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Exploring carbon cycle dynamics in an observationally constrained CLM6 PPE

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& CLM community



Applications of perturbed parameter ensembles

PPEs have enabled new lines of inquiry with CTSM

- Parameter sensitivity
- Calibration
- Scientific exploration



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Applications of perturbed parameter ensembles

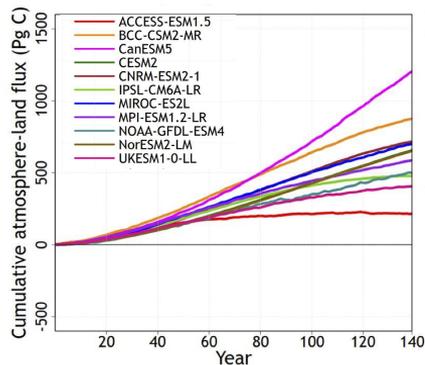
PPEs have enabled new lines of inquiry with CTSM

- Parameter sensitivity
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Quantify and constrain parametric uncertainty in projections

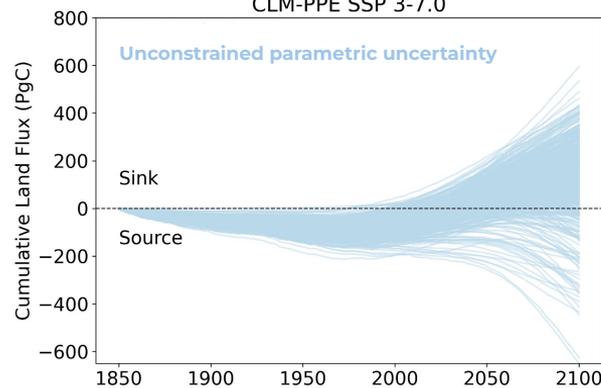
- Observationally constrained PPE

CMIP6: Response to 1pctCO2



Arora et al. (2020)

CLM-PPE SSP 3-7.0



32 parameters in the Community Land Model v5
500 member perturbed parameter ensemble



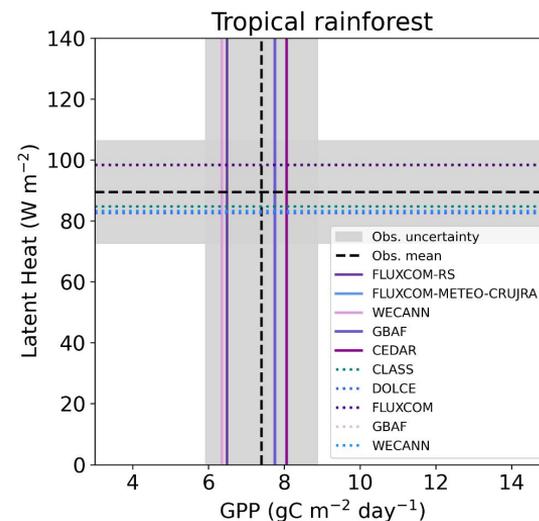
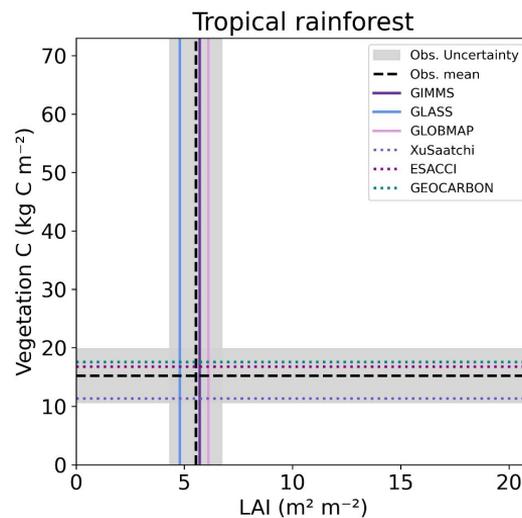
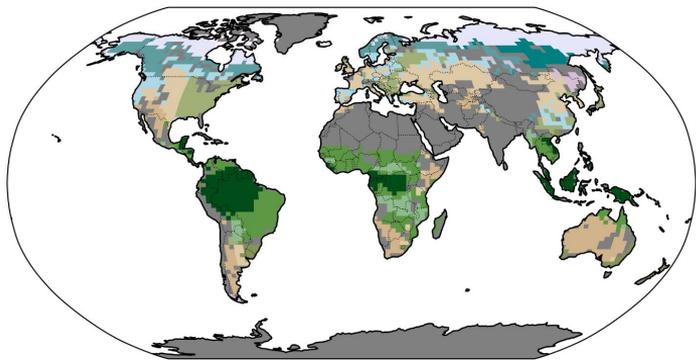
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Constructing an observationally constrained PPE

Observational Data

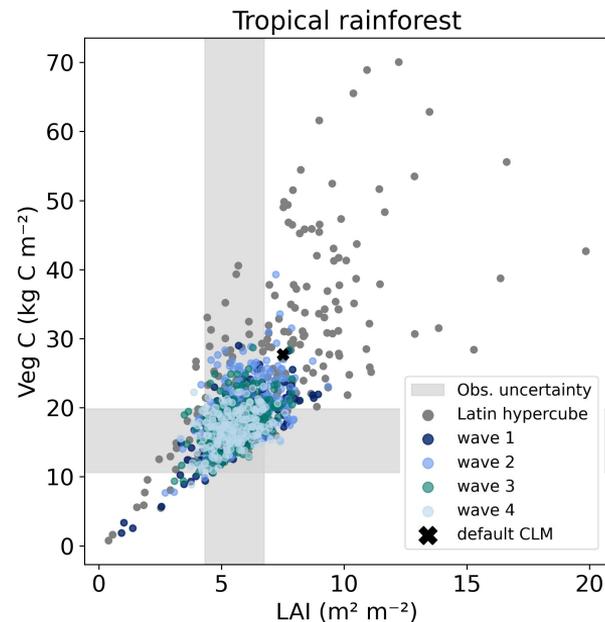
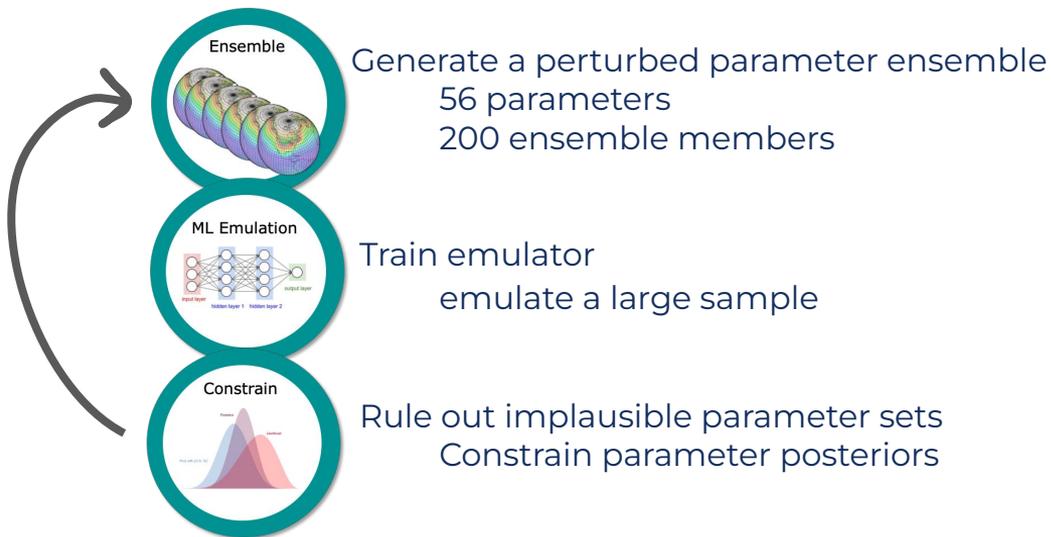
- Leaf Area Index, GPP, Vegetation Carbon, Latent Heat
- Products available on ILAMB

