

# Biogeochemical Cycling in the CLM-PPE

**persistent uncertainty in the terrestrial carbon sink**

*Daniel Kennedy, Linnia Hawkins, Katie Dagon, Dave Lawrence  
and the CLM5-PPE working group*

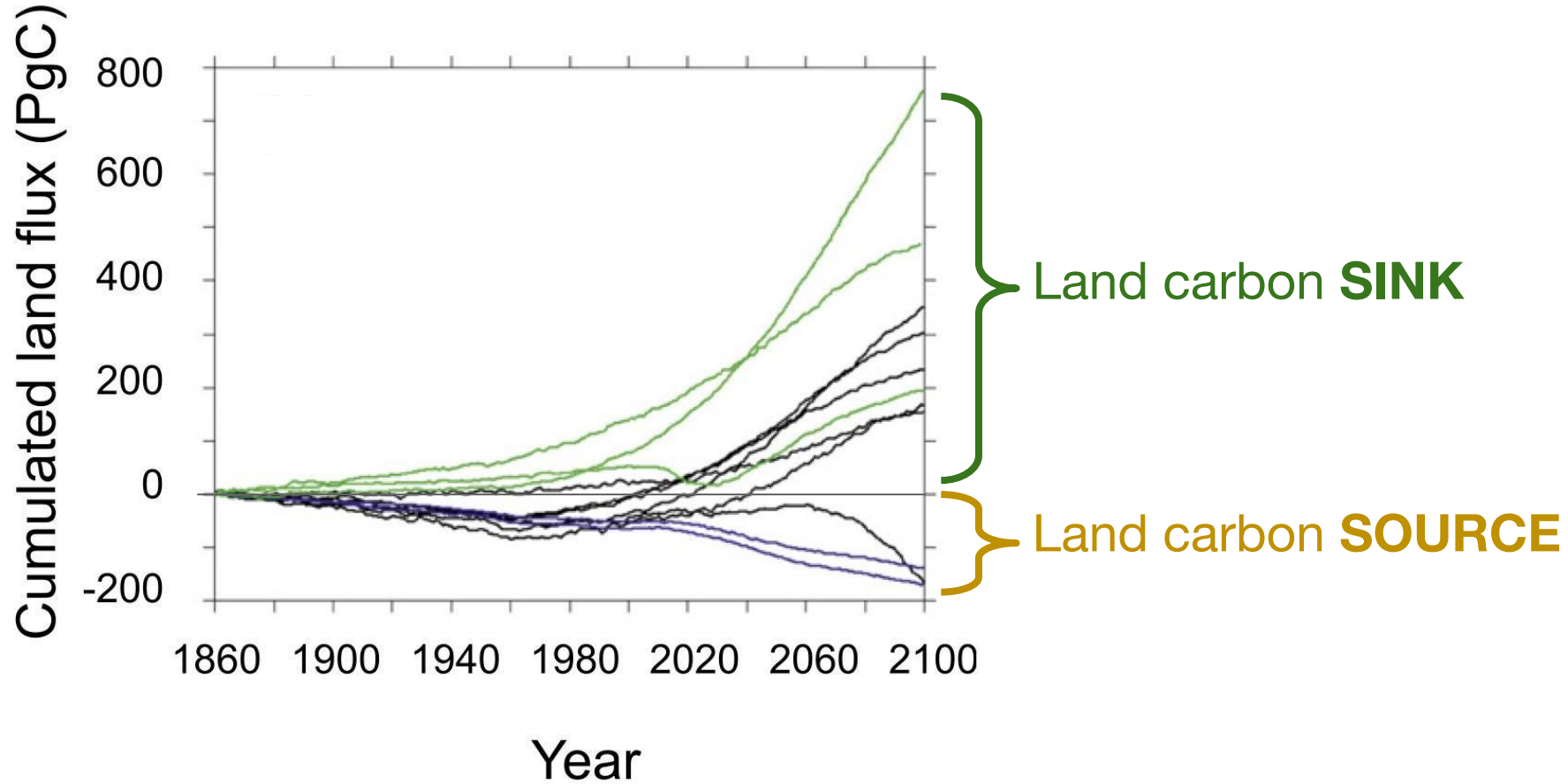


CESM workshop  
June 14, 2023



# Carbon Cycle Uncertainty in Land Model Projections

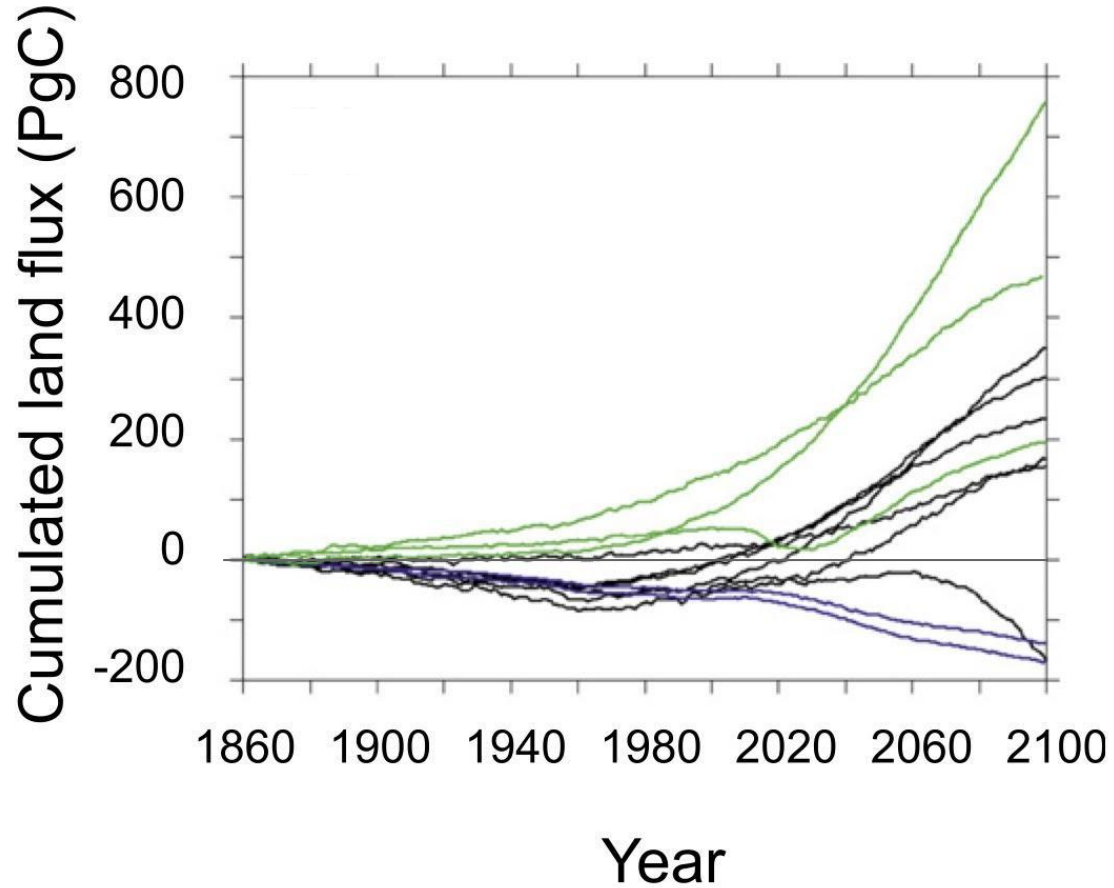
## CMIP5: RCP8.5



Friedlingstein et al. (2014)

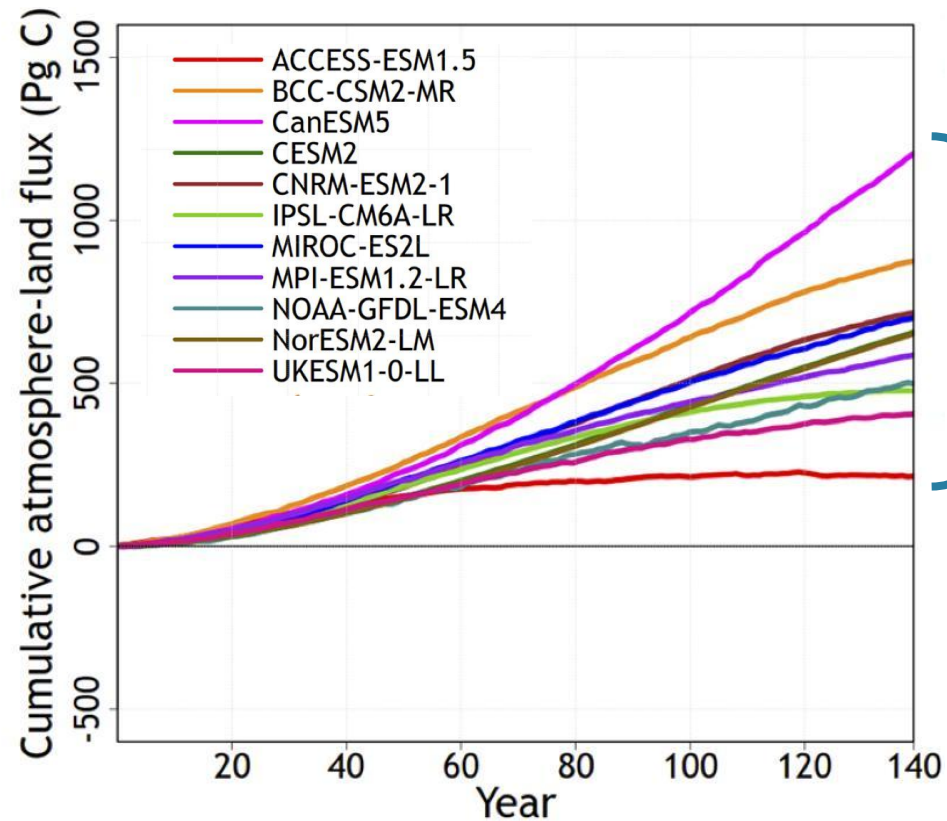
# Carbon Cycle Uncertainty in Land Model Projections

## CMIP5: RCP8.5



Friedlingstein et al. (2014)

## CMIP6: Response to 1pctCO2



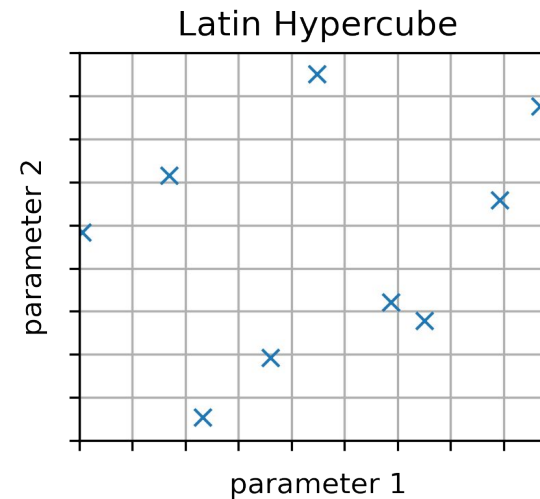
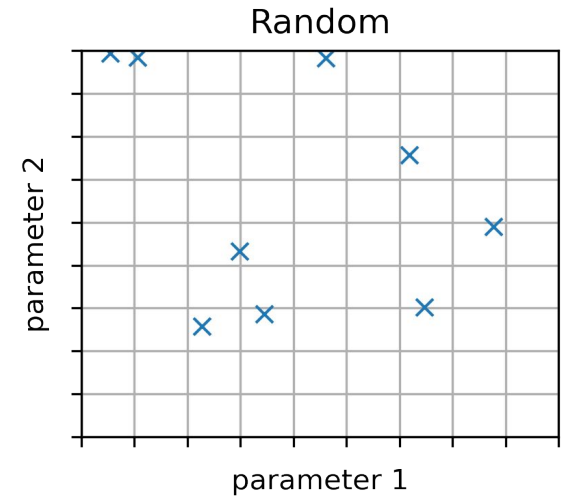
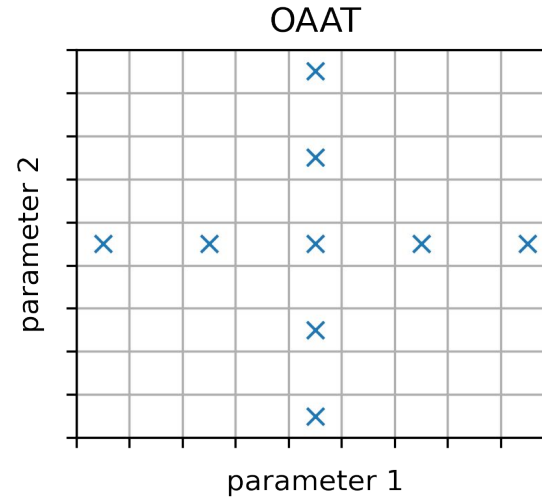
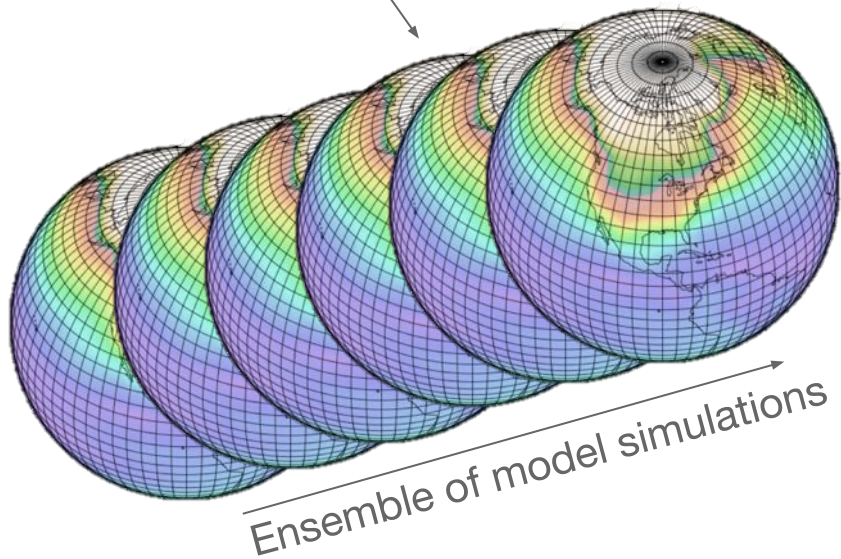
Next generation models agree on the sign, but feature roughly equivalent spread (~1000 PgC)

Arora et al. (2020)

# What is a PPE?

Perturbed parameter ensemble (PPE)

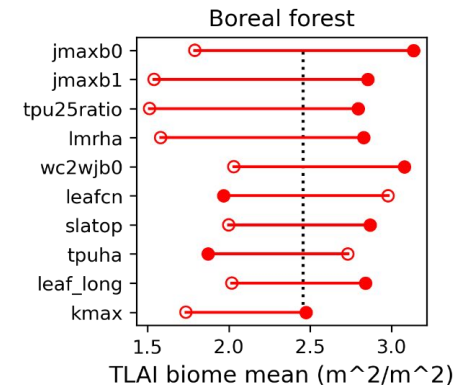
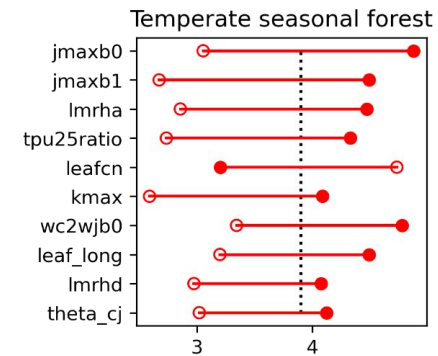
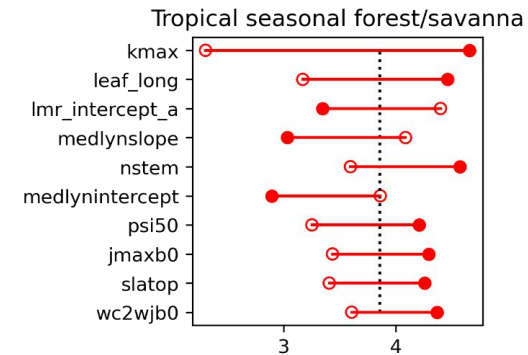
- strategically vary parameters
- run 1 or more simulations per parameter set



...

