A New Coupled PPE Under Transient Forcing to Quantify Drivers of ET

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Land Model Working Group Meeting

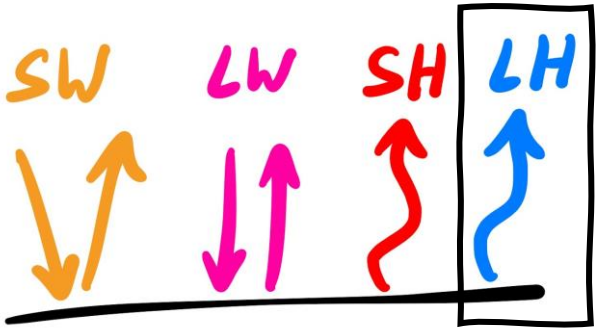
02.25.25

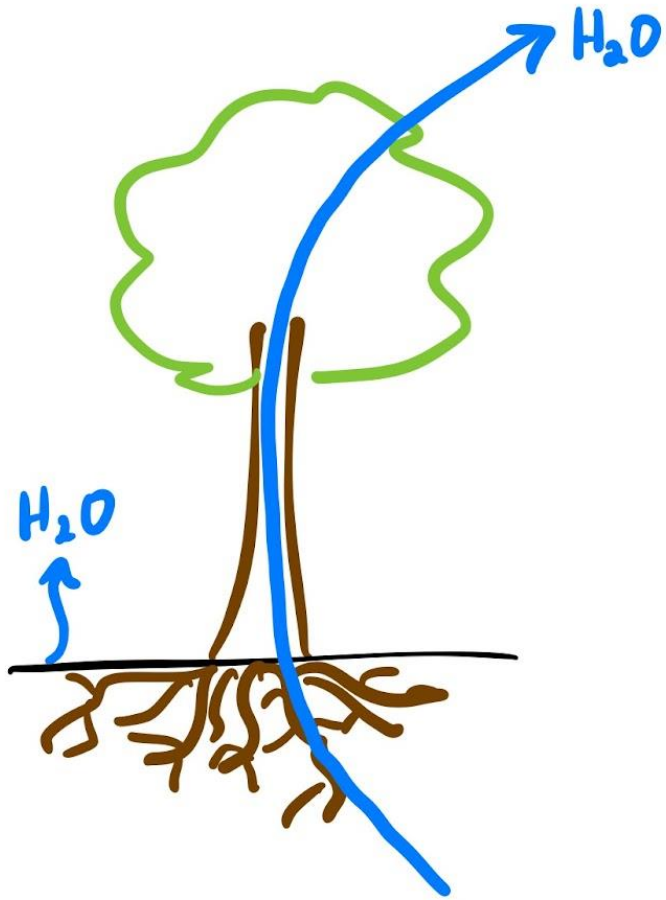
Surface Energy Balance

Evapotranspiration (ET) depends on **physical** and **biological** processes *across many scales*

Soil Hydrology &
Large-Scale Vegetation

Surface Energy Balance





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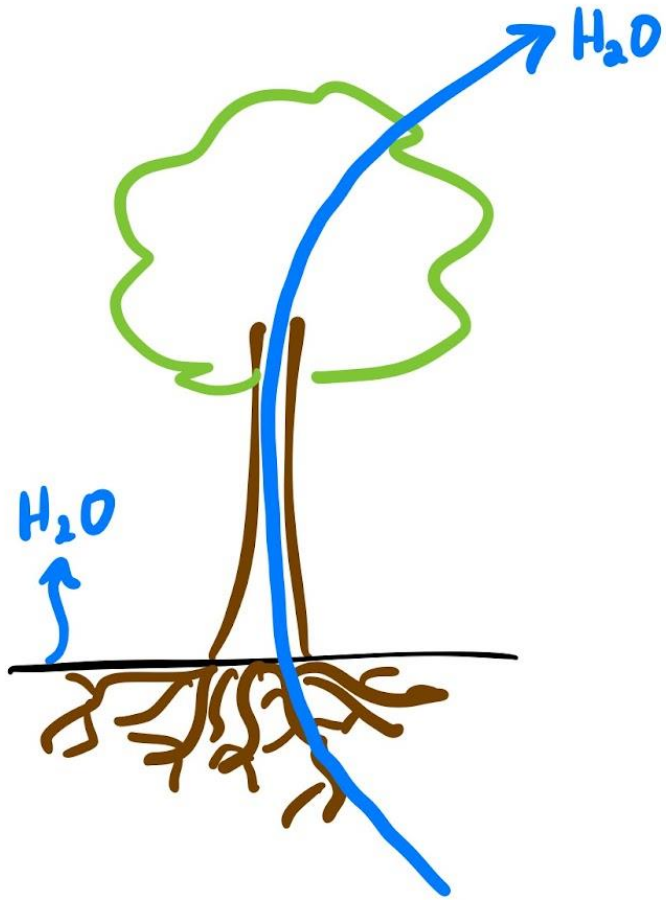
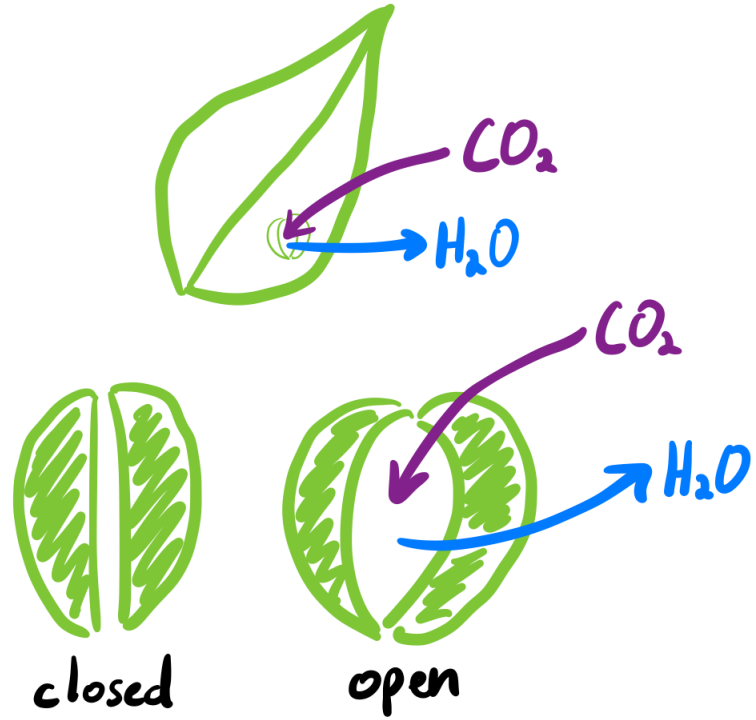
Soil Hydrology & Large-Scale Vegetation



Stomatal Processes



Evapotranspiration (ET) depends on **physical** and **biological** processes *across many scales*

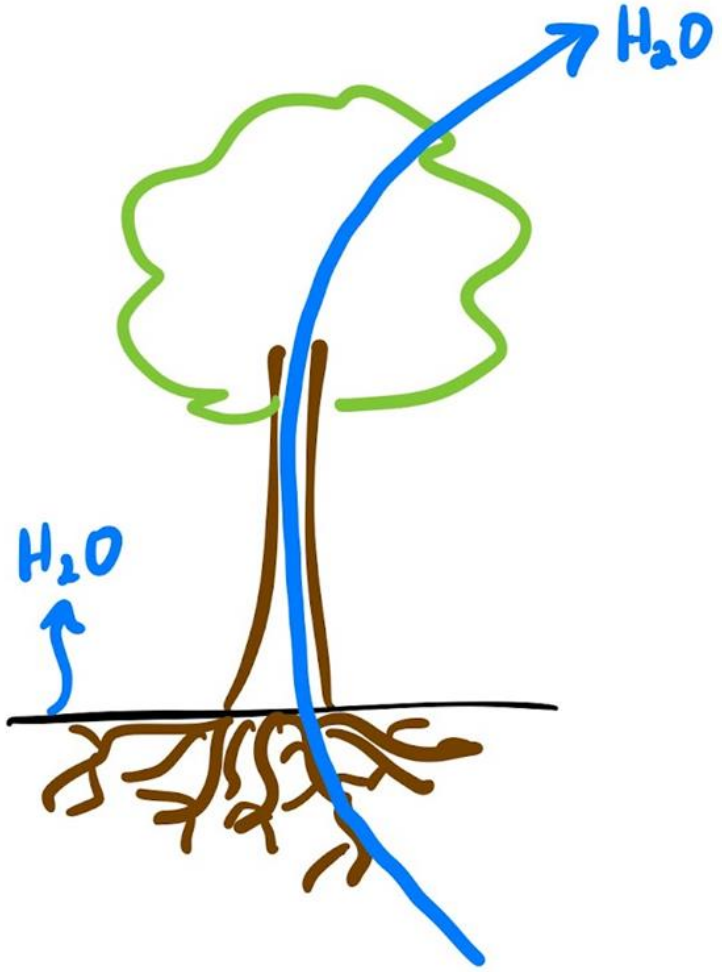
Why do we care?

→ returns 60% of terrestrial rainfall

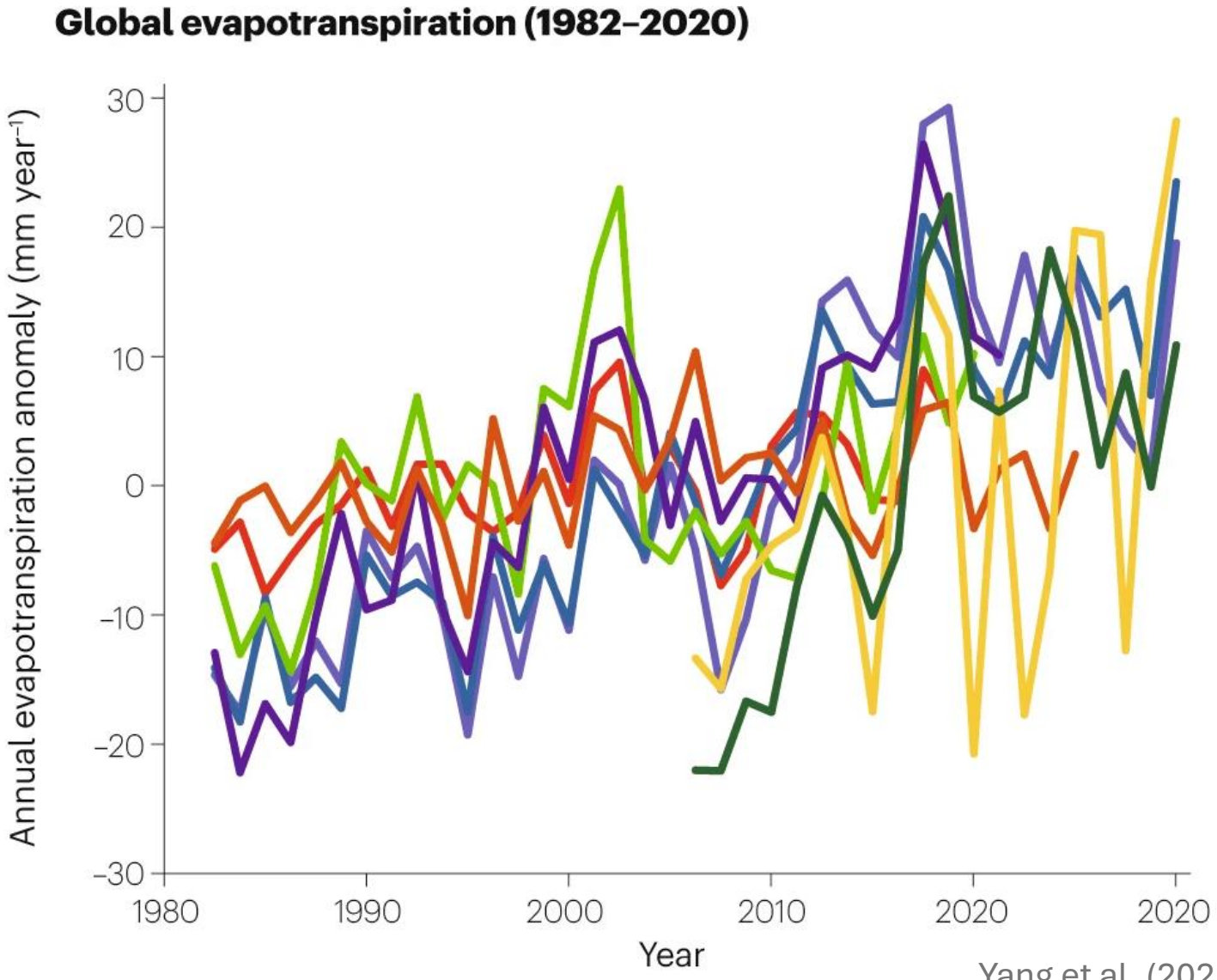
Trenberth (2007)

→ water availability (e.g., droughts)

→ ecosystem functioning



Observed global ET increased since 1980



Dataset	Model
BESS	Penman-Monteith (PM)
CAMELE	optimal ensemble
GLEAM	Priestley-Taylor (PT)
MTE	observations + model tree ensemble
P-LSH	PM
PML-AVHRR	PM
PML-MODIS	PM
MOD16	PM

mostly **approaches**

Yang et al. (2023)