Biomes



Constructing an observationally constrained PPE

Apply History Matching



Constructing an observationally constrained PPE

Characterize parametric uncertainty using Bayesian inference

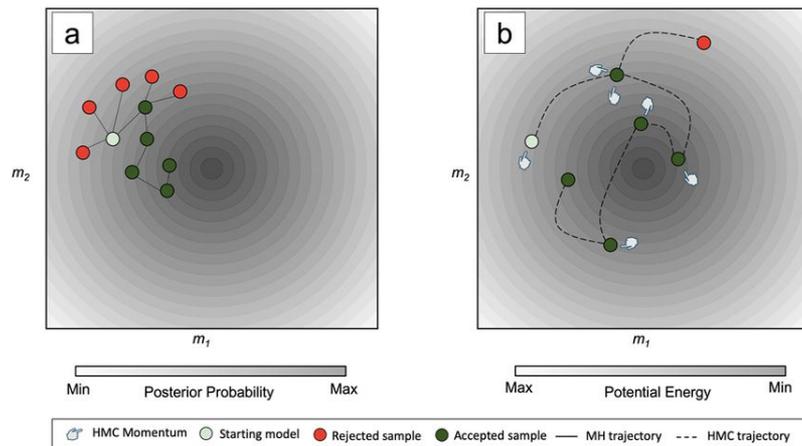
- High probability assigned to the mean of the observational products

Hamiltonian Monte Carlo

- Differentiable emulators enable gradient-based sampling
- Uses gradient information to make large, informed proposals
 - avoids random walk inefficiency
- Scales well to high-dimensional, multimodal posteriors

Sampling design

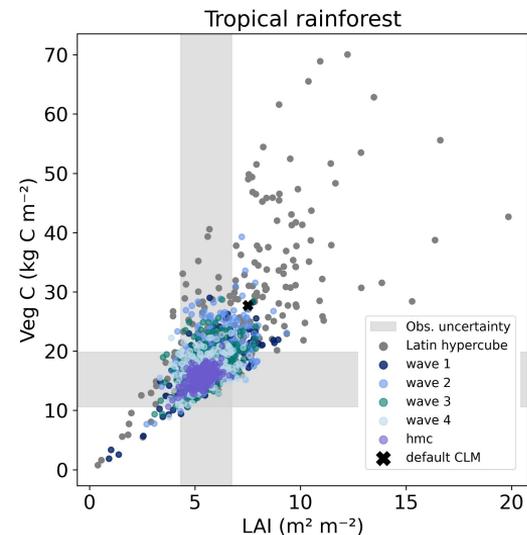
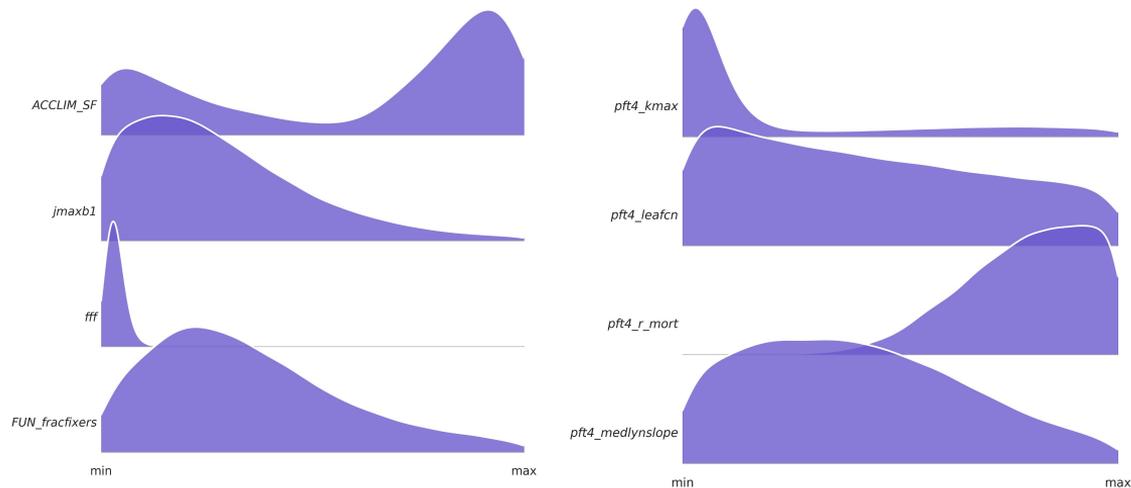
- 30 chains
- 1000 burnin steps, 5000 samples
- <24 hours on 1 GPU



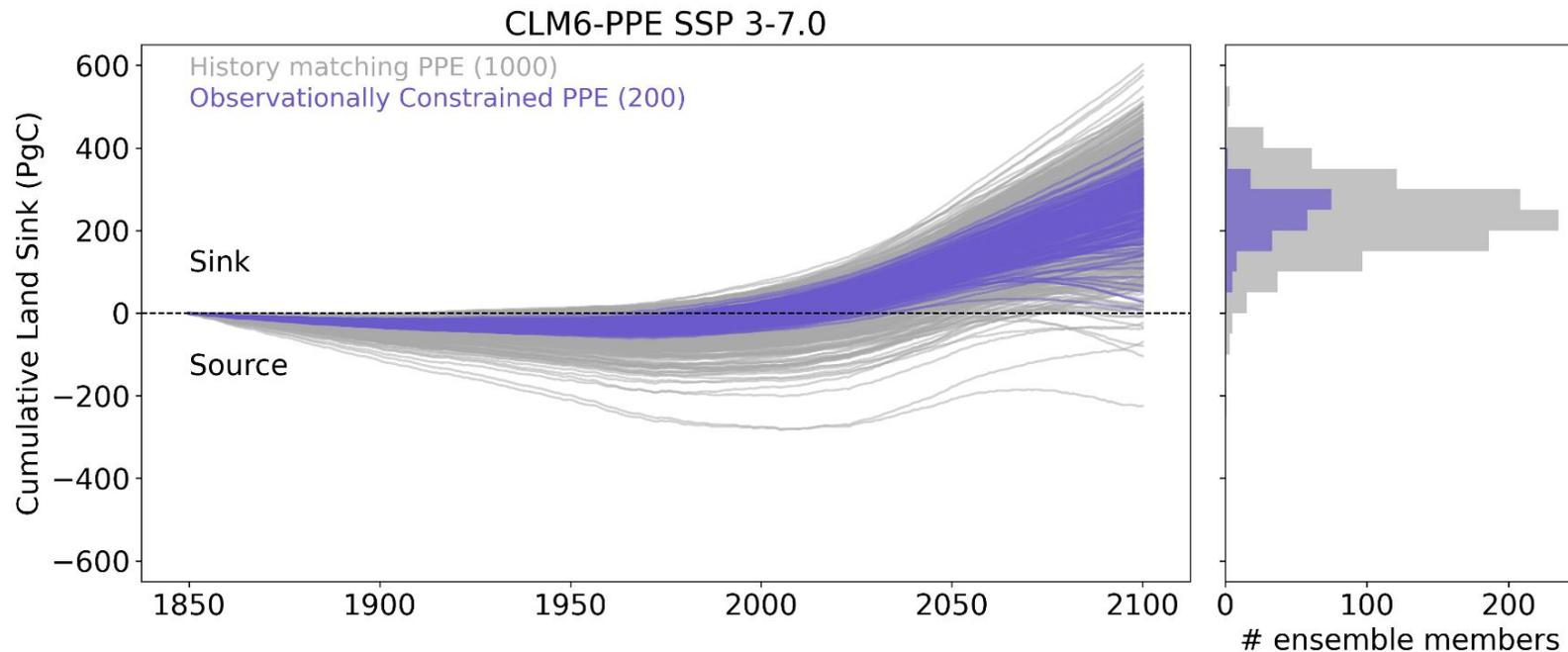
Constructing an observationally constrained PPE