# First pass: vary parameters one-at-a-time

1. Identified 200 CLM parameters
2. Defined parameter ranges
3. Developed low-cost CLM configuration
4. Varied parameters one-at-a-time (min/max)

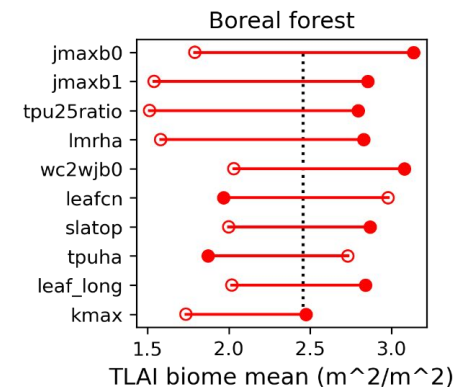
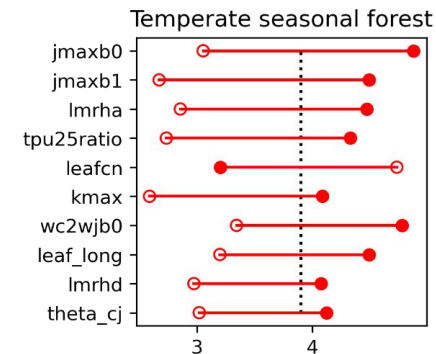
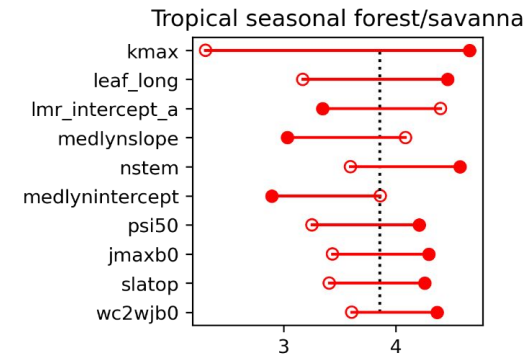


Leaf  
Area  
Index

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[webext.cgd.ucar.edu/I2000/PPEn11\\_OAAT](http://webext.cgd.ucar.edu/I2000/PPEn11_OAAT)



Leaf  
Area  
Index

## Focused on LAI calibration:

- challenging, but tractable
- foundational variable within CLM5-bgc
- observational constraints

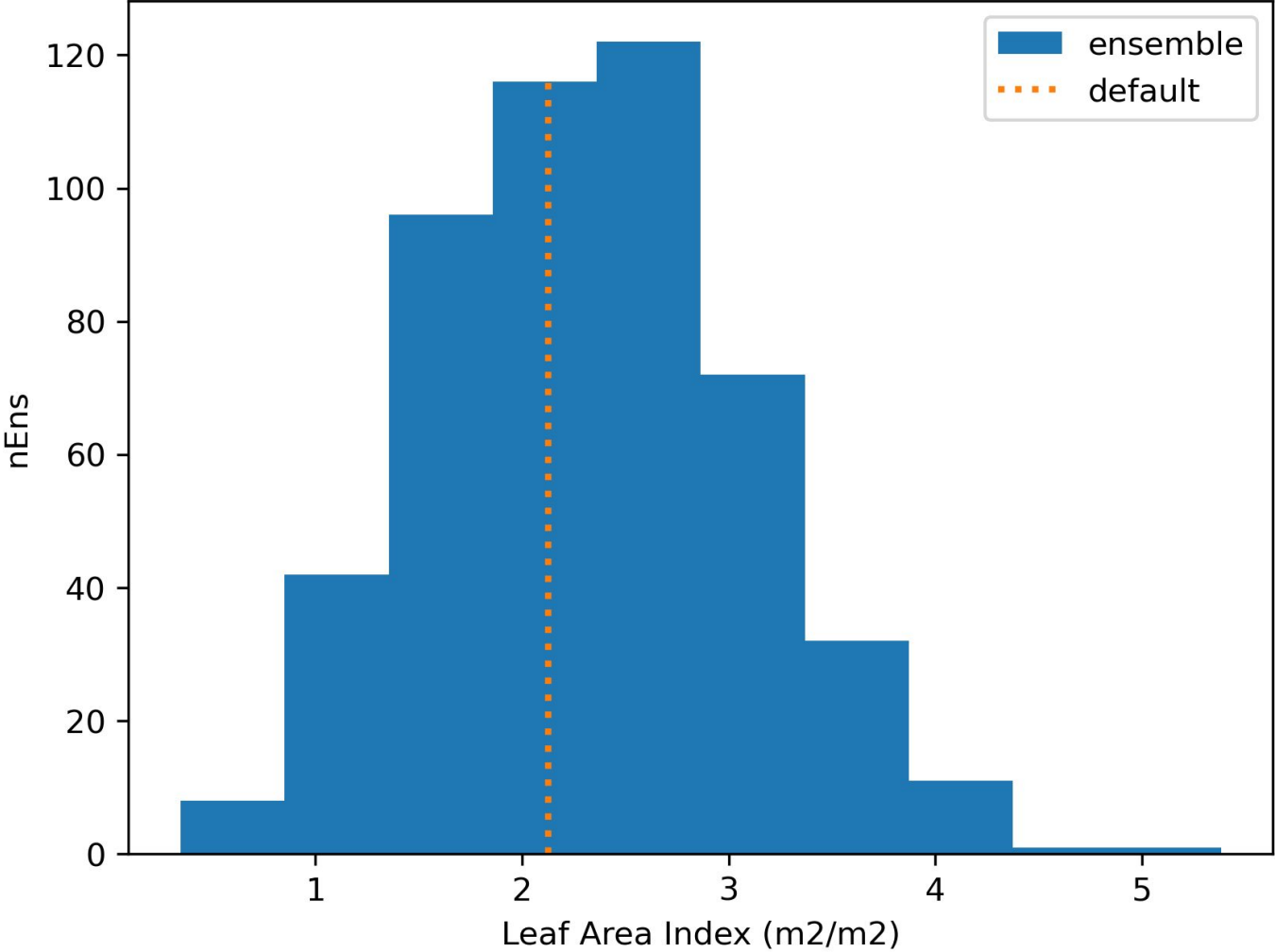


## Experimental Design:

- subset 32 relevant parameters
- 500 simulations
- fully transient, 1850-2014
- Latin hypercube (LHC) sampling

# Large variations in LAI

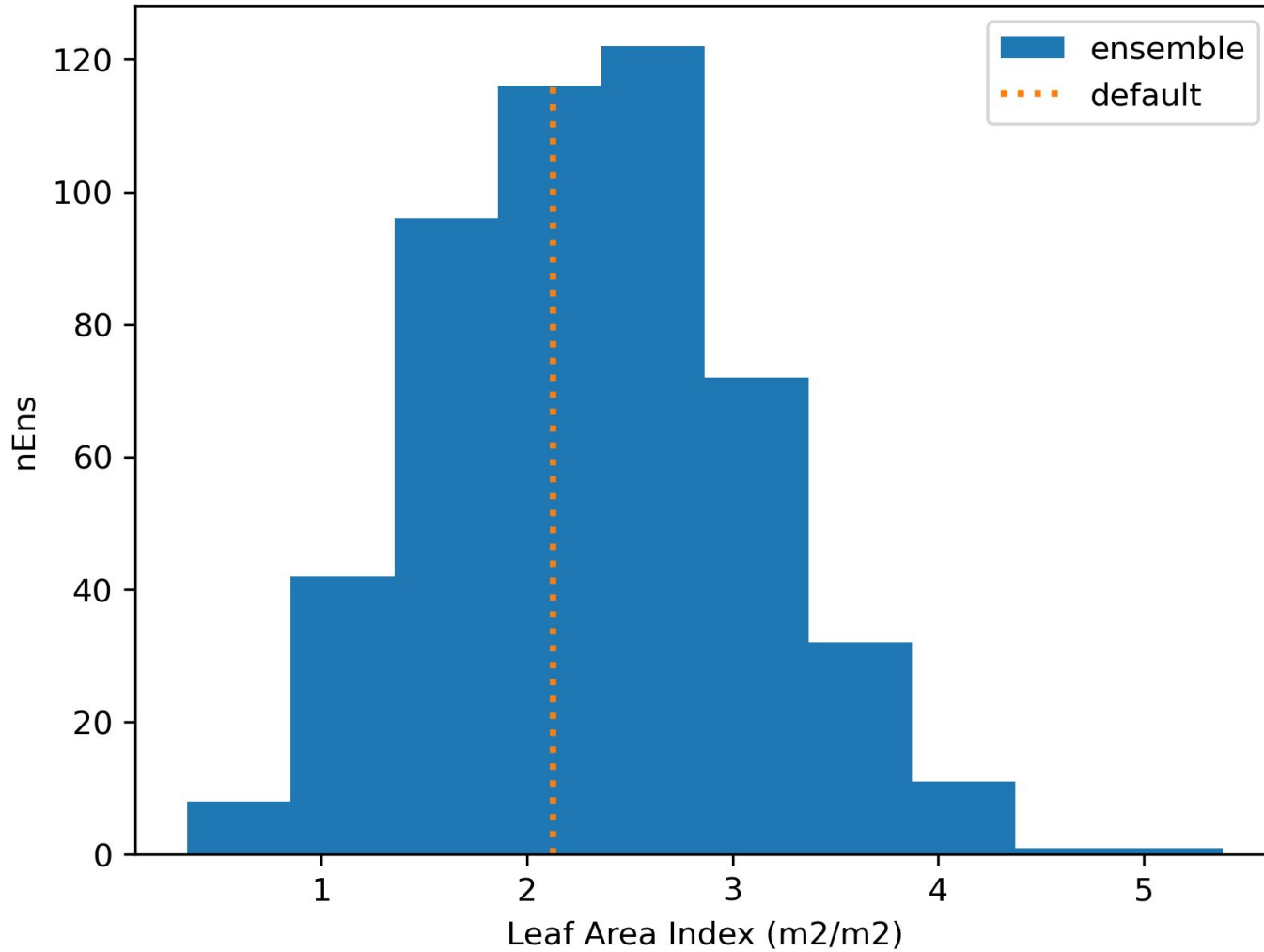
Global Average (2005-2014)



