Distinct patterns of ET across a coupled perturbed parameter ensemble

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Land Model Working Group Meeting

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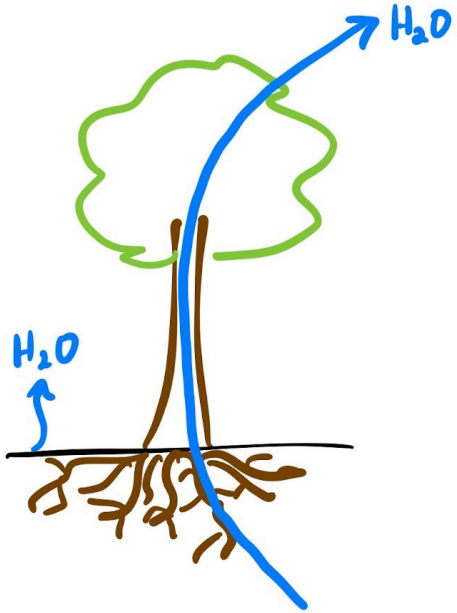
Funded by

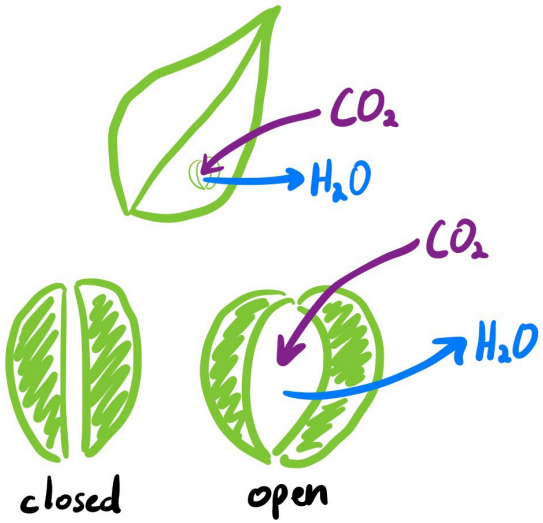
ET plays a crucial role in land hydroclimate

Surface Energy Balance

Soil Hydrology & Large-Scale Vegetation



Stomatal Processes



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

ET plays a crucial role in land hydroclimate

ET = f (biology, climate)

clouds
temperature
precipitation

climate = f (…, ET, …)

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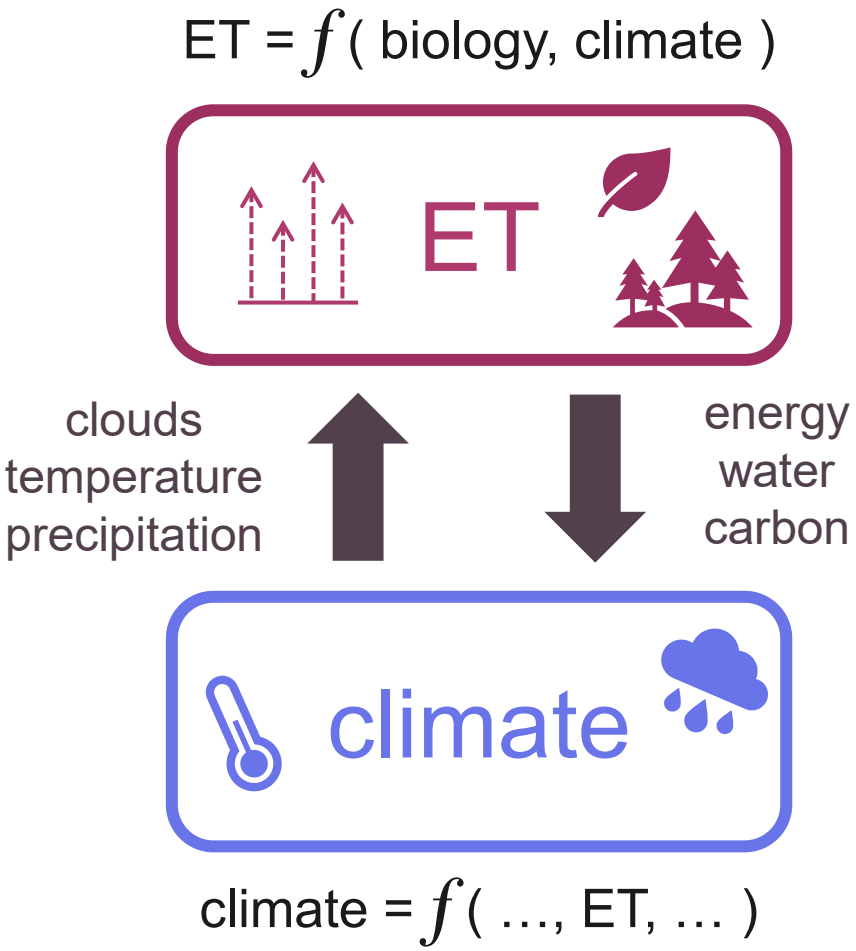

ET plays a crucial role in land hydroclimate

ET = f (biology, climate)

clouds
temperature
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energy
water
carbon

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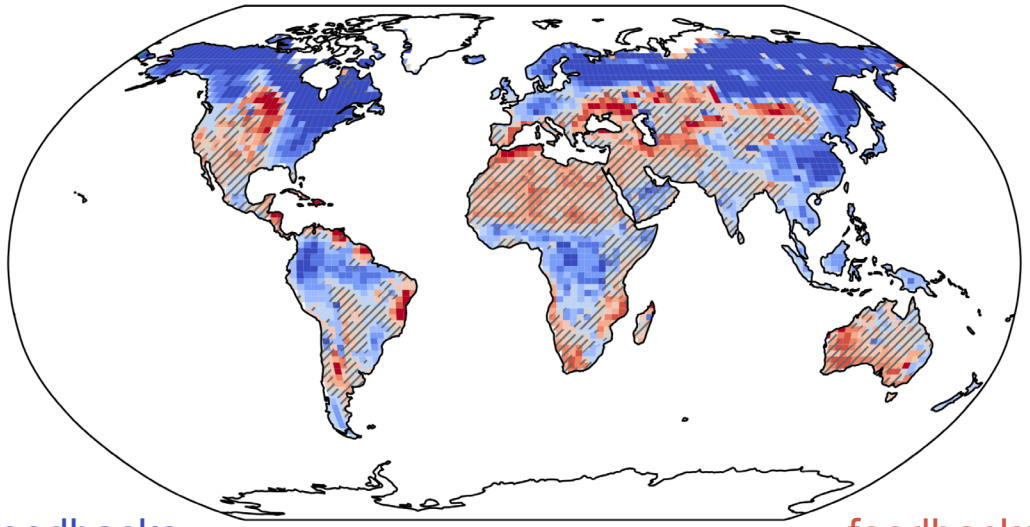
Land-atmosphere feedbacks matter