No consensus on main drivers of ET trend

- Vegetation greening drives (+) trend Forzieri et al. (2020)
- Soil moisture limitation drives (-) trend with El Niño Jung et al. (2010) Miralles et al. (2014)
- Stomatal closure drives (-) trend Xiao et al. (2020)
- Others: **temperature (+/-)**, **plant WUE (-)**, **Pacific SSTs (+/-)** …

Wang et al. (2021) Mankin et al. (2019) Dong & Dai (2017)

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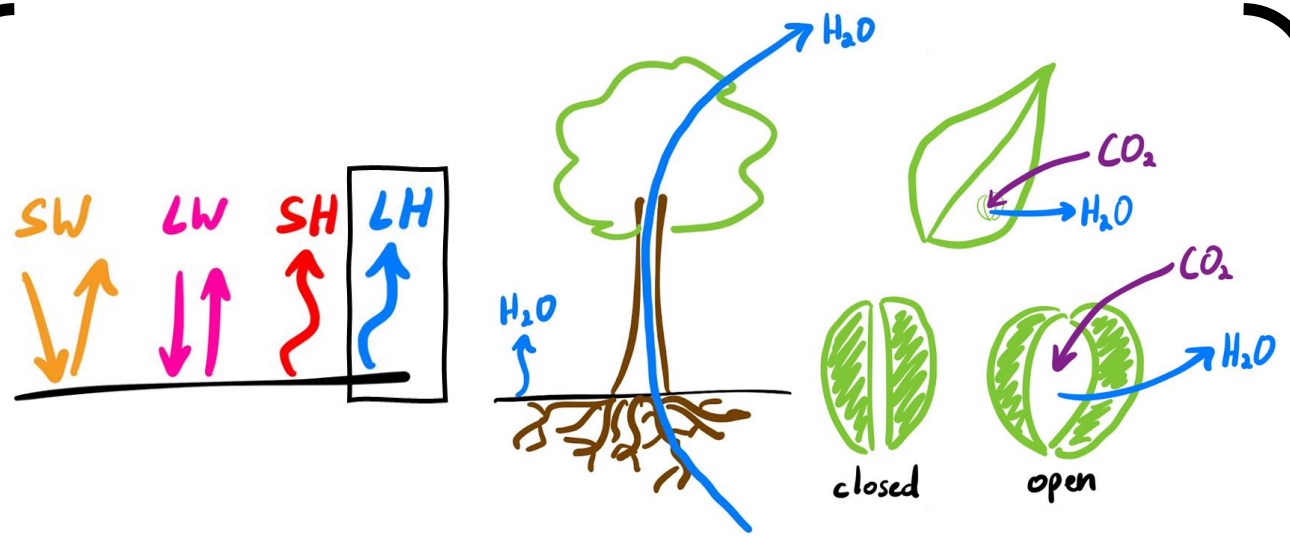
It's complicated!

$$ET = f\left(\right.$$

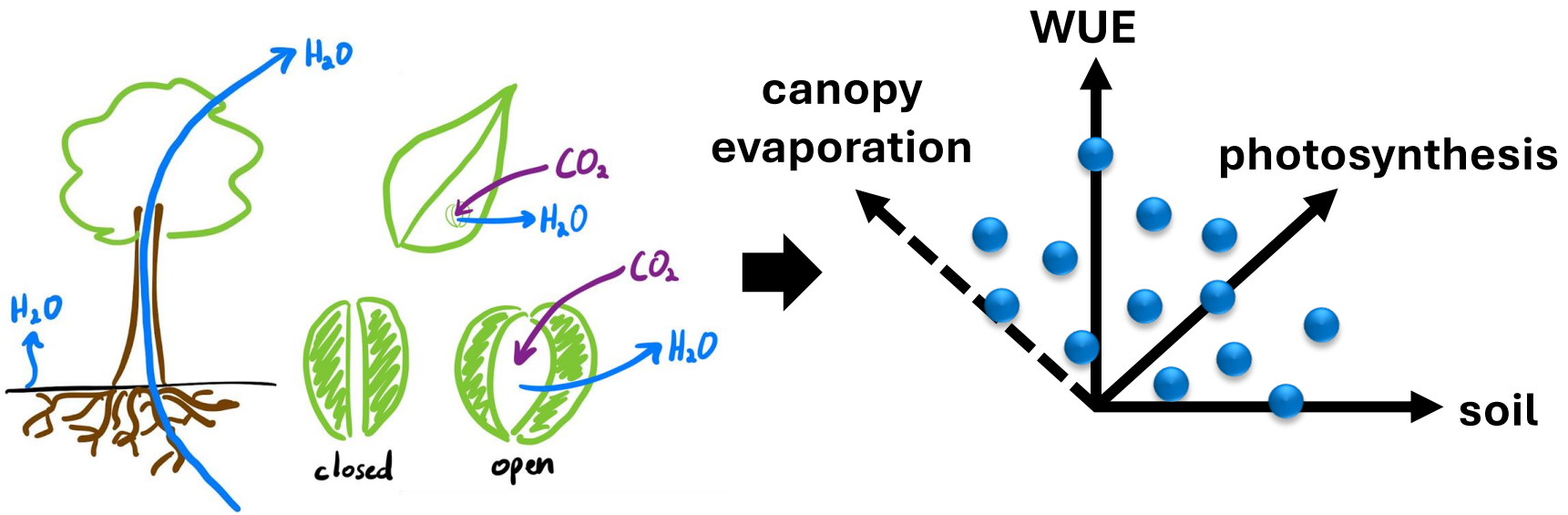


$$\left.\right)$$

We can gain insight with a coupled PPE

Let's enter model world! (self-consistent, can isolate processes)

1. Make different assumptions about land surface functioning



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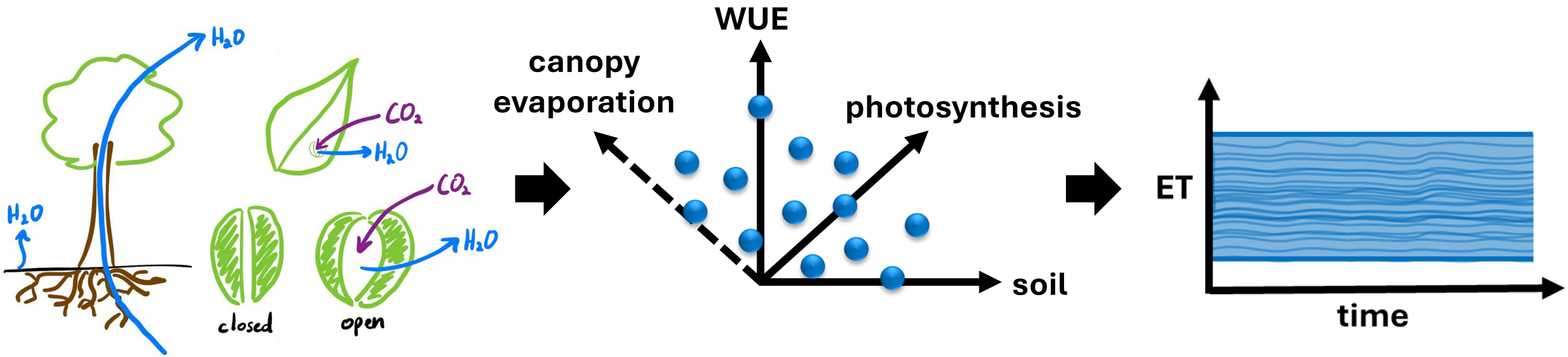
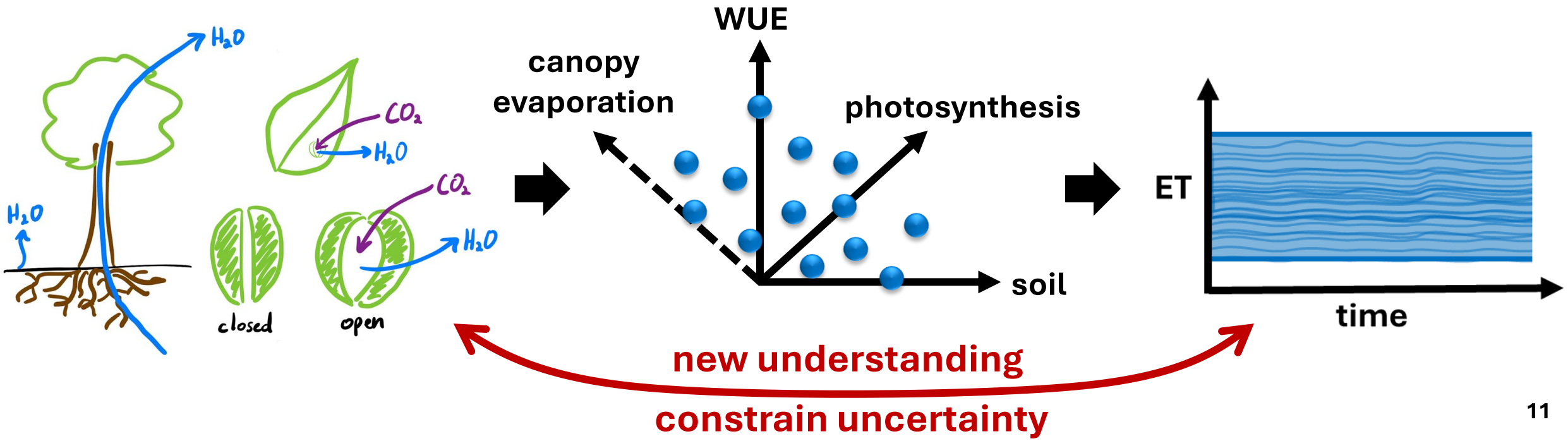


We can gain insight with a coupled PPE

Let's enter model world! (self-consistent, can isolate processes)

1. Make different assumptions about land surface functioning
2. Quantify response of ET
3. Identify key processes that drive ET change



Overview of planned experimental design

- CESM2 with perturbed CLM parameters
  - Coupled land-atmosphere
  - AMIP-style prescribed SST fields
- One-at-a-time low/high perturbations of ~18 parameters
- Historical period (1950-2015)
- Future period (2015-2100)
- Constrain ET spread with observational benchmarks, tentatively
- Planning to run identical land-only simulations as well

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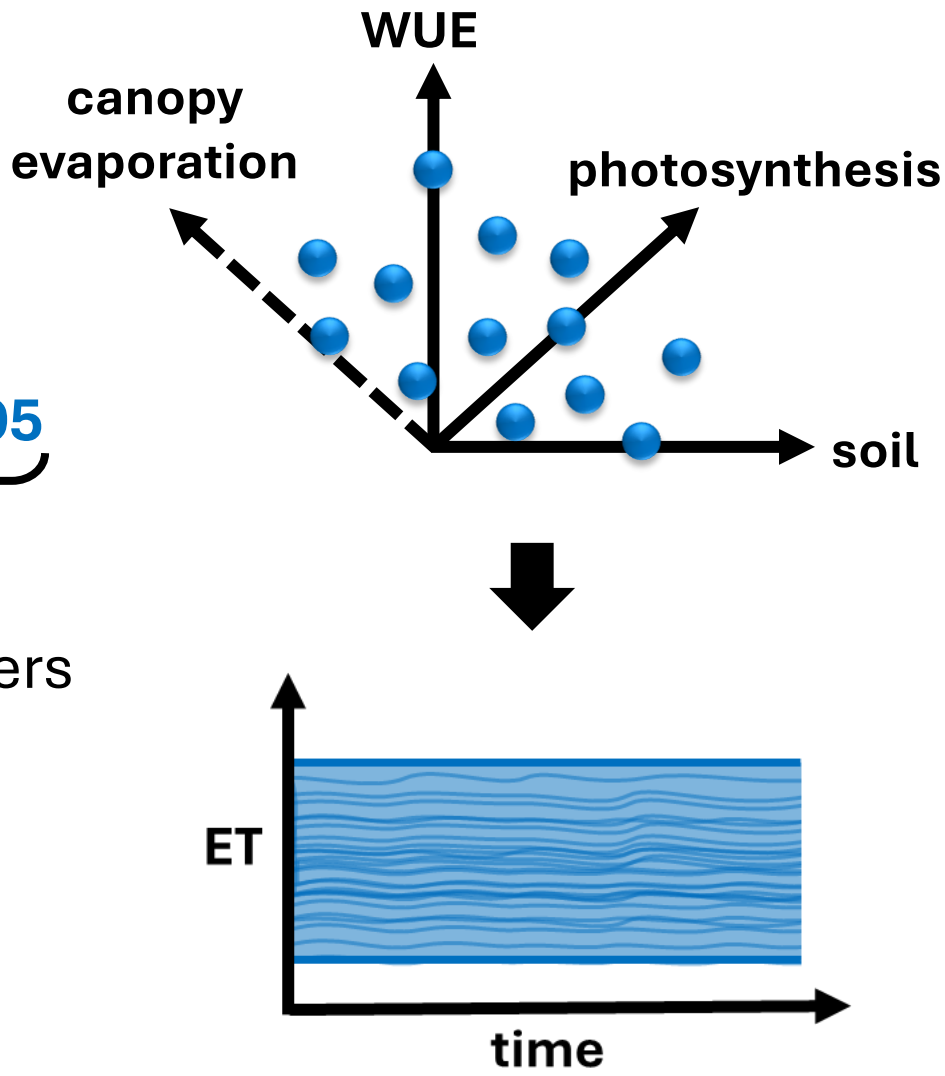
What parameters should we perturb?