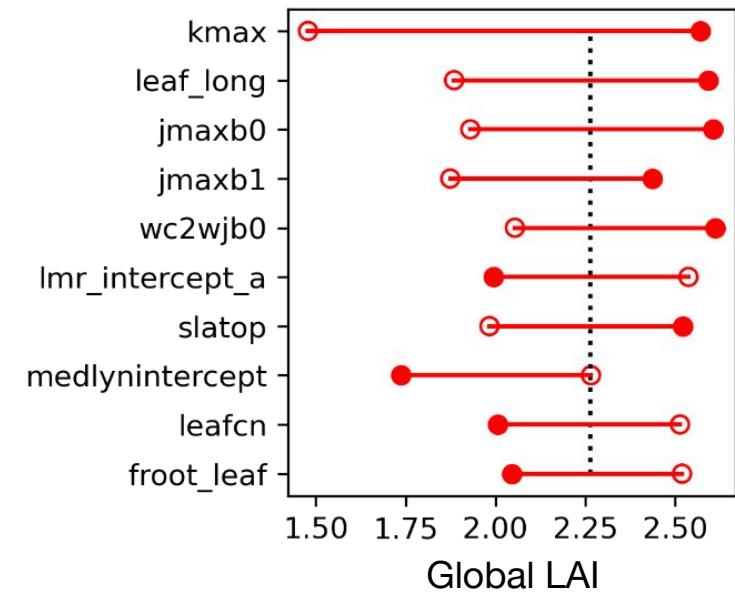


# Large variations in LAI

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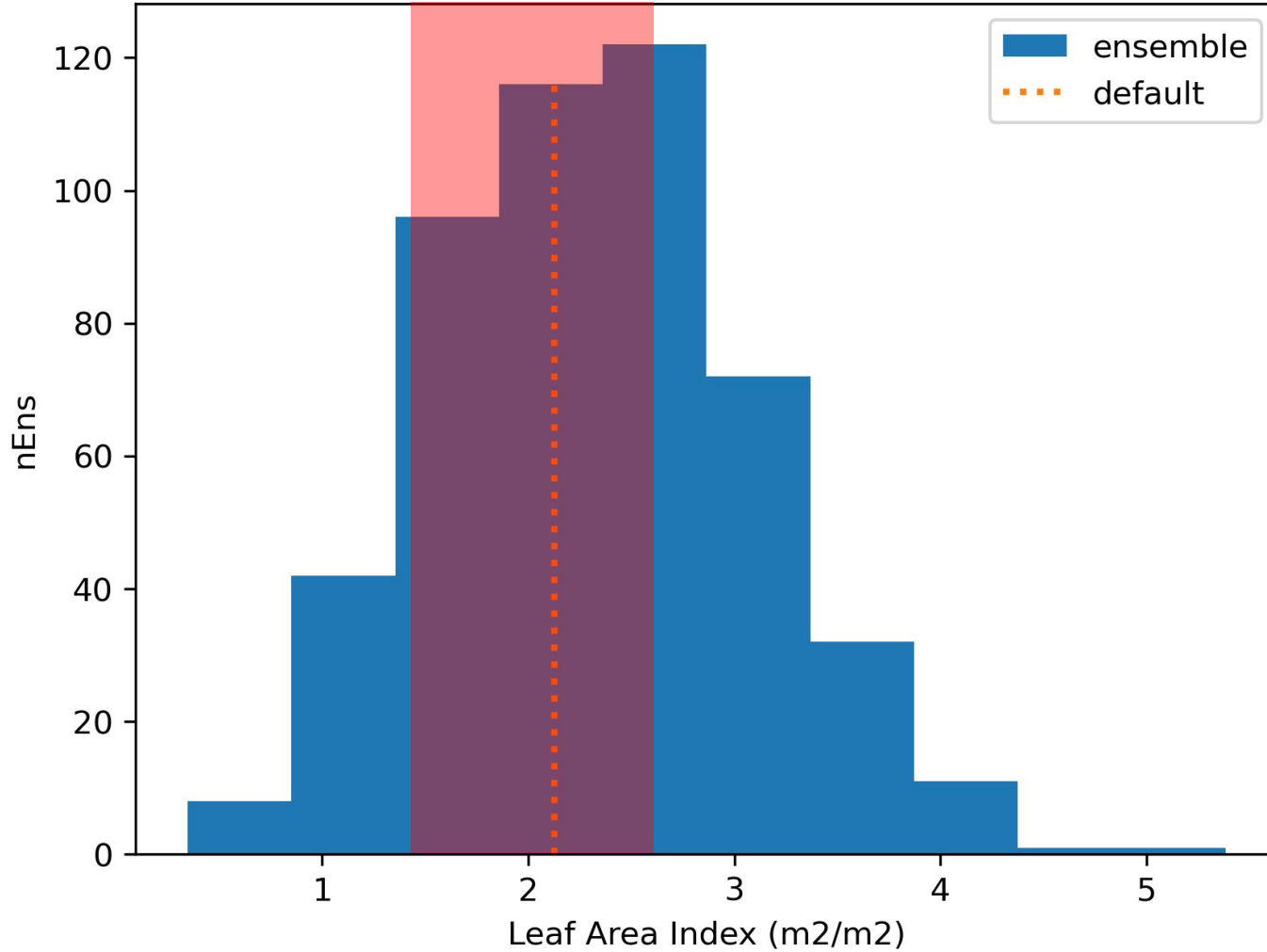


One-at-a-time response

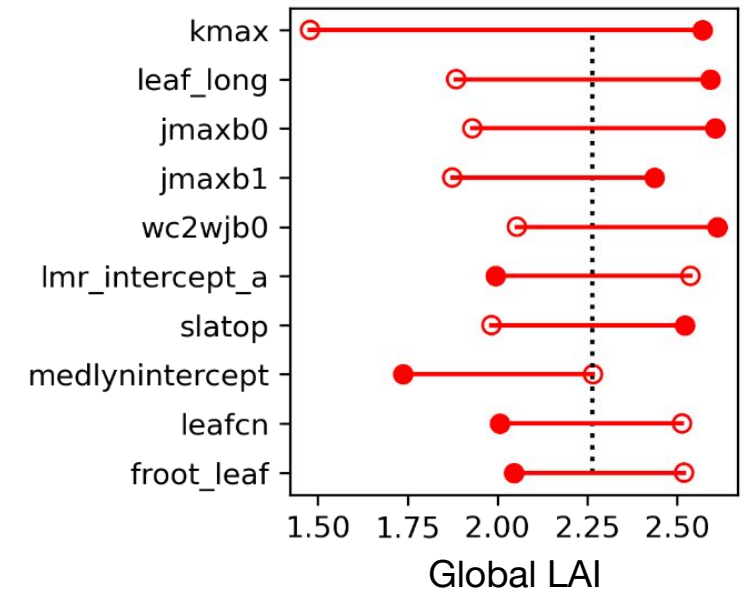


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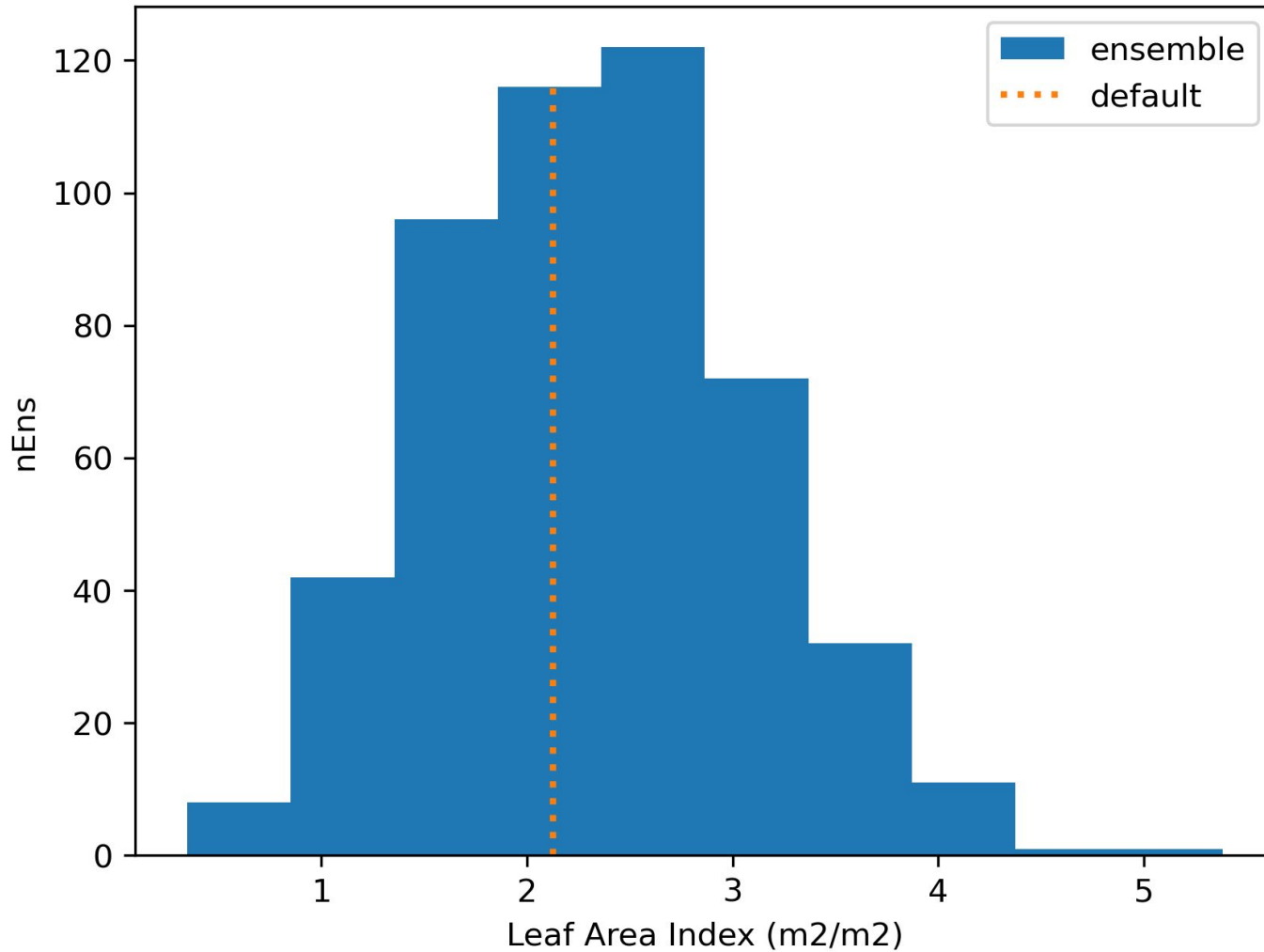


One-at-a-time response

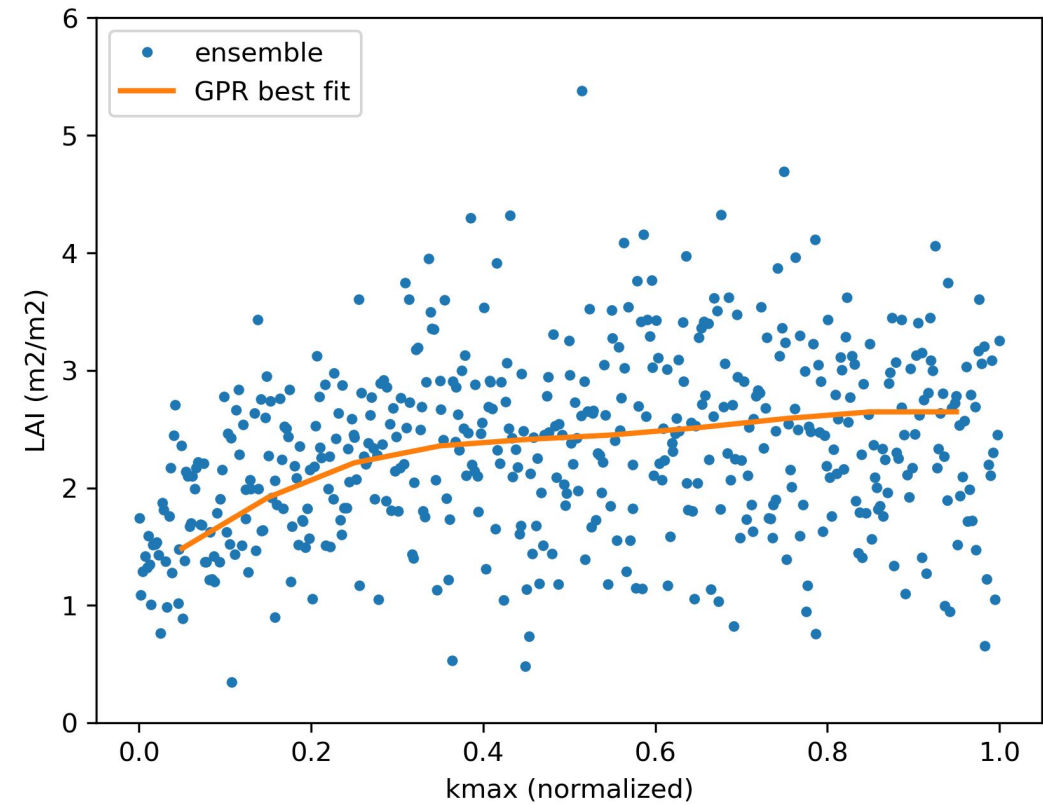


# Large variations in LAI

Global Average (2005-2014)