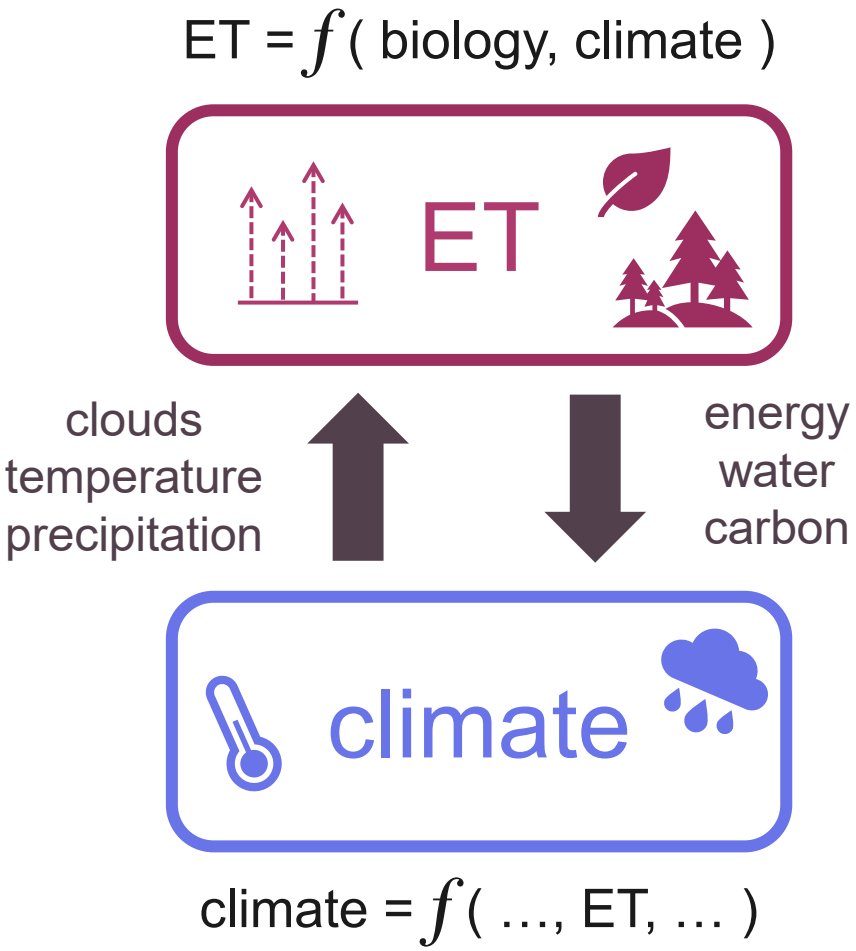


feedbacks
dampen ΔET

feedbacks
amplify ΔET

Claire Zarakas

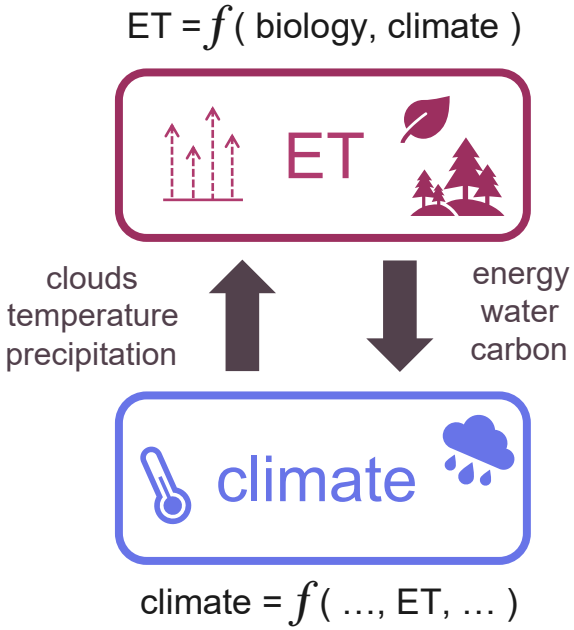
ET plays a crucial role in land hydroclimate



ET is crucial for climate projections

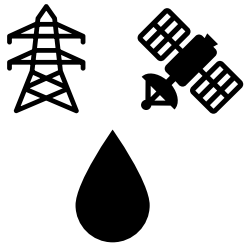
- Water availability
- Drought
- Heatwaves
- Precipitation

Difficult to untangle individual controls of ET



Challenging to quantify ET globally

- Sparse *in situ* measurements
- Remote sensing + energy budget
- Basin-scale water and mass balance



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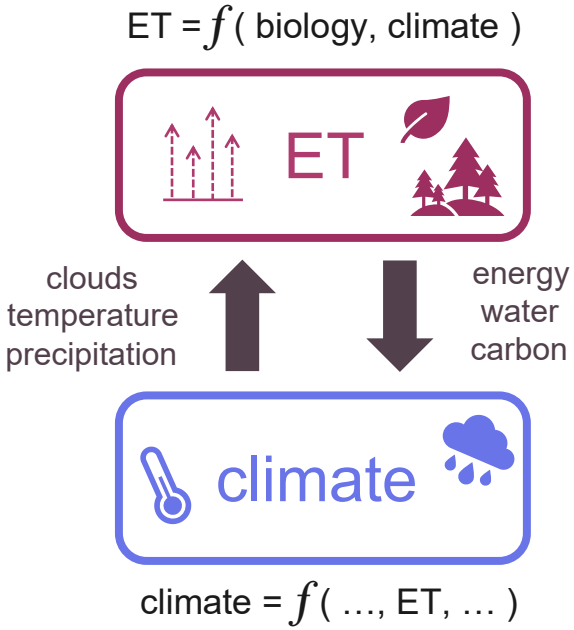

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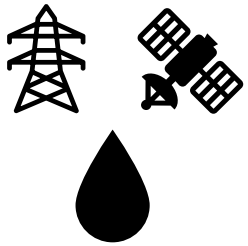

Contradictory explanations for historical ET trends

- 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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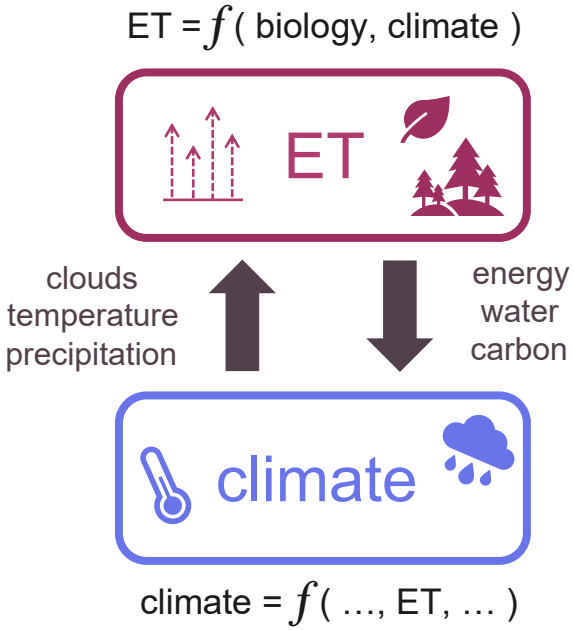

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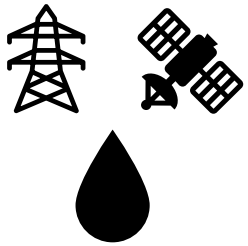

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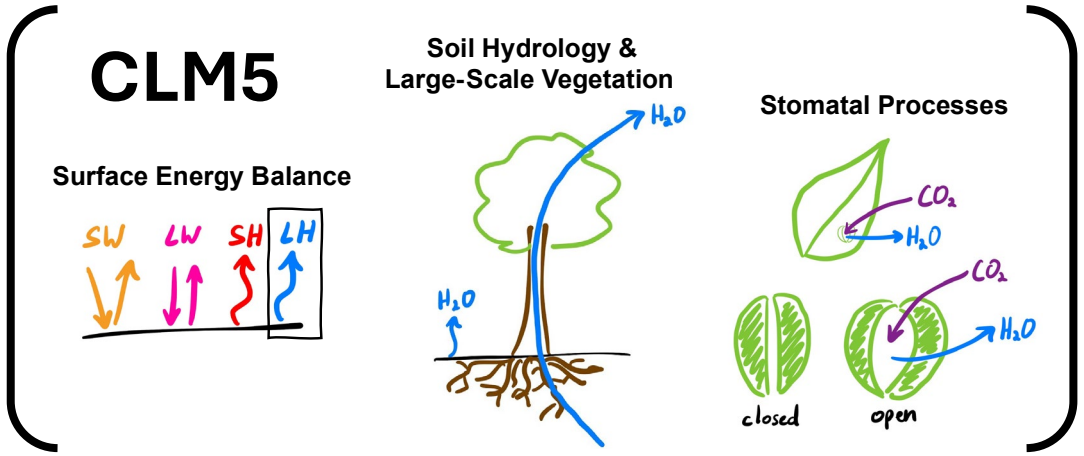
What will dictate ET under future climate?