Hamiltonian Monte Carlo Results:

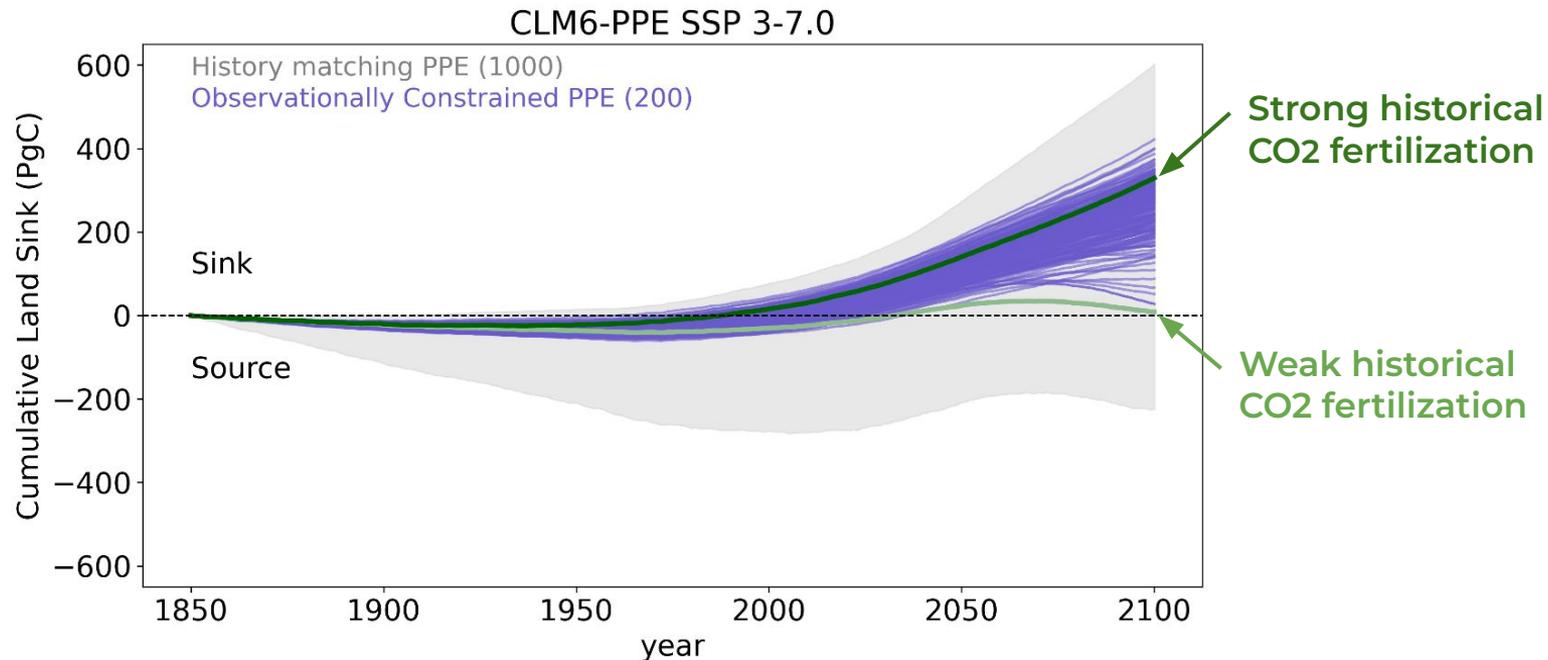
- Able to capture high dimensional, multimodal posterior.
- Posteriors consistent with history matching (billions of random samples)
- Ensemble is concentrated near the observational mean.



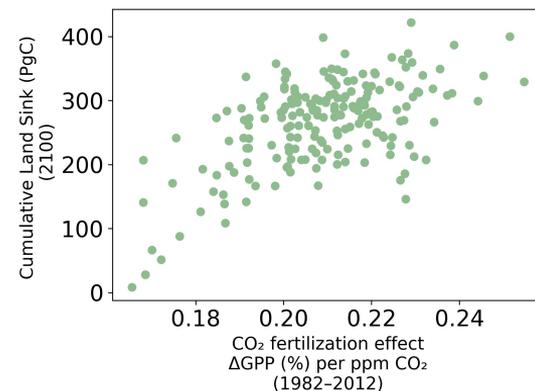
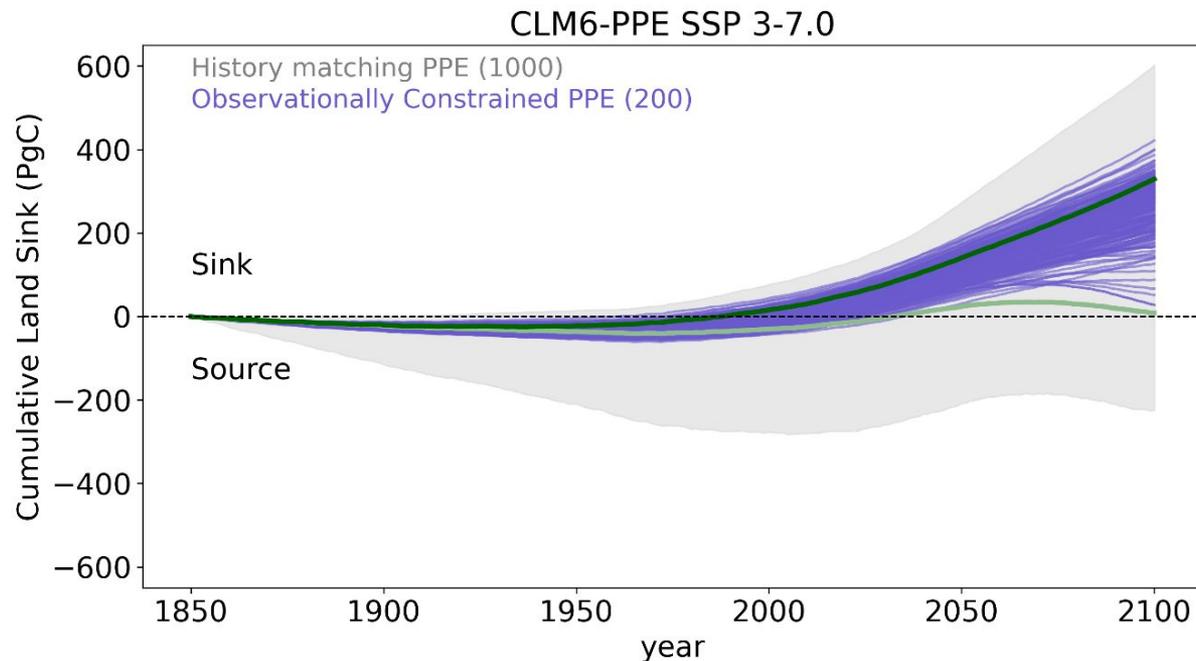
Land carbon sink in an observationally constrained PPE