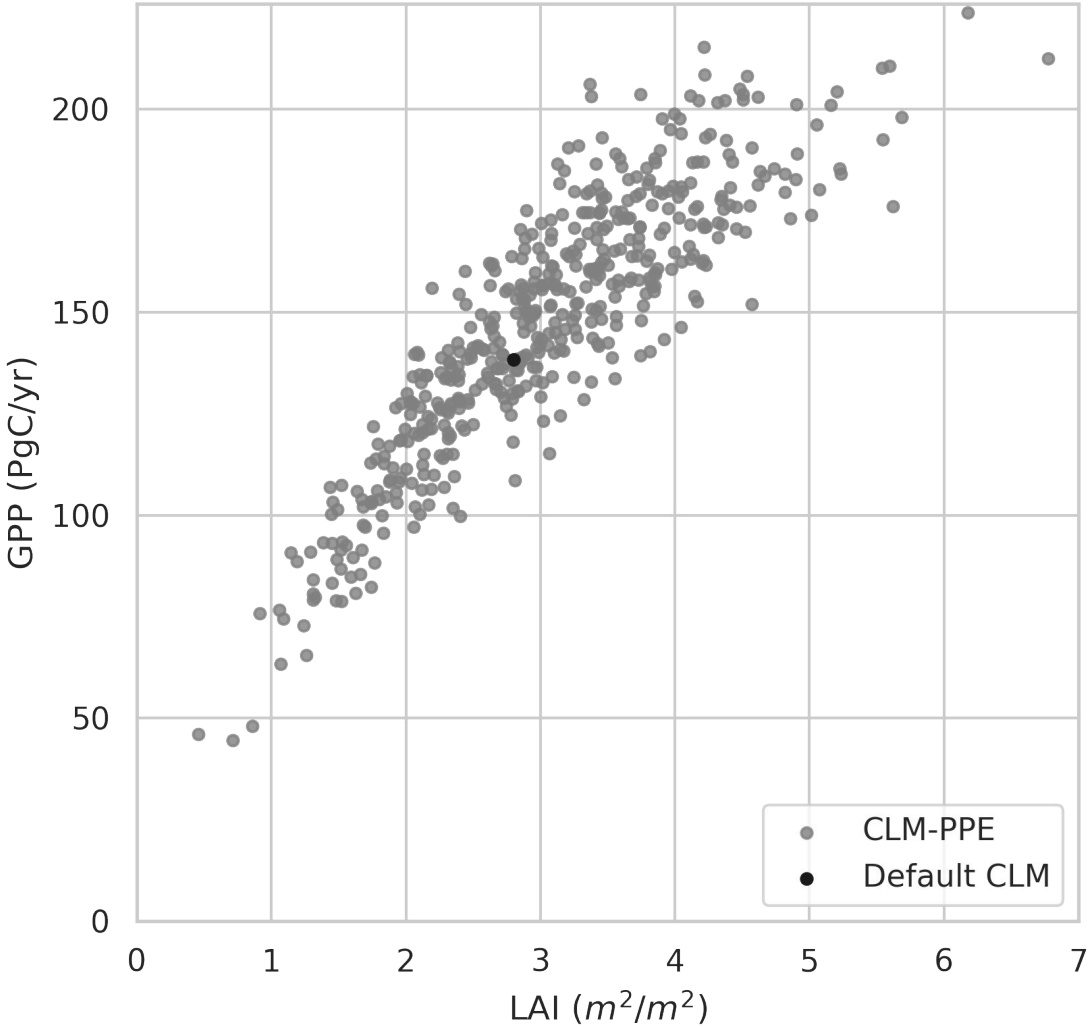


parameter response example

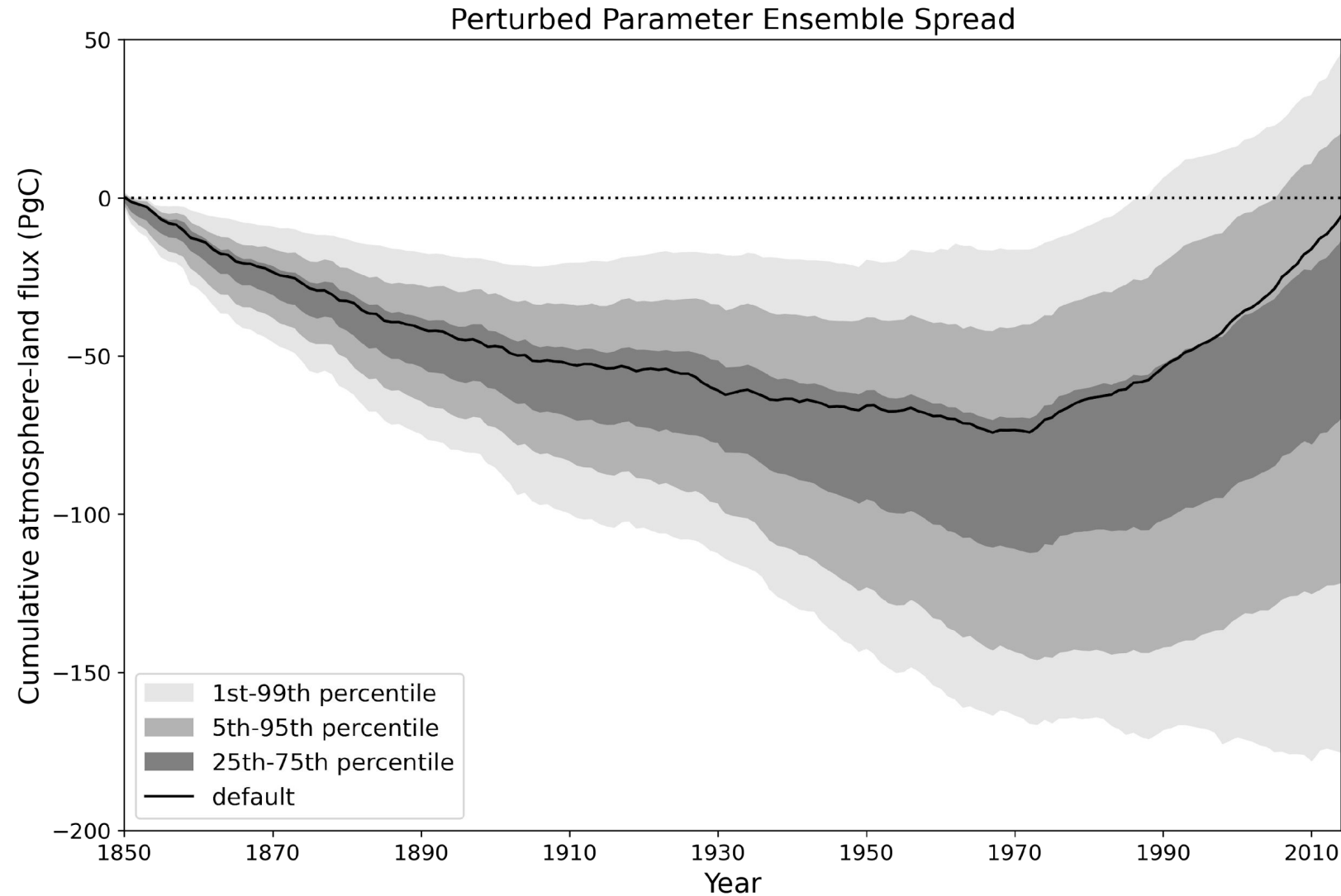


# How does LAI variance influence other variables?

global photosynthesis

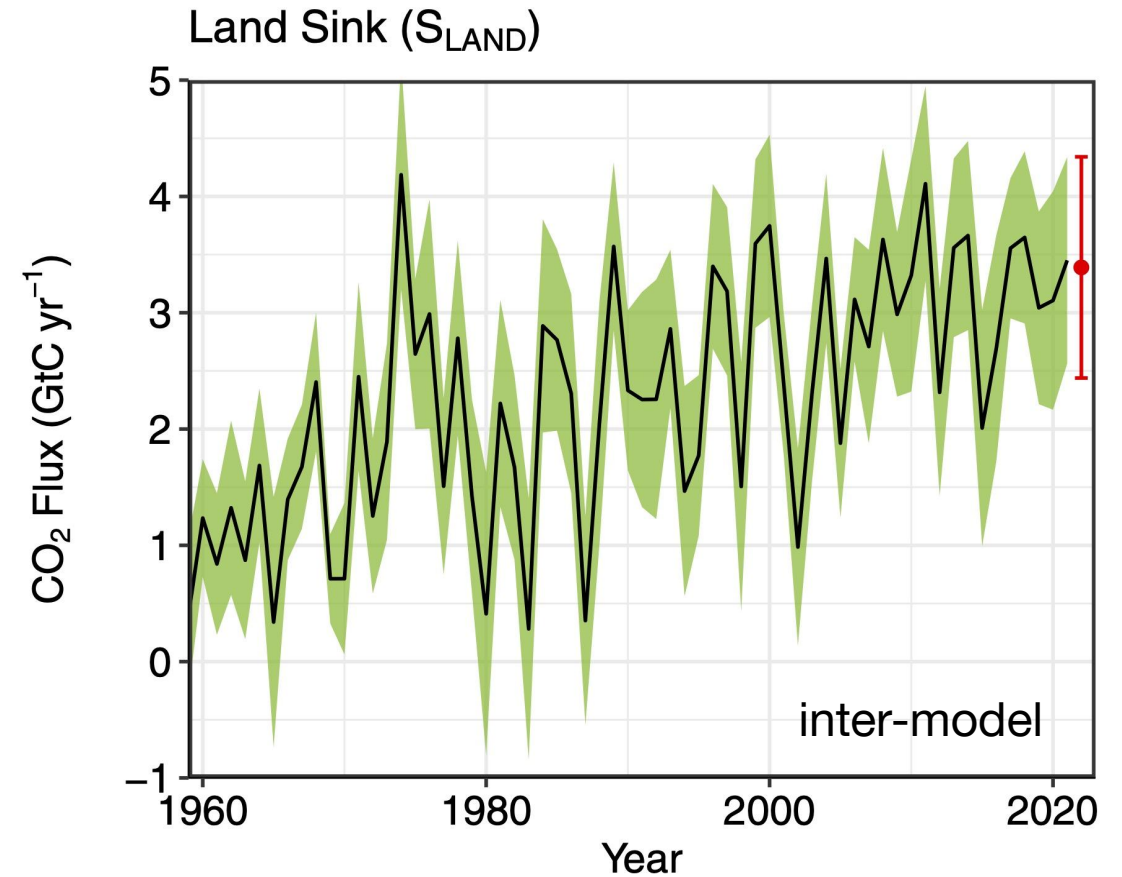
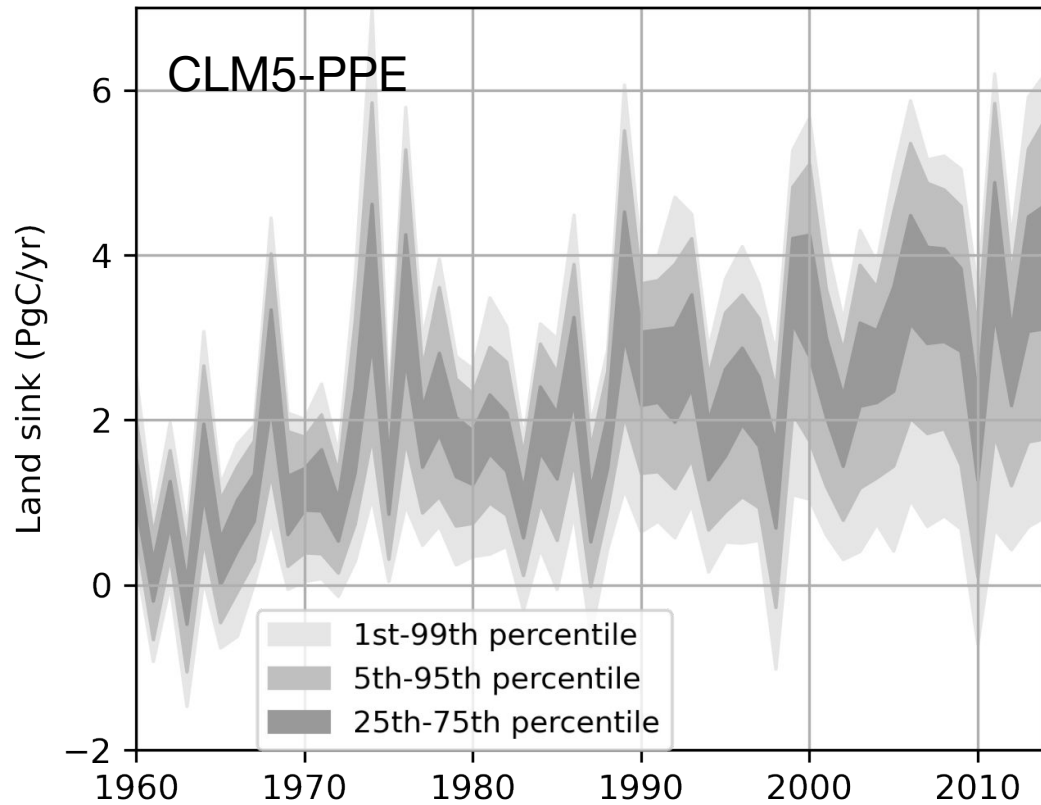


# PPE Spread in Carbon Fluxes



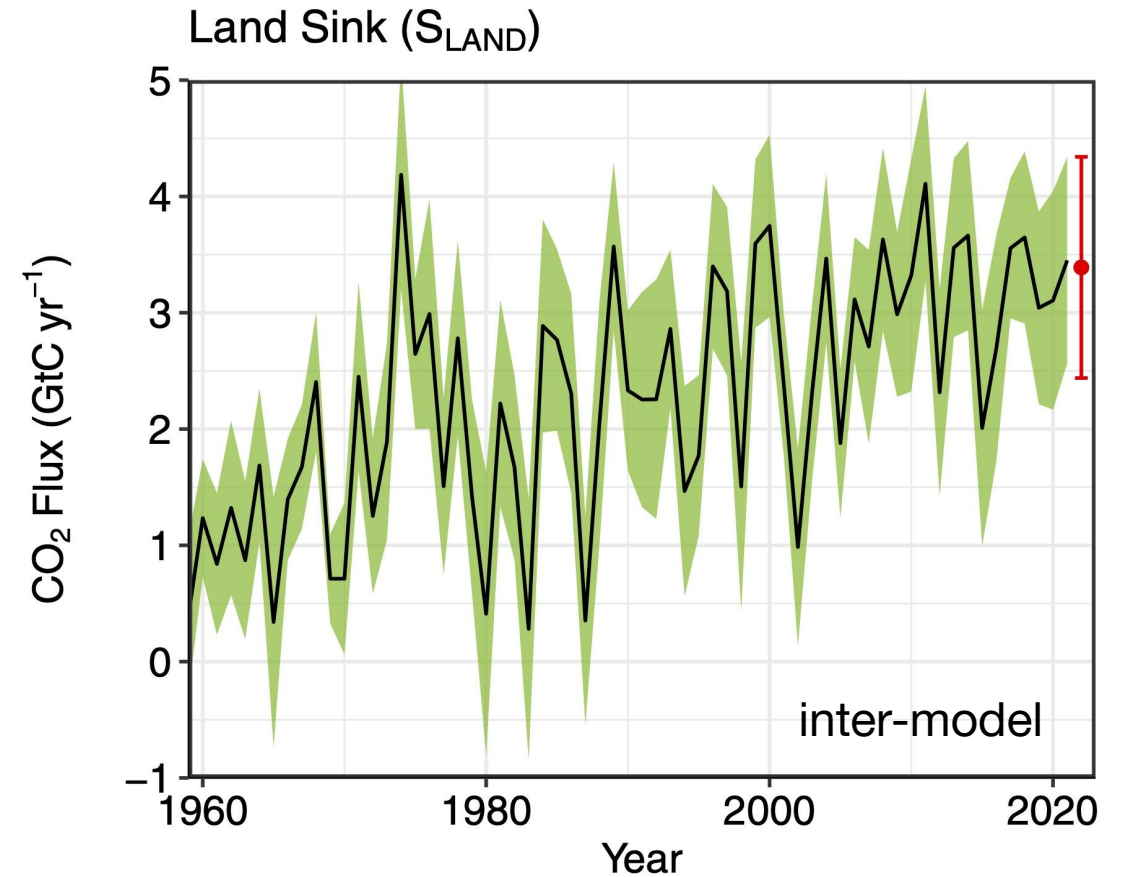
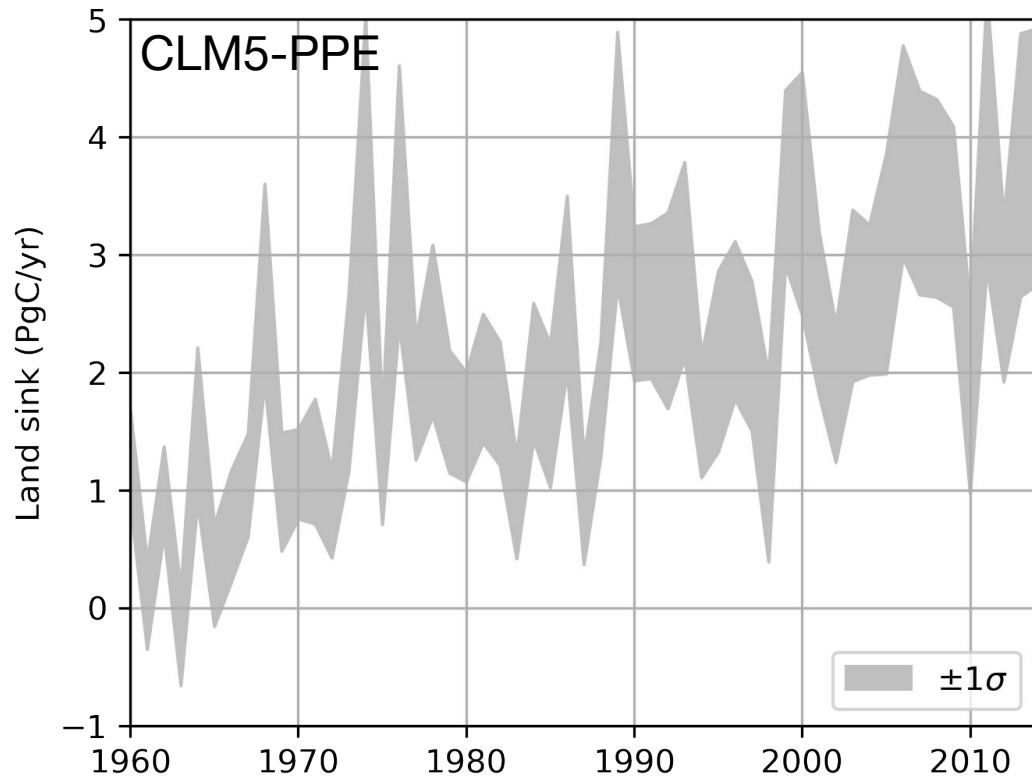
Parameter sampling generates ~200 PgC spread!

