Atmospheric feedbacks change the sensitivity of photosynthesis to stomatal functioning in CESM2

CLM + BGC Working Group Meeting | February 24, 2025

Amy Liu[1], Claire Zarakas[1], Abigail Swann[1]

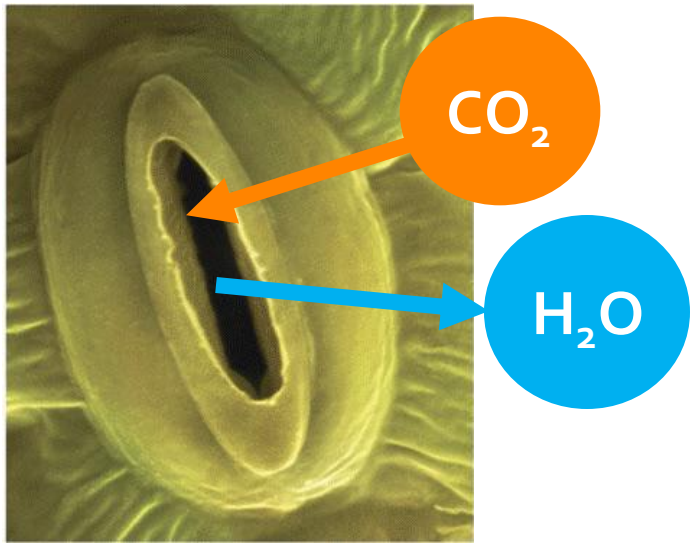
Collaborators: Ben Buchovecky[1], Linnia Hawkins[2,3], Alana Cordak[4], Ashley Cornish[4], Marja Haagsma[5], Gabriel Kooperman[4], Christopher Still[5], Charles Koven[6], Alex Turner[1], David Battisti[1], Jim Randerson[7], Forrest Hoffman[8]

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

Funding from DOE and NSF

Stomatal functioning alters …

carbon and water fluxes
between leaf and atmosphere



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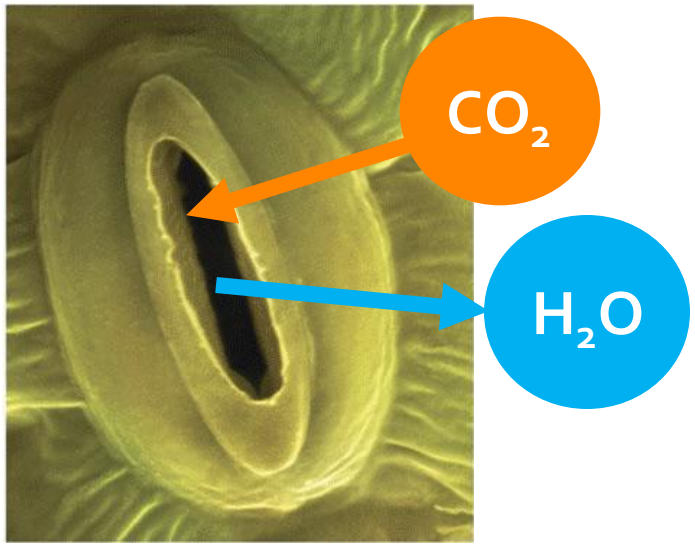
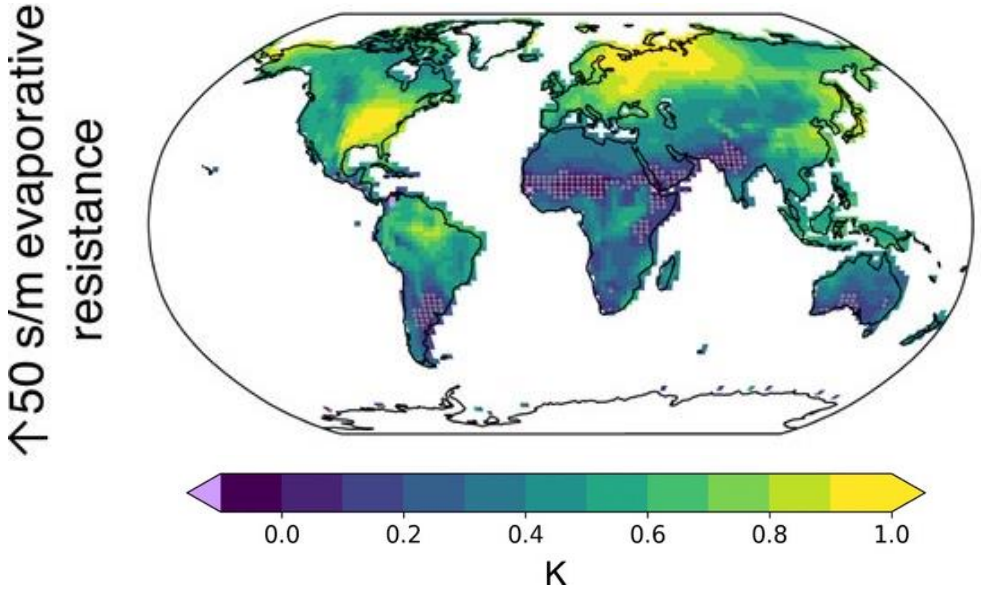
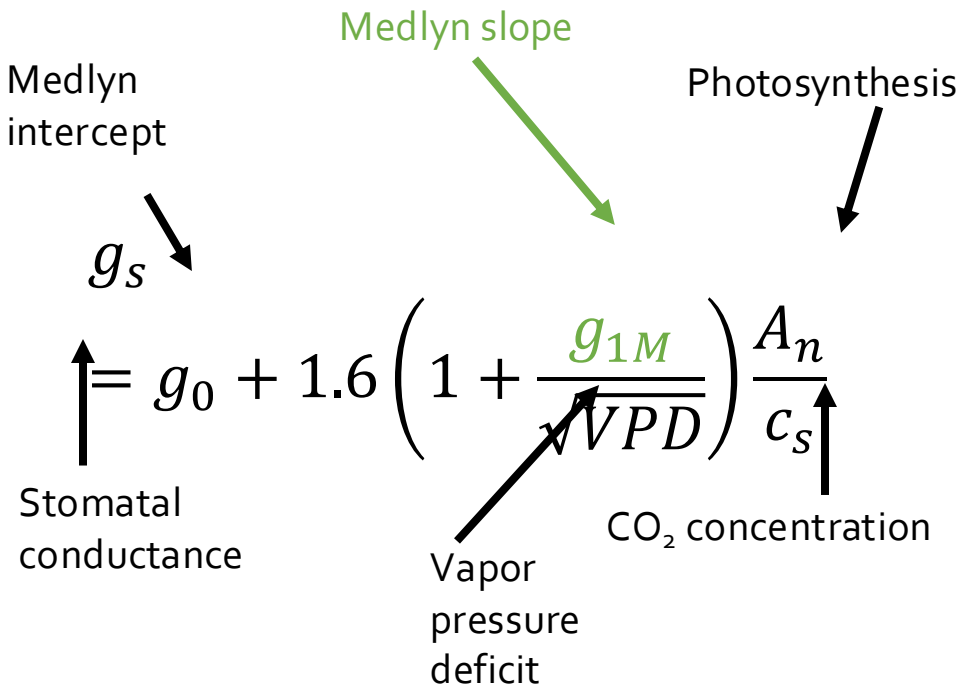


surface properties which then affect climate



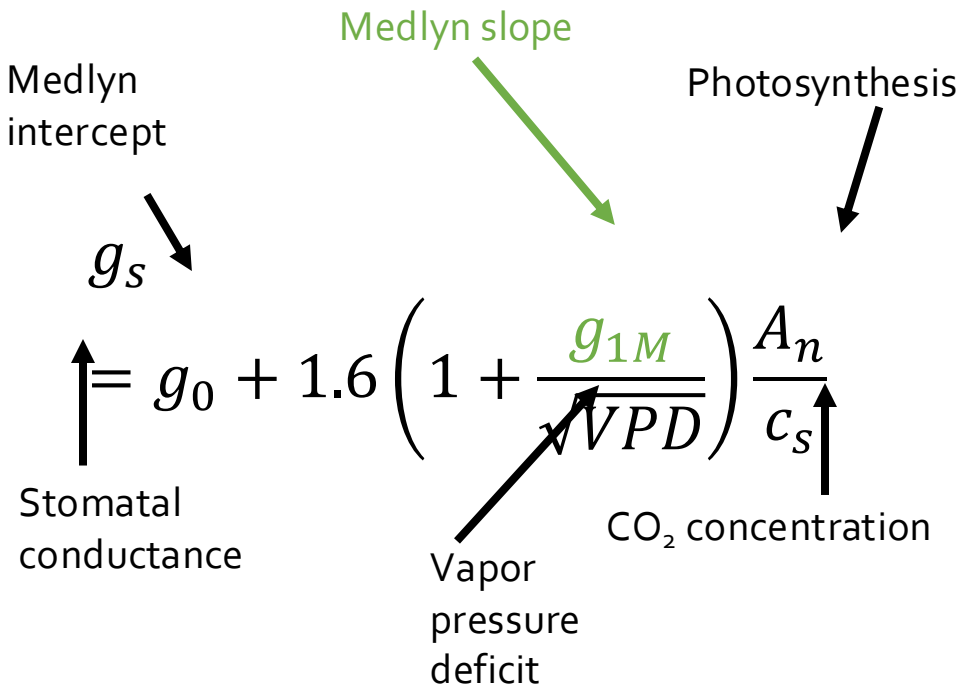
Laguë et al. 2019

Stomatal functioning can be modulated by g_{1M} within CLM



Medlyn et al. 2011

g_{1M} represents *water cost* per carbon uptake

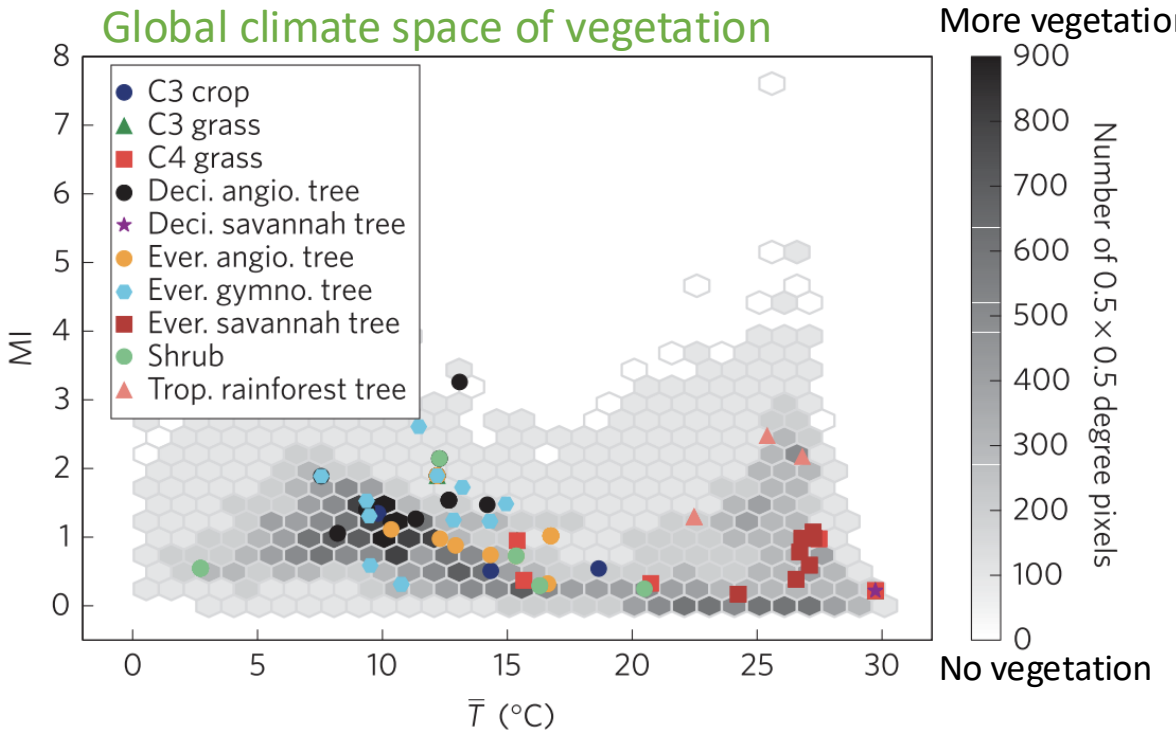


High g_{1M} = High water cost

Low g_{1M} = Low water cost

Medlyn et al. 2011

Global climatic space is broad, and observations of g_{1M} are only a small subset

