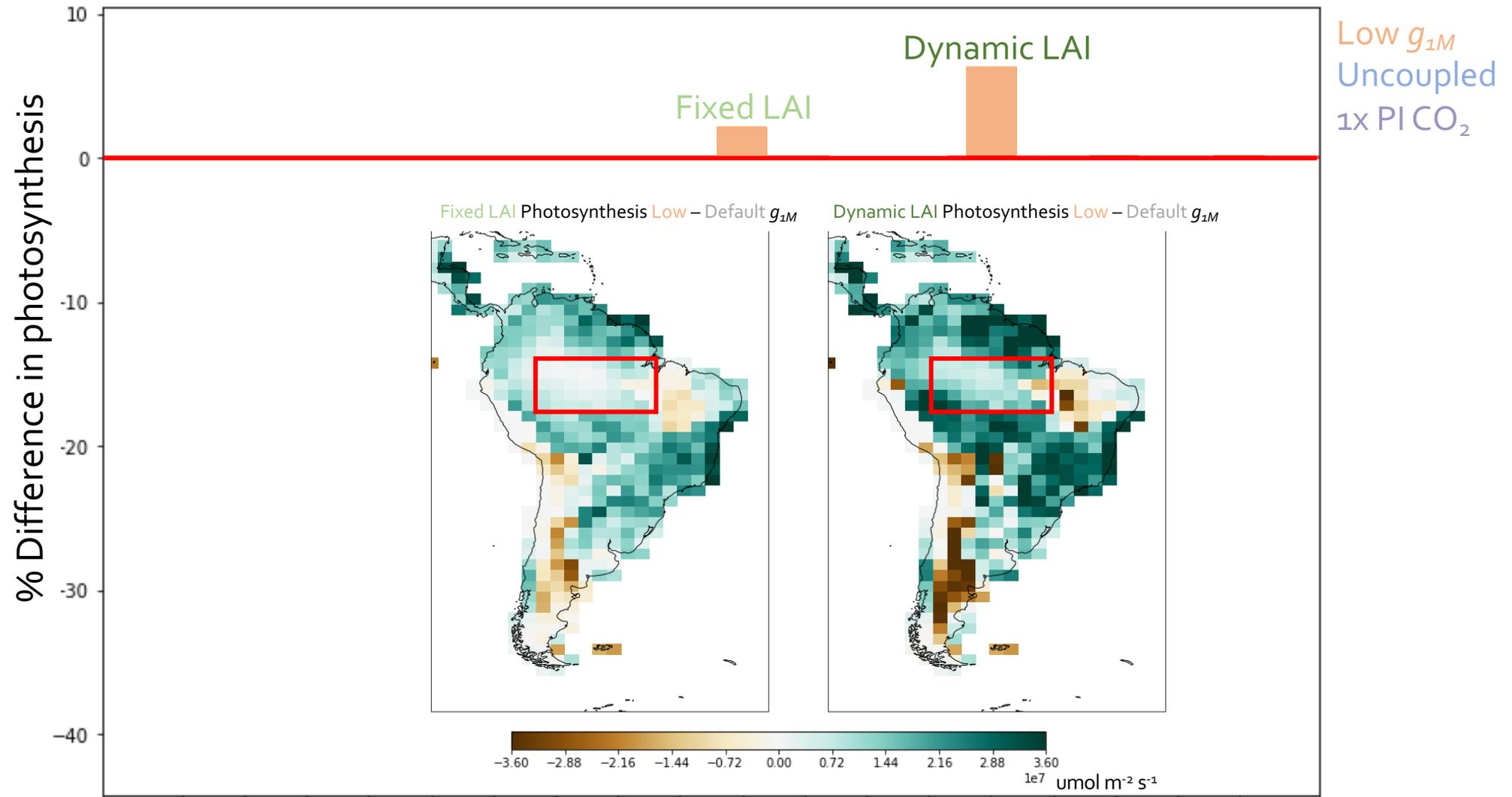
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Percentage differences of Photosynthesis in the Amazon