# PPE spread is larger than multi-model spread



Friedlingstein et al. Global Carbon Budget 2022

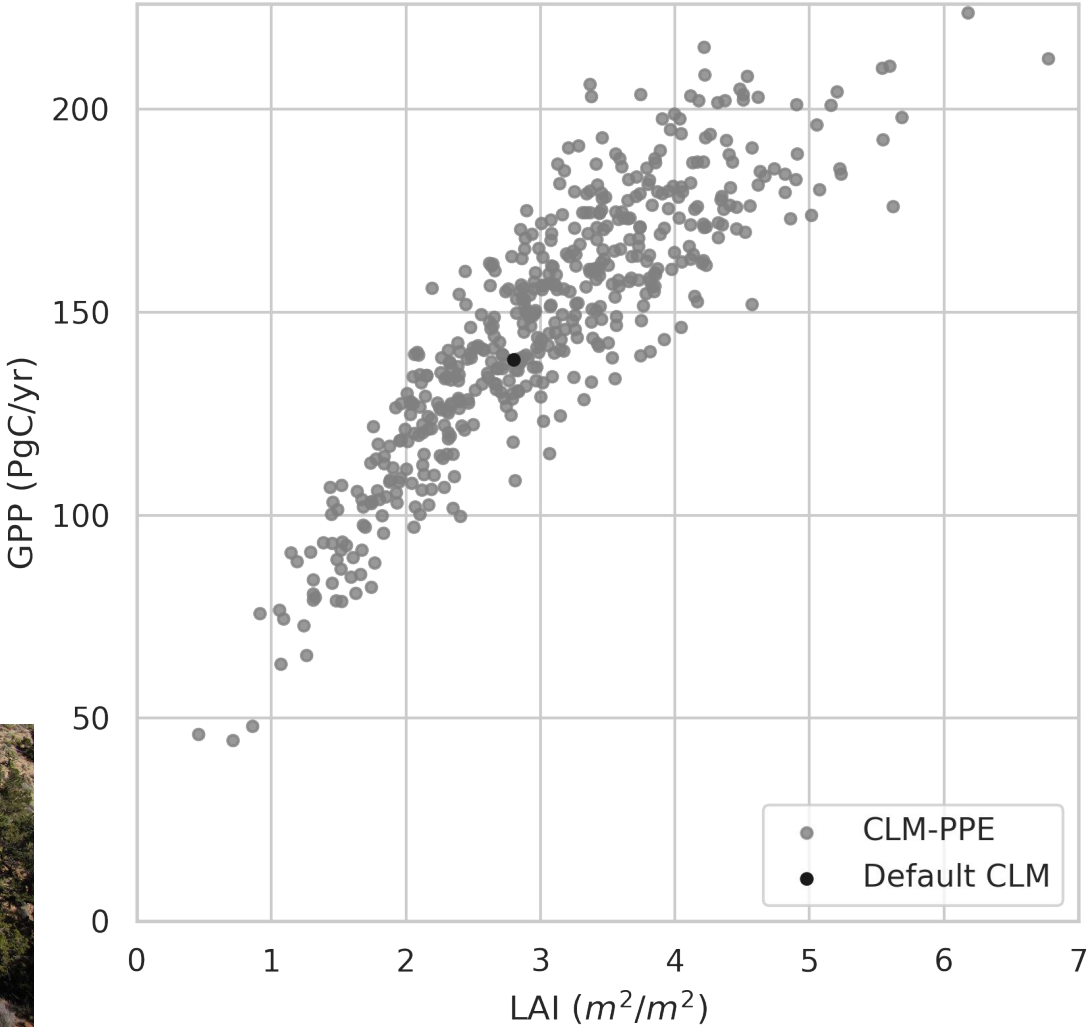
# PPE spread is larger than multi-model spread



Friedlingstein et al. Global Carbon Budget 2022

# Are all simulations equally plausible / likely?

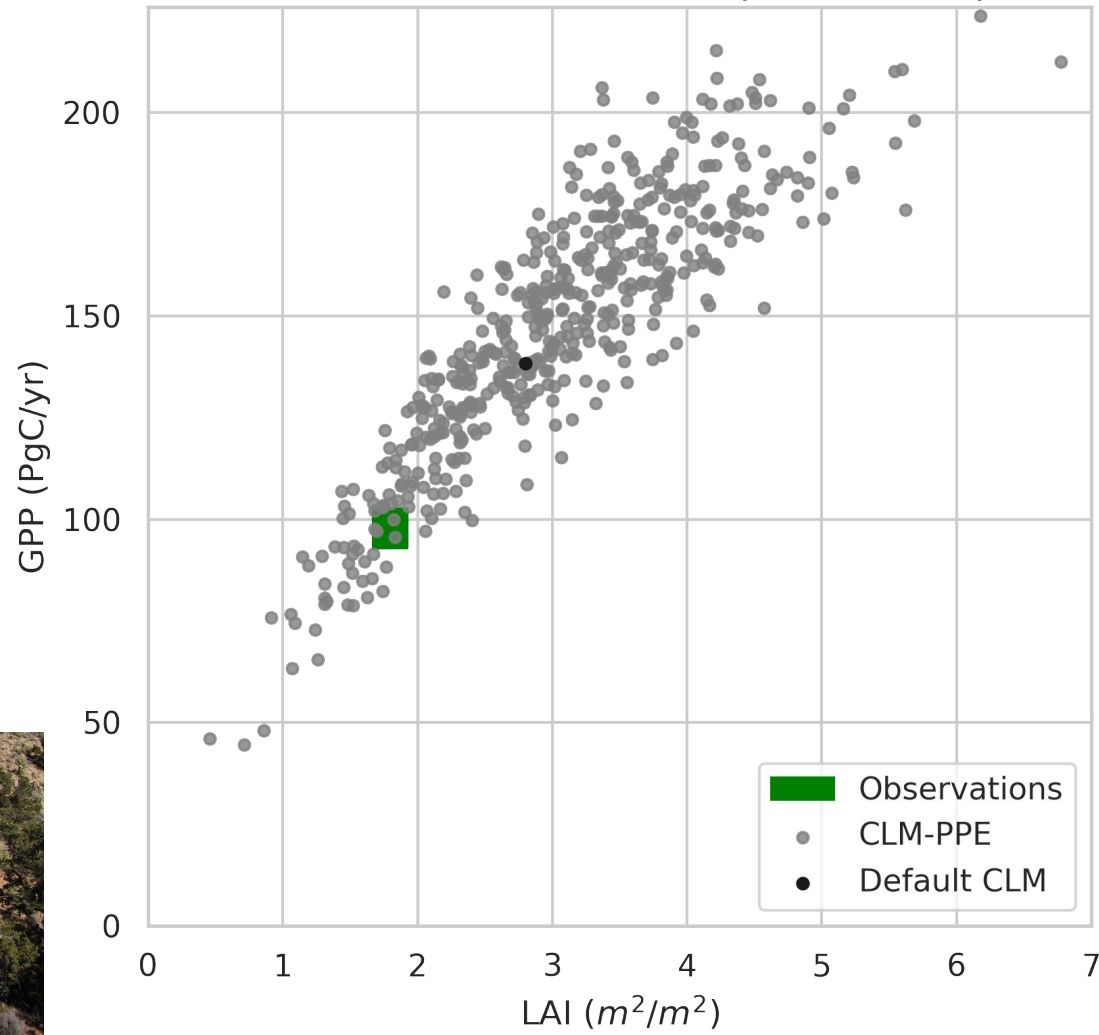
Global Annual Average (2000-2005)