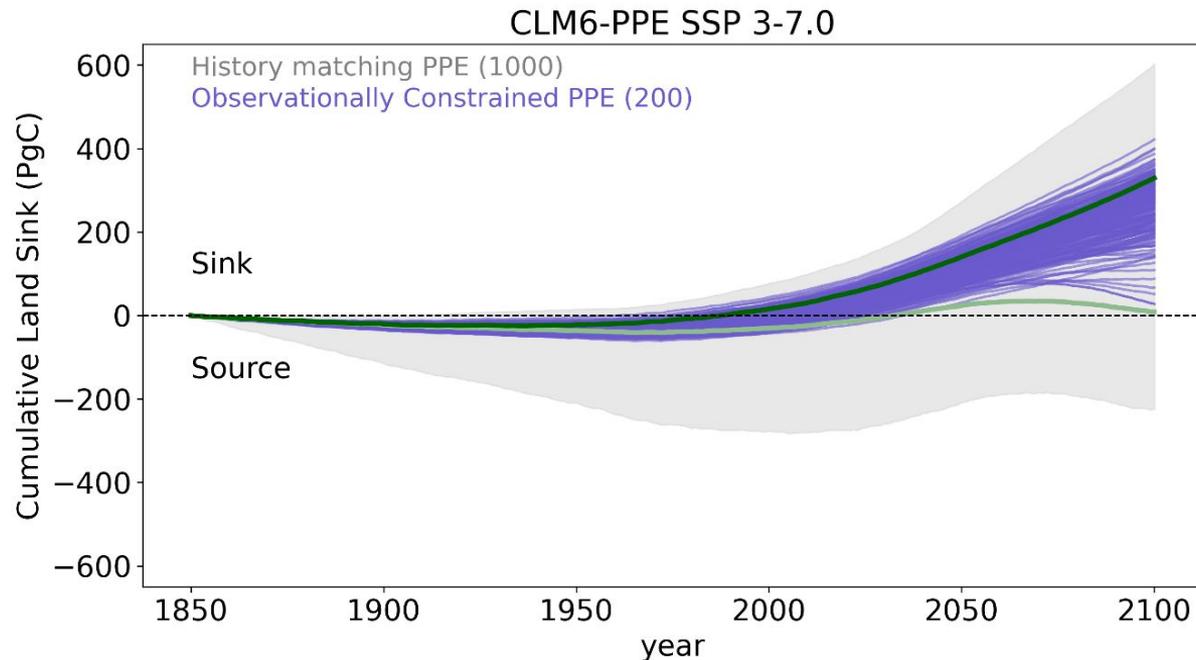
Land carbon sink in an observationally constrained PPE



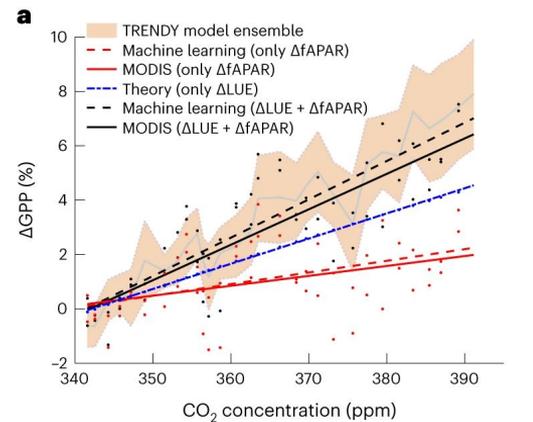
Land carbon sink in an observationally constrained PPE



Land carbon sink in an observationally constrained PPE



Observed CO₂ fertilization effect

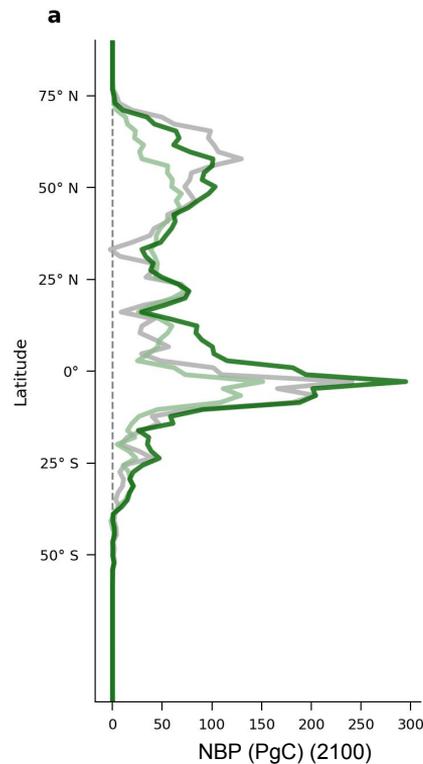
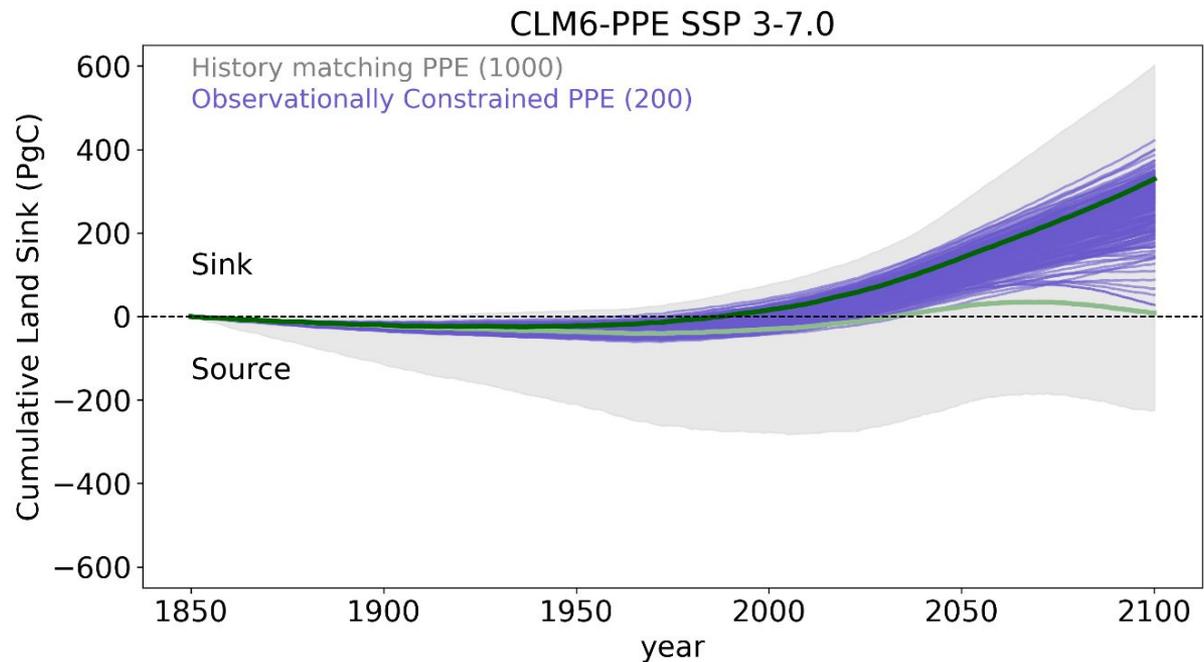