We can gain insight with a historical coupled PPE



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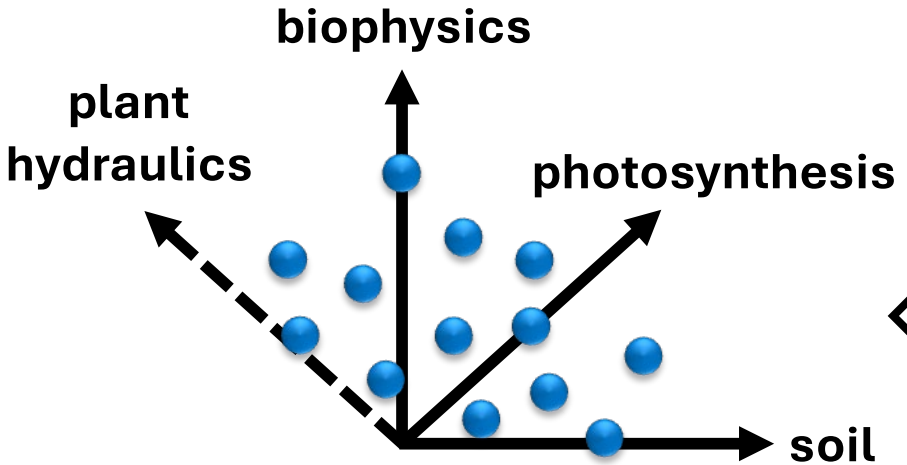
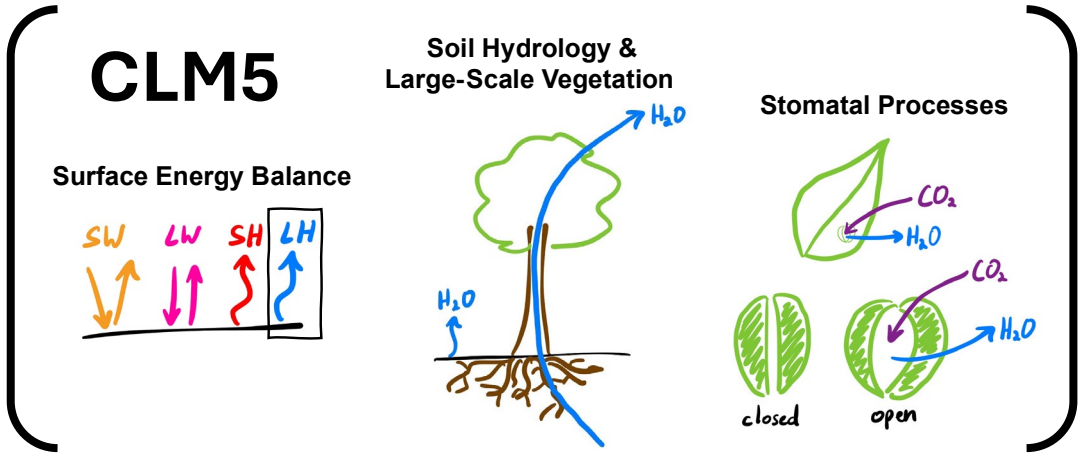


perturb CLM parameters across functional space



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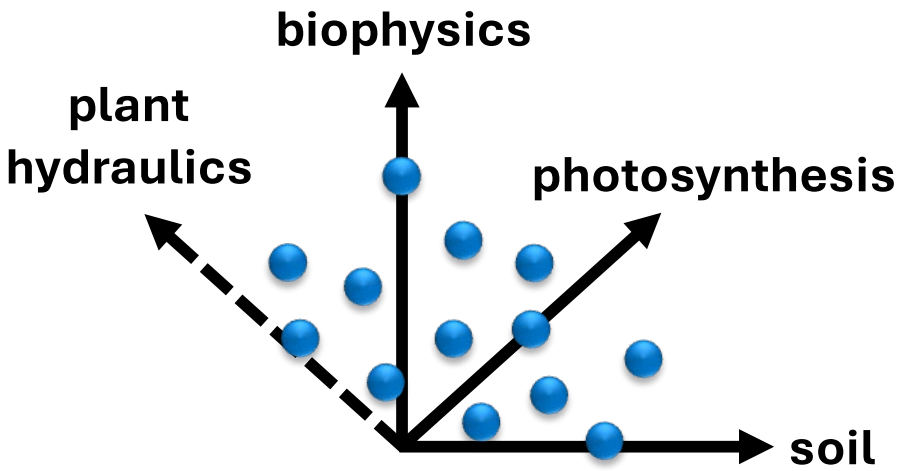
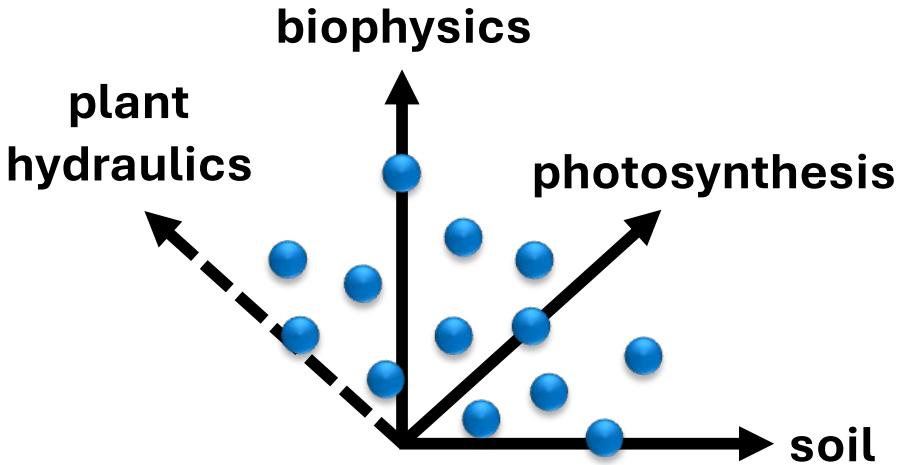


perturb CLM parameters across functional space

Used land-only PPEs to select parameters

- Which "axes" to sample?
  (soil hydrology, plant hydraulics, photosynthesis)
- What parameters generate greatest ΔET?
  (e.g., `leafcn` = C:N ratio in leaves)

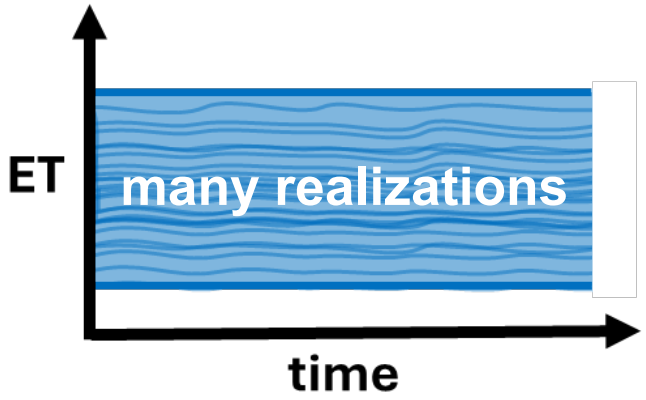
We can gain insight with a historical coupled PPE



perturb CLM parameters across functional space

historical forcing

(+ CO_2 + aero + LUC + observed SSTs)