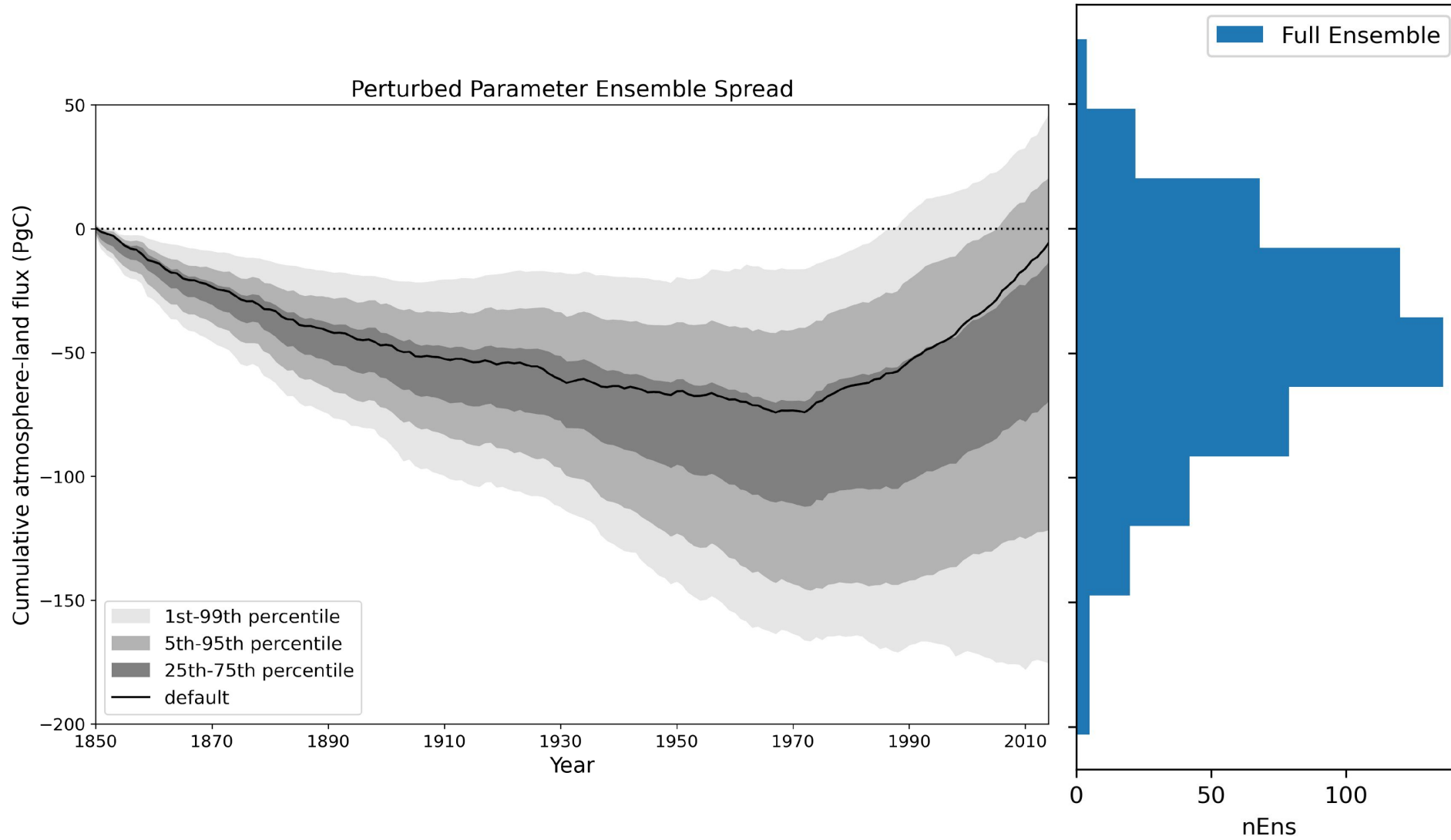


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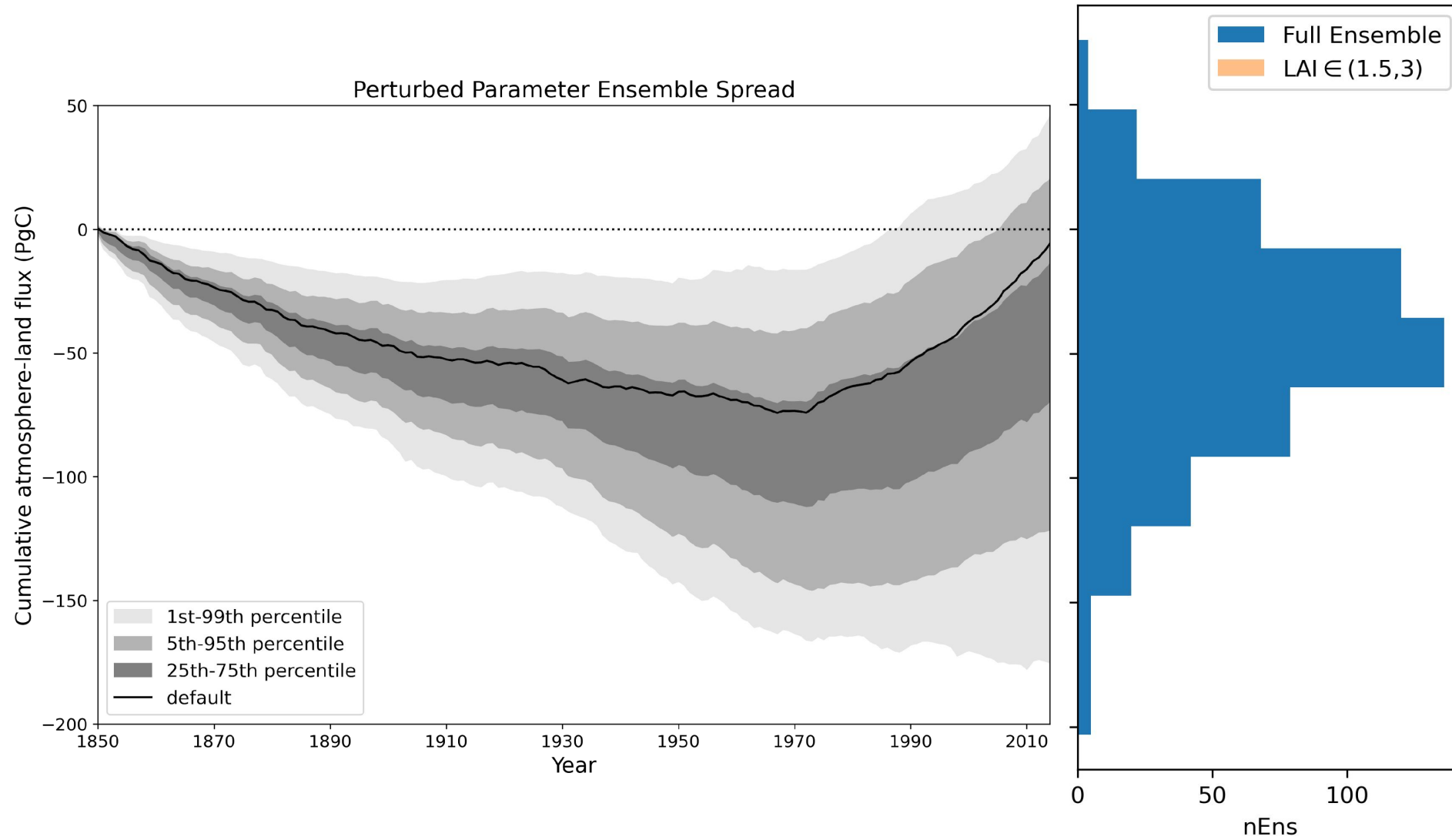
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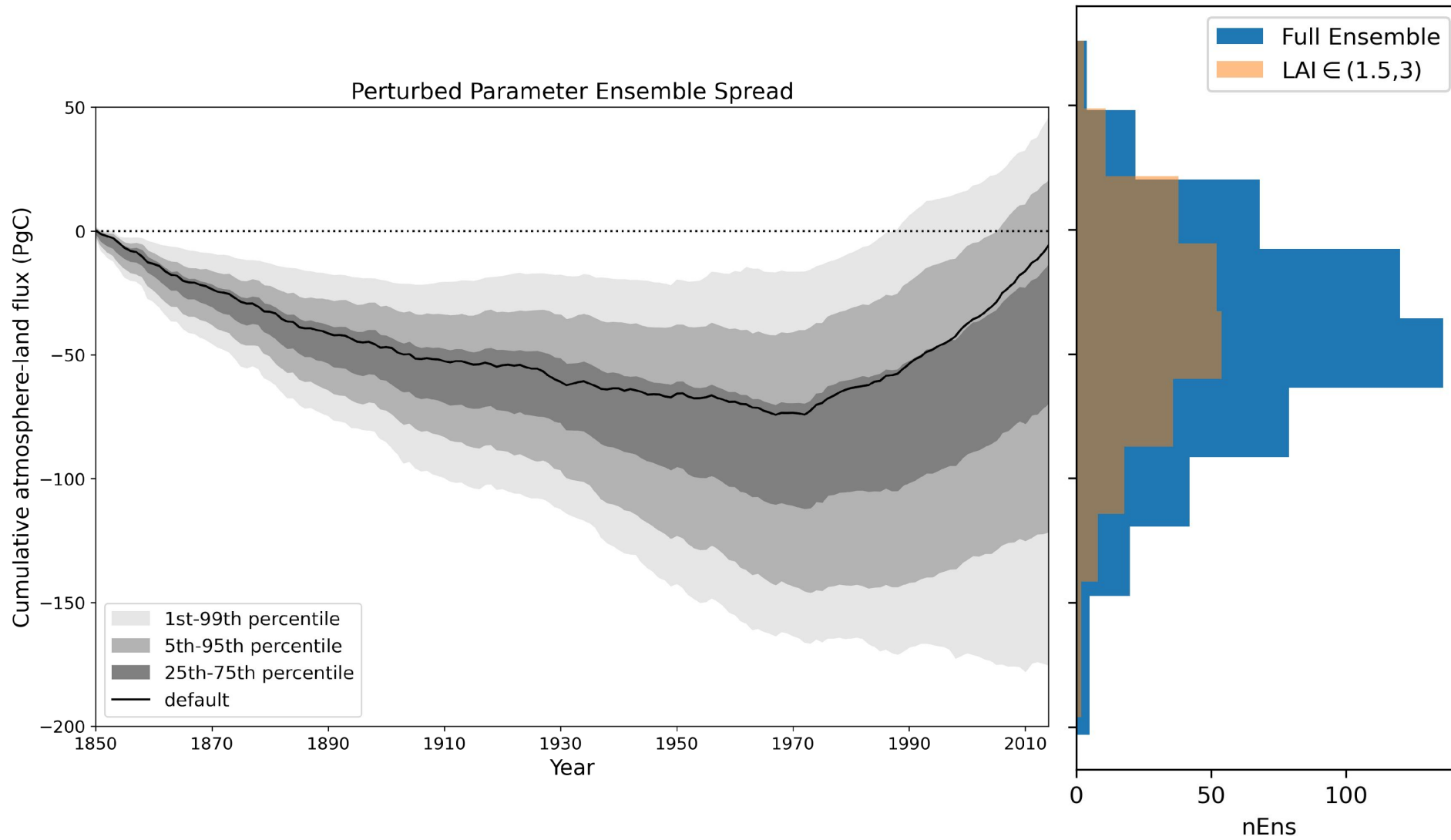
# PPE Spread in Carbon Fluxes



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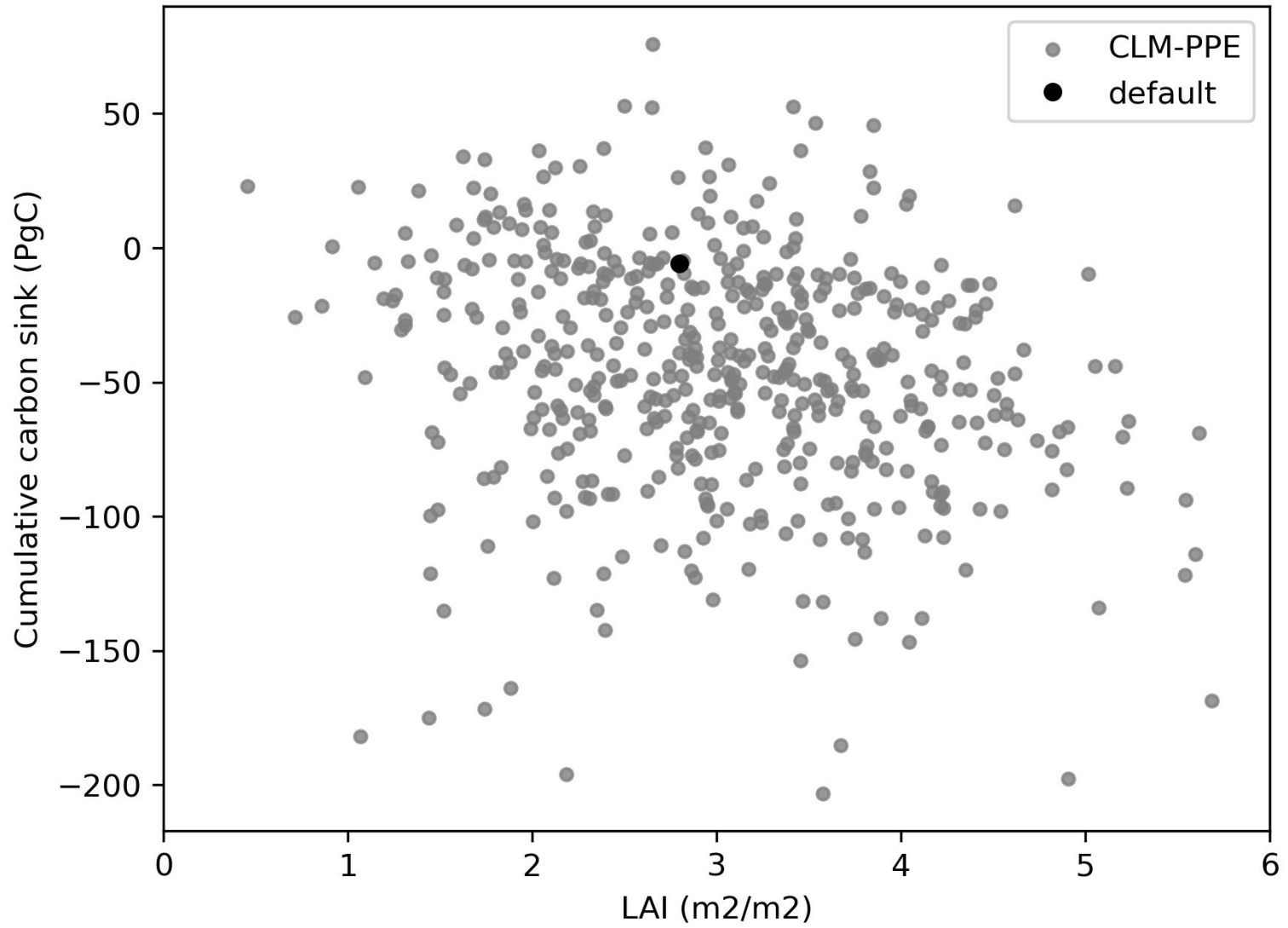


# PPE Spread in Carbon Fluxes

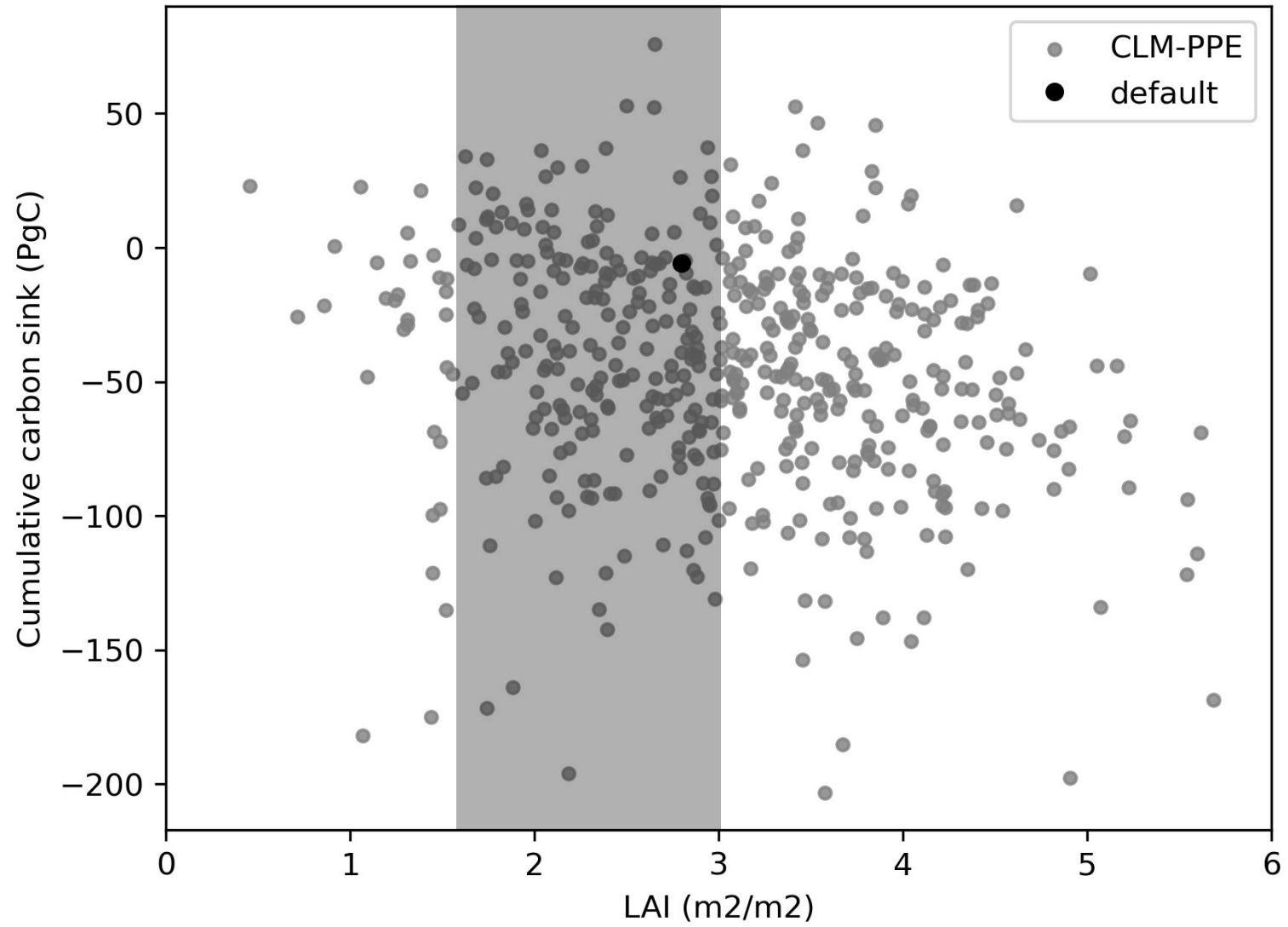


no reduction in spread  
despite ruling out  
>50% of ensemble

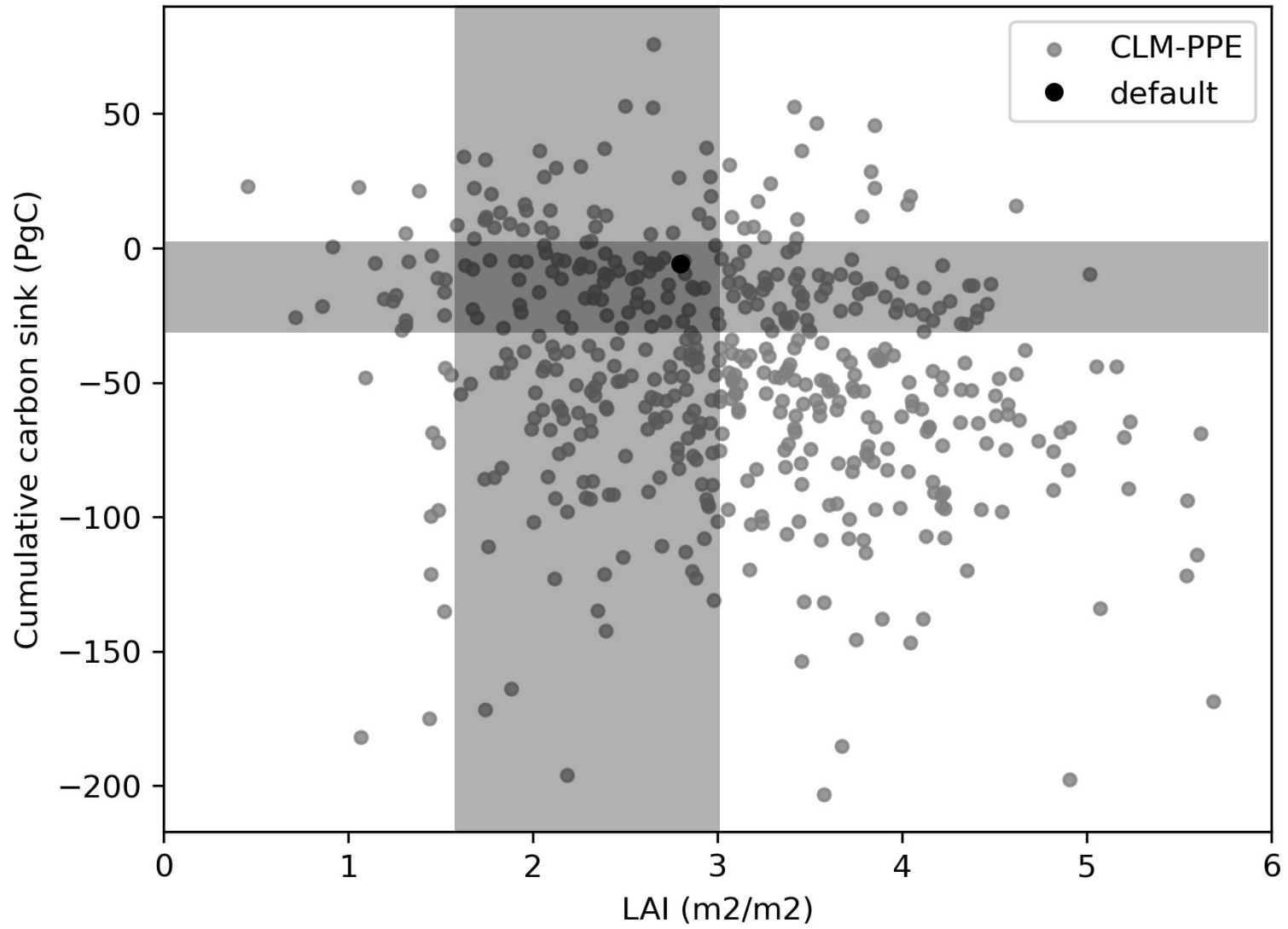
# Global annual LAI not a viable constraint on NBP