Keenan et al., (2023)



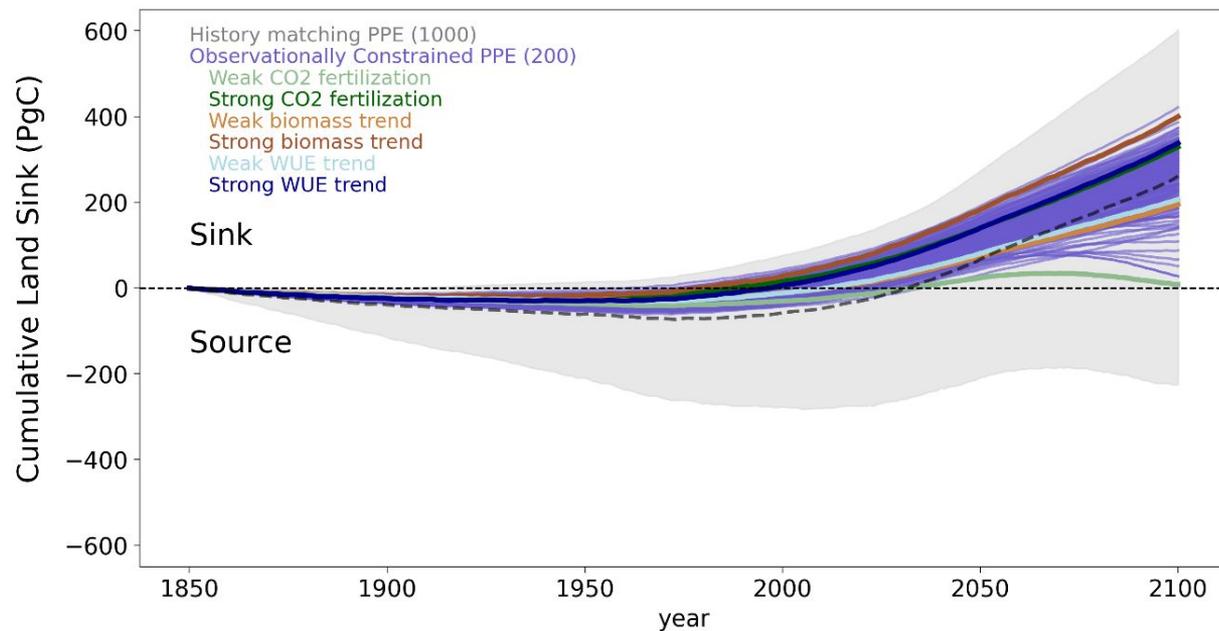
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Land carbon sink in an observationally constrained PPE

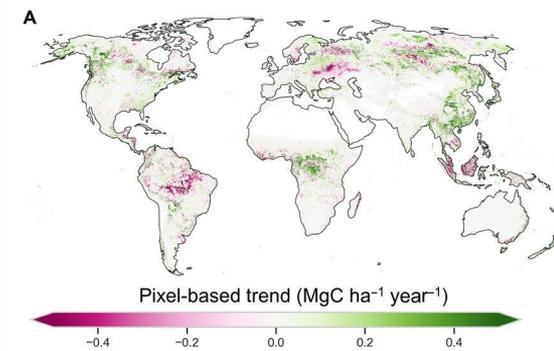


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Land carbon sink in an observationally constrained PPE



Trend in live biomass



Xu, Saatchi et al., (2021)

Takeaways:

- Historical mean state constraints moderately constrain parametric uncertainty in the land carbon sink.
- The CO₂ fertilization effect and the trend in biomass explain most of the spread in the projected land carbon sink.
- Assumptions about observational uncertainty influence the assessment of parametric uncertainty.



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Opportunities:

- Observationally constrained CLM6 PPE soon available to the community
- Basis for selecting alternate parameter sets for CLM6
- Explore carbon-climate feedbacks in the emissions driven coupled model?



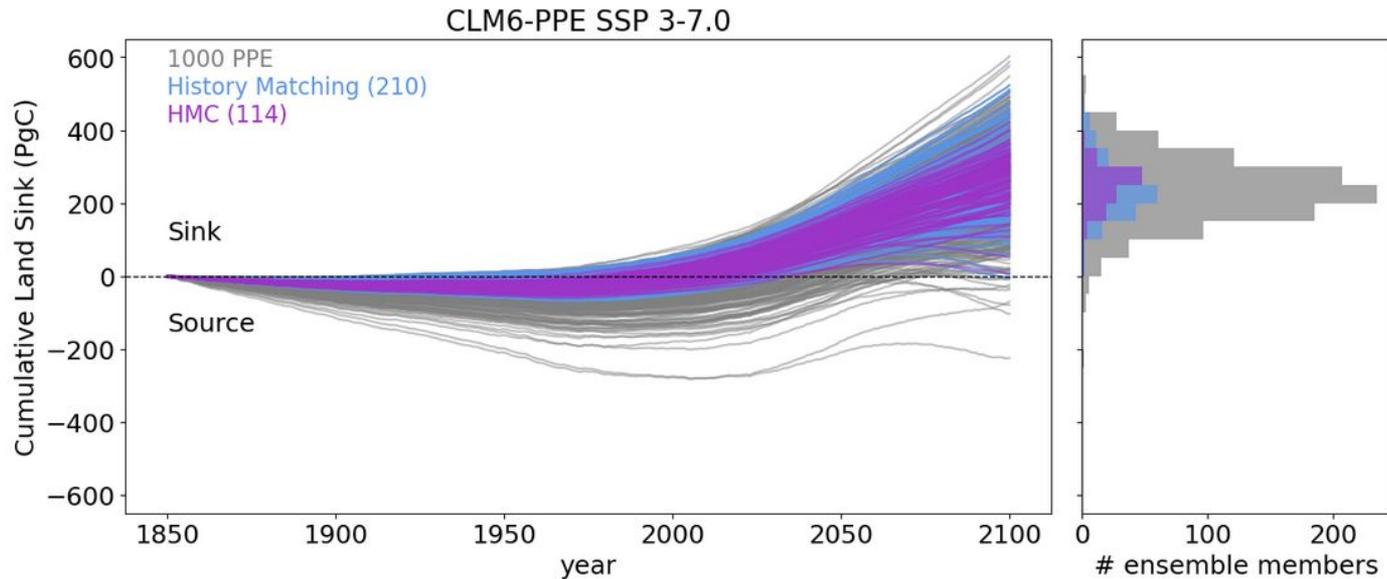
Extra slides



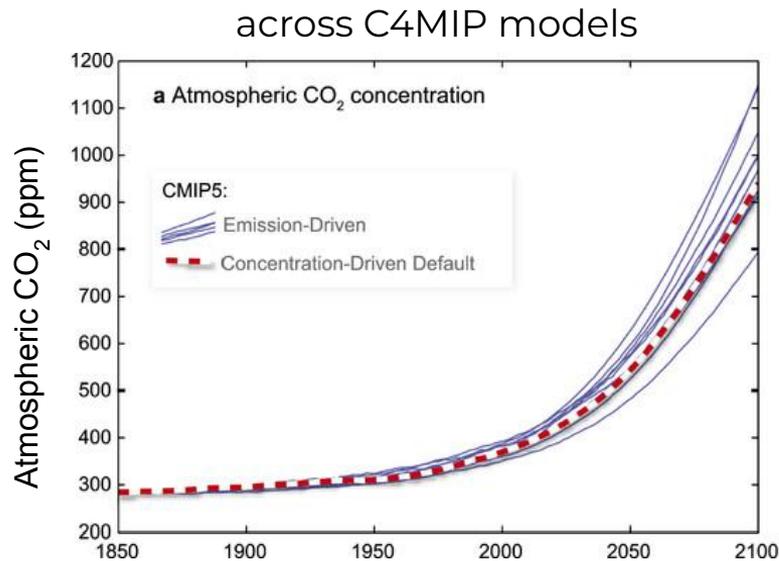
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Observationally constrained ensembles