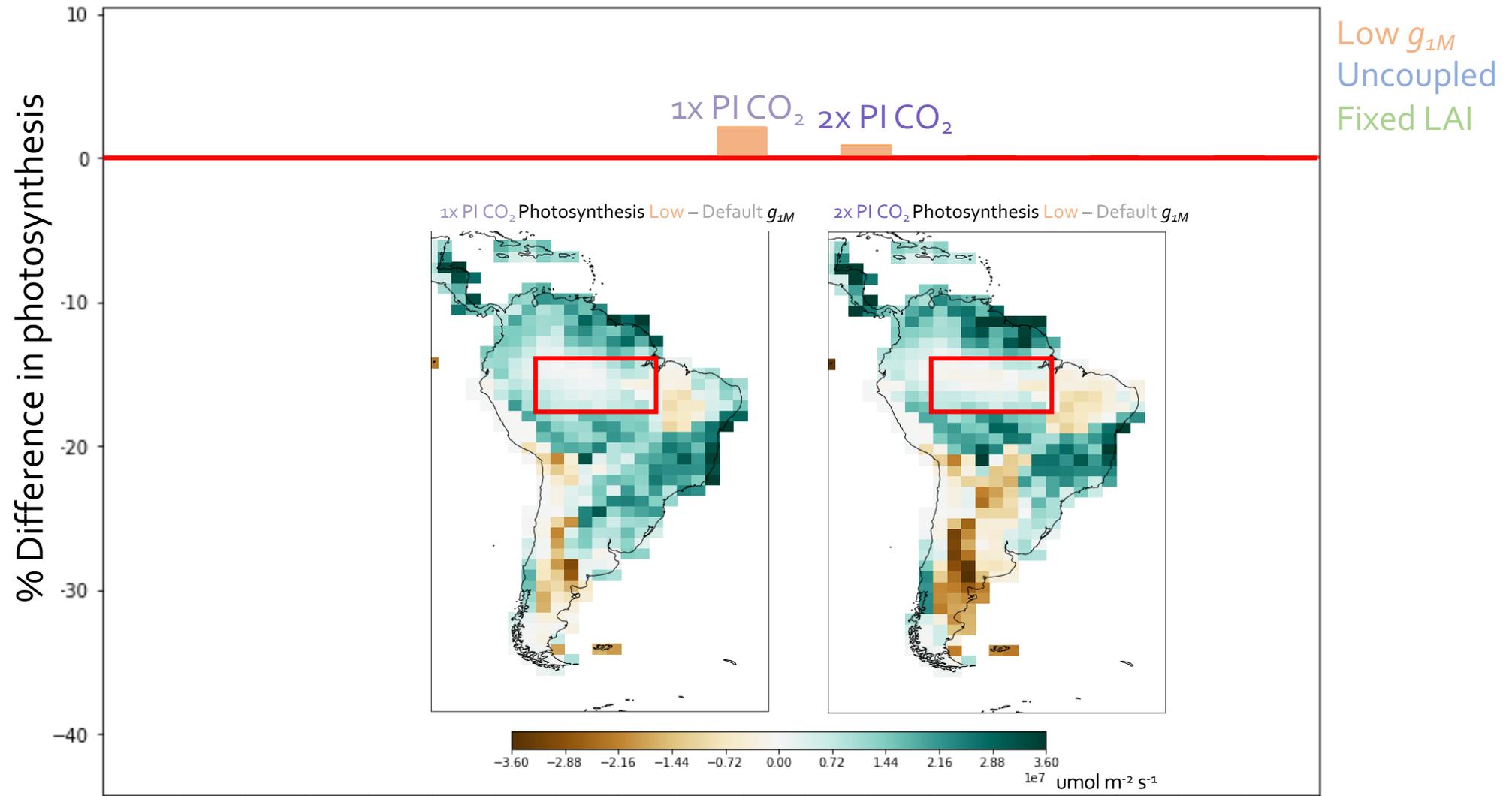
Case

Percentage differences of Photosynthesis in the Amazon



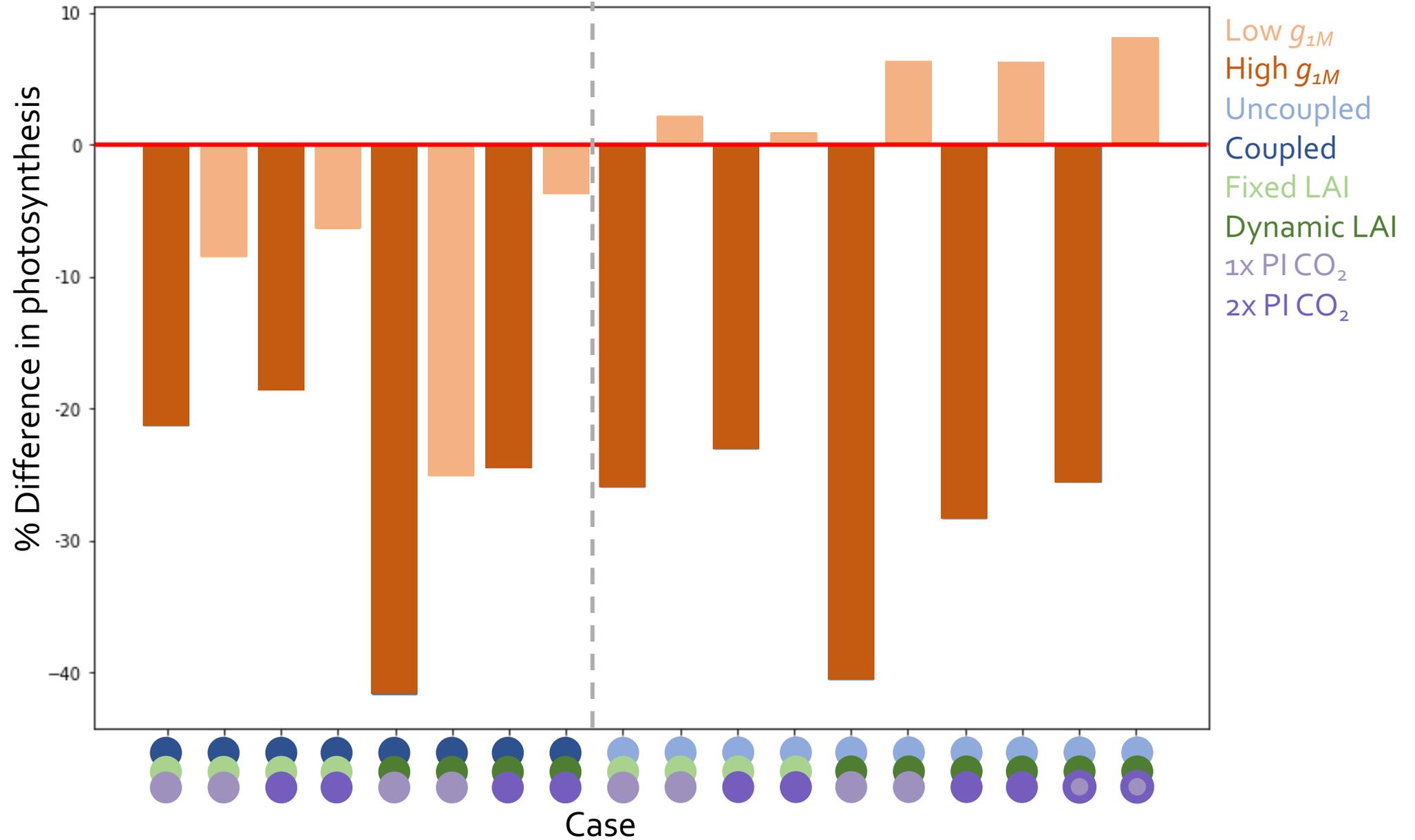
Case

Percentage differences of Photosynthesis in the Amazon



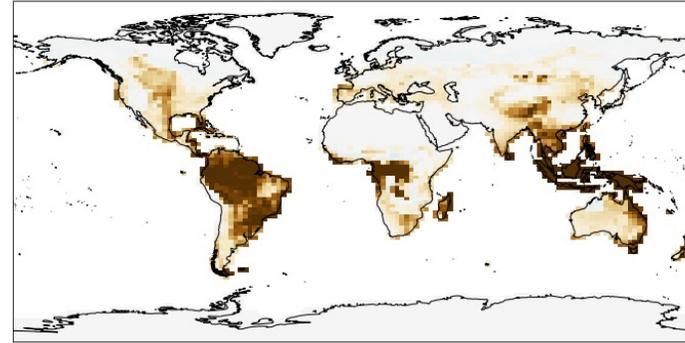
Case

Percentage differences of Photosynthesis in the Amazon



To summarize

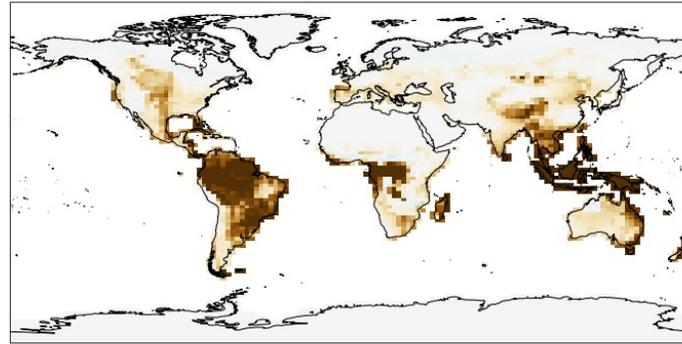
- A high Medlyn slope results in low WUE, consistent with global decreases in photosynthesis