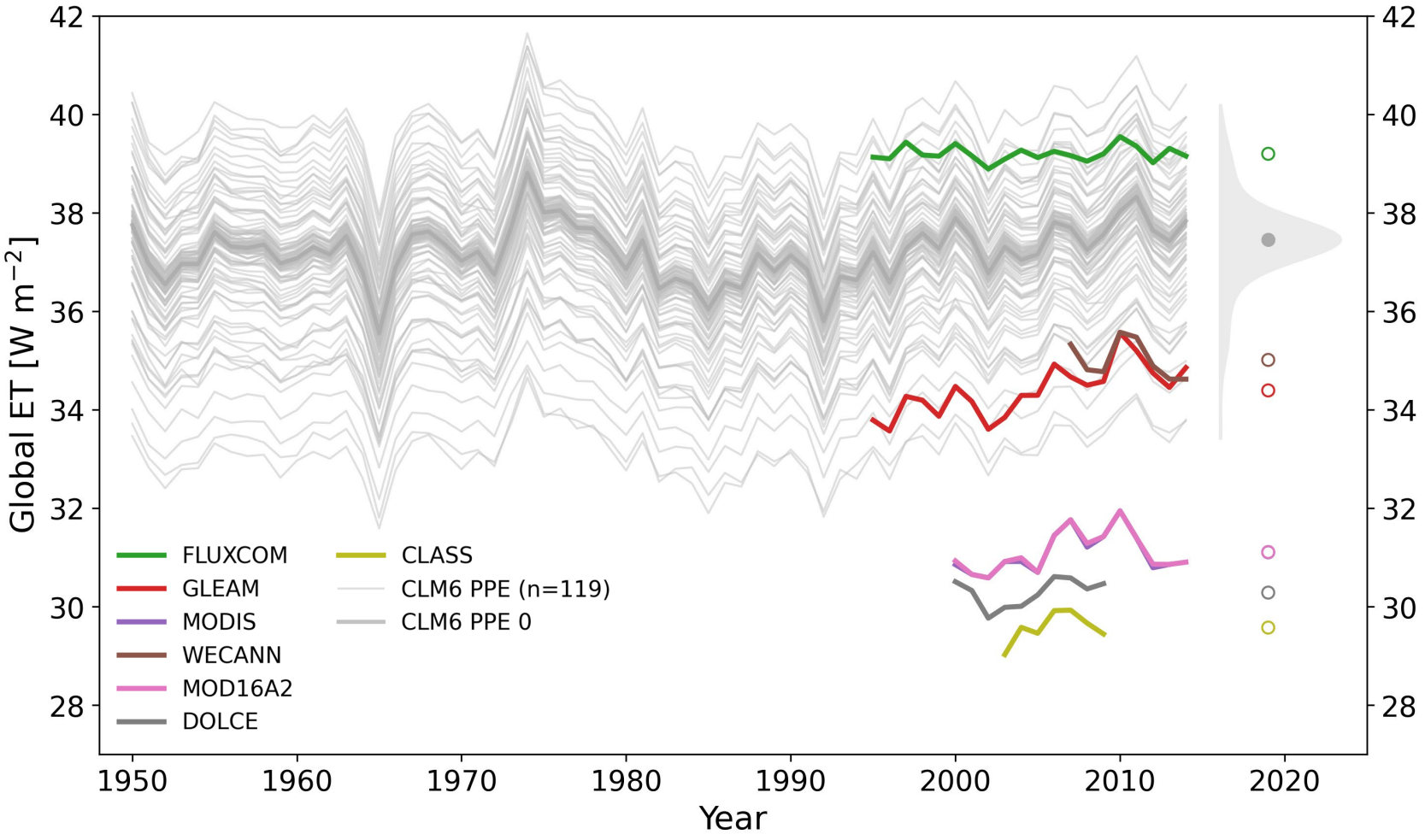


Historical coupled PPE design and configuration

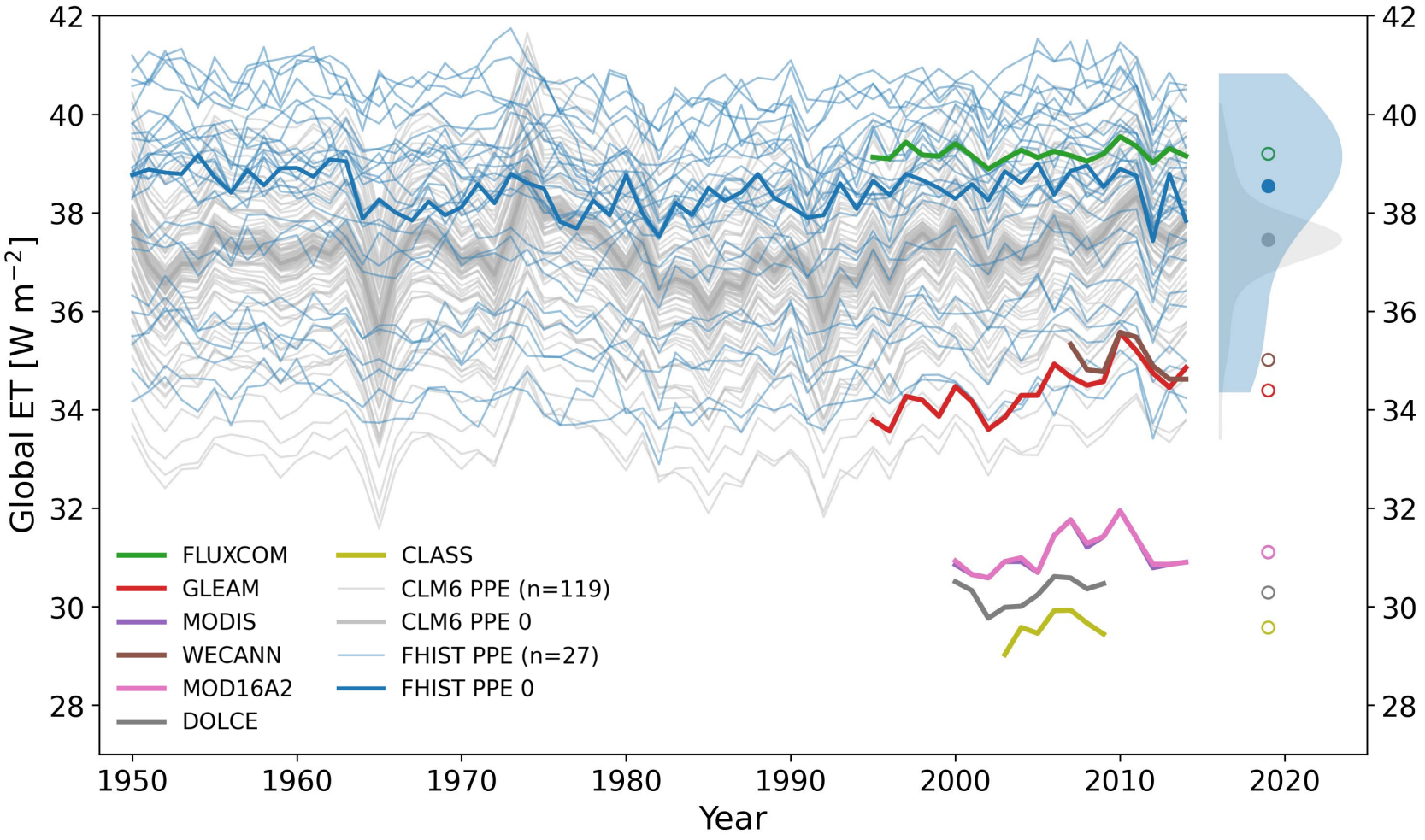
- **Coupled land-atmosphere:** FHIST_BGC with CAM6, CLM5
- **Prescribed time-varying SSTs:** HadOIBI observational product
- **28 ensemble members:** 14 parameters × high/low perturbations
  - Perturbed to min/max of parameter uncertainty range
  - Selected based on ET spread in offline CLM PPEs (CLM5 pseudo-equilibrium, CLM6 transient)
- Start from *equilibrated land ICs* in 1950 → run until 2015