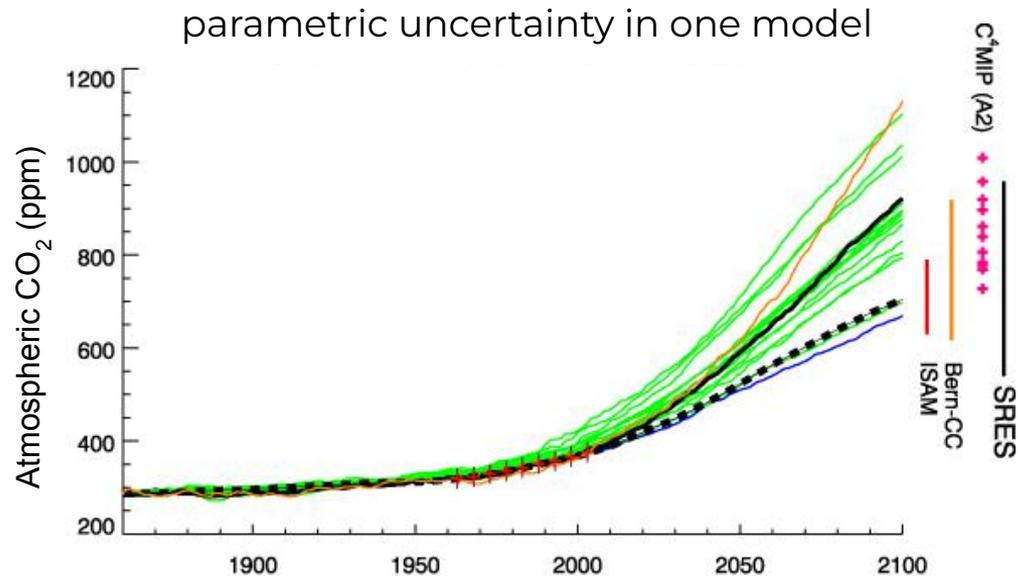
Assumptions about observational uncertainty influence the assessment of parametric uncertainty.



Carbon-climate feedbacks emerge in emissions driven simulations



Friedlingstein et al. (2014)

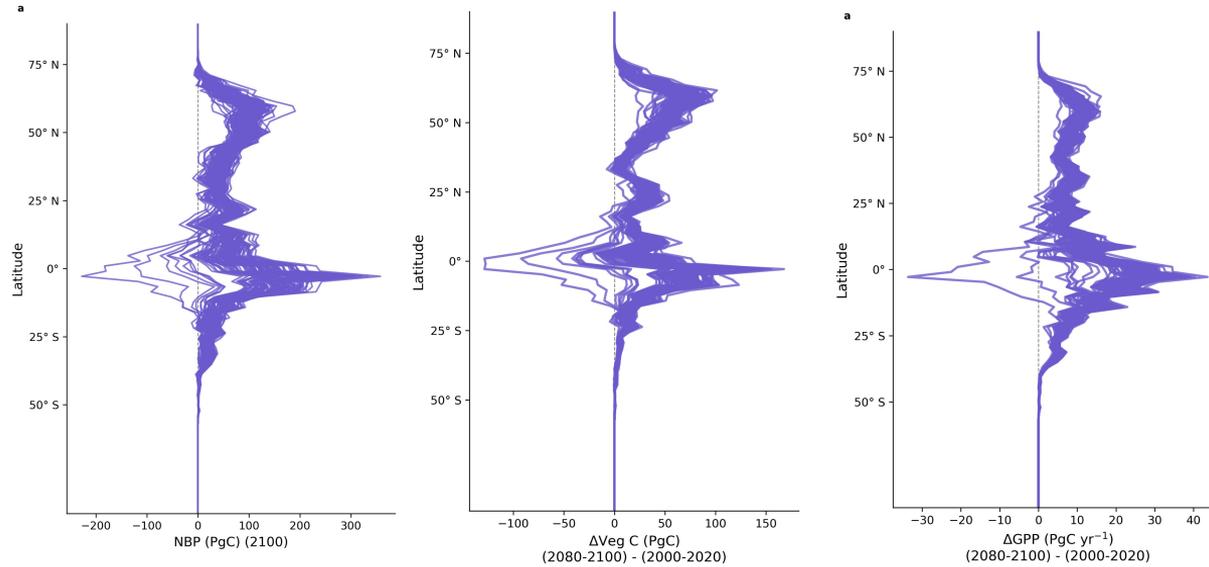


Booth et al., (2012)



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Observationally constrained PPE



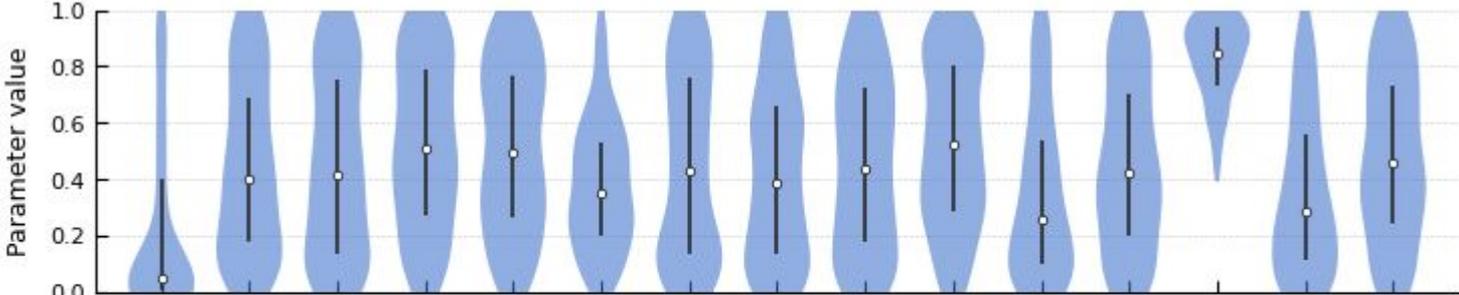
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Calibration