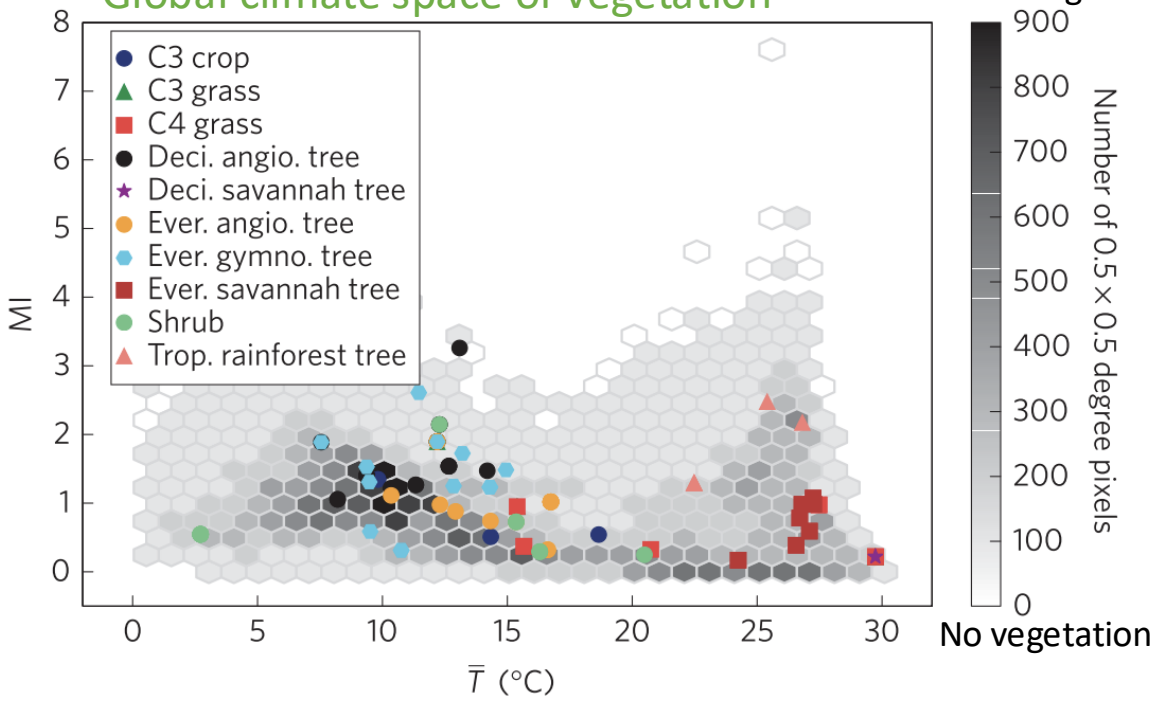


Color = where we have data!

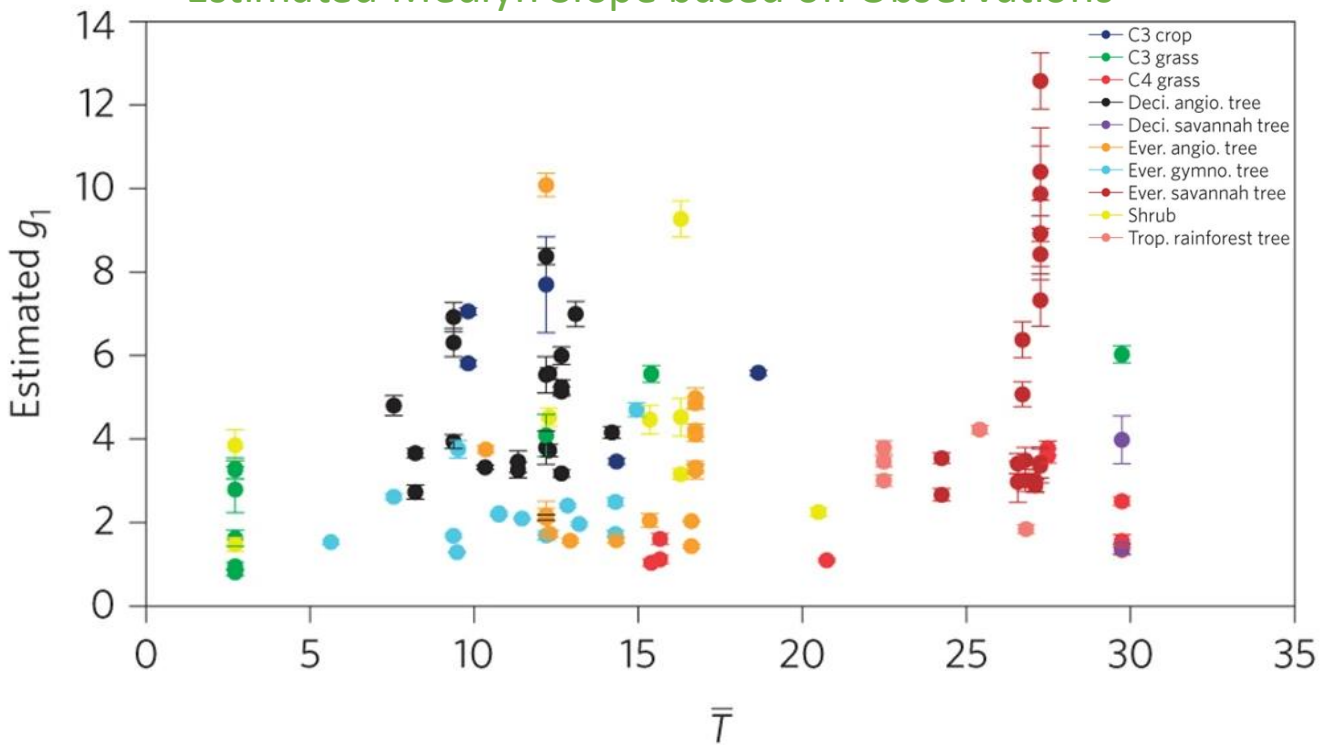
Lin et al. 2015

Even within the small subset, estimated g_{1M} varies

Global climate space of vegetation



Estimated Medlyn Slope based on Observations



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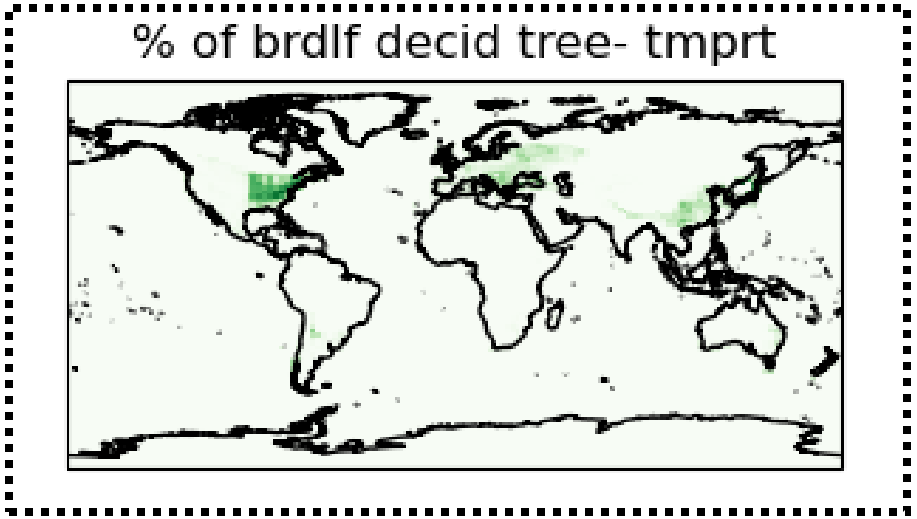
Large range of g_{1M} across a single PFT



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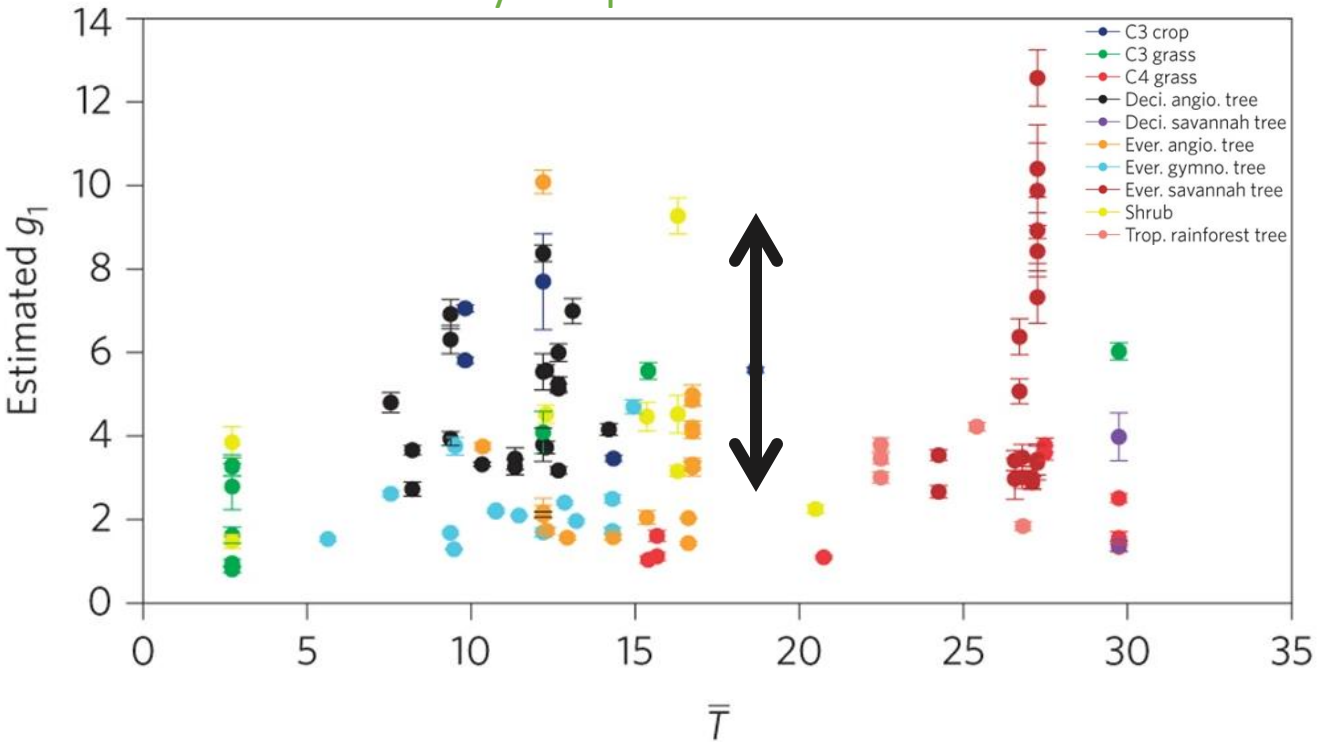