Large spread in global-mean ET across observations

Large spread in global-mean ET across land-only PPE



Large spread in global-mean ET across coupled PPE



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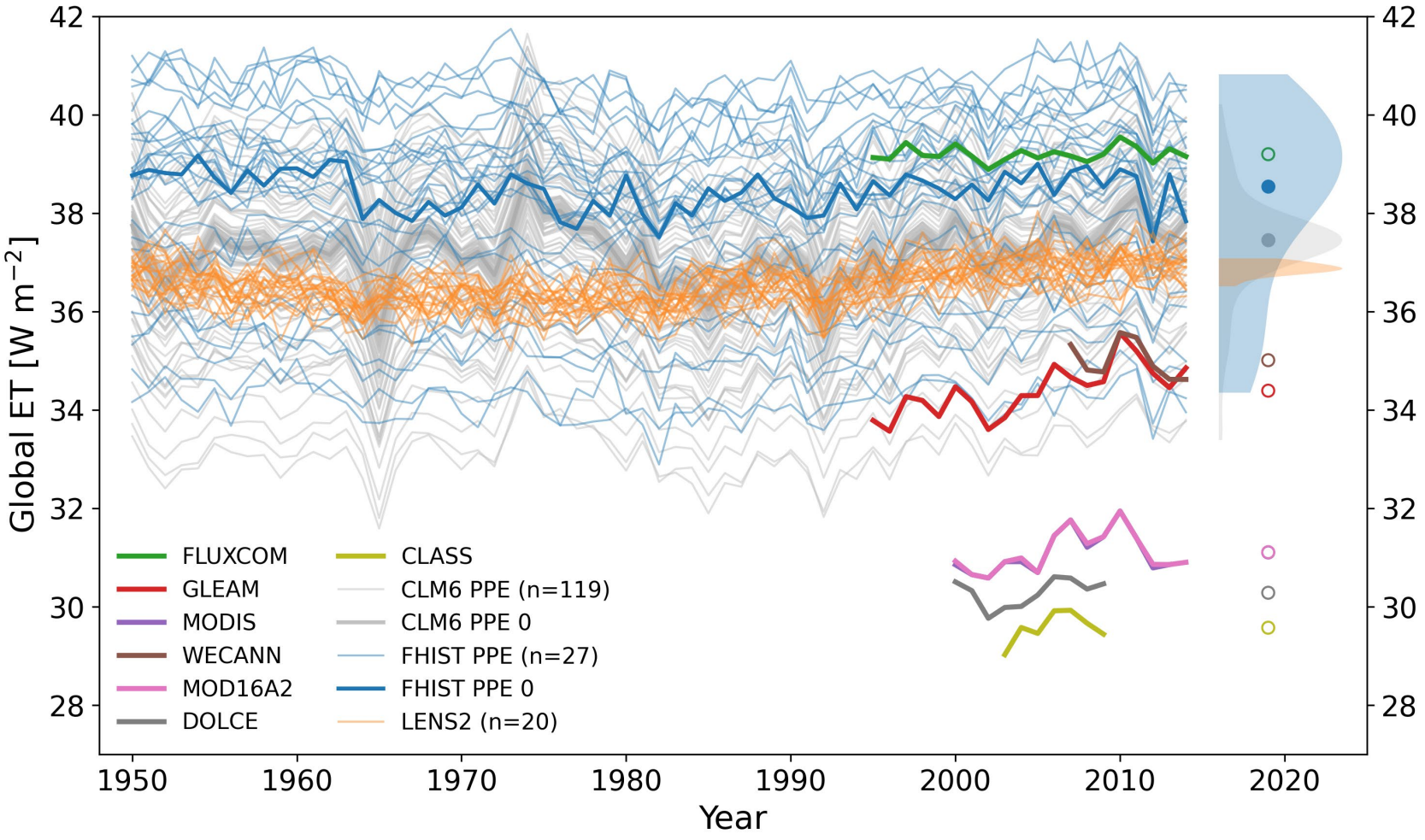
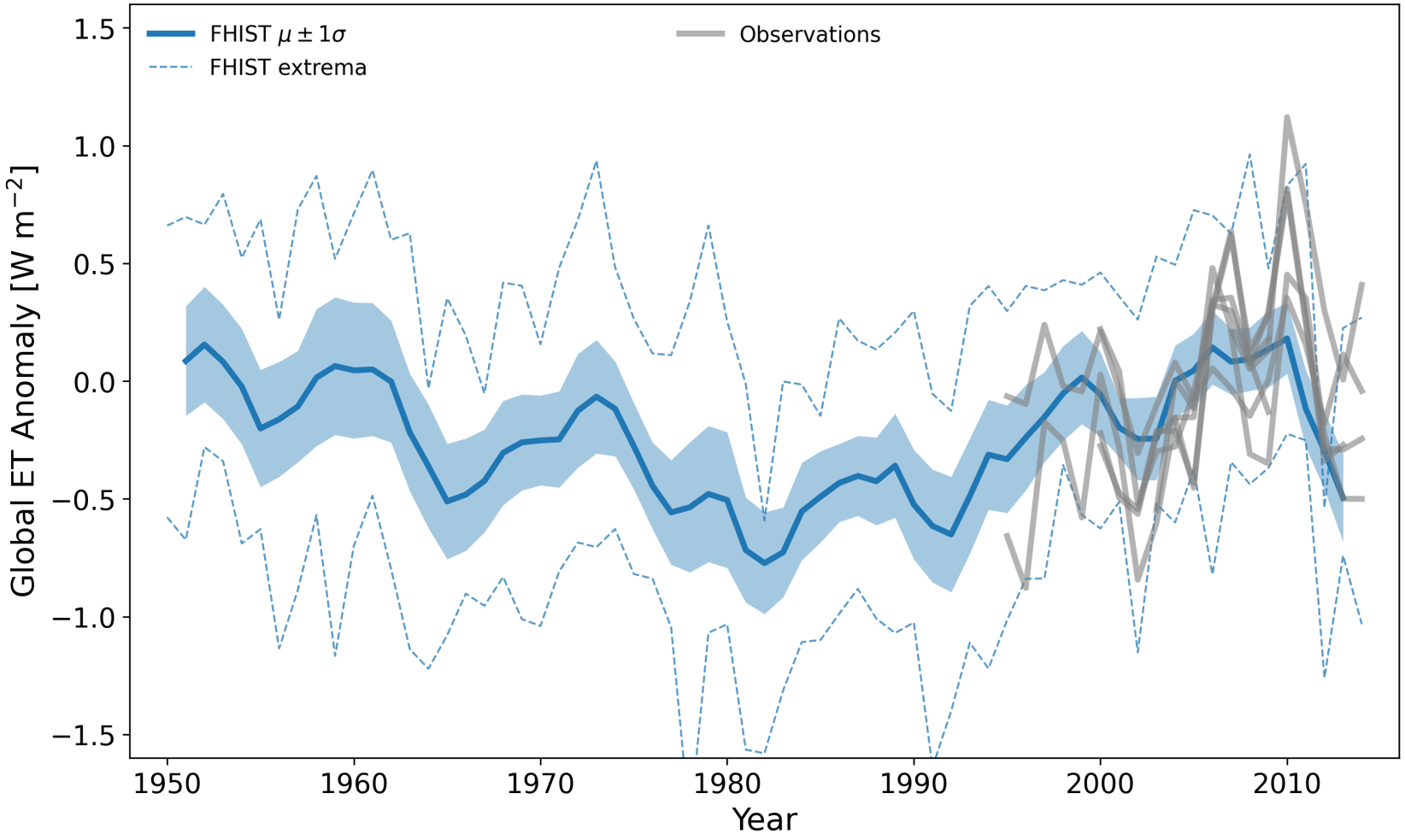