- **Goal:** generate spread in ET
- Leverage the CLM PPEs Kennedy et al. (2024)
  - Uncoupled, land-only simulations
  - Perturbed ~200 parameters one-at-a-time
  - Four forcings: **C285**, **C867**, **AF1855**, **AF2095**

    CO_2 | atmosphere
  - Additional transient PPE with fewer members

    Linnia Hawkins



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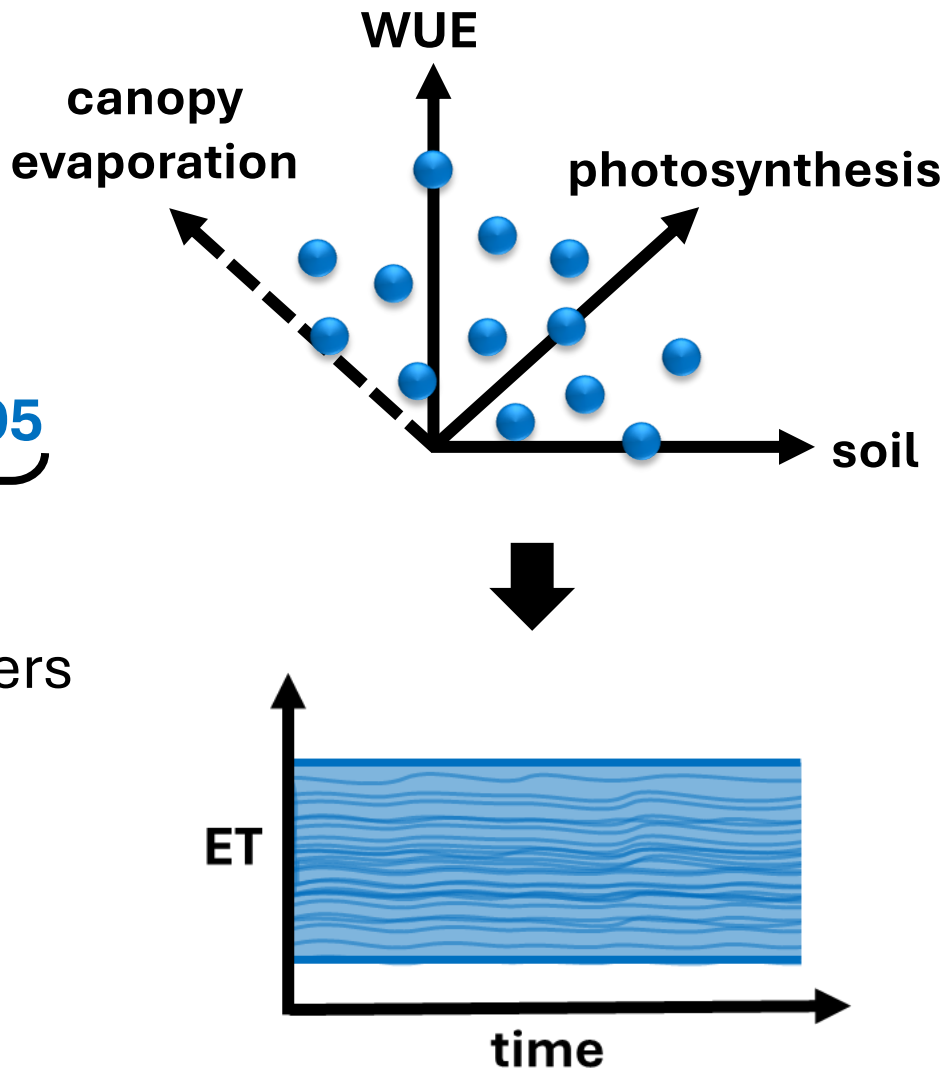
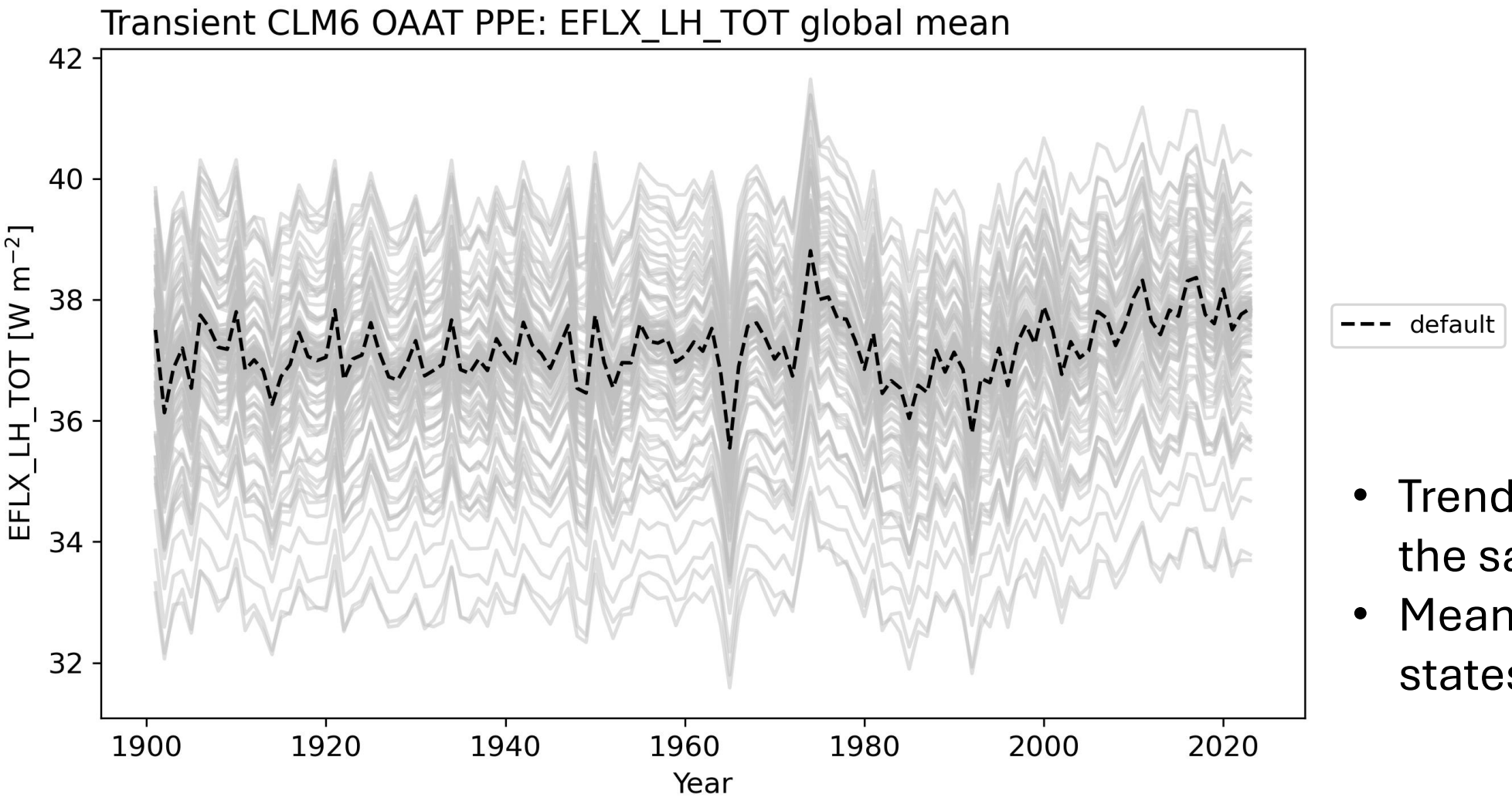
    - C285, C867: CO_2
    - AF1855, AF2095: atmosphere
  - Additional transient PPE with fewer members
    Linnia Hawkins
- Need to select ~18 parameters
  - Metrics: mean, interannual variability
  - Regions: global, 9 biomes



Parameter influence is ~constant in time



- Trends are approx. the same
- Mean climate states differ

simulations from Linnia Hawkins

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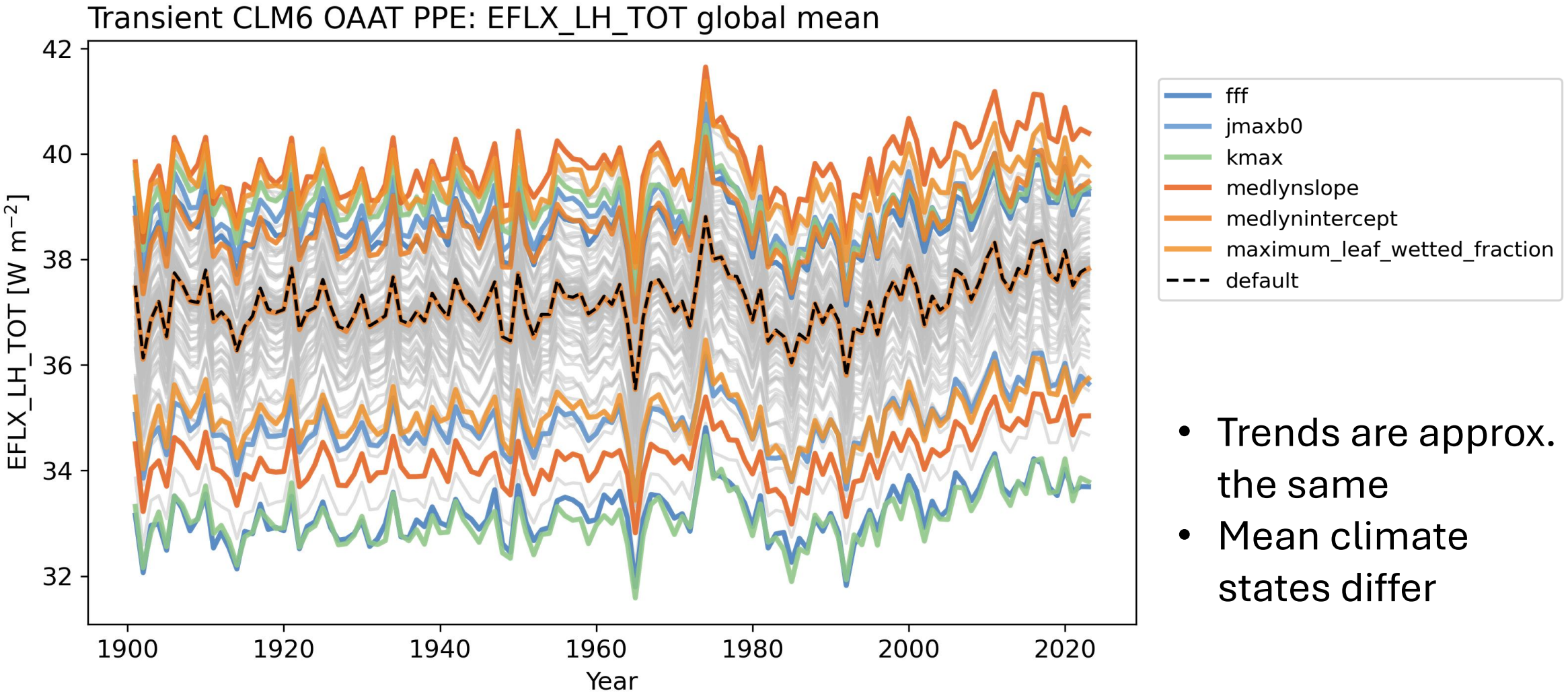