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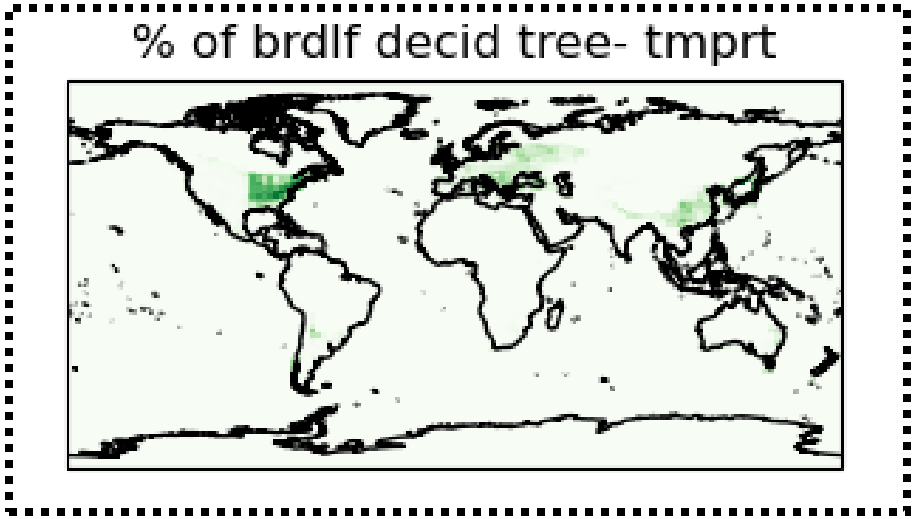

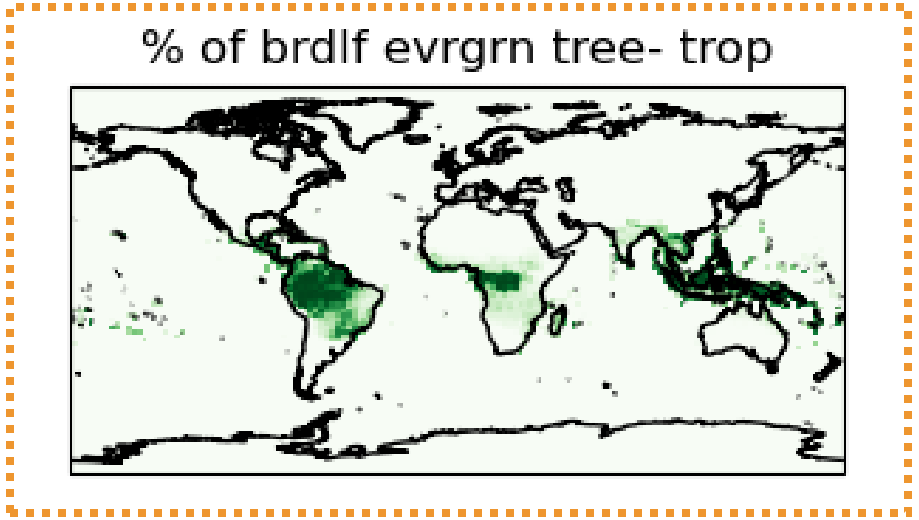

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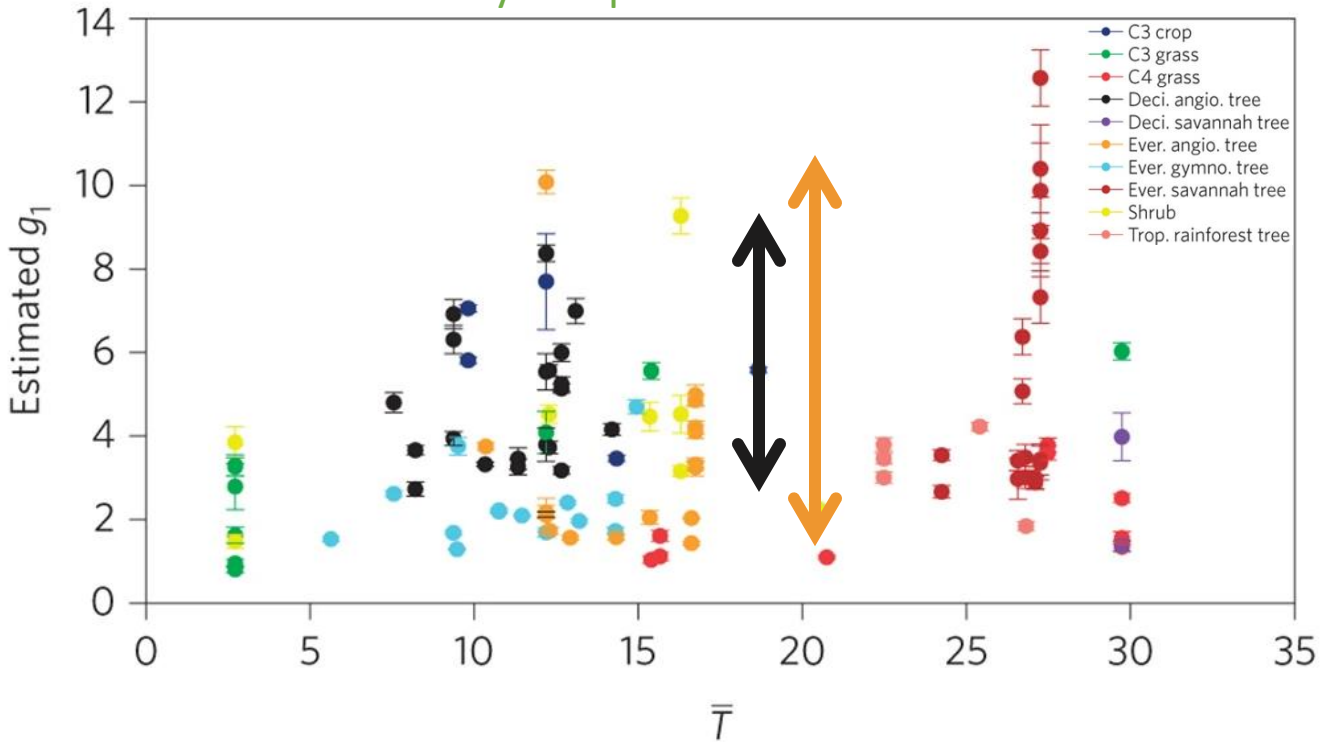
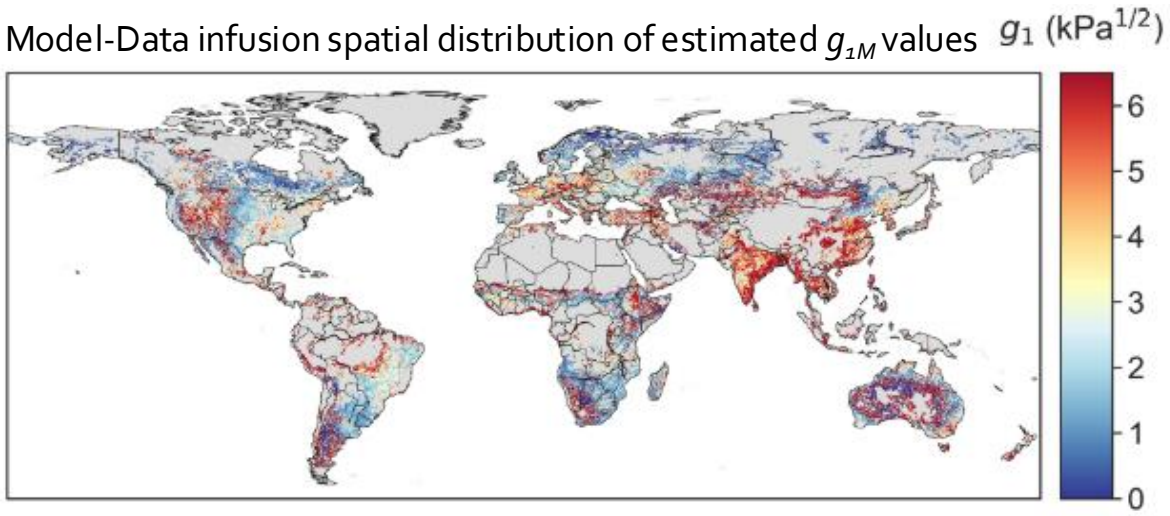