No meaningful difference in global-mean ET anomalies



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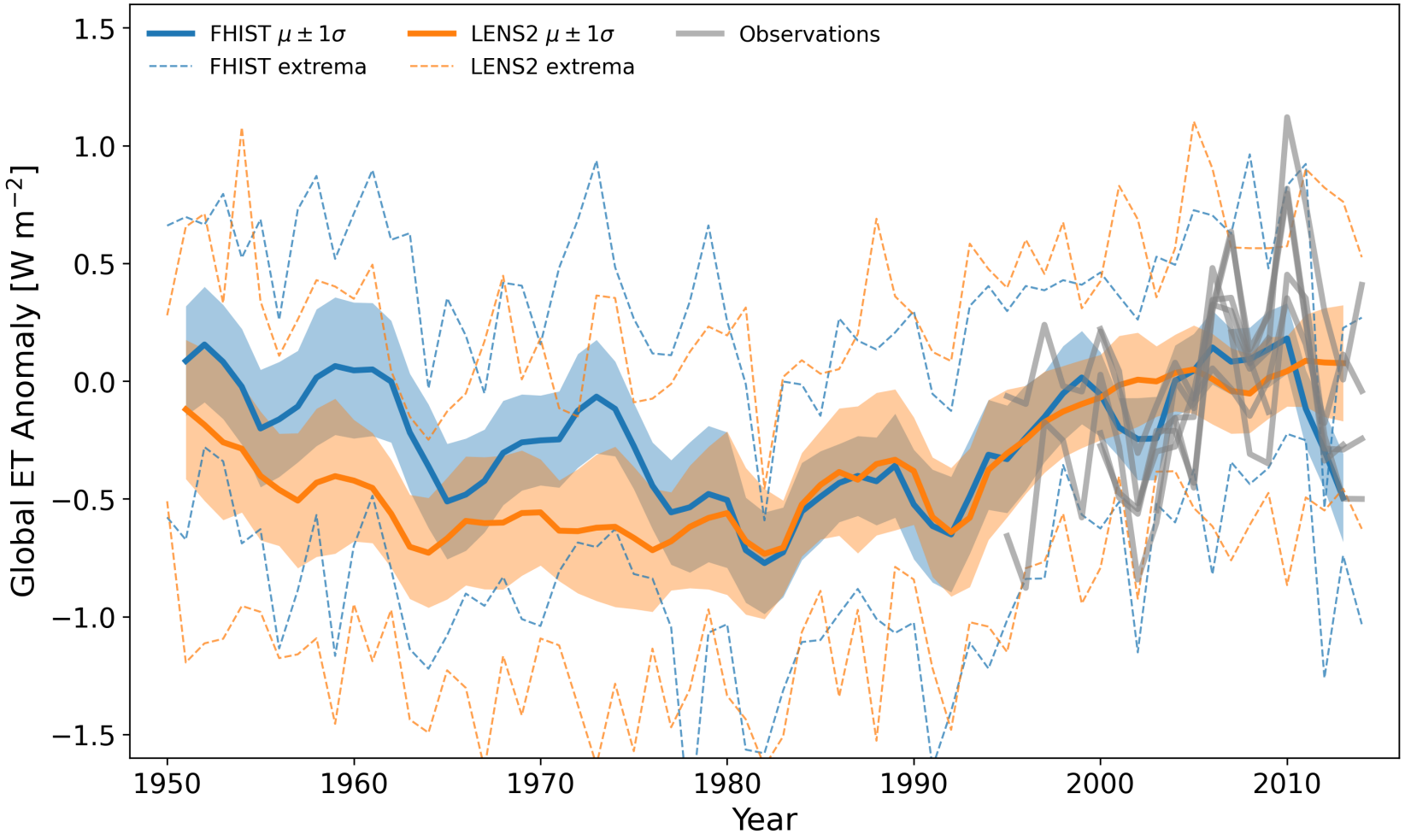