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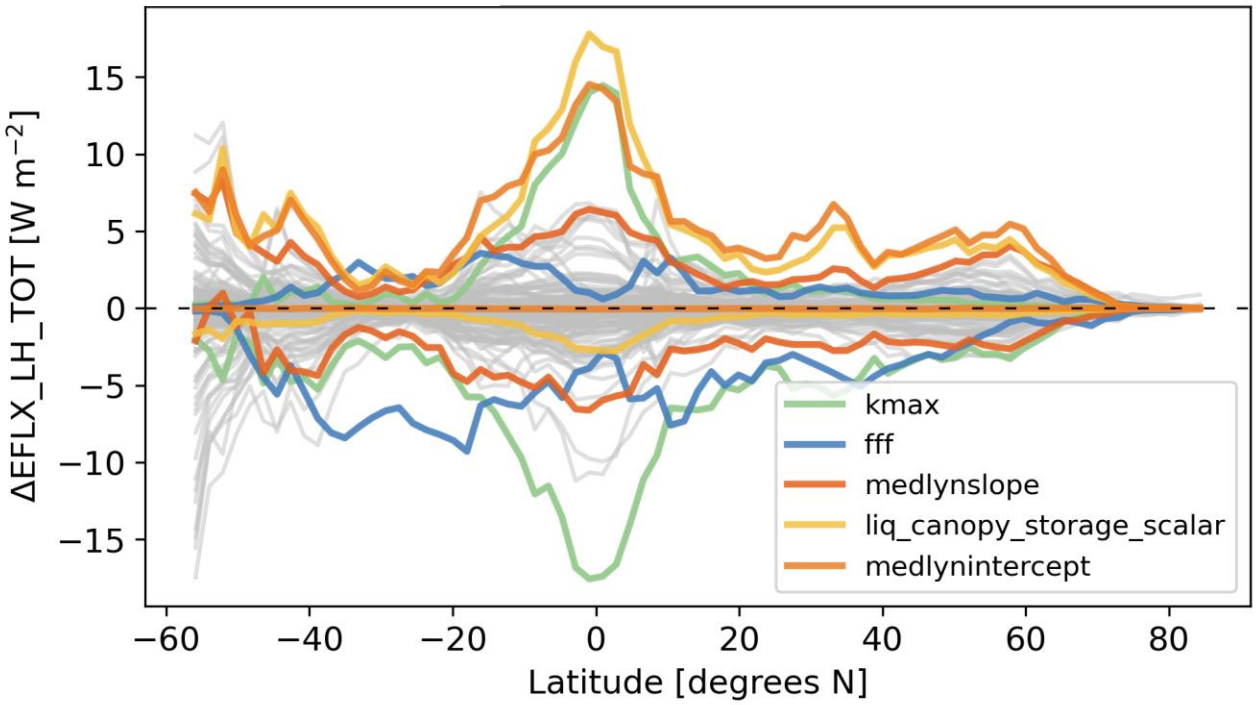
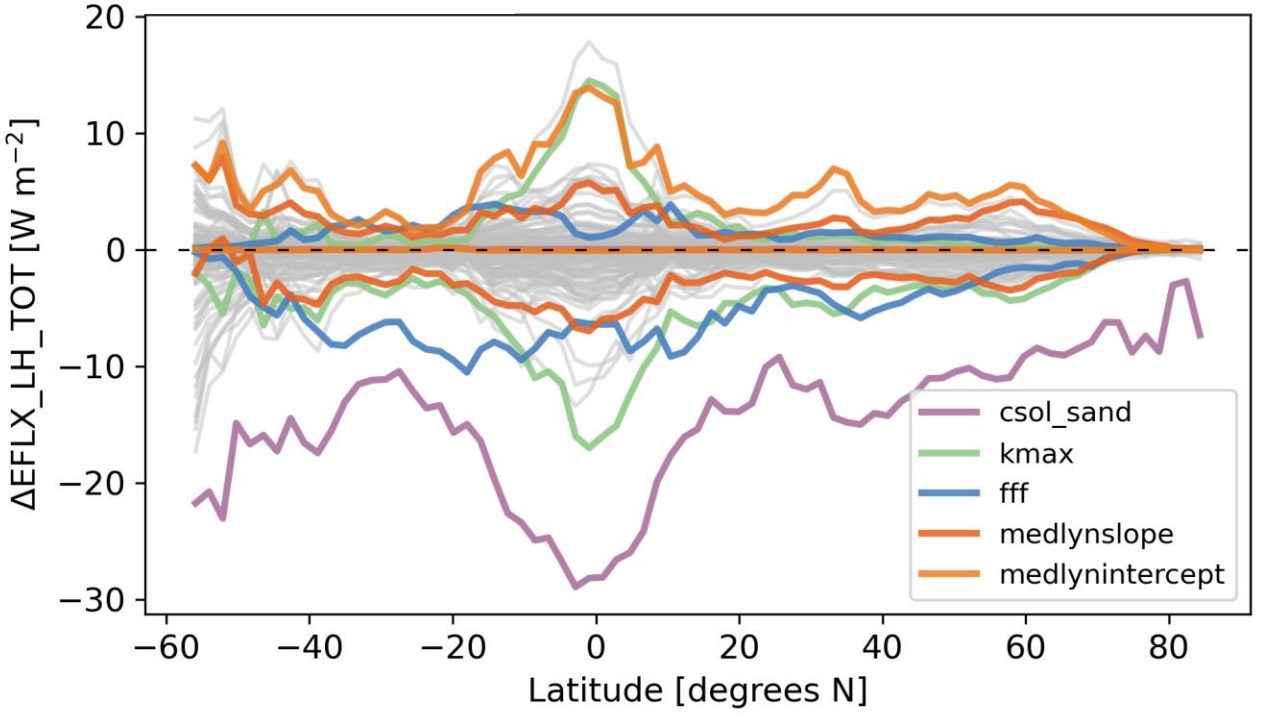
Same parameters have largest influence at preindustrial and future atmospheric forcing

Atmospheric forcing (quasi-equilibrium)

Preindustrial



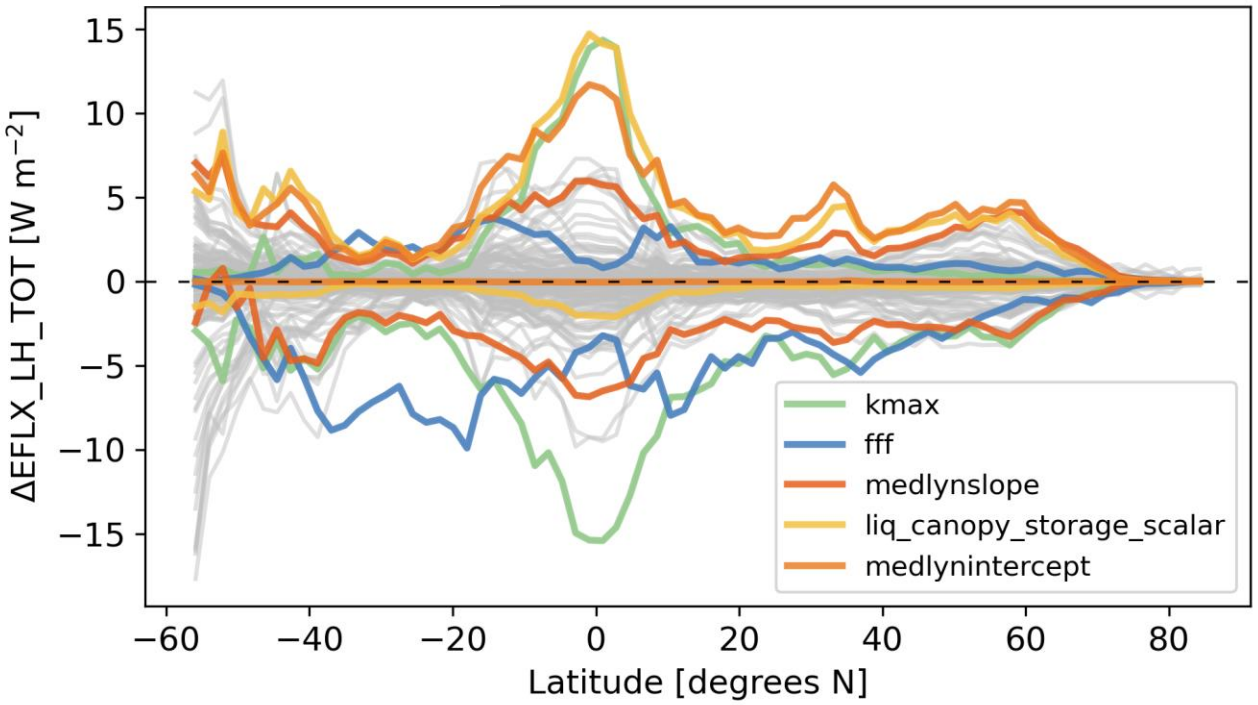
SSP3-7.0



Same parameters have largest influence at high and low CO_2 forcing

CO_2 forcing (quasi-equilibrium)

Preindustrial



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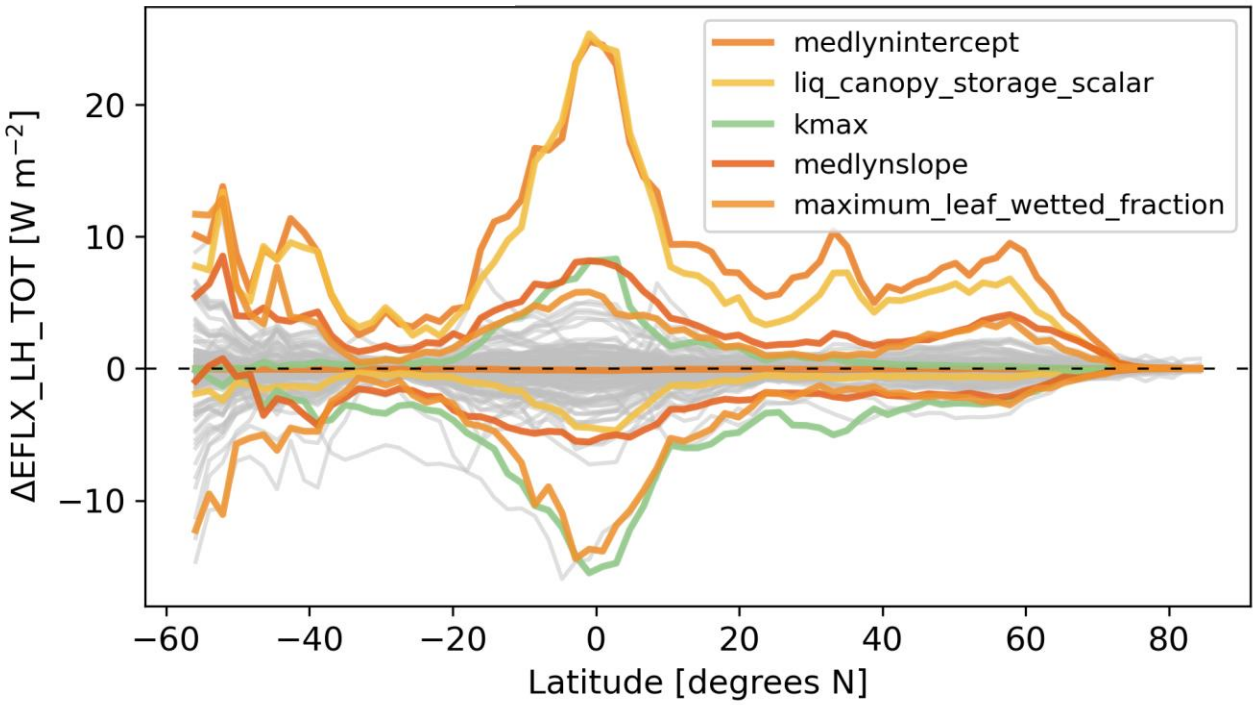

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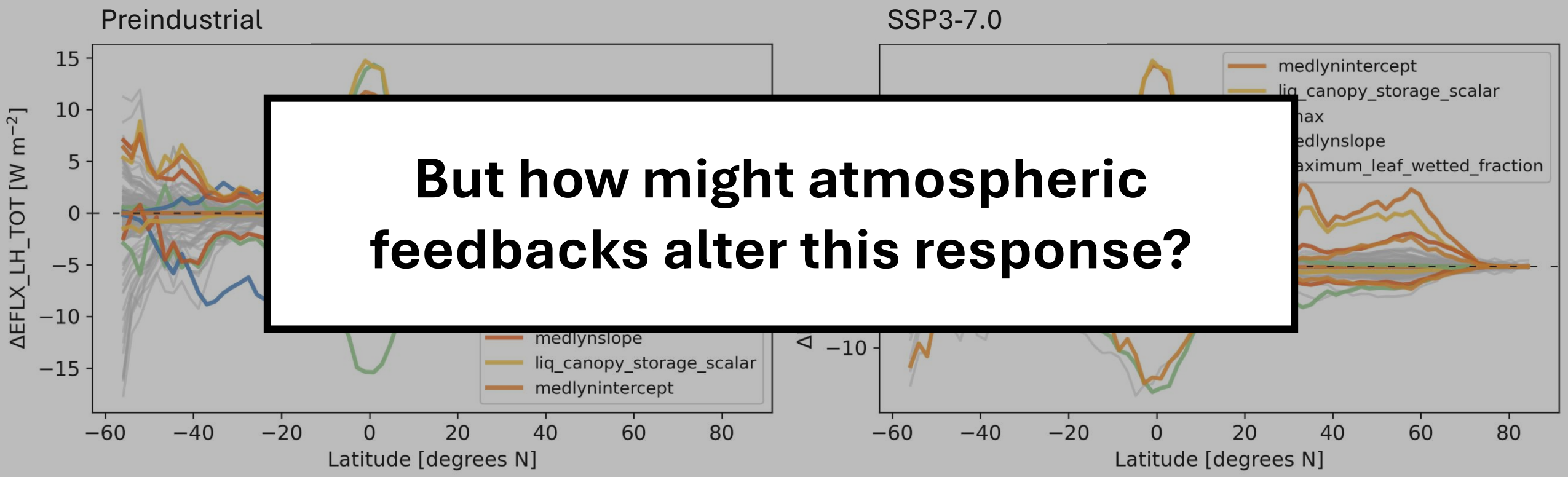

But how might atmospheric feedbacks alter this response?