Lin et al. 2015

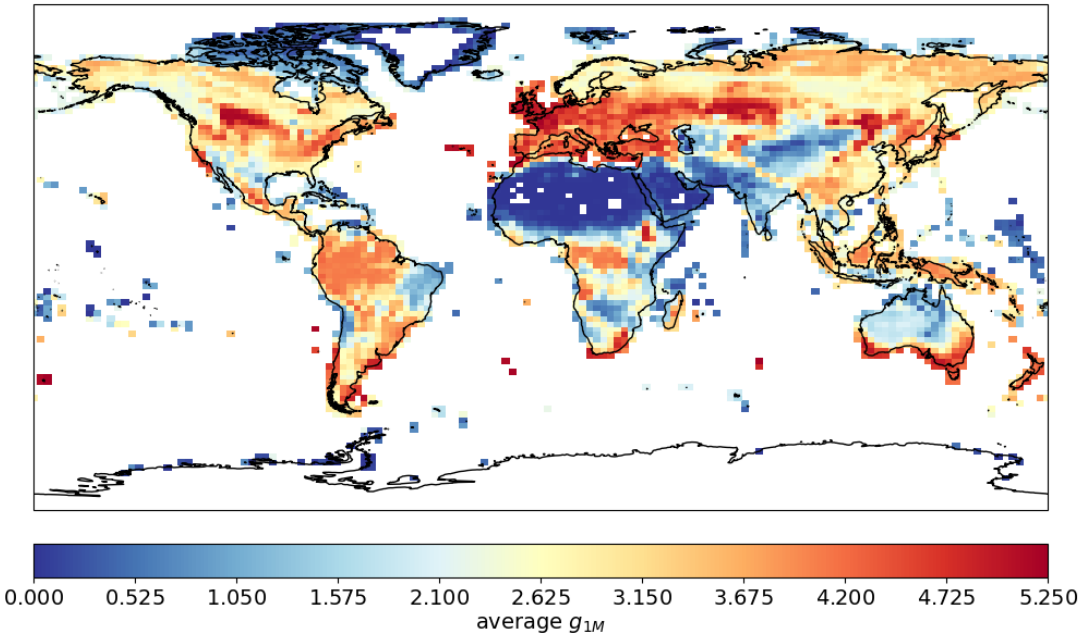
CLM and model-data infusion estimates of g_{1M} do not spatially agree

Model-Data infusion spatial distribution of estimated g_{1M} values



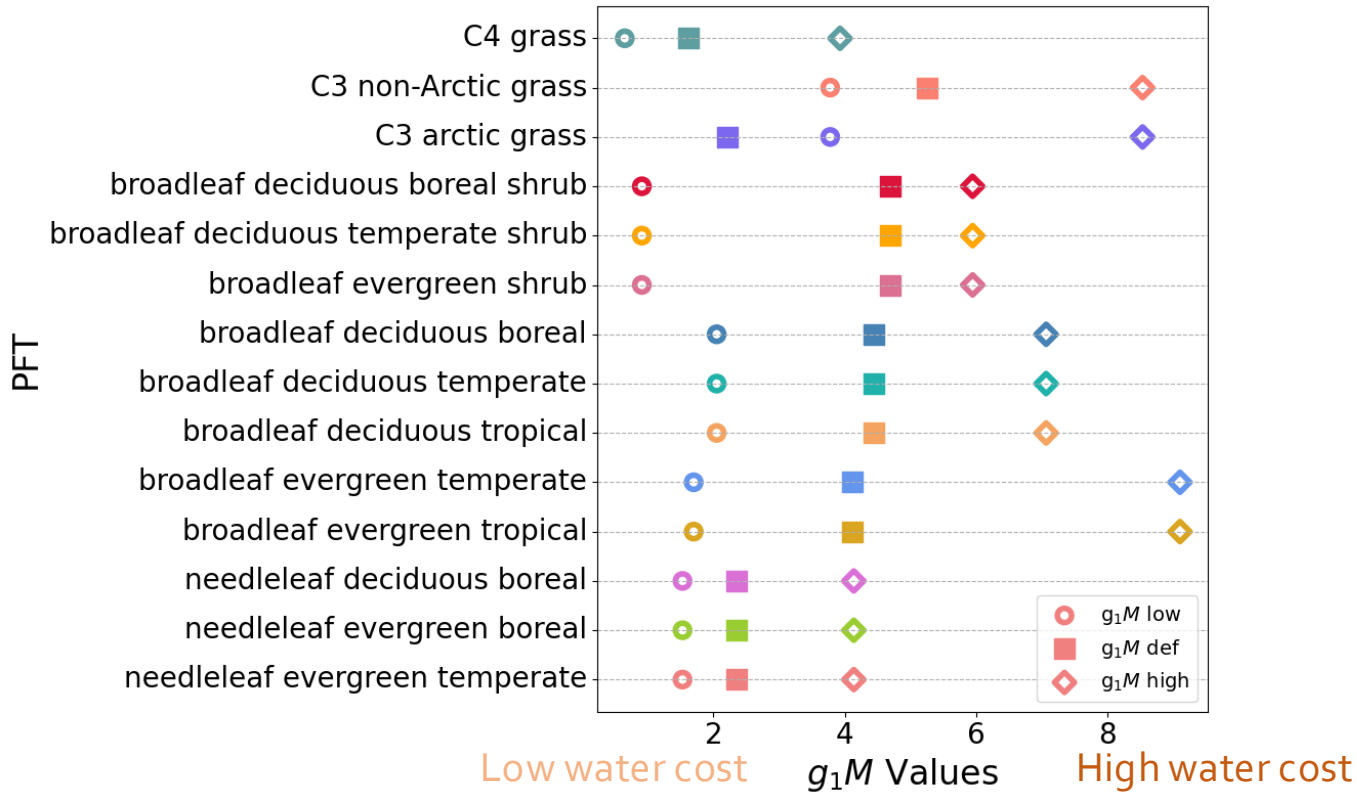
Liu et al. 2021

CLM spatial distribution of Default g_{1M} values



We perturbed g_{1M} within CLM according to Lin et al. 2015

Low, Default, and High g_{1M} values for each PFT



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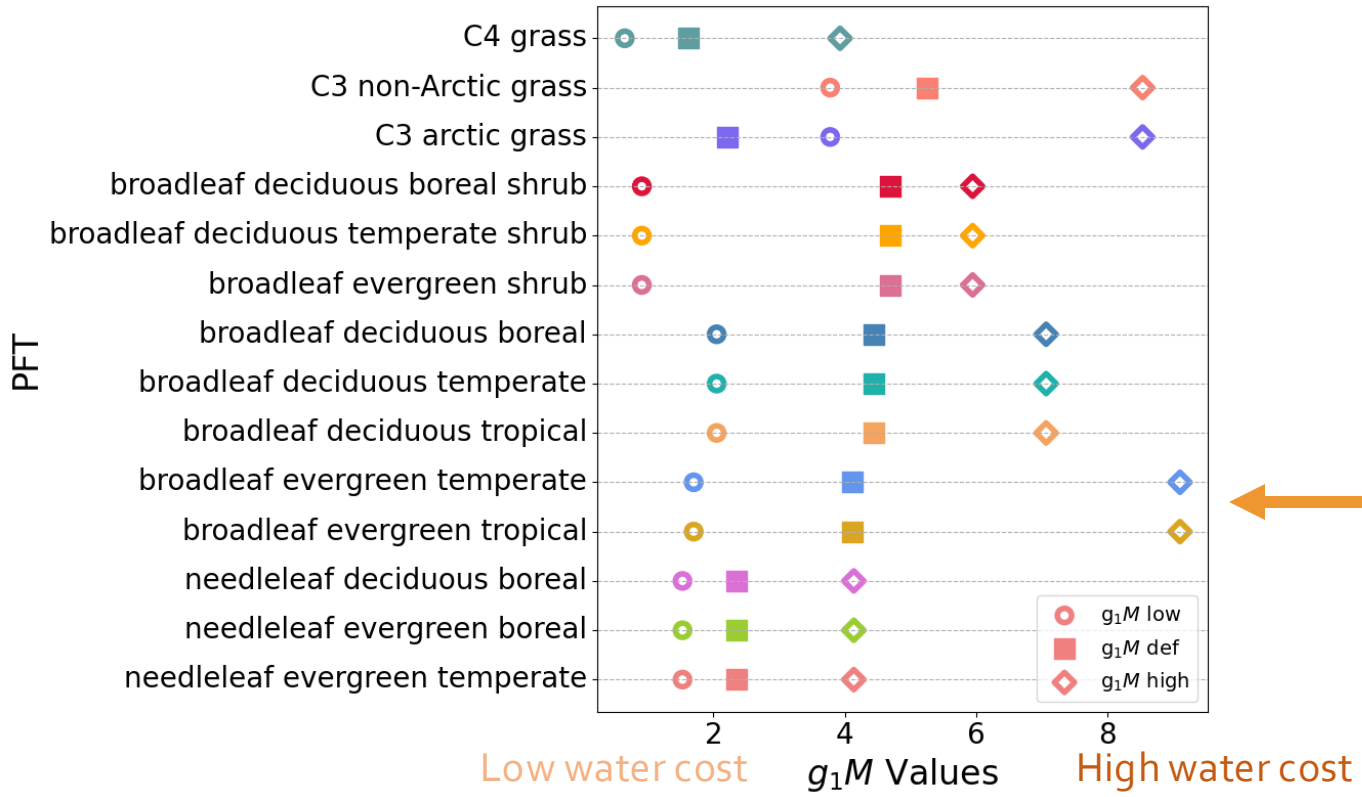