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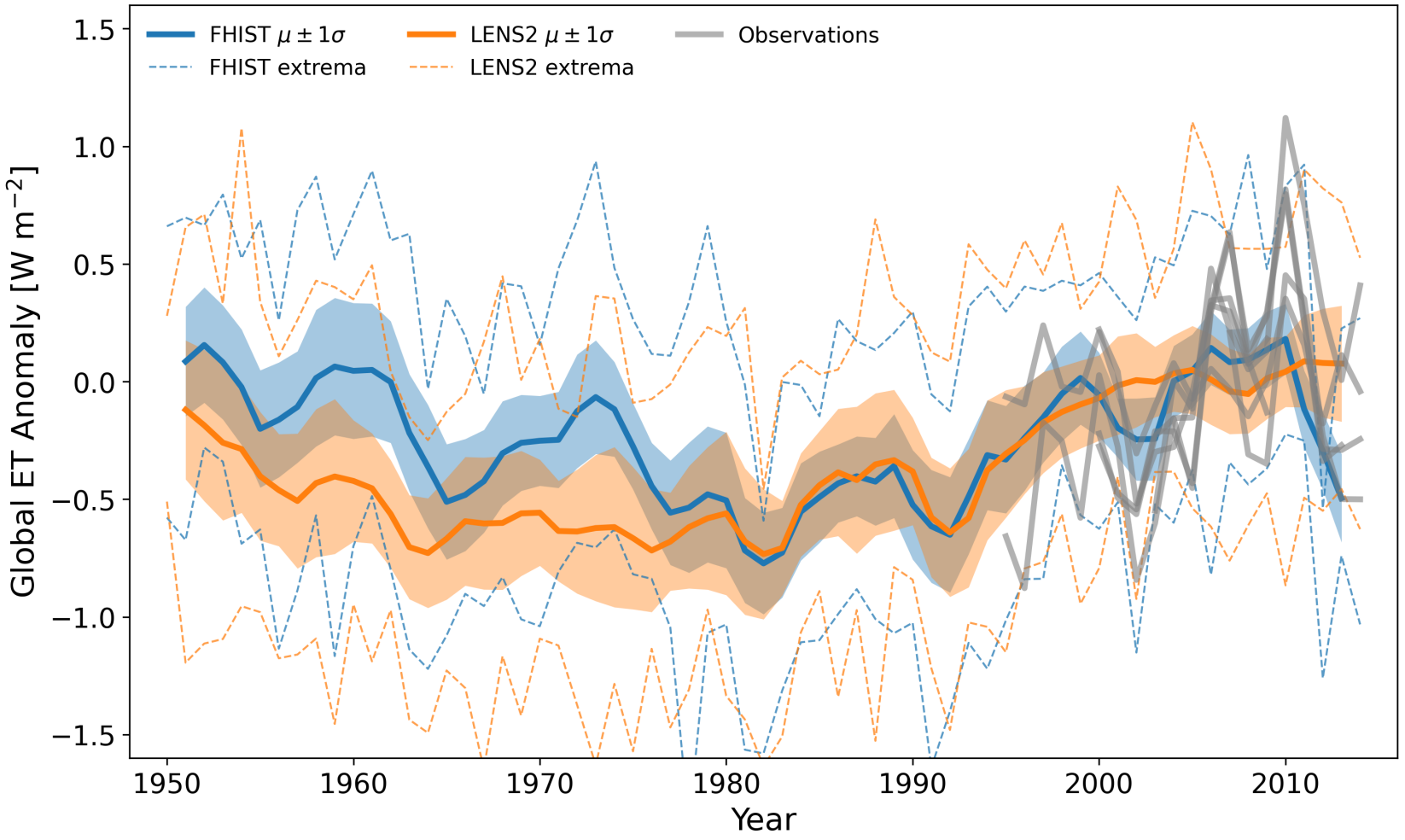
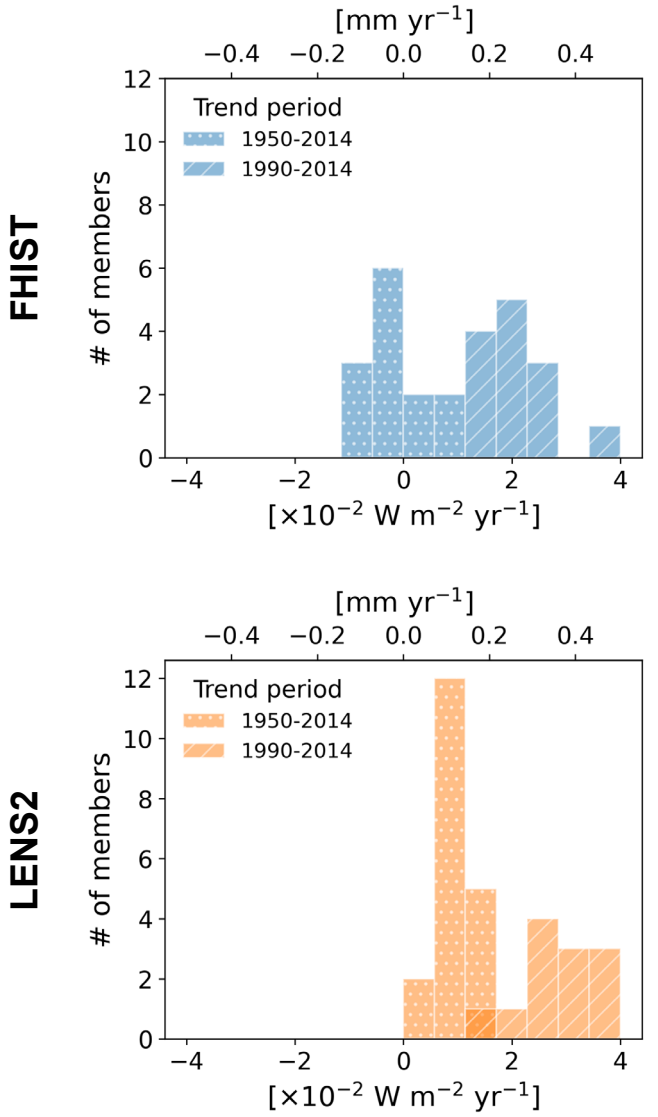
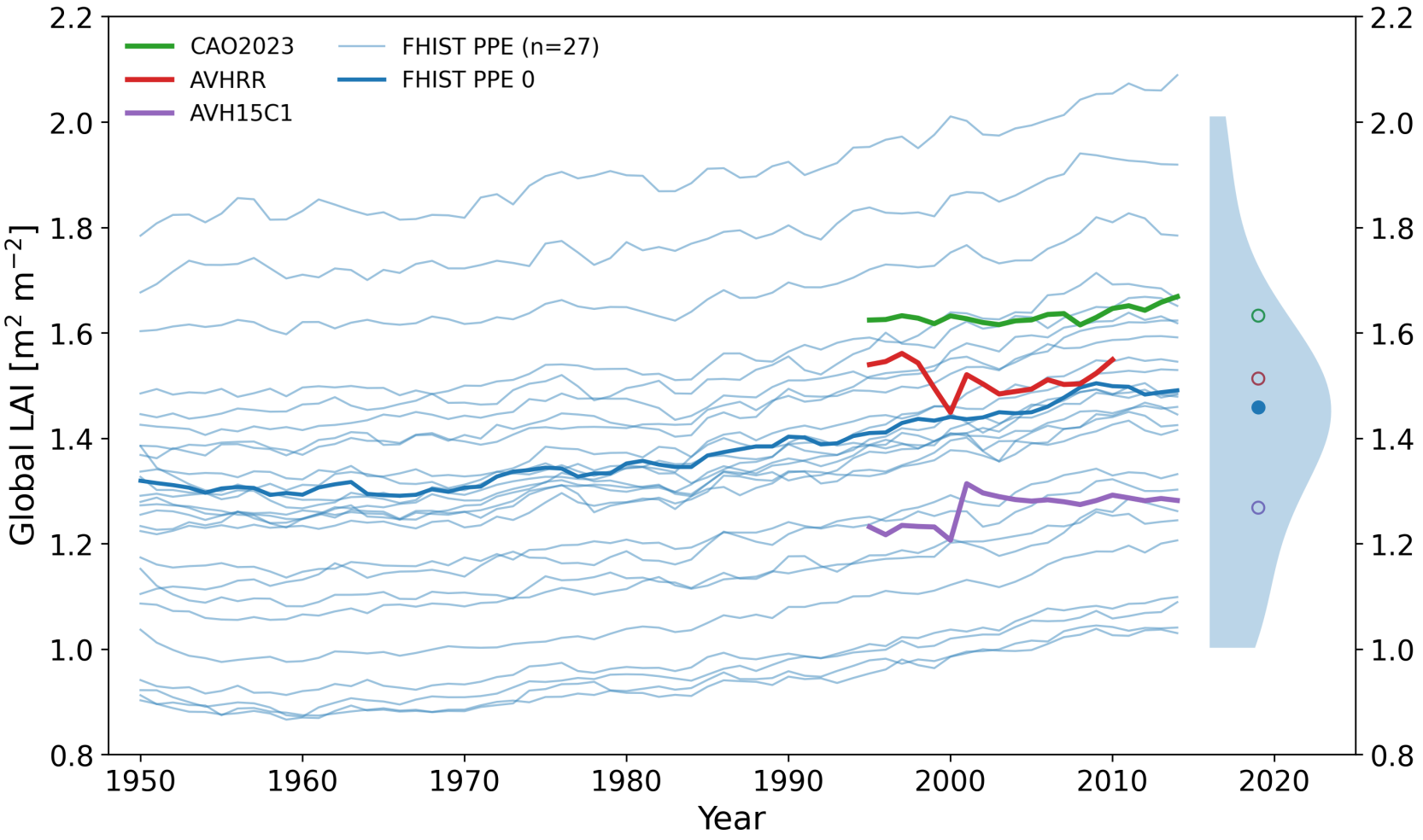