We can estimate the coupled response using a previous coupled PPE Zarakas et al. (2024)

- Preindustrial coupled PPE with CESM
- Identical simulations with/out atmospheric coupling
- Quantified the land-atmosphere feedback, or coupling "sensitivity"

$$\left(\frac{\Delta ET_{coupled}}{\Delta ET_{land-only}}\right)$$

Zarakas et al. (preprint)

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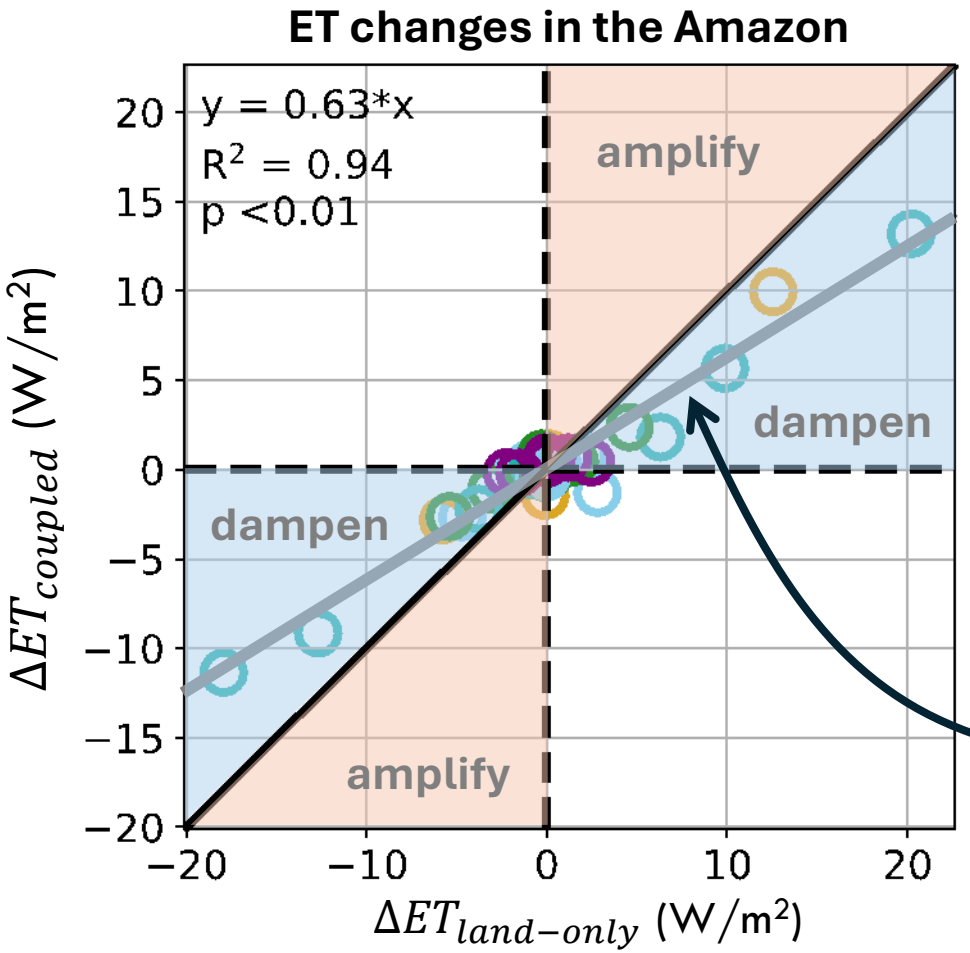

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slope of gray line $\left(\frac{\Delta ET_{coupled}}{\Delta ET_{land-only}}\right)$

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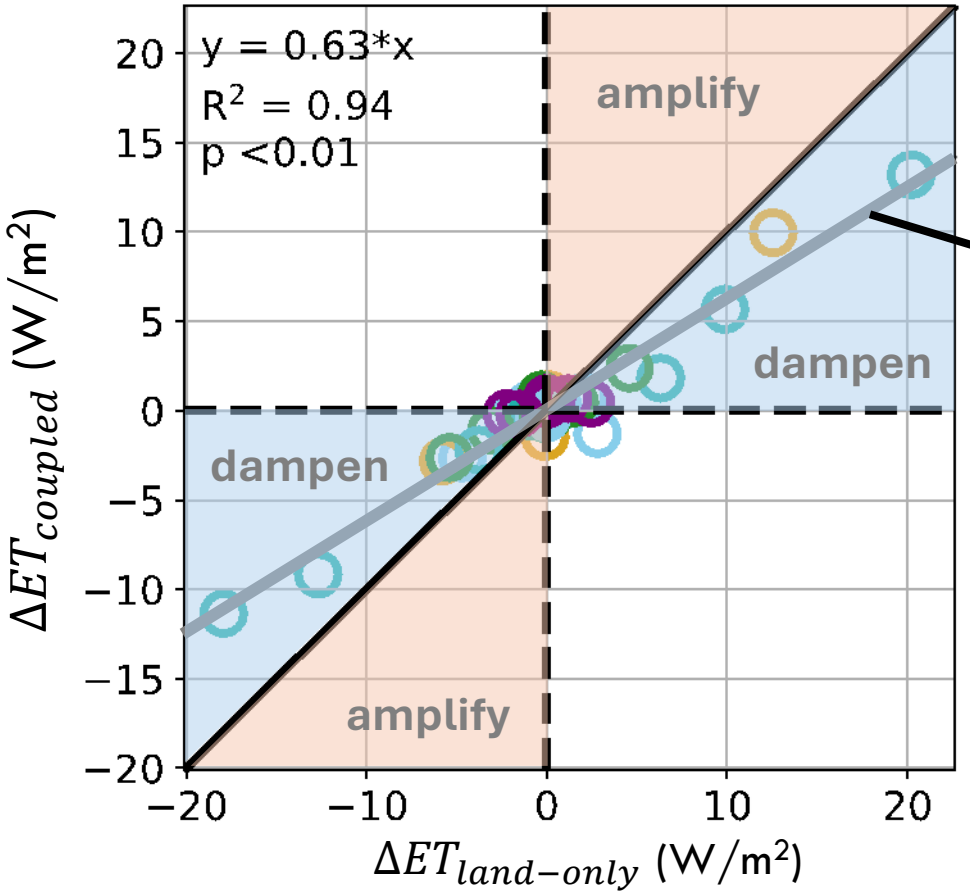
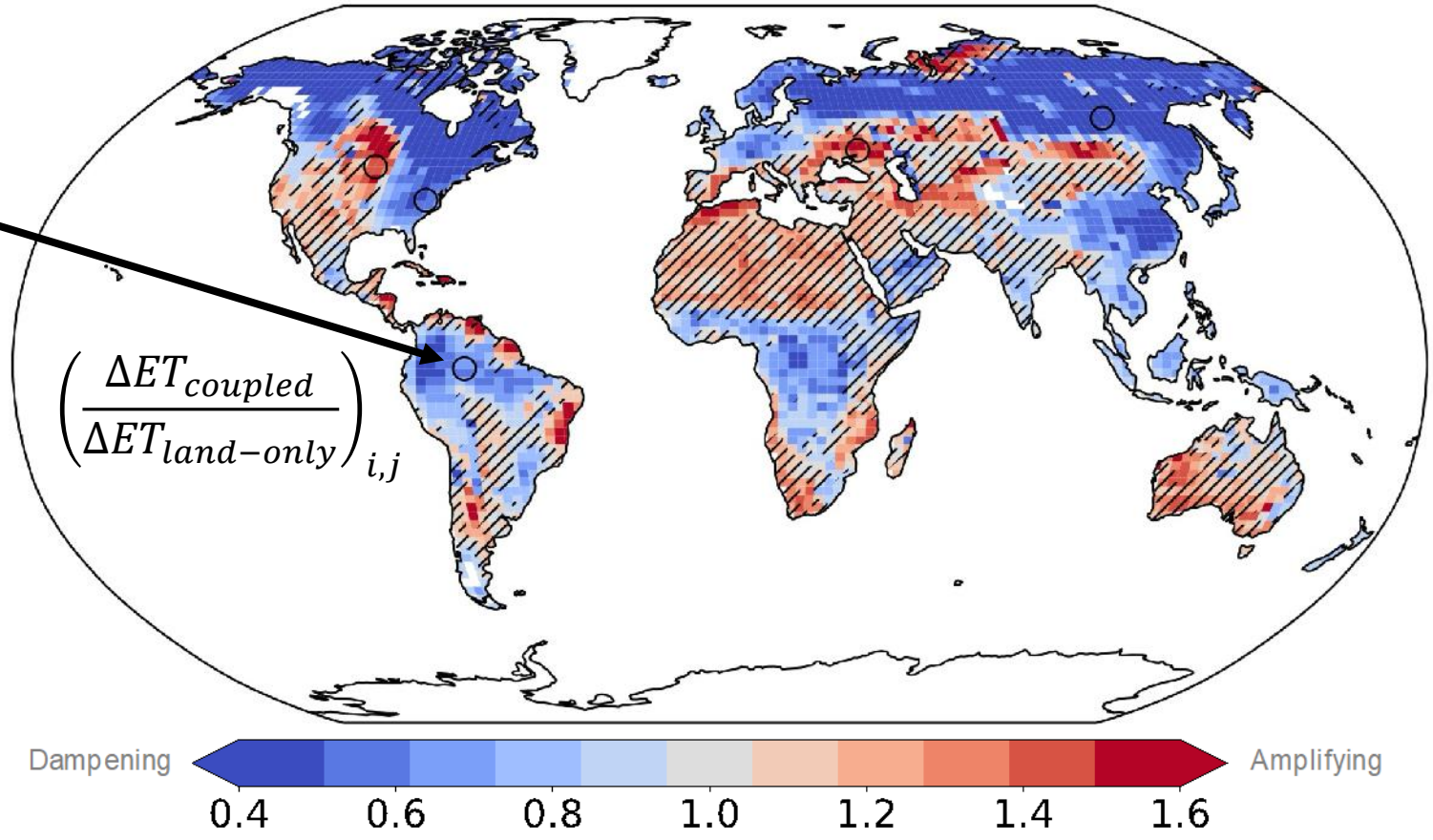
ET changes in the Amazon



Atmospheric modulation of ET changes



Zarakas et al. (preprint)

$$\left(\frac{\Delta ET_{feedback}}{\Delta ET_{land-only}}\right) \times \overbrace{\Delta ET_{i,land-only}}^{\text{CLM PPE}} \approx \overbrace{\Delta ET_{i,coupled}}^{\text{estimate of coupled response}}$$

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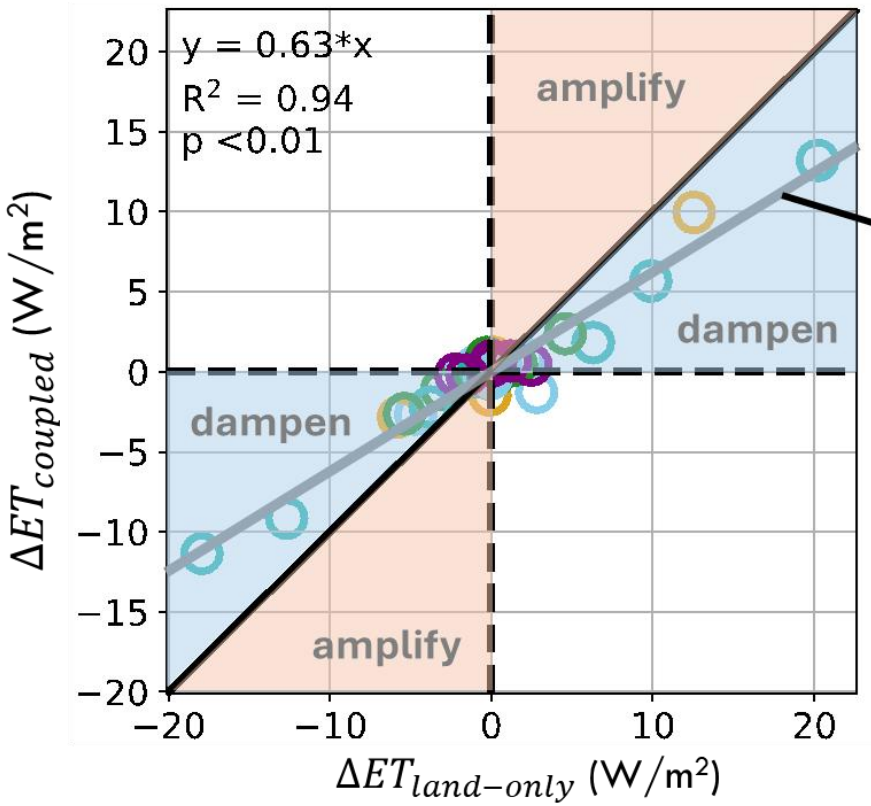