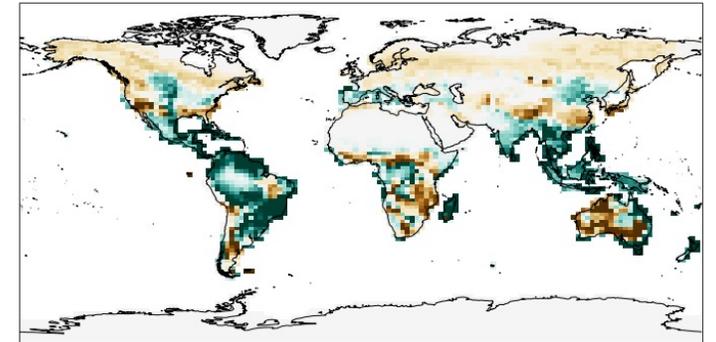
To summarize

- A high Medlyn slope results in low WUE, consistent with global decreases in photosynthesis
- A low Medlyn slope's effect on photosynthesis is regionally dependent

Photosynthesis **High** – Default g_{1M}



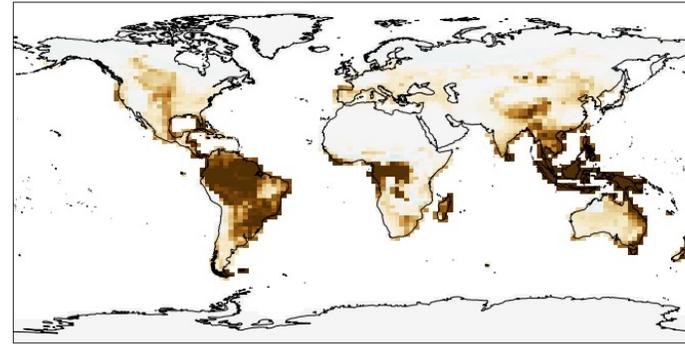
Photosynthesis **Low** – Default g_{1M}



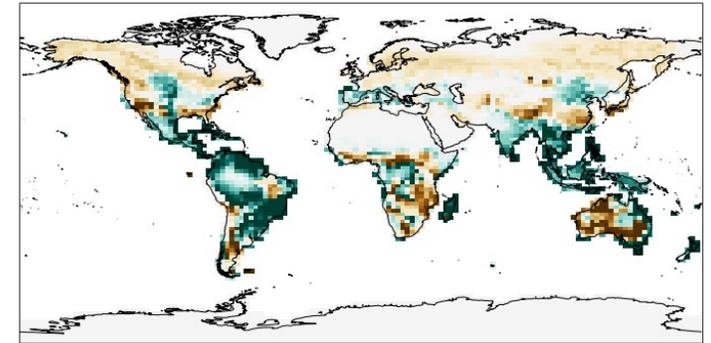
To summarize

- A high Medlyn slope results in low WUE, consistent with global decreases in photosynthesis
- A low Medlyn slope's effect on photosynthesis is regionally dependent
- The impacts of Medlyn slope on photosynthesis, water flux, and climate is complicated and varies across model configurations

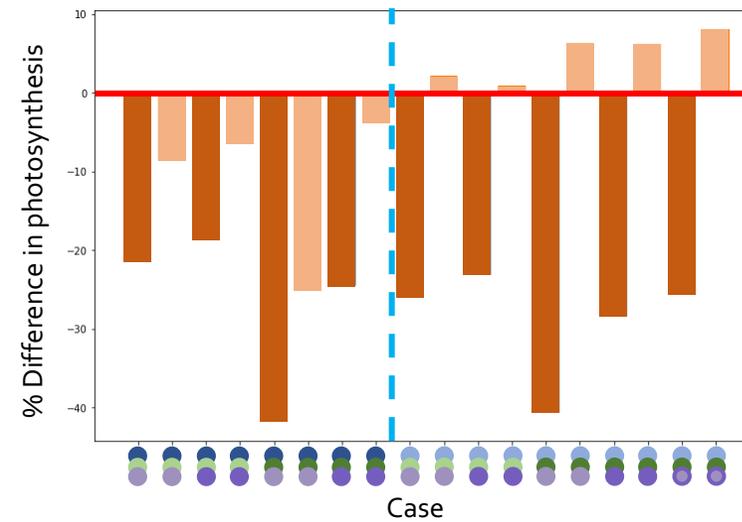
Photosynthesis High – Default g_{1M}



Photosynthesis Low – Default g_{1M}



Percentage differences of Photosynthesis in the Amazon



Thank you