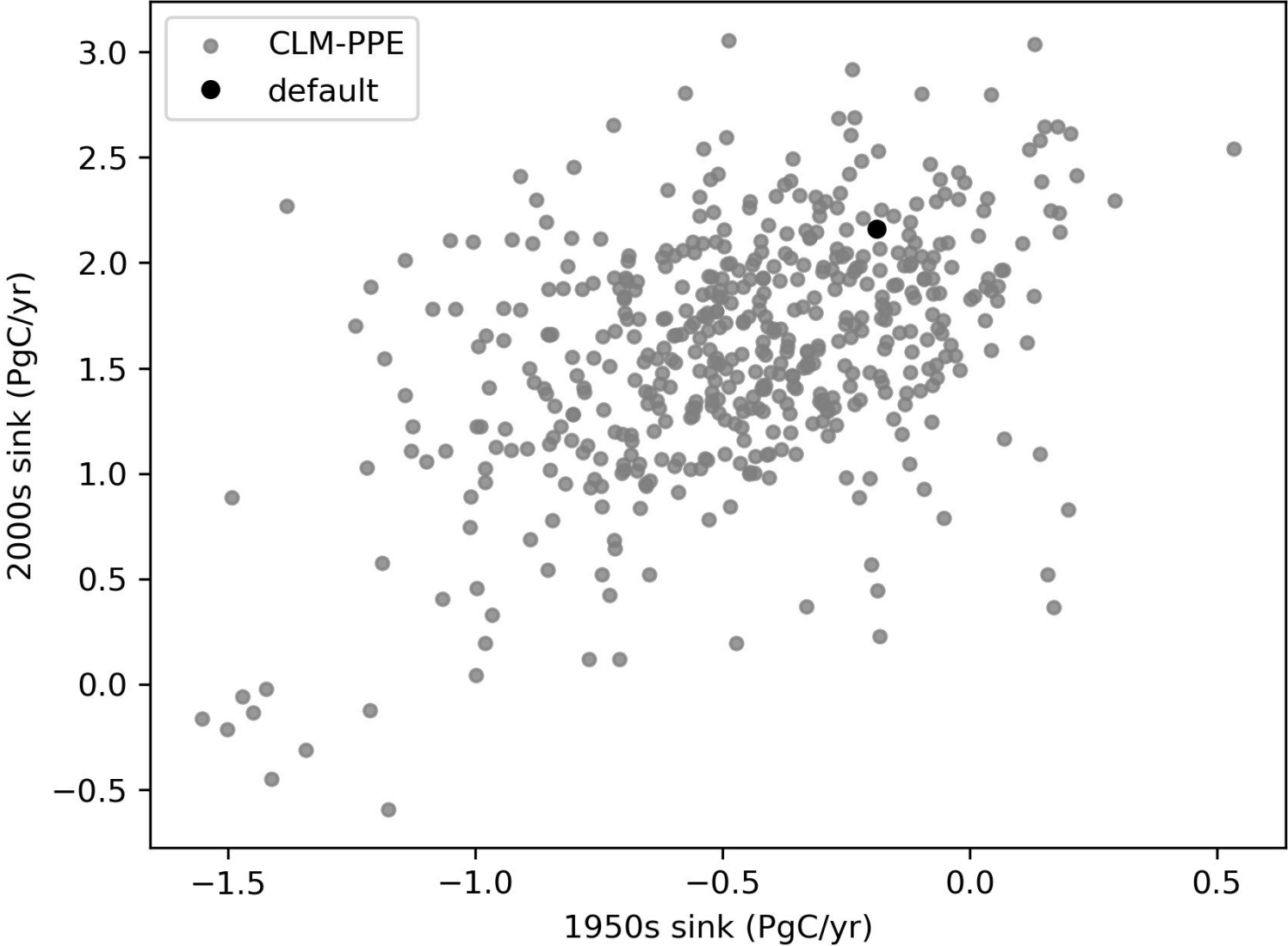
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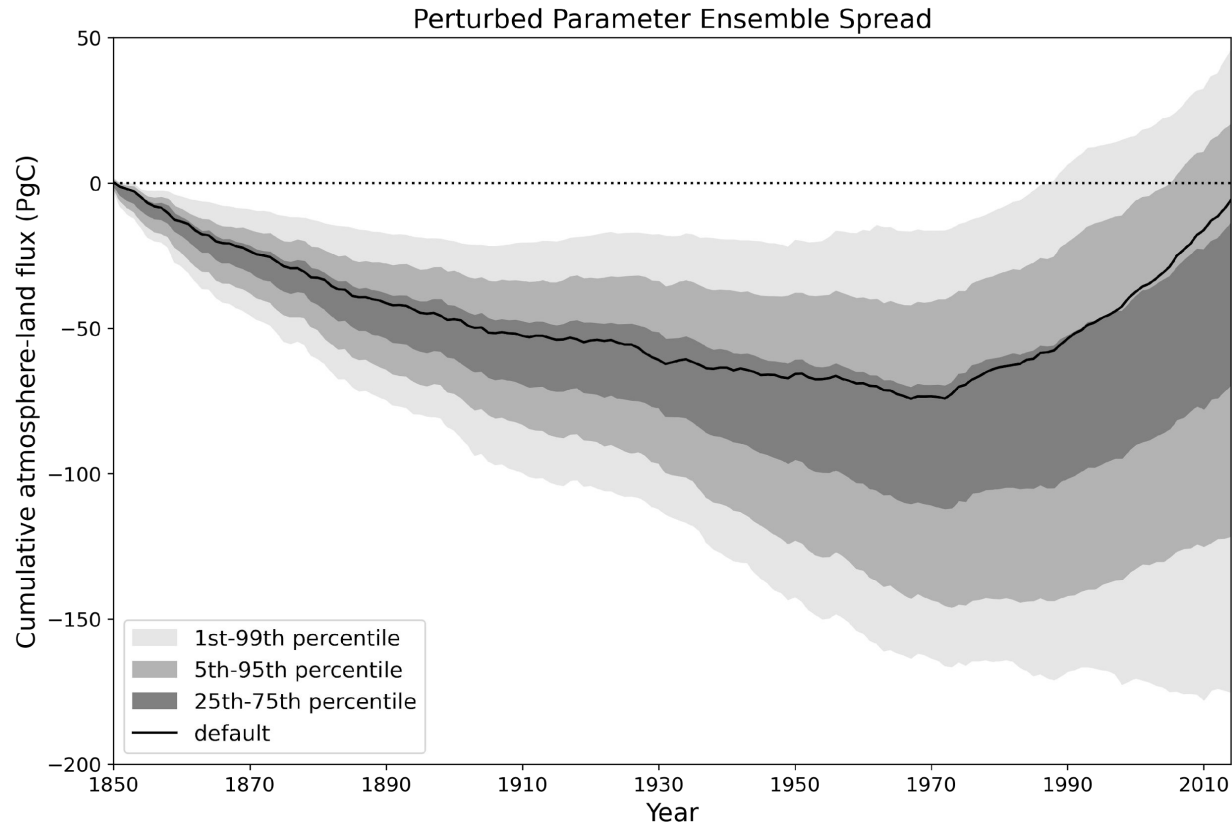


# Not looking promising...



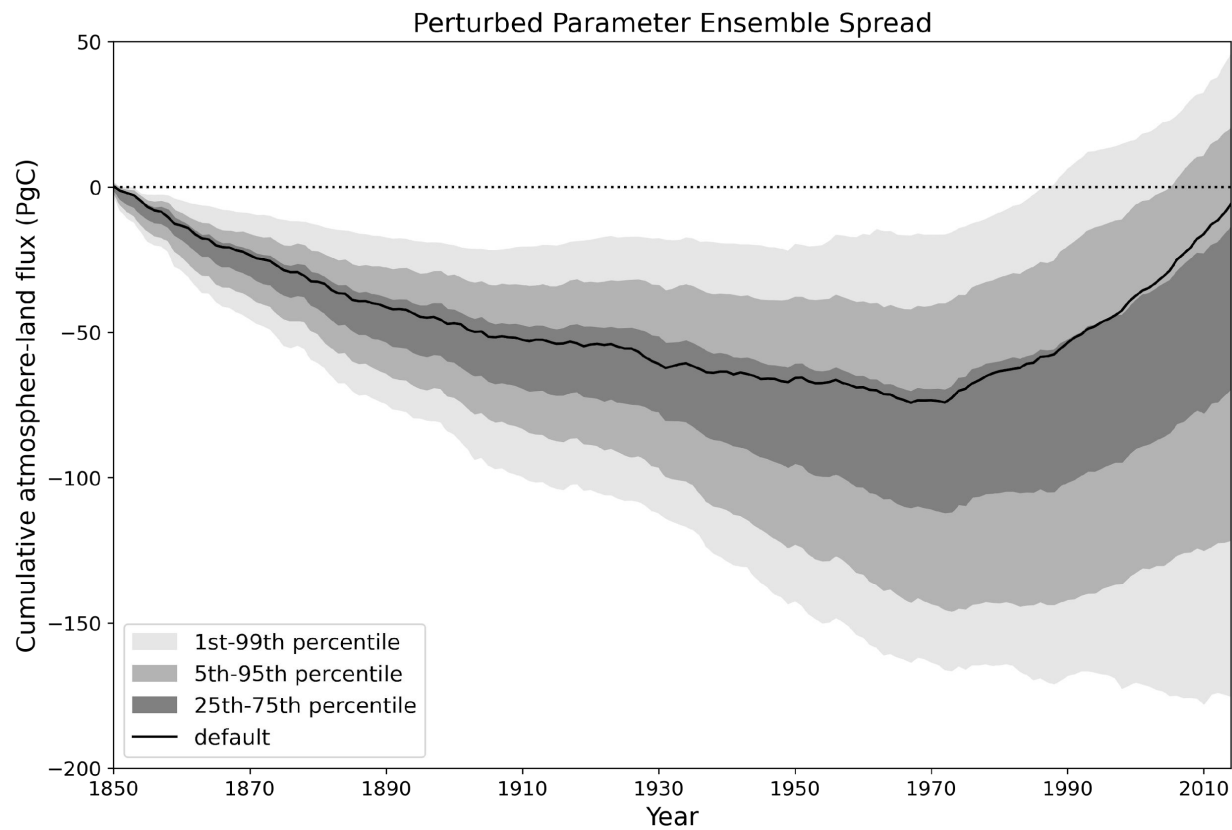


# Next step: extend our simulations



→ **2100**

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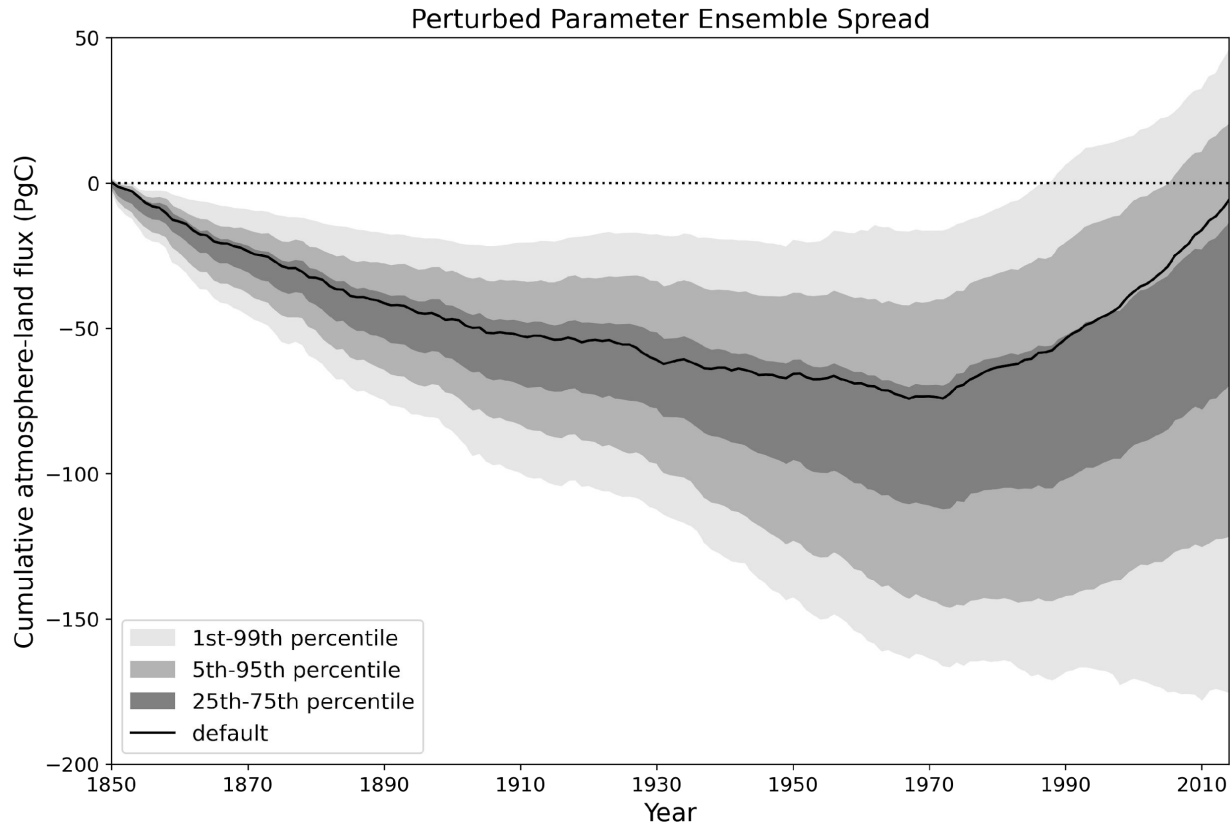


How large is the spread?