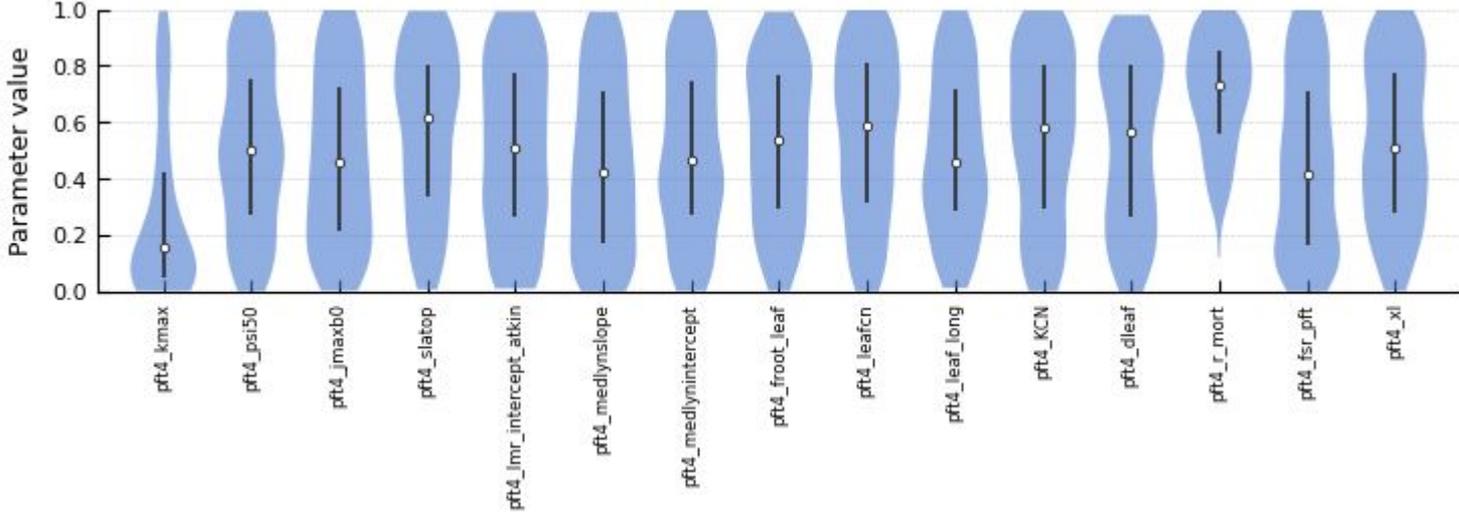
Posteriors for HMC (5000 samples)

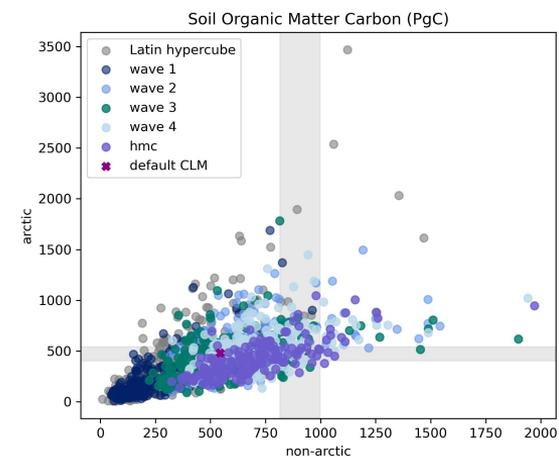
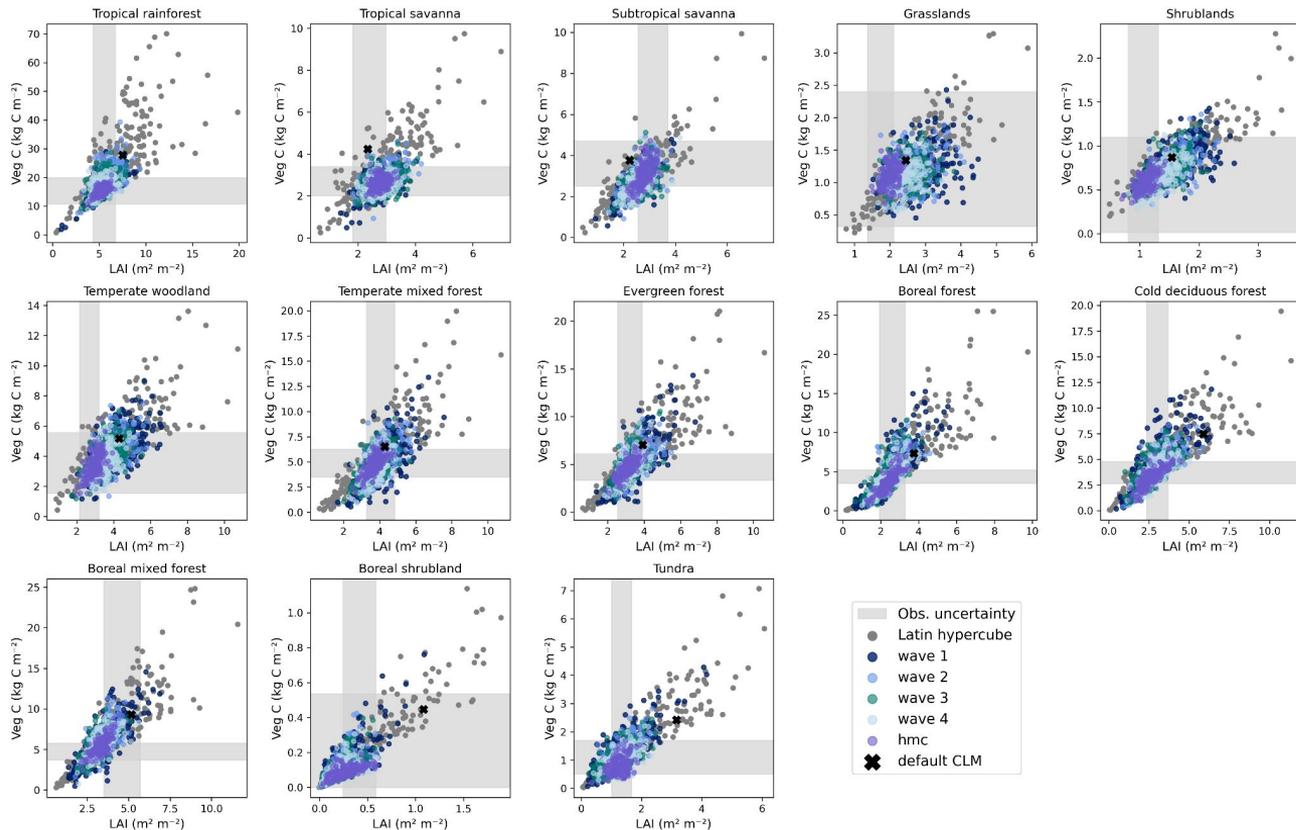
Posteriors from History Matching (billions of samples)