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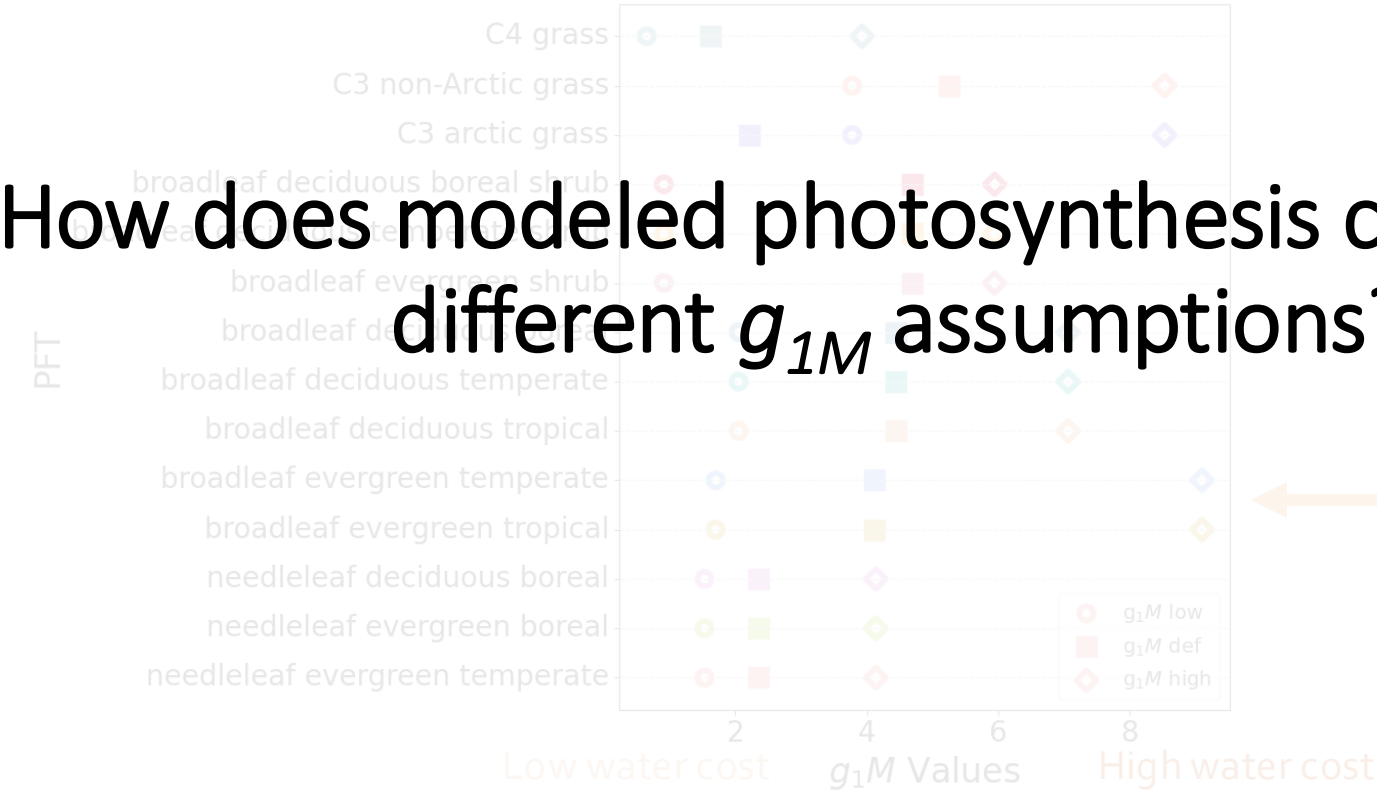
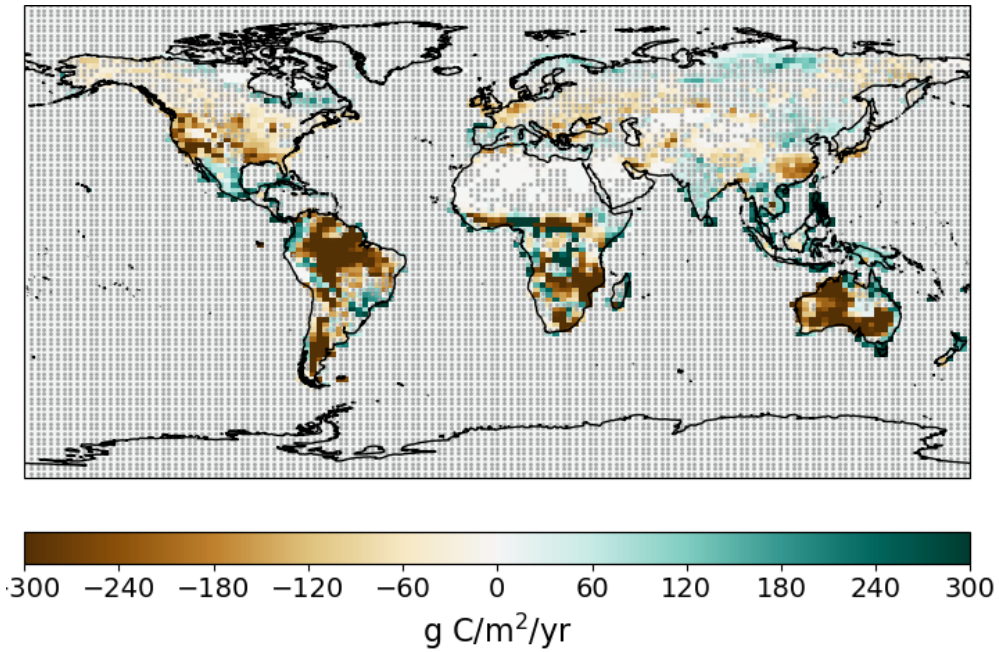


How does modeled photosynthesis change with different g_{1M} assumptions?

A very large range of g_{1M} within a PFT!

Photosynthesis decreases with high g_{1M} and regionally varies with low g_{1M}

Land-Atmosphere: Photosynthesis Low – Default g_{1M} *(water cost)*



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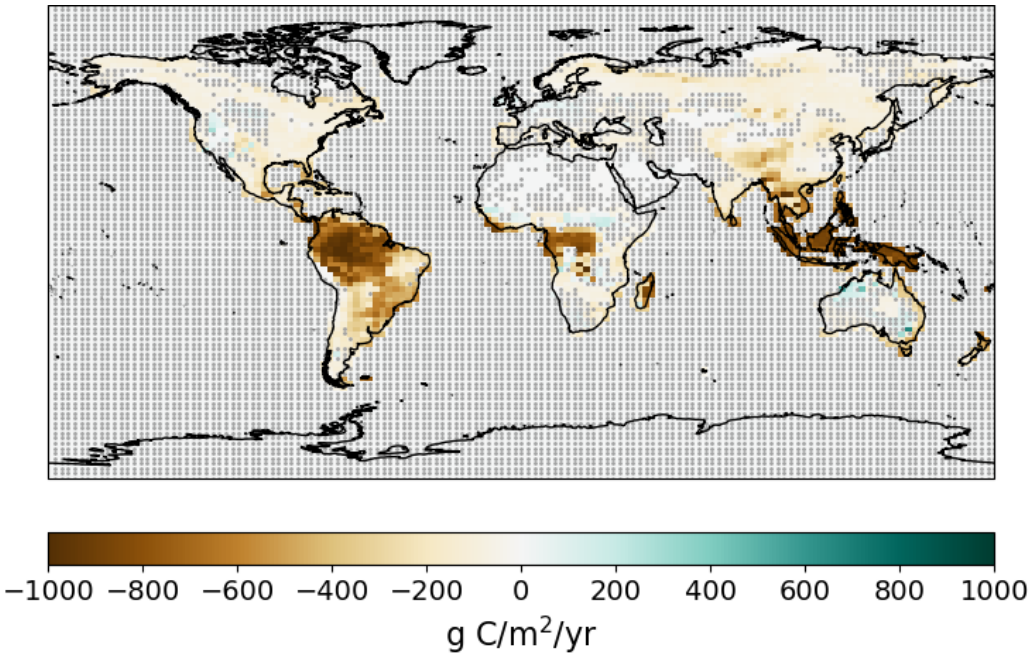

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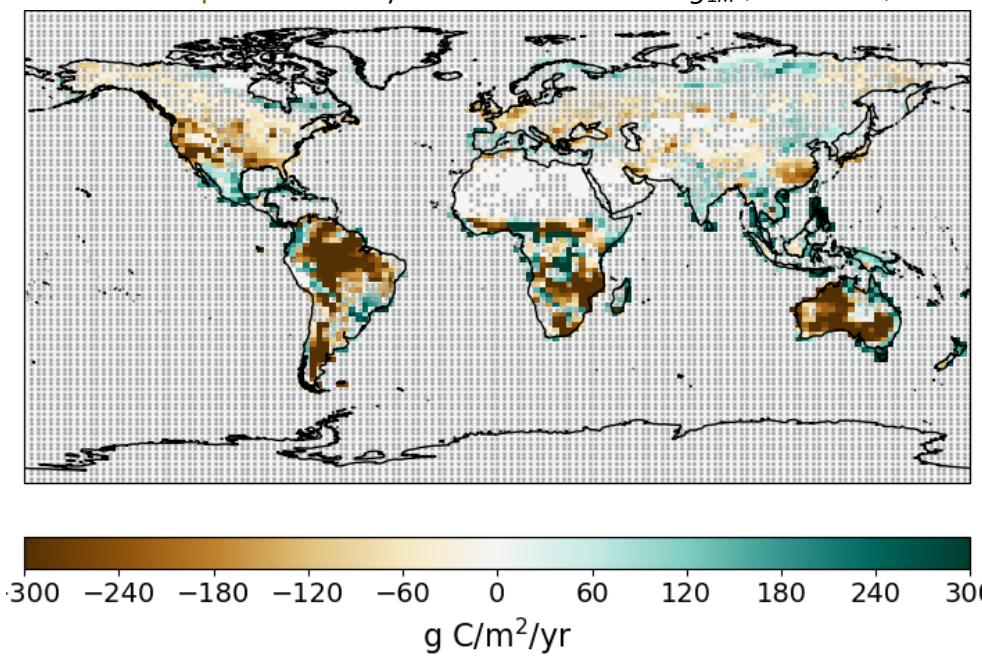

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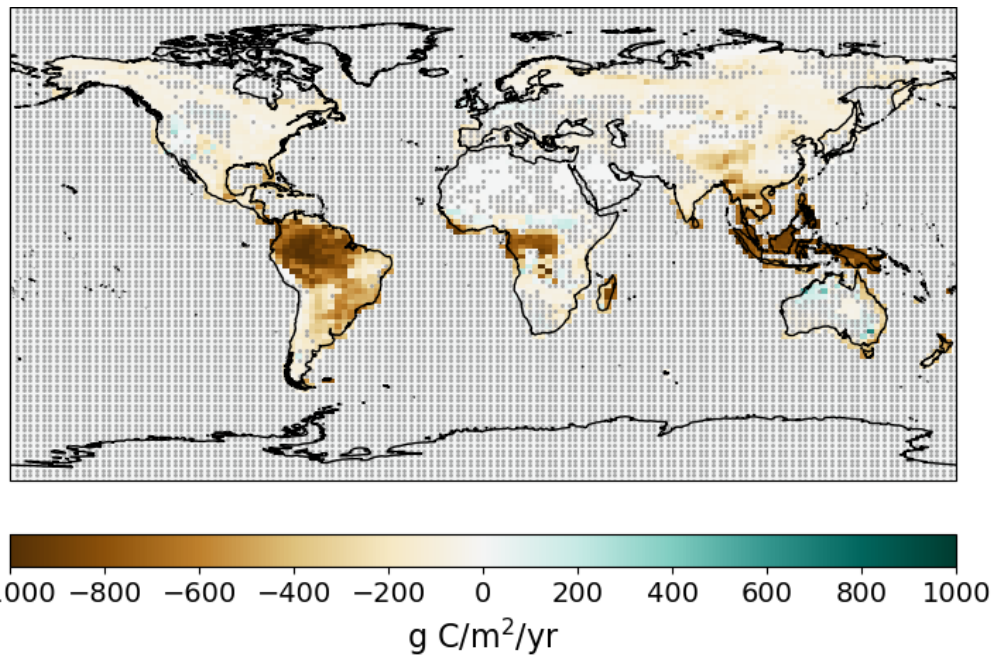
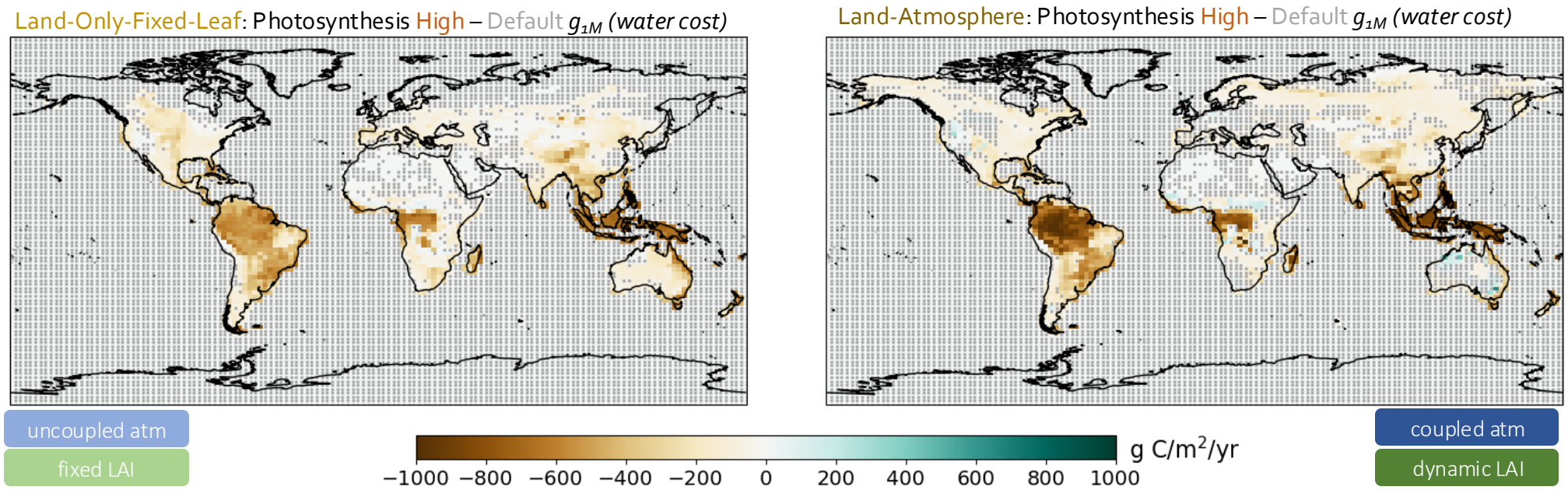


What happens when we remove atmospheric feedbacks and LAI feedbacks?