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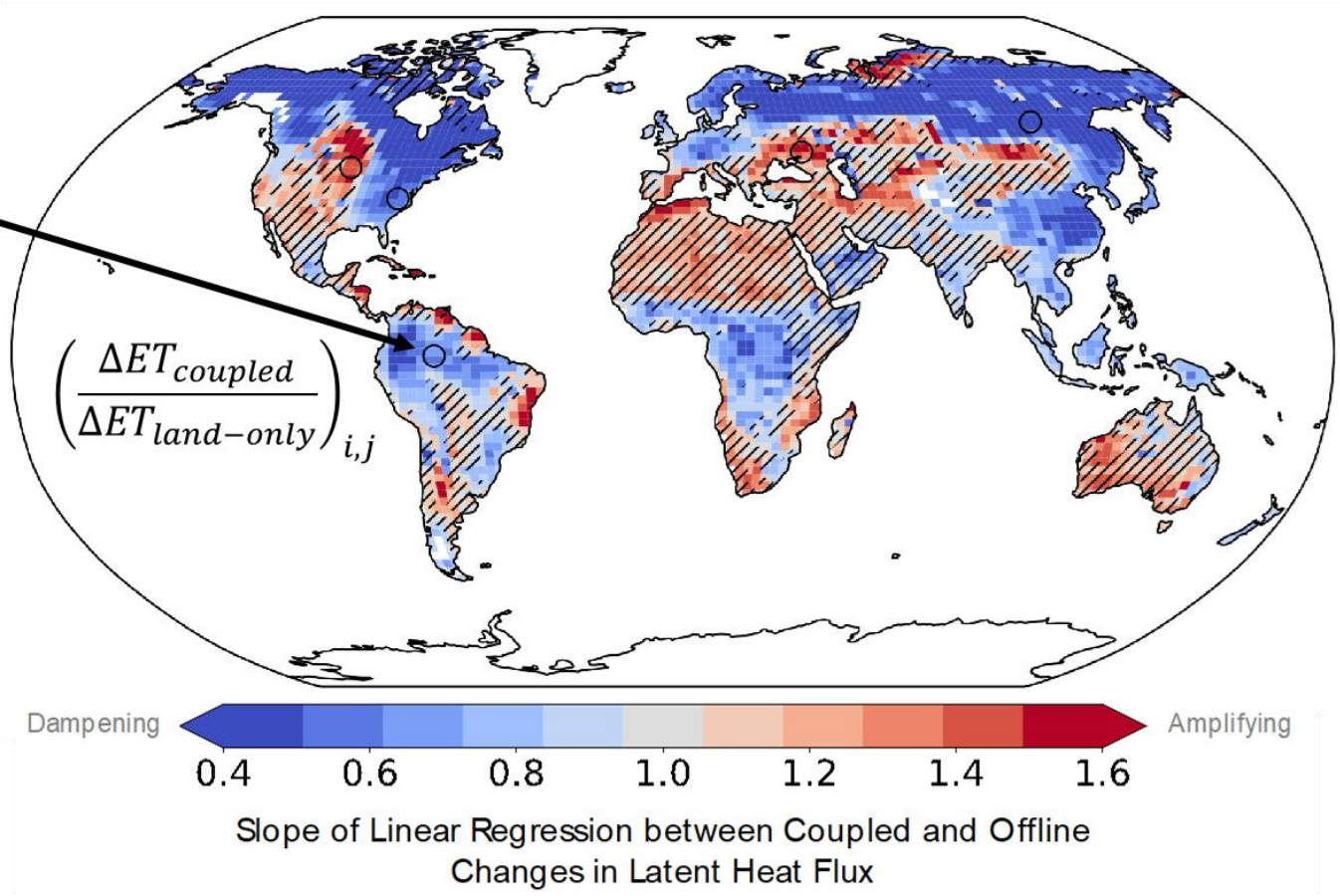


Zarakas et al. (preprint)

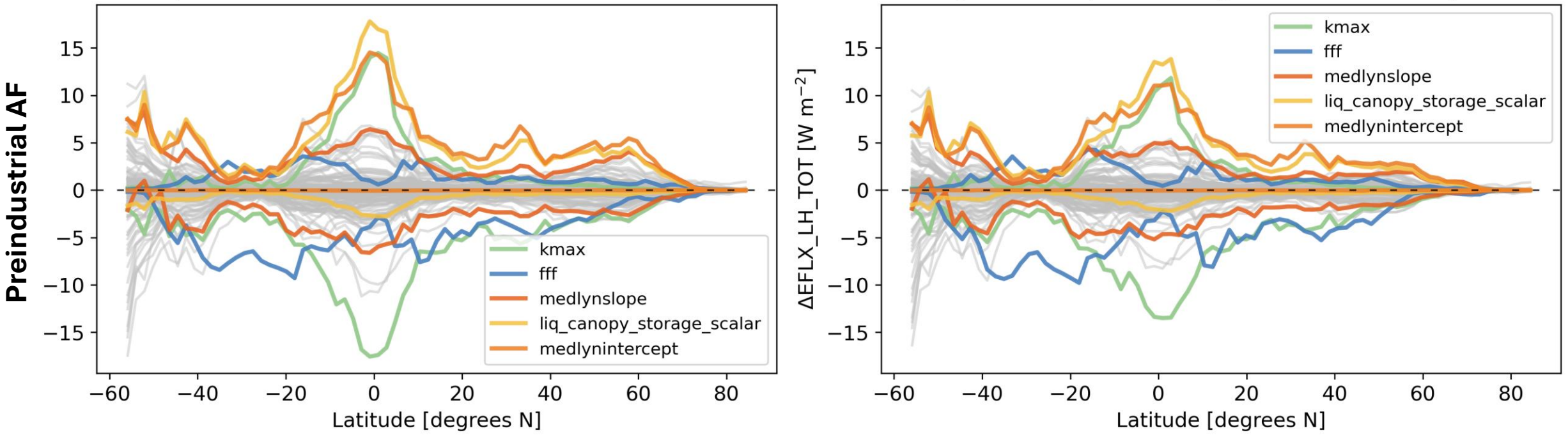
Atmosphere feedbacks don't significantly change spread in ET

$\Delta ET_{i,land-only}$

$$\left(\frac{\Delta ET_{feedback}}{\Delta ET_{land-only}}\right) \times \Delta ET_{i,land-only}$$

Original CLM5 PPE

Scaled using land-atmos feedback sensitivity



slightly dampened ET response but no large changes in relative influence of parameters

Creating parameter lists from the CLM PPE

CLM PPEs

AF1855

AF2095

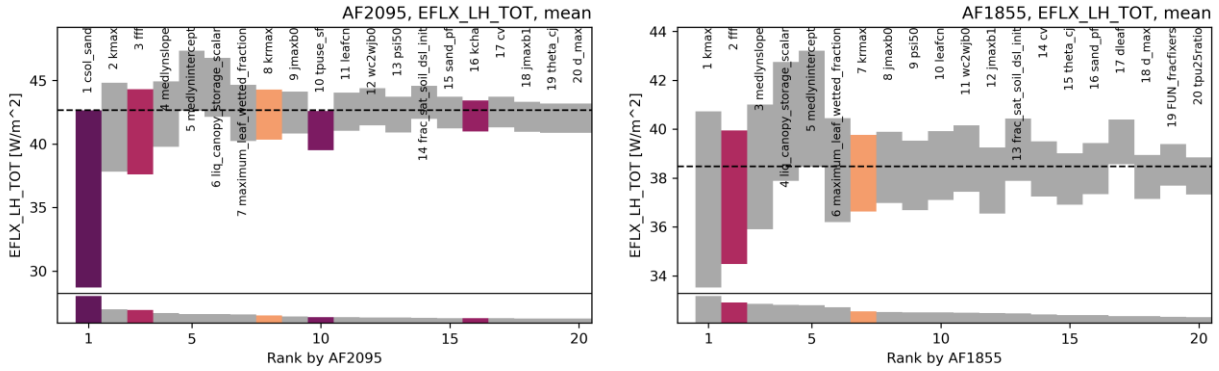
C285

C867

historical

Top 5 parameters with greatest influence on ET

- global
- indv. biomes



parameter rankings

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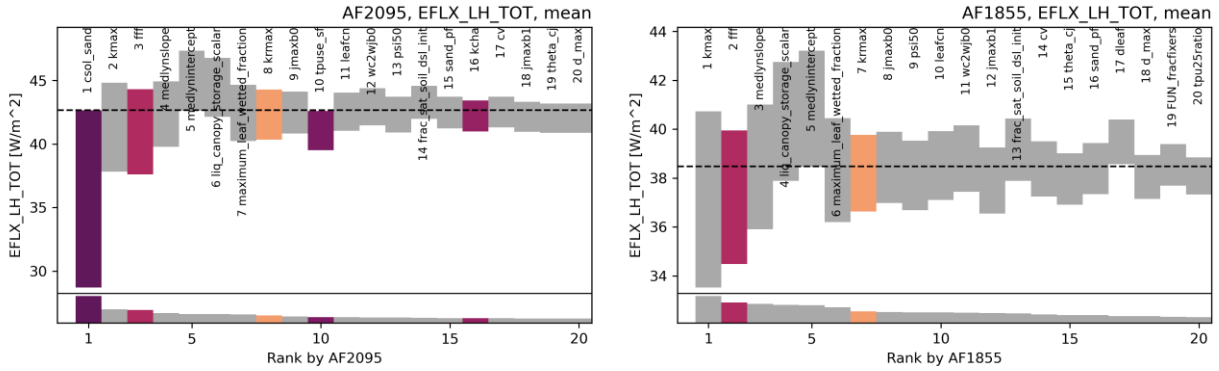
liq_canopy_storage_scalar
medlynintercept
maximum_leaf_wetted_fraction
leafcn
krmax
jmaxb0
...
```



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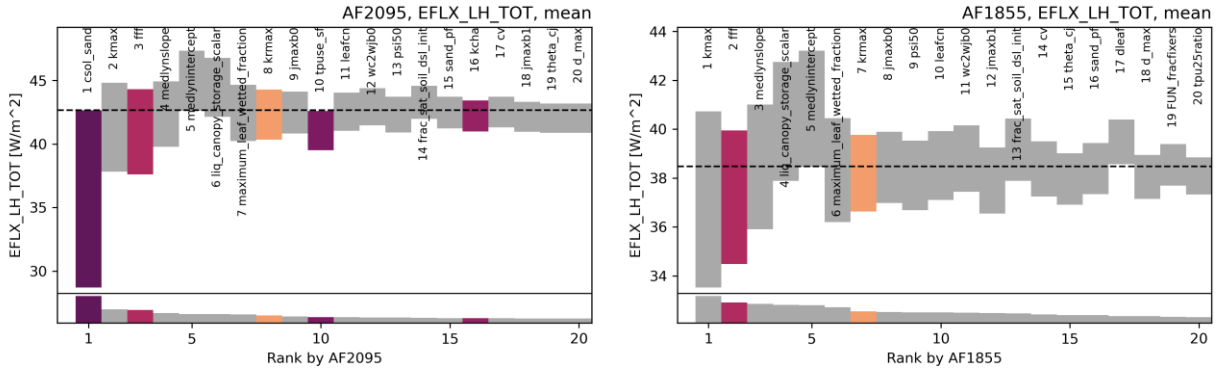


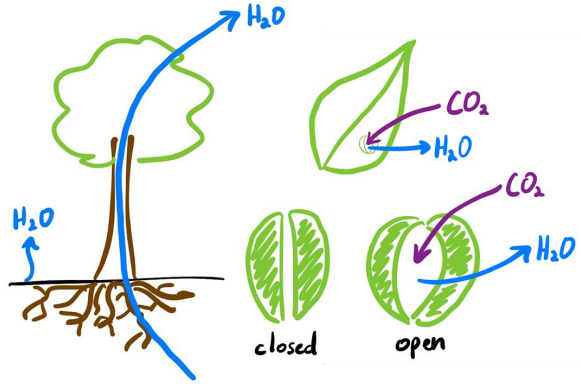
parameter rankings

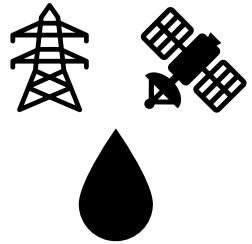
Other considerations:

- different functional areas
- spatial pattern correlation
- the min/max perturbation ranges

ET is a hard but important problem

- Many competing processes
- Sparse observations





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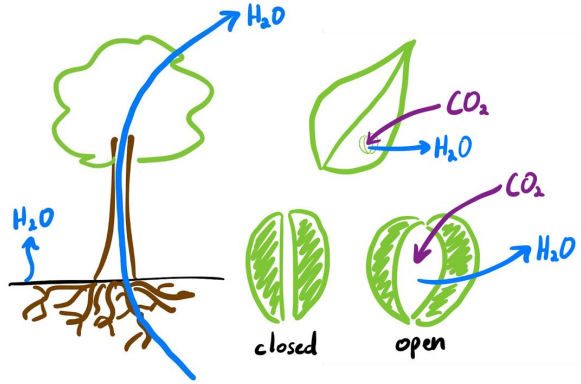
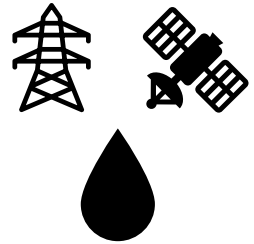
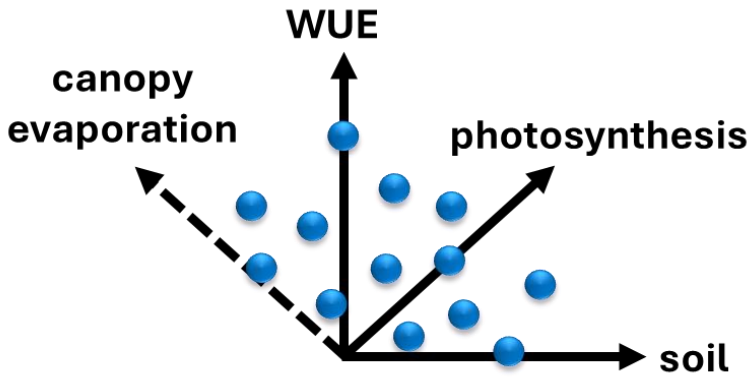




Plan to perform a CESM2 PPE to quantify the drivers of ET in the historical and future



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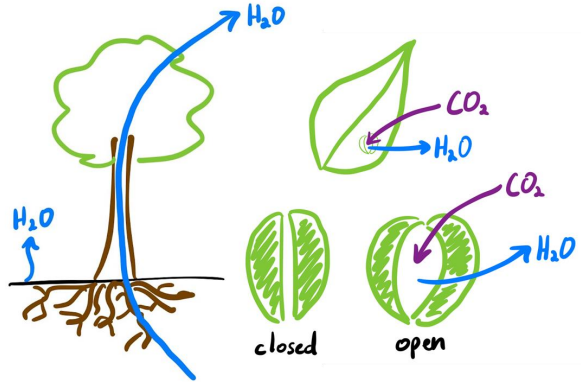

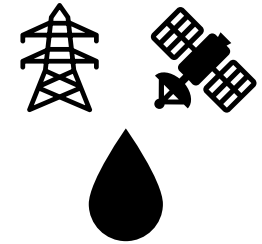

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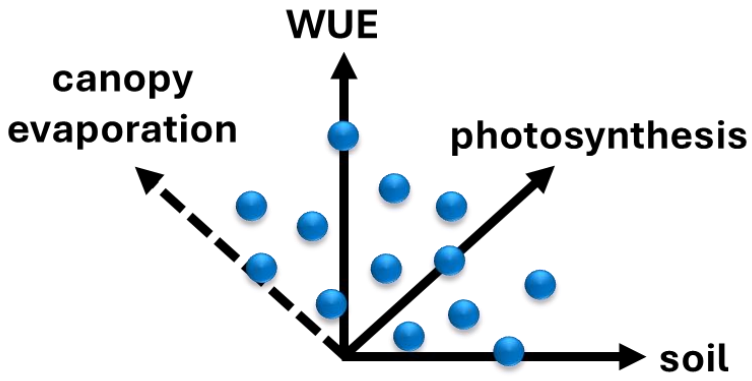

Preliminary exploration of CLM5 PPE provides guidance on parameter selection