**2100**

# Next step: extend our simulations



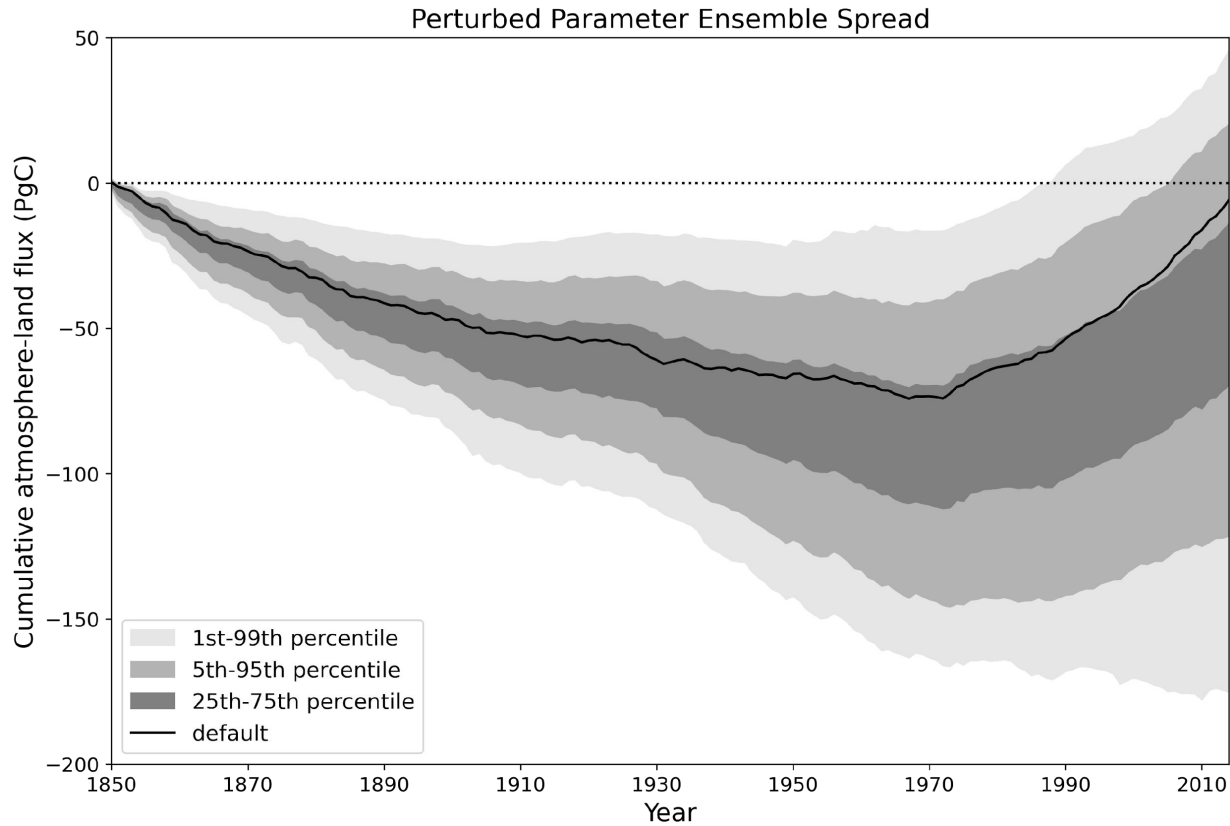
How large is the spread?

→ **2100**

What information could reduce uncertainty?

- interannual variability?
- trends?

# Next step: extend our simulations



How large is the spread?

→ 2100

What information could reduce uncertainty?

- interannual variability?
- trends?
- carbon use efficiency?
- carbon turnover times?

## Key points:

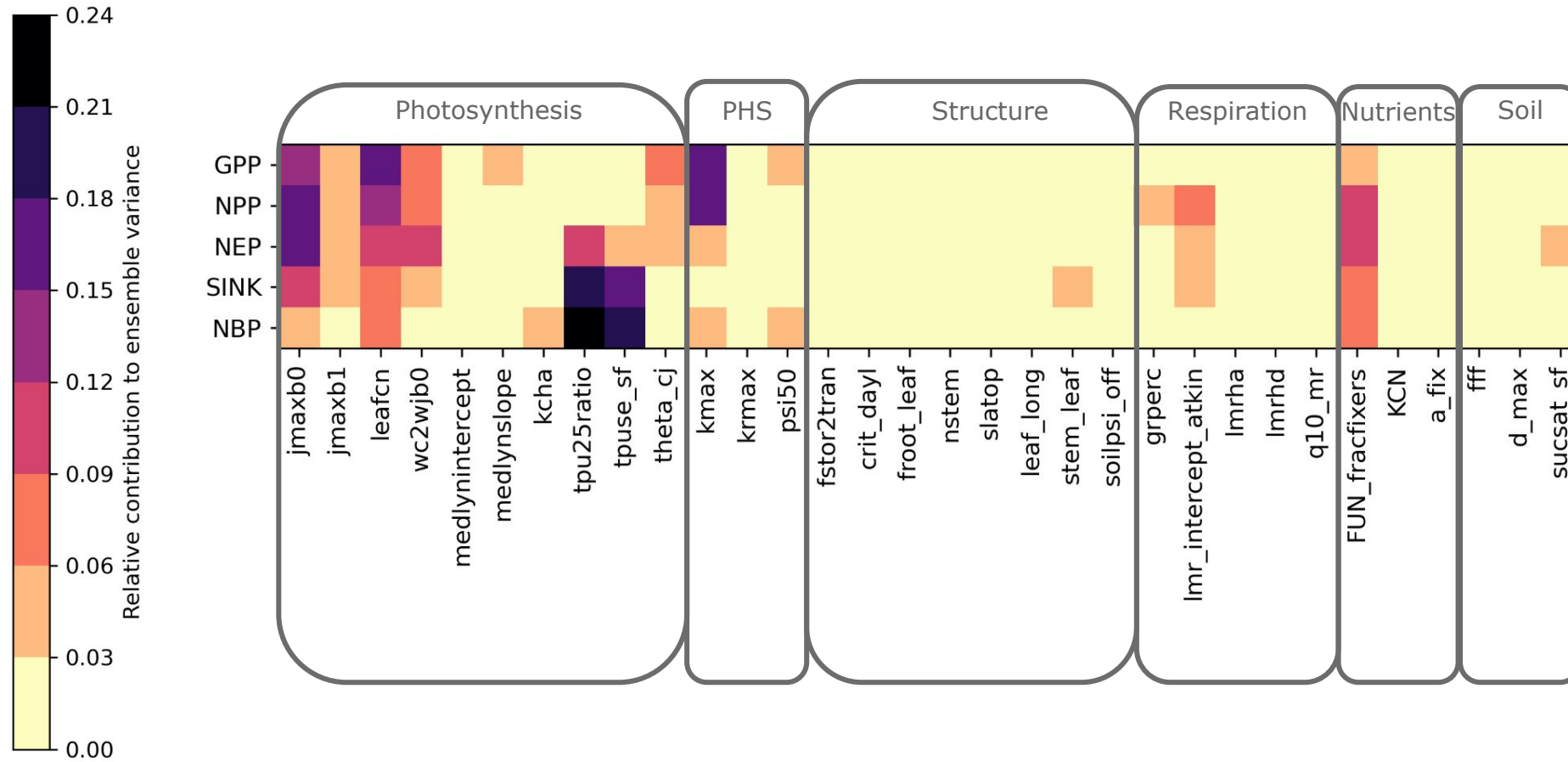
- CLM-PPE has generated useful infrastructure and two valuable datasets
- Parameter perturbations generated a wide range of Leaf Area Index
- With accompanying spread in carbon fluxes
- Global annual LAI not a meaningful constraint on the terrestrial carbon sink

## Next steps:

- Extend ensemble to 2100 (SSP1-2.6 & SSP3-7.0)
- Test a wider range of observational constraints
- Compare to CAM6+DART reanalysis (observational uncertainty)



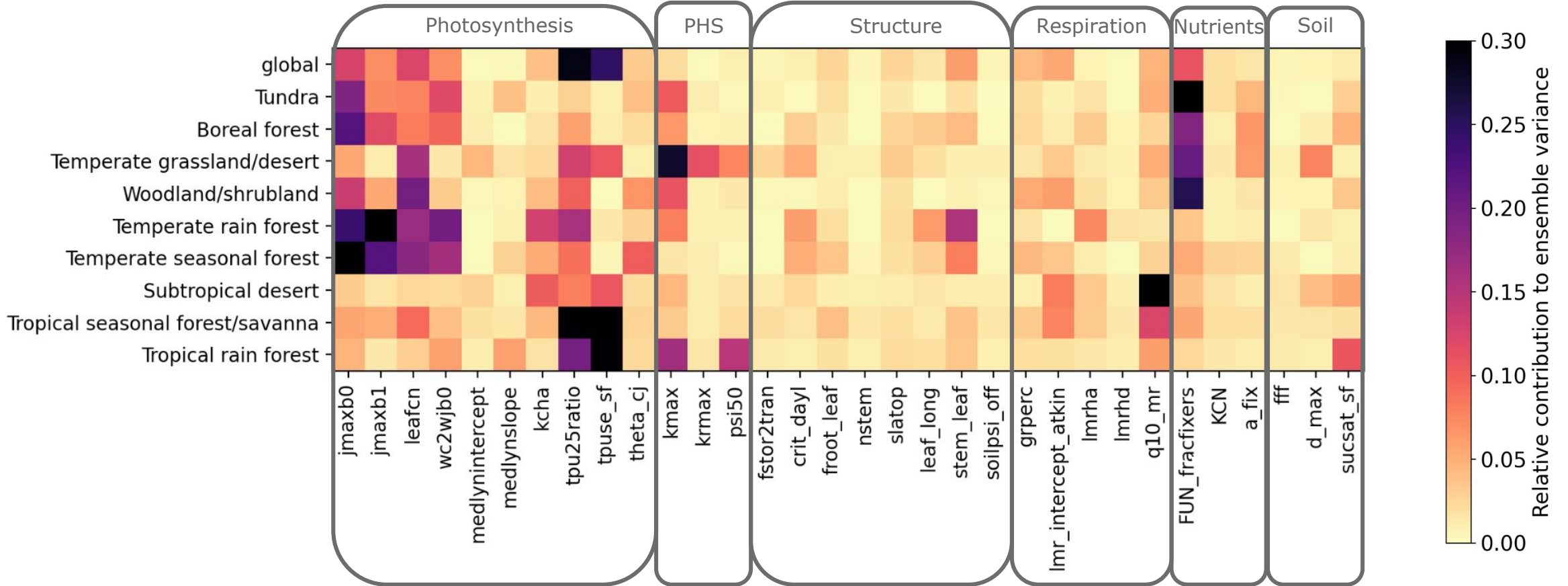
# Parameter sensitivity



Fourier amplitude sensitivity testing

# Parameter sensitivity

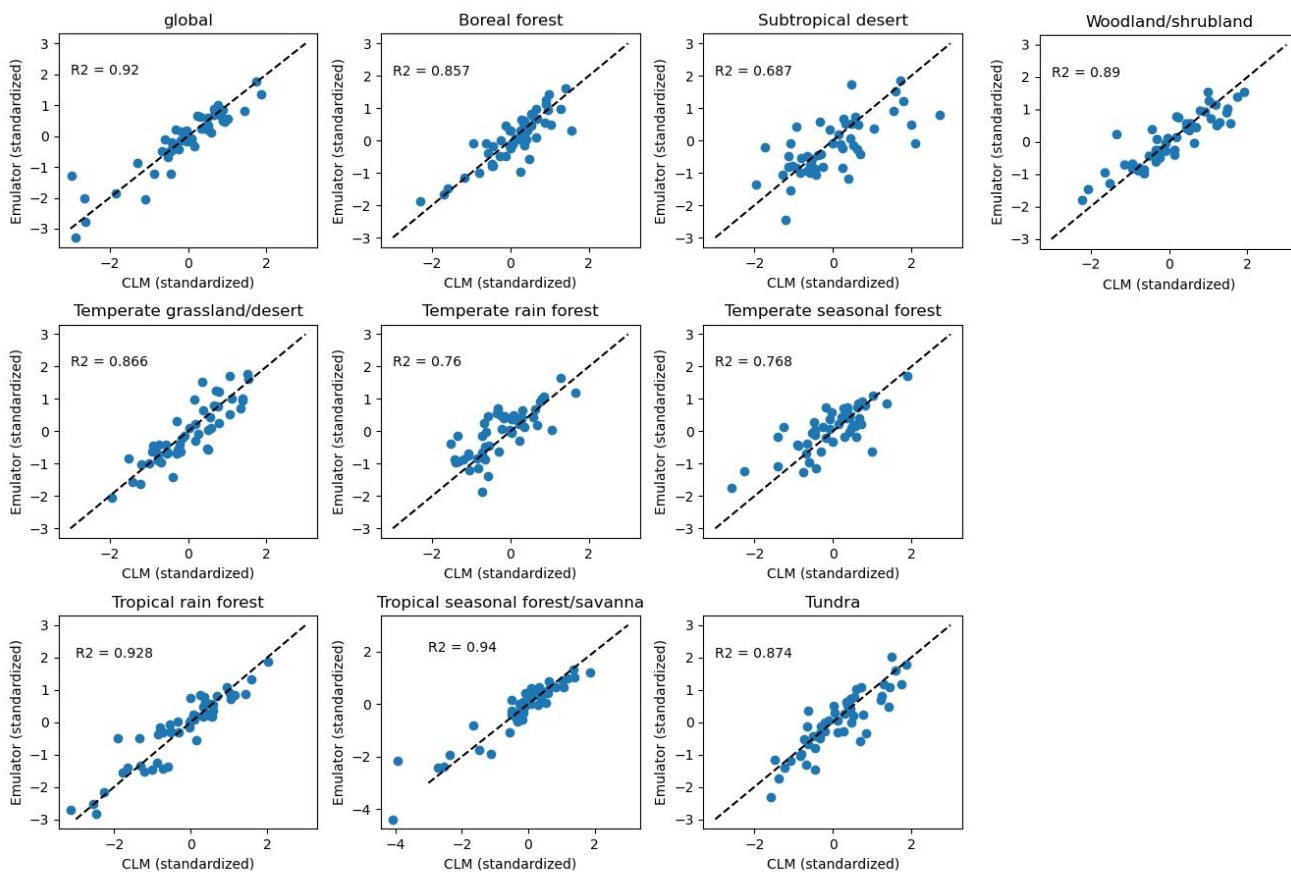
Land Sink: GPP-AR-HR-FIRE





# Gaussian process emulator validation

## Land sink (biome)



## Components of land sink (global)