Atmospheric + LAI feedbacks amplify photosynthesis decrease for high g_{1M}



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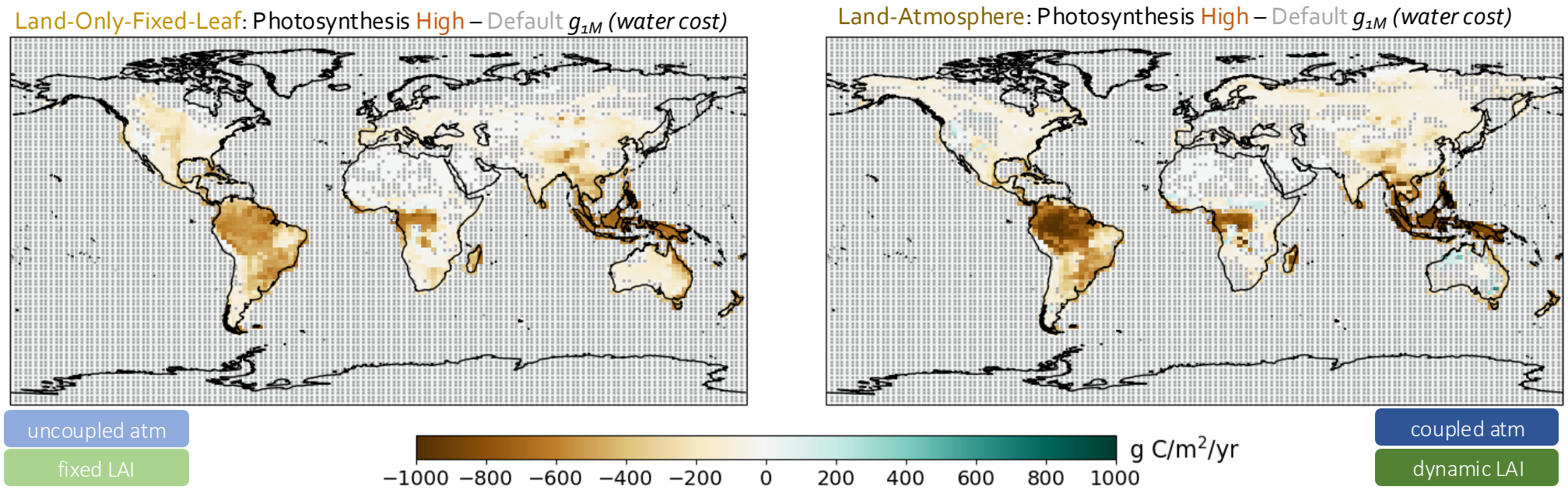
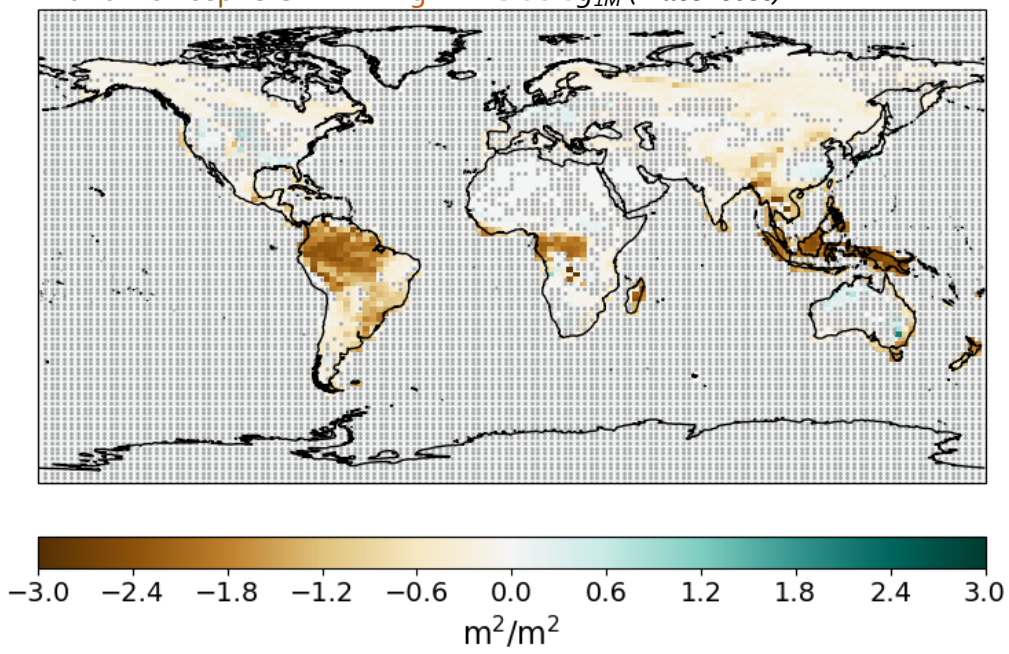


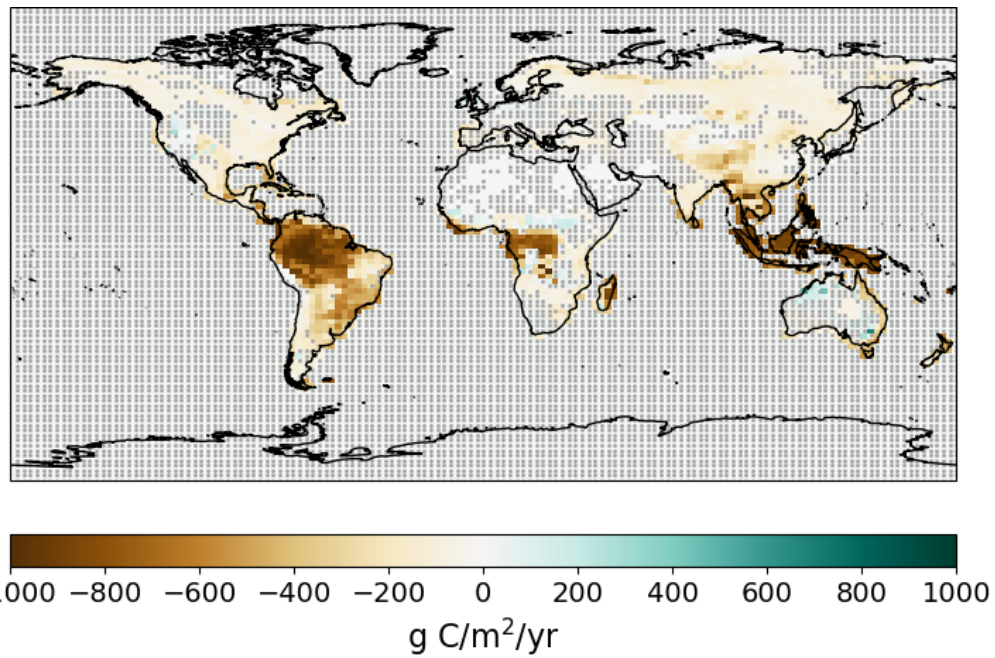
Is this decrease in photosynthesis plausible?

Large LAI decreases in the tropics, making high g_{1M} in that region less plausible

Land-Atmosphere : TLAI High – Default g_{1M} *(water cost)*

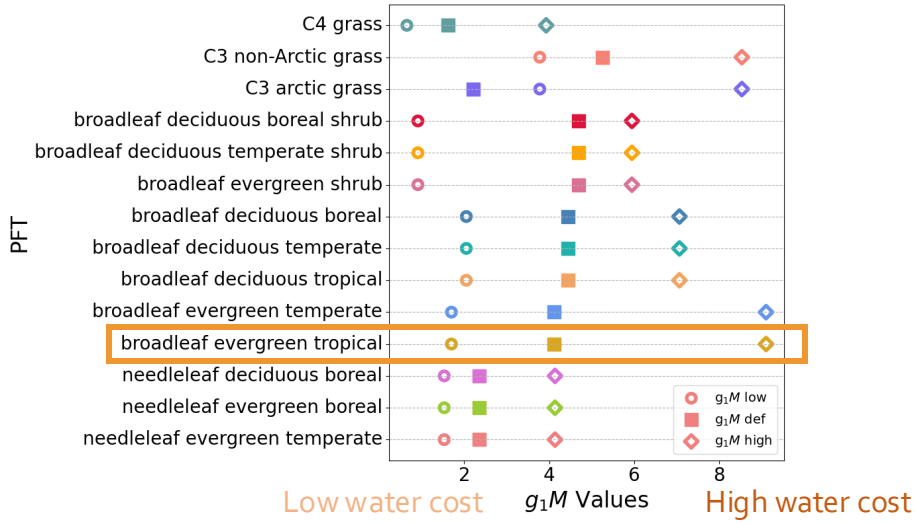


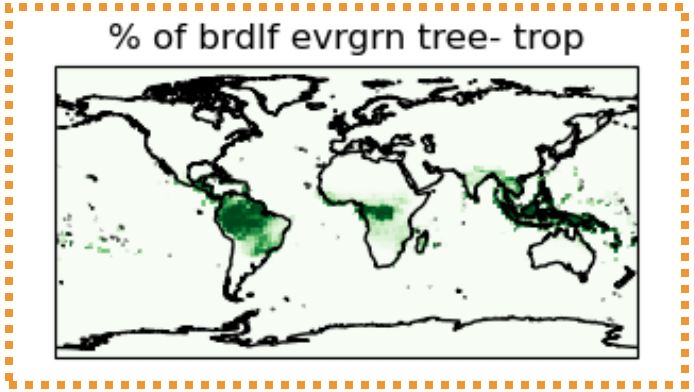
Land-Atmosphere: Photosynthesis High – Default g_{1M} *(water cost)*