```
kmax,fff, medlynslope, liq_canopy_storage_scalar, medlynintercept,
maximum_leaf_wetted_fraction, leafcn, krmax, jmaxb0, ...
```

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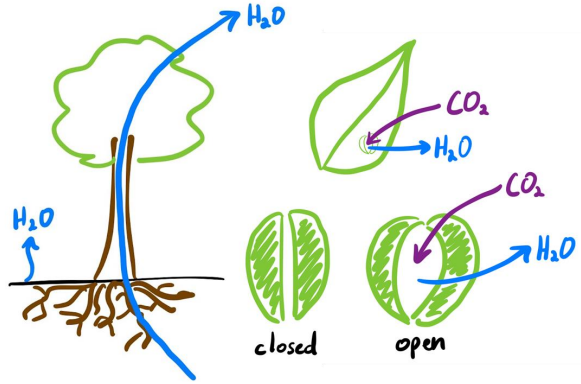

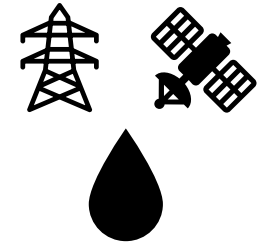

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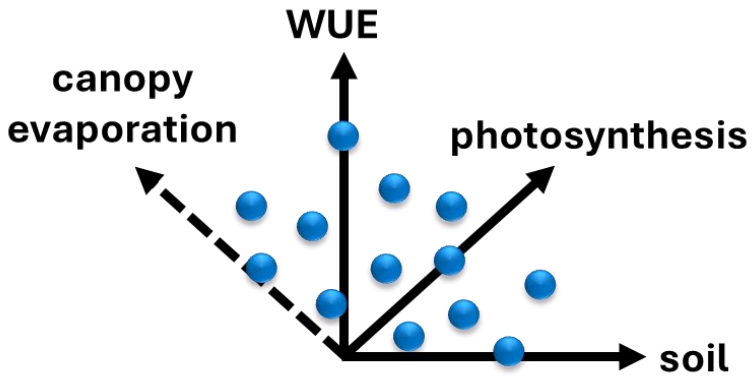

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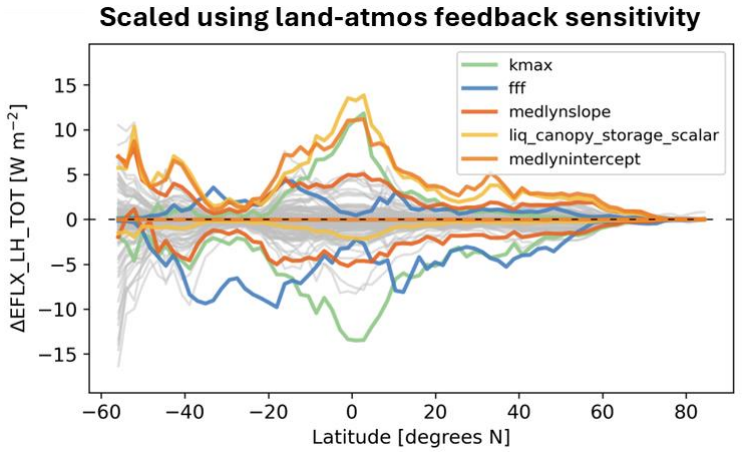

Atmospheric feedbacks do not have significant influence on parameter-driven spread in ET

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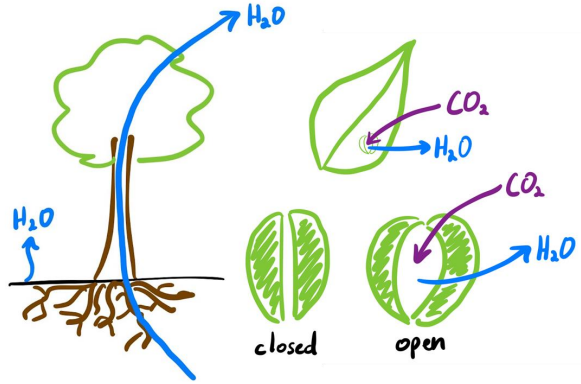

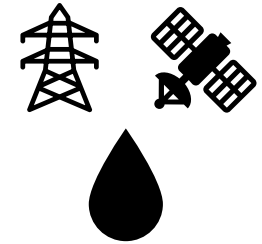

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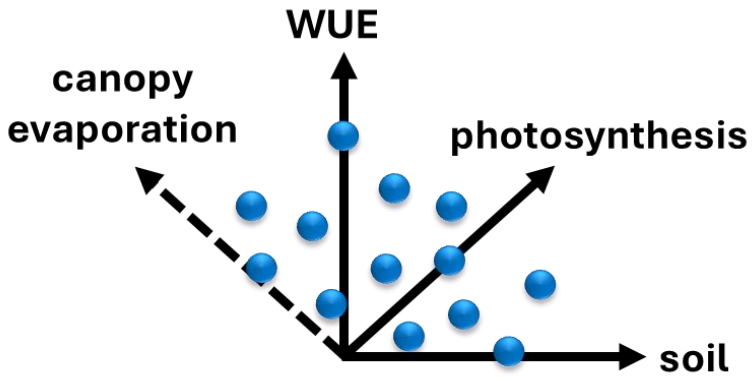

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Atmospheric feedbacks do not have significant influence on parameter-driven spread in ET

Thanks!