HMC

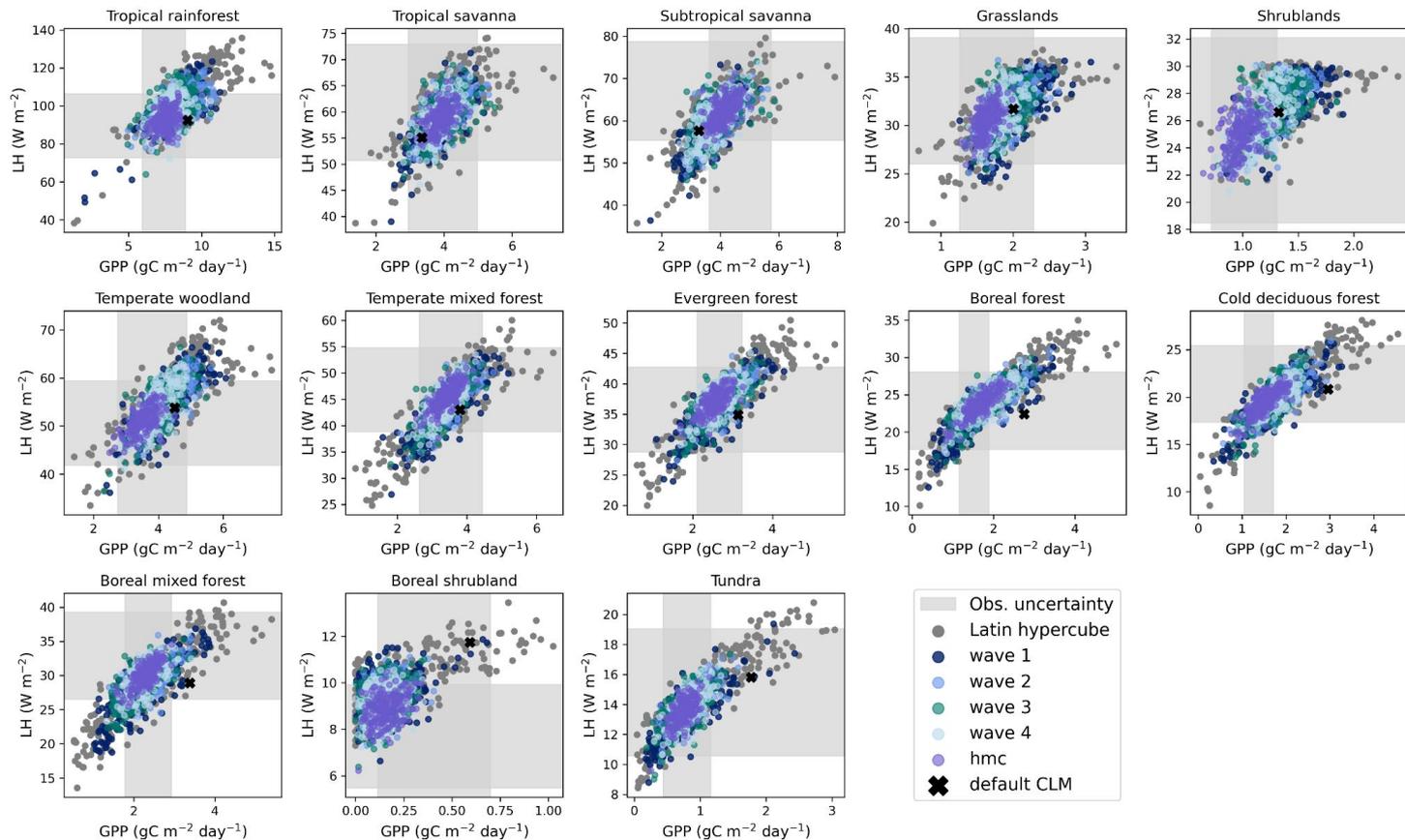


Wave 4





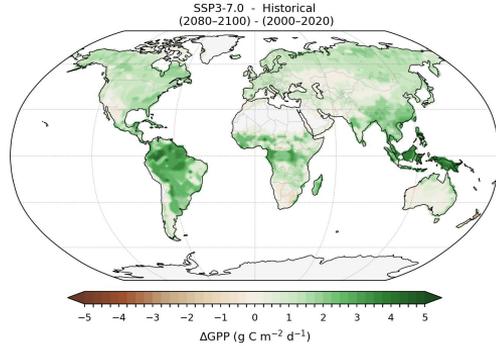
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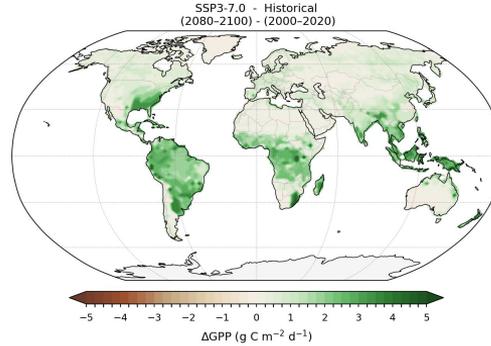
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What do these future worlds look like?

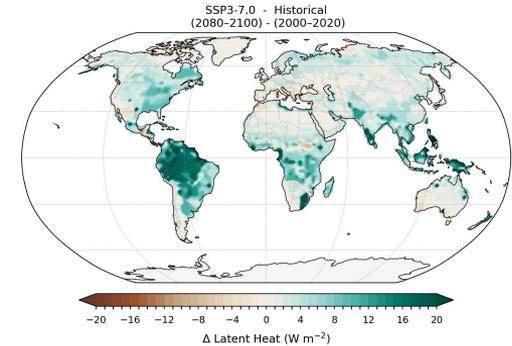
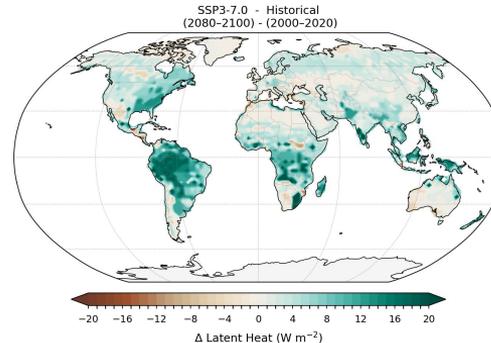
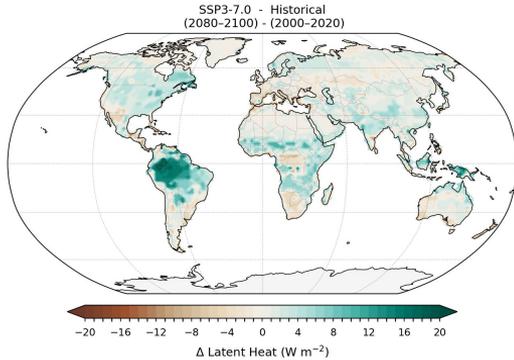
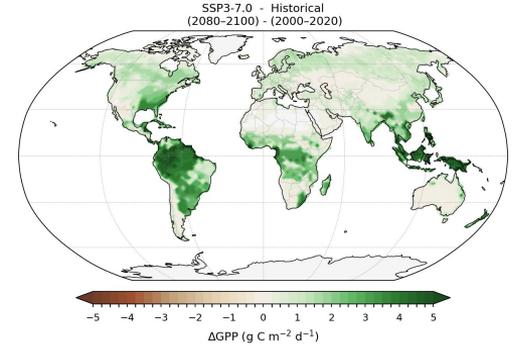
CLM5



Min CO2 fertilization

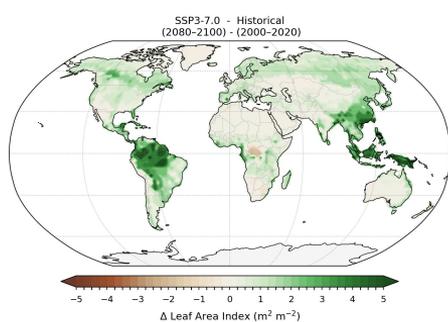


Max CO2 fertilization

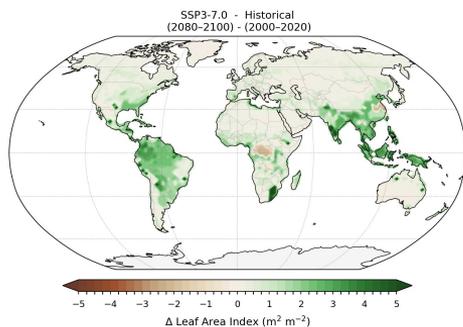


What do these future worlds look like?

CLM5



Min CO2 fertilization



Max CO2 fertilization