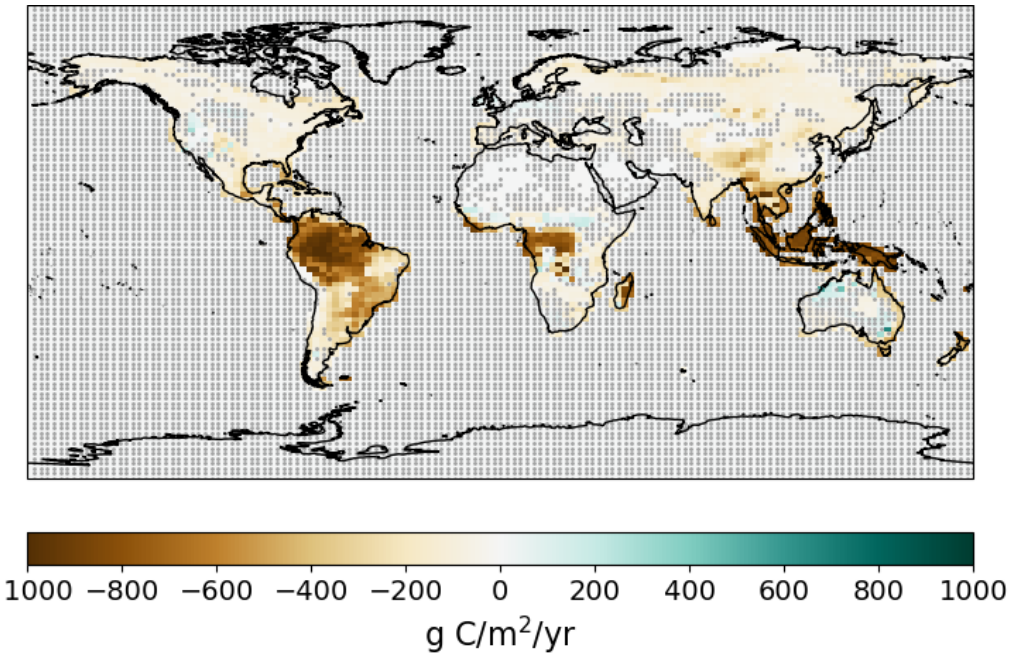
High g_{1M} in the tropics is less plausible

Low, Default, and High g_{1M} values for each PFT



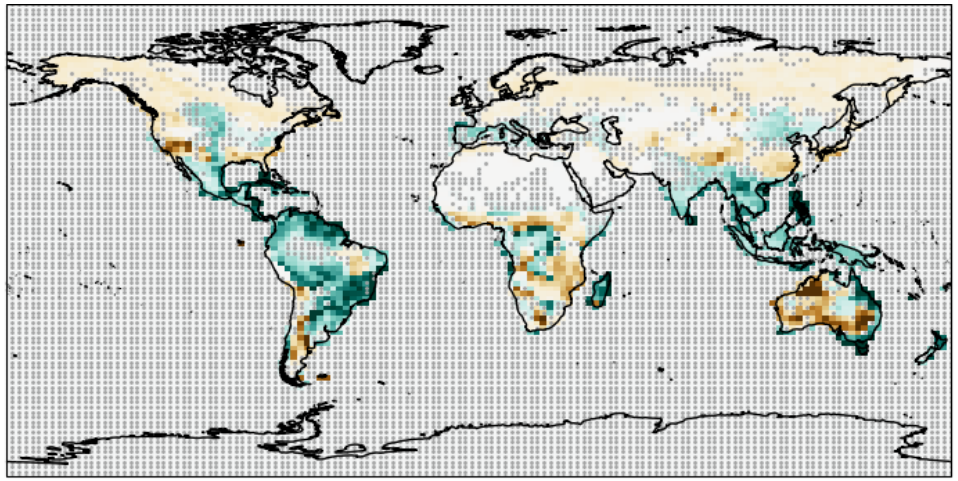


Land-Atmosphere: Photosynthesis High – Default g_{1M} *(water cost)*

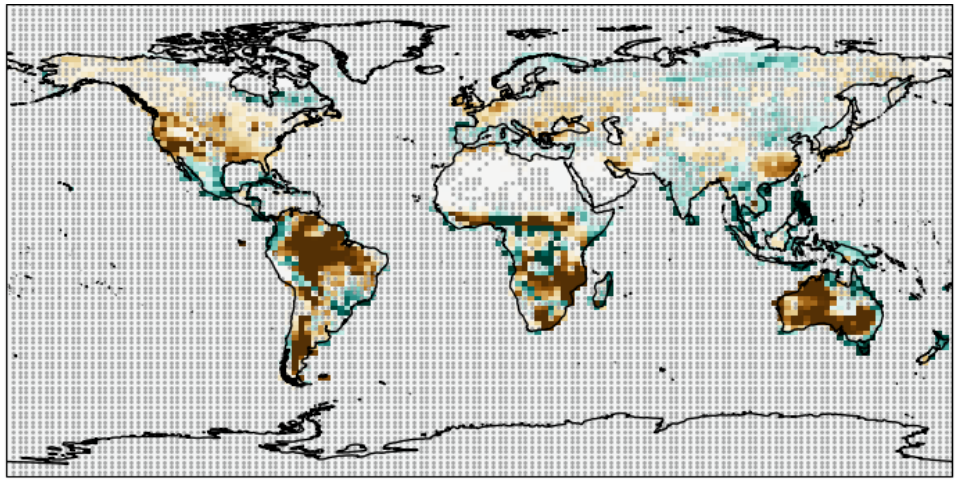


Atmospheric feedbacks can change sign of photosynthetic response for low g_{1M}

Land-Only-Fixed-Leaf: Photosynthesis Low – Default g_{1M} *(water cost)*

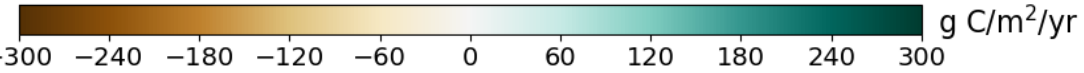


Land-Atmosphere: Photosynthesis Low – Default g_{1M} *(water cost)*



uncoupled atm

fixed LAI

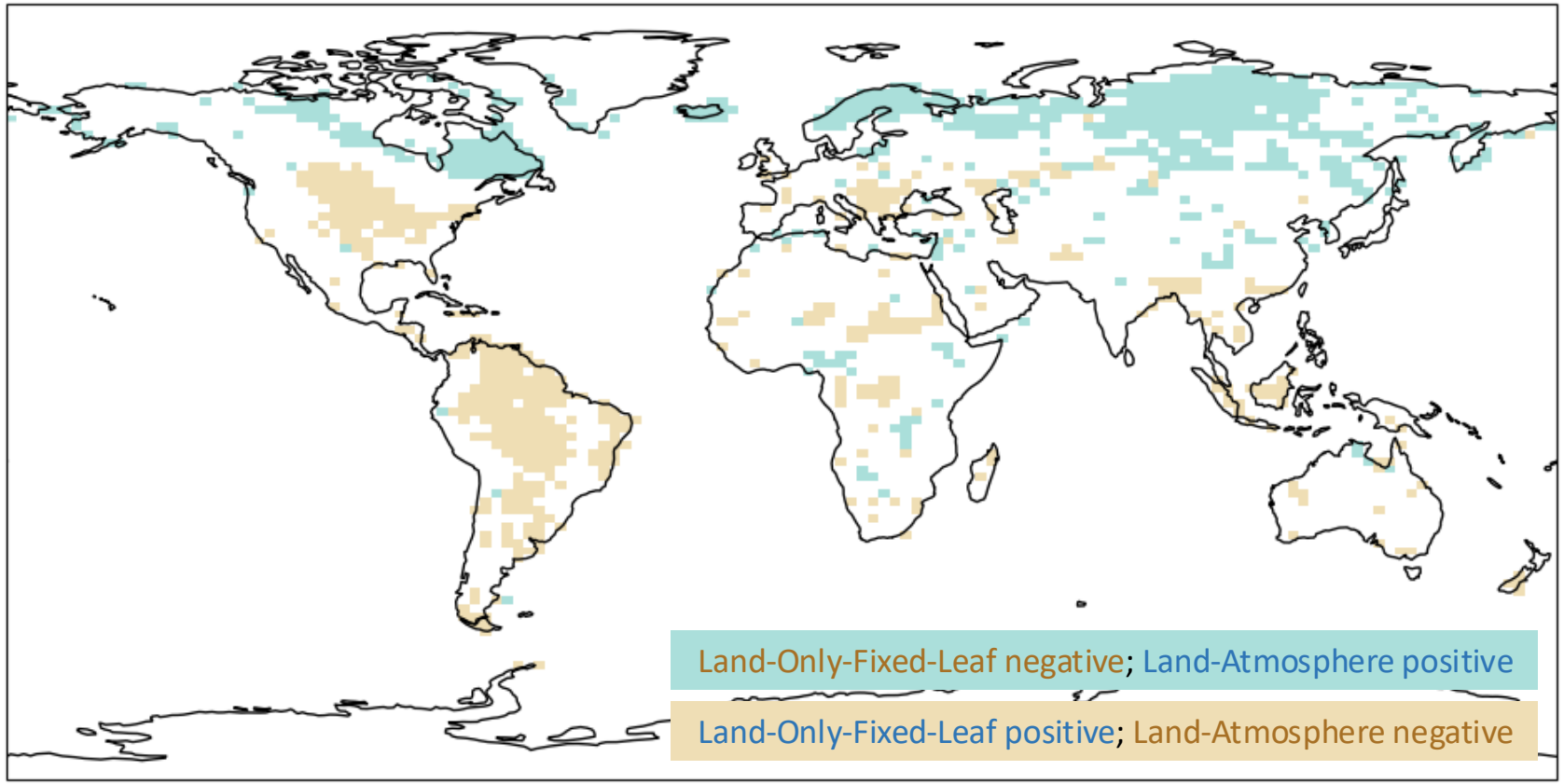


coupled atm

dynamic LAI

Atmospheric feedbacks can change sign of photosynthetic response for low g_{1M}

Photosynthesis Sign Change Map between Land-Only-Fixed-Leaf and Land-Atmosphere for Low – Default g_{1M} *(water cost)*