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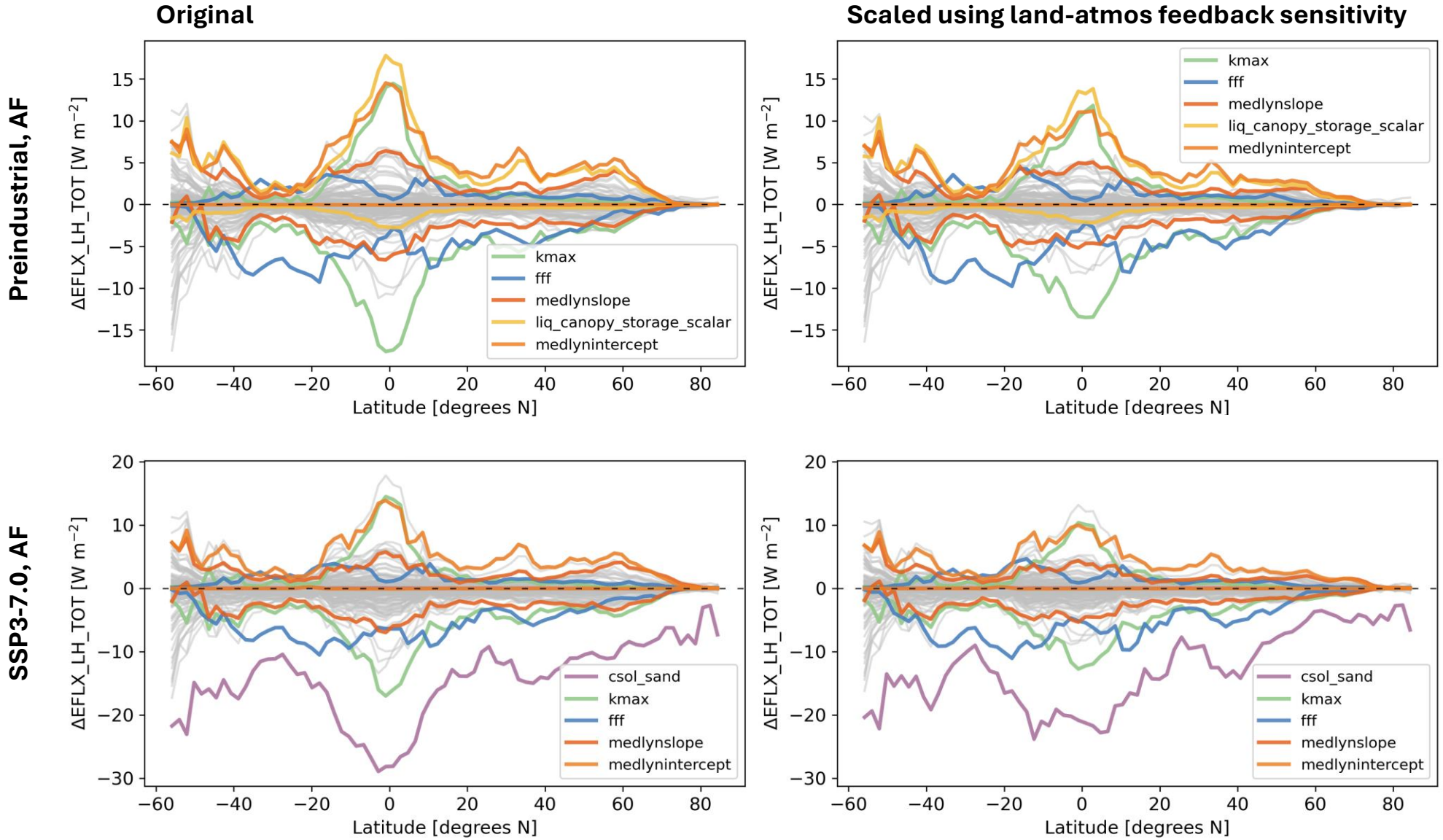
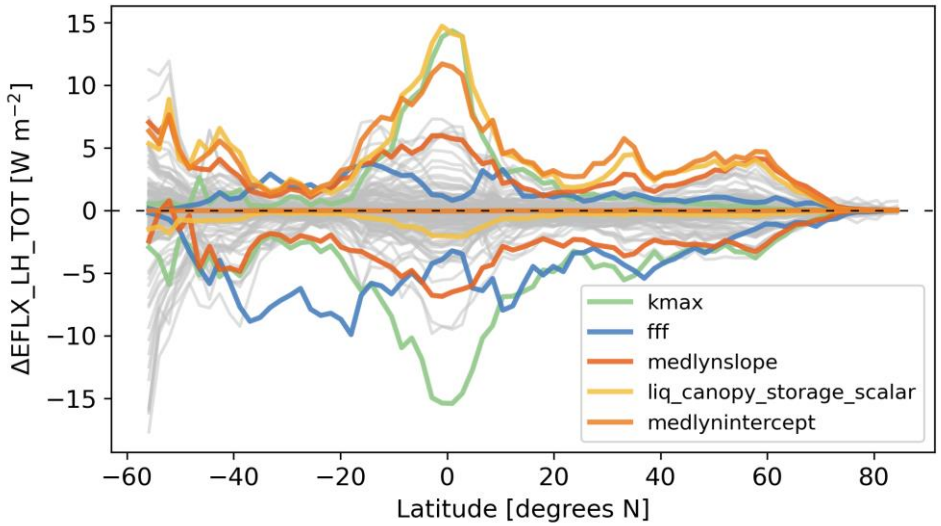
Atmosphere feedbacks don’t significantly change spread in ET

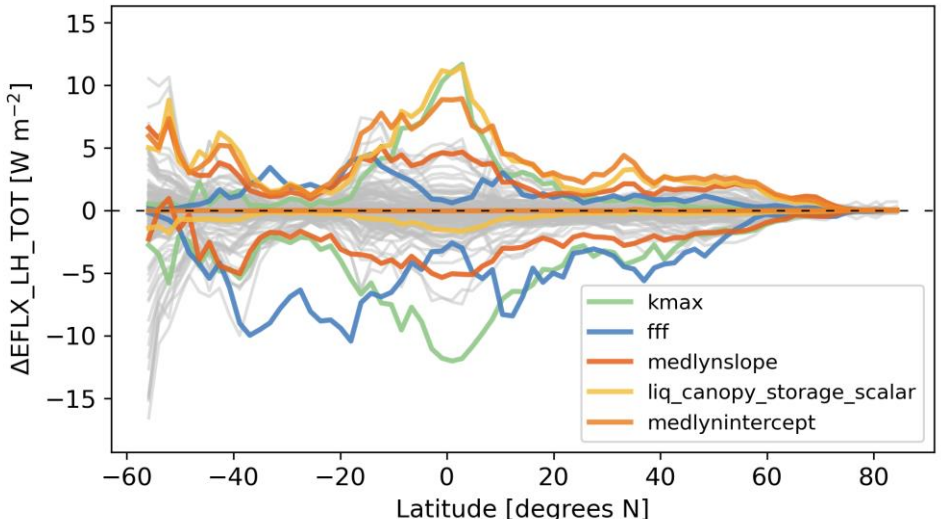


Atmosphere feedbacks don’t significantly change spread in ET

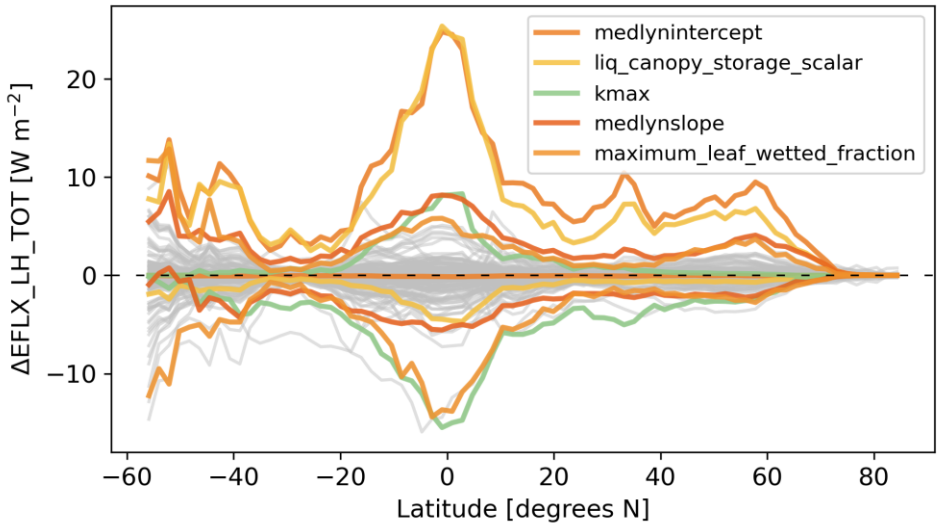
Original | **Scaled using land-atmos feedback sensitivity**

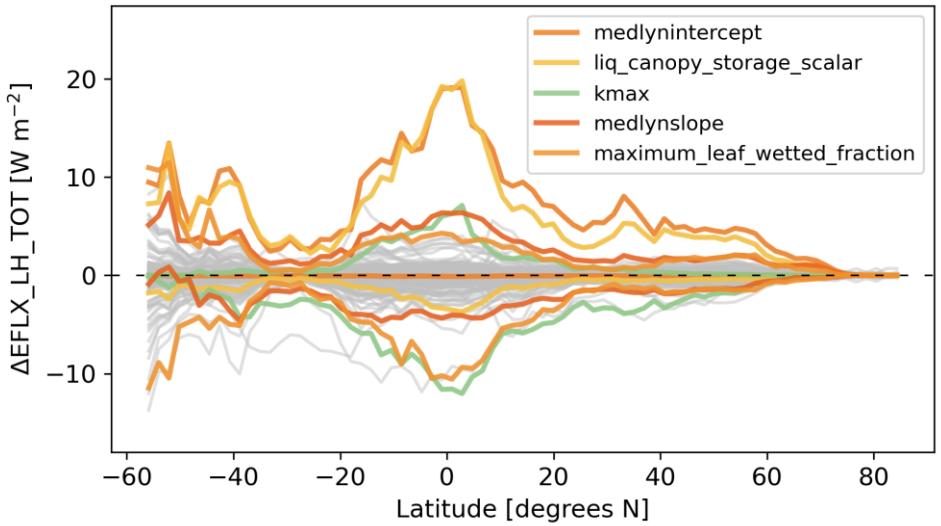
Preindustrial, CO2

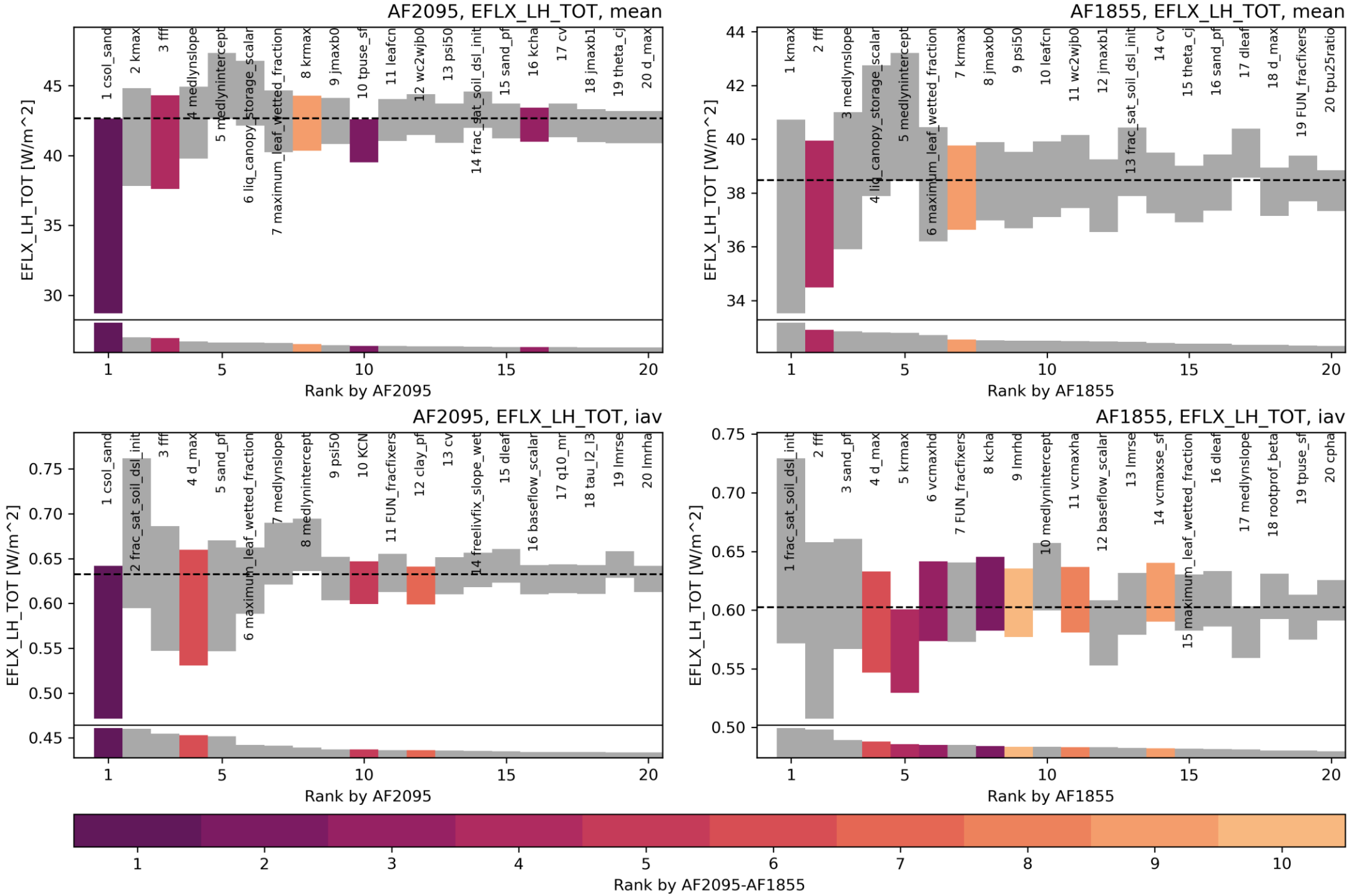




SSP3-7.0, CO2






AF2095, EFLX_LH_TOT, mean
EFLX_LH_TOT [W/m^2]
Rank by AF2095
AF1855, EFLX_LH_TOT, mean
EFLX_LH_TOT [W/m^2]
Rank by AF1855
AF2095, EFLX_LH_TOT, iav
EFLX_LH_TOT [W/m^2]
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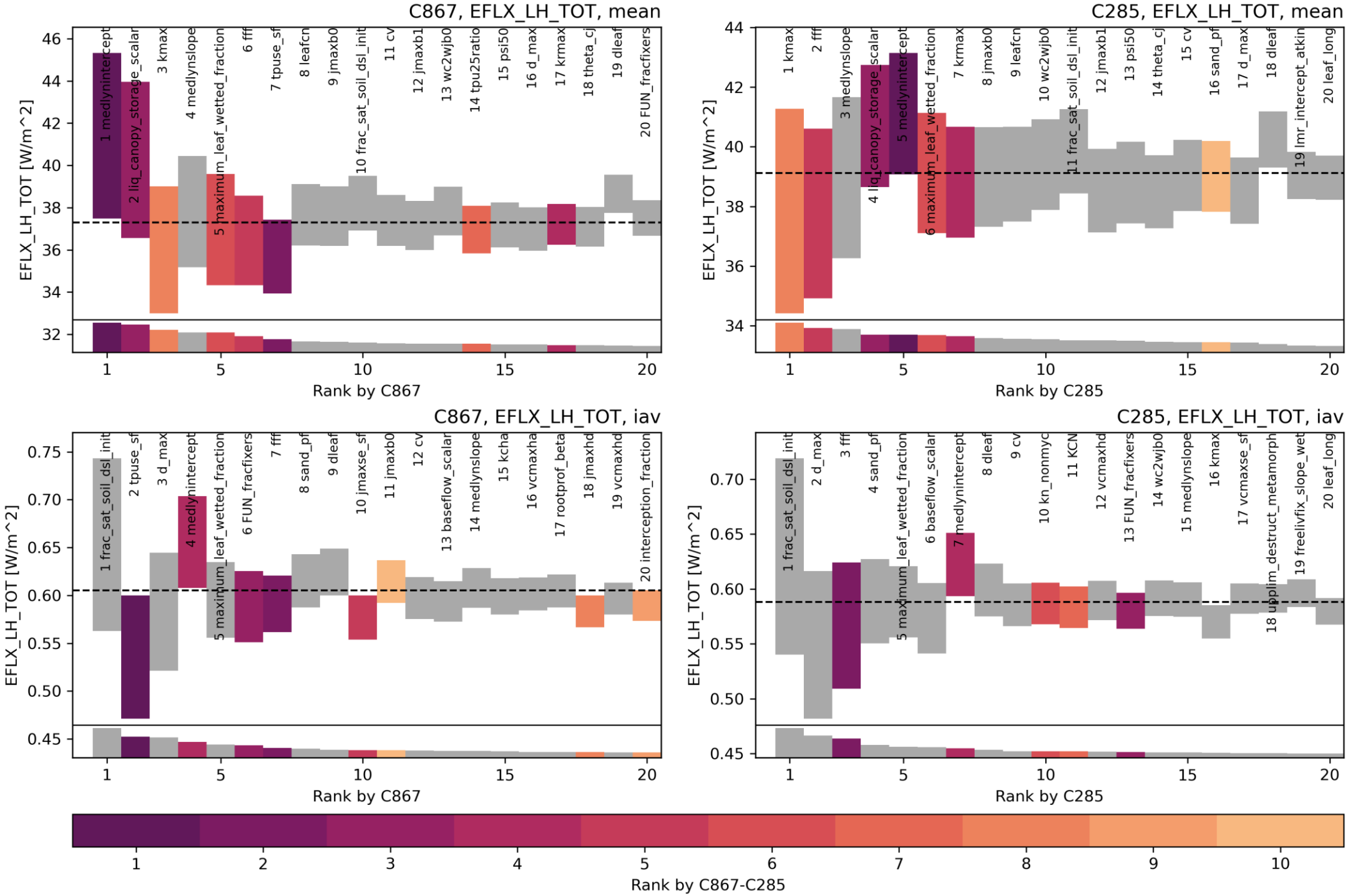
C867, EFLX_LH_TOT, mean
EFLX_LH_TOT [W/m^2]
Rank by C867
C285, EFLX_LH_TOT, mean
Rank by C285
C867, EFLX_LH_TOT, iav
Rank by C867
C285, EFLX_LH_TOT, iav
Rank by C285
Rank by C867-C285