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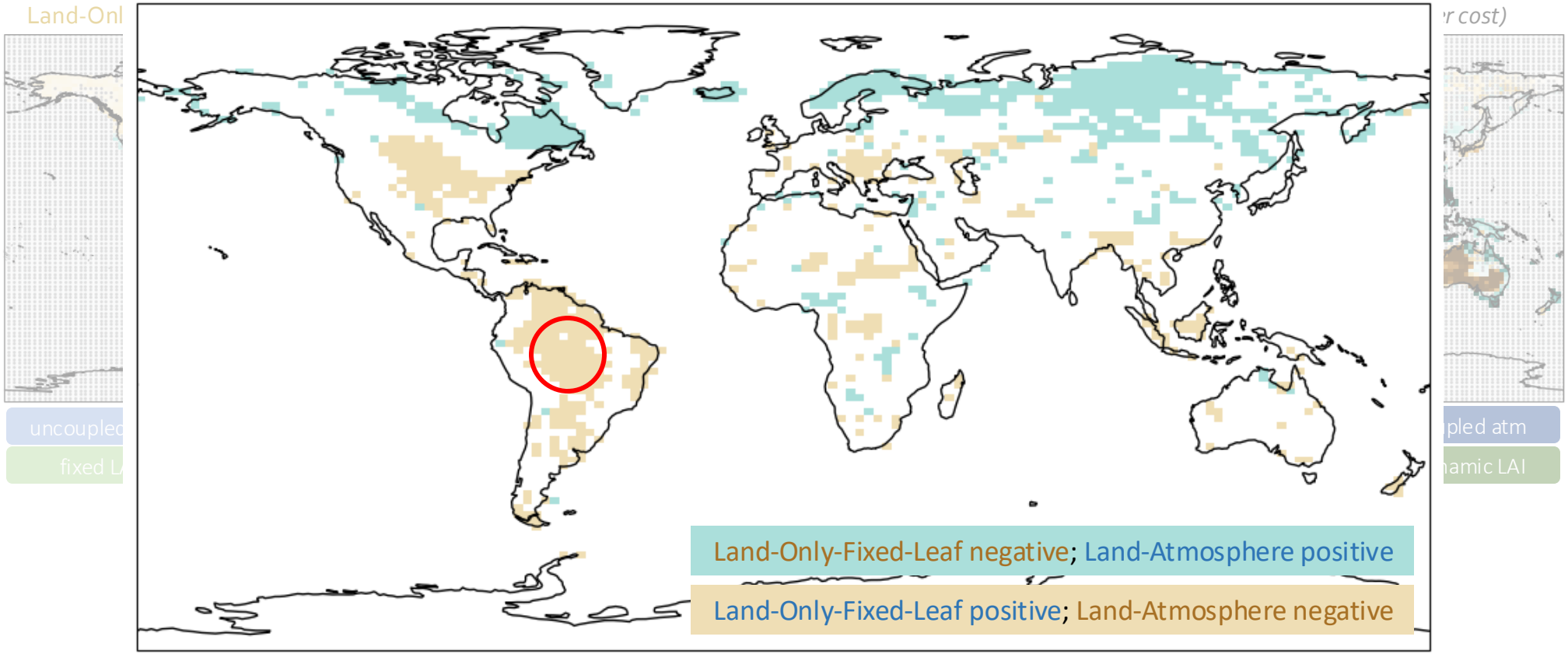
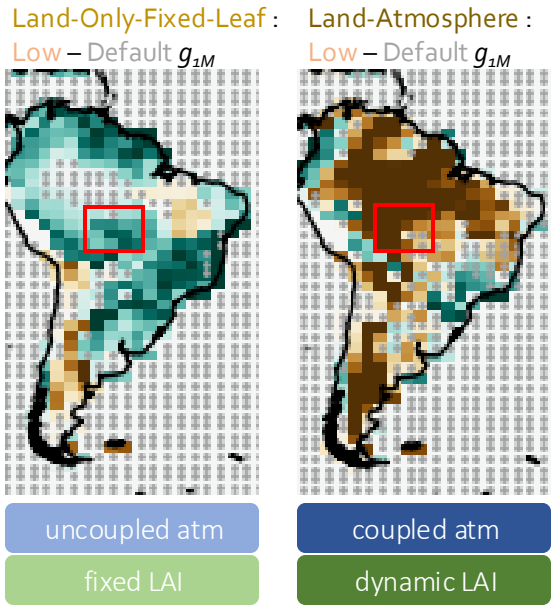


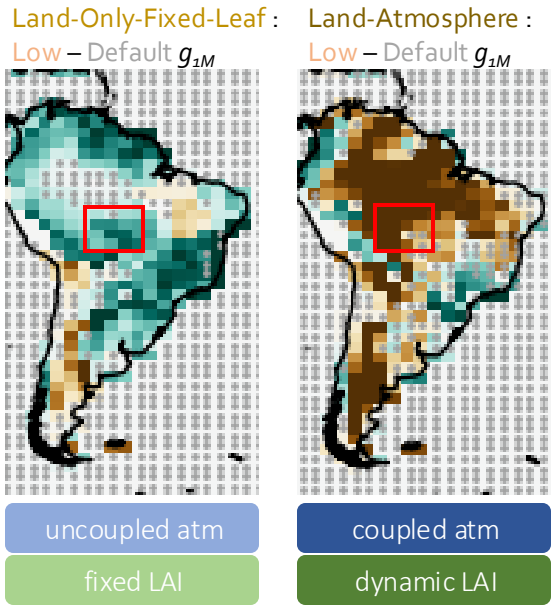
Why does photosynthetic response change sign when atmospheric feedbacks are included in the Amazon?



Why does photosynthetic response change sign when atmospheric feedbacks are included in the Amazon?

Hypothesis 1: Increase in *temperature* pushes plants beyond thermal optimum for photosynthesis

(but CLM includes a representation of photosynthetic acclimation which reduces the negative impact of hot temperatures)



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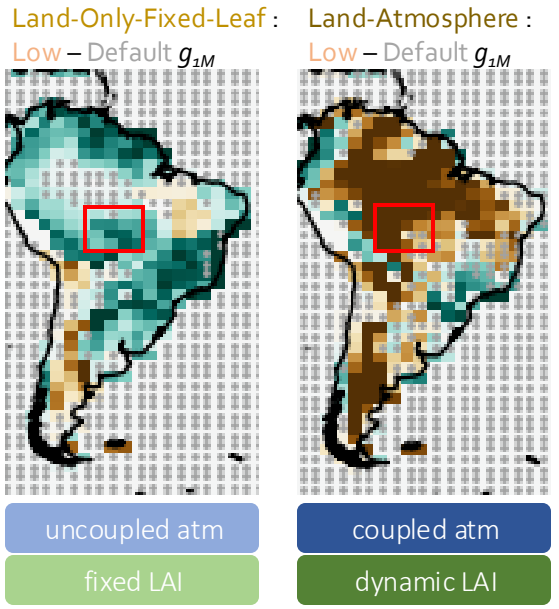
Hypothesis 2: Increase in *VPD* closes stomata and decreases photosynthesis



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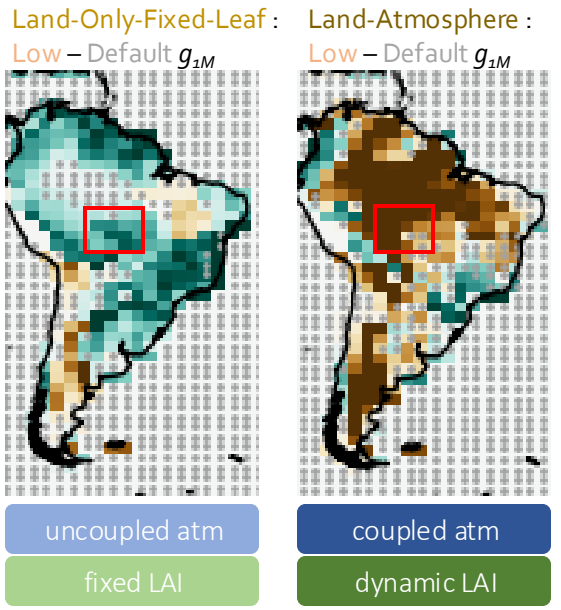
We use perturbed meteorology simulations attribute their effects on photosynthesis

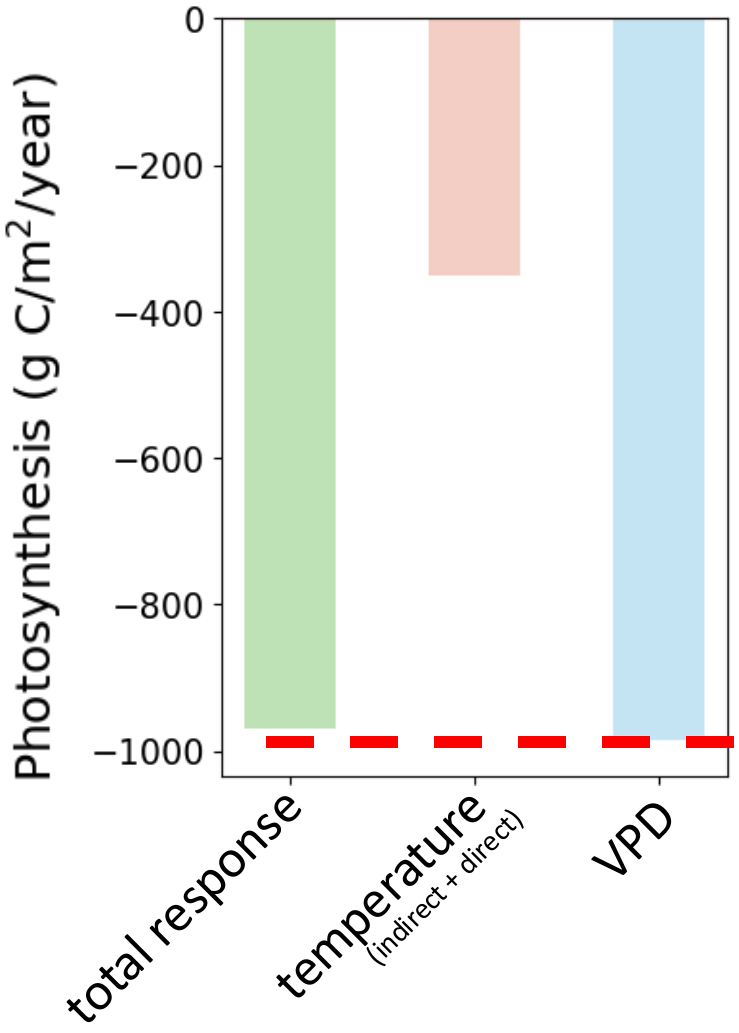


Control Simulation

Temperature increase *(constant specific humidity)*

VPD increase *(constant temperature)*

Photosynthetic responses to Low g_{1M} *(water cost)*



Photosynthetic decreases under a dynamic atmosphere in the Amazon can be attributed primarily to a response to VPD

Similar magnitudes!

Implications

- High g_{1M} **is unlikely in the tropics:** Photosynthesis greatly decreases, which may not be realistic
- **Spatial gradient of g_{1M} matters:** If there is g_{1M} spatial variation in the real world, CESM2 will over- or under-estimate local photosynthesis by up to ~40%
- **Atmospheric feedbacks may reverse photosynthetic response to low g_{1M} :** If g_{1M} is calibrated in land-only simulations, that calibration might give poor answers in land-atmosphere simulations