No significant difference in global-mean* ET trends

Large spread in global-mean LAI



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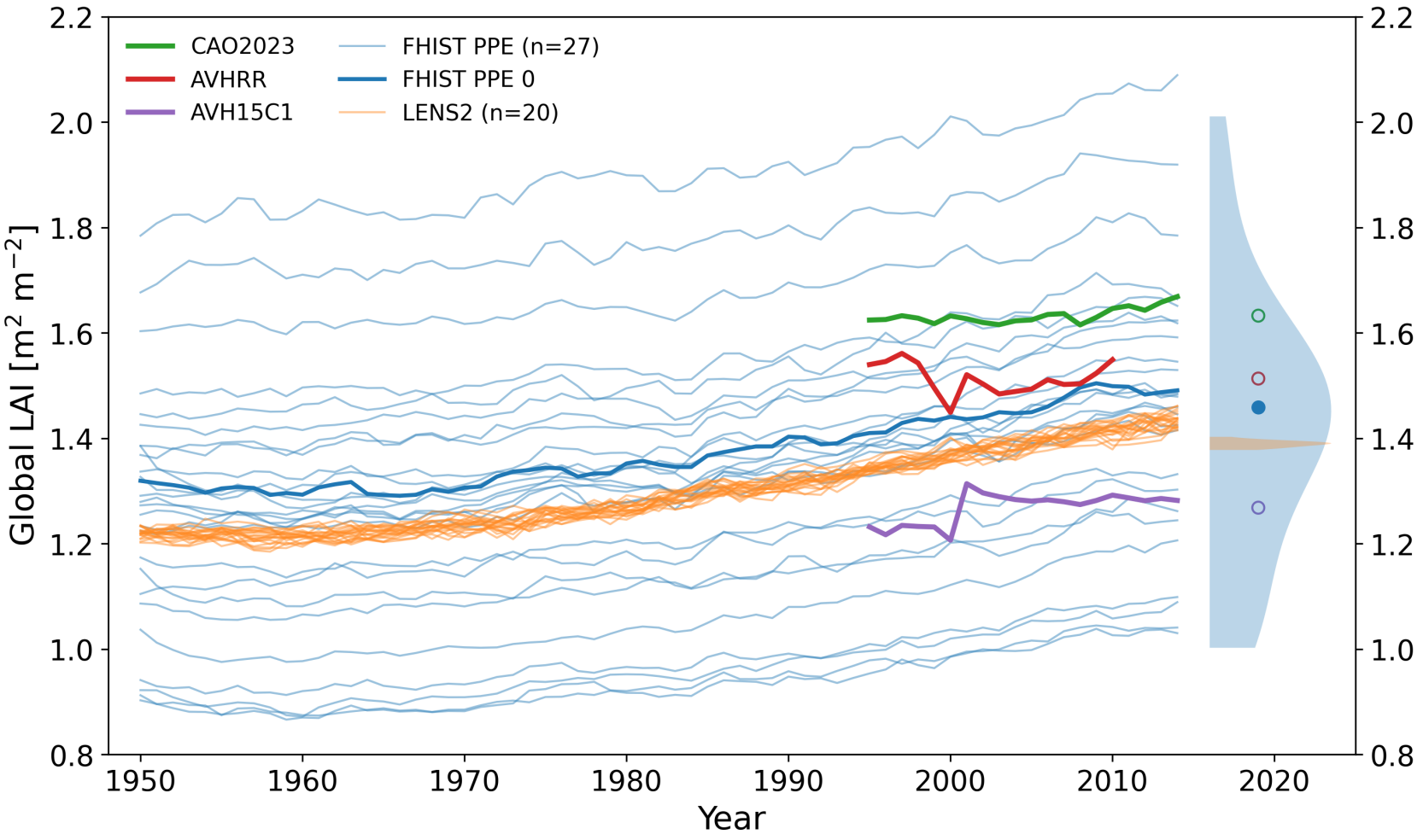
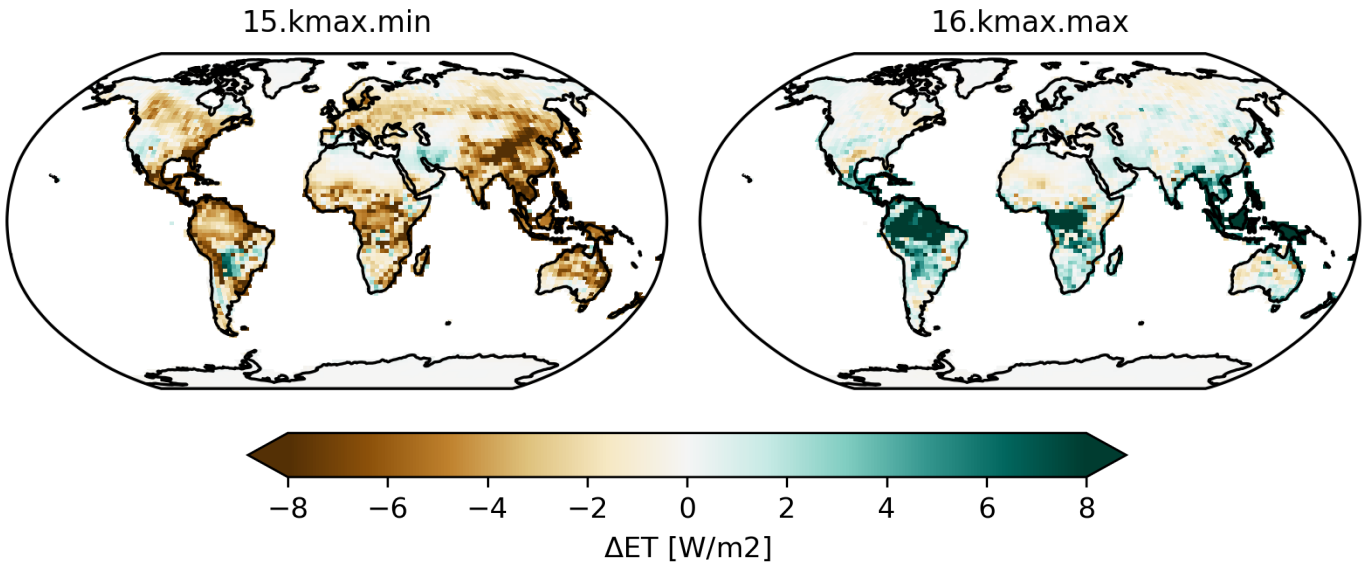
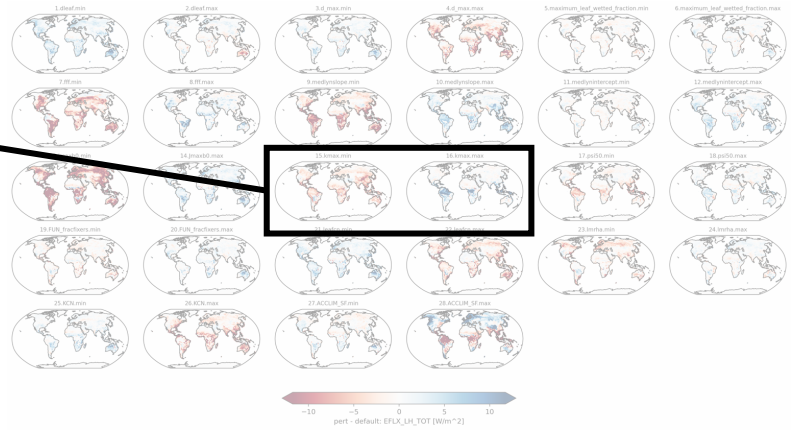


Where and how do parameter perturbations change ET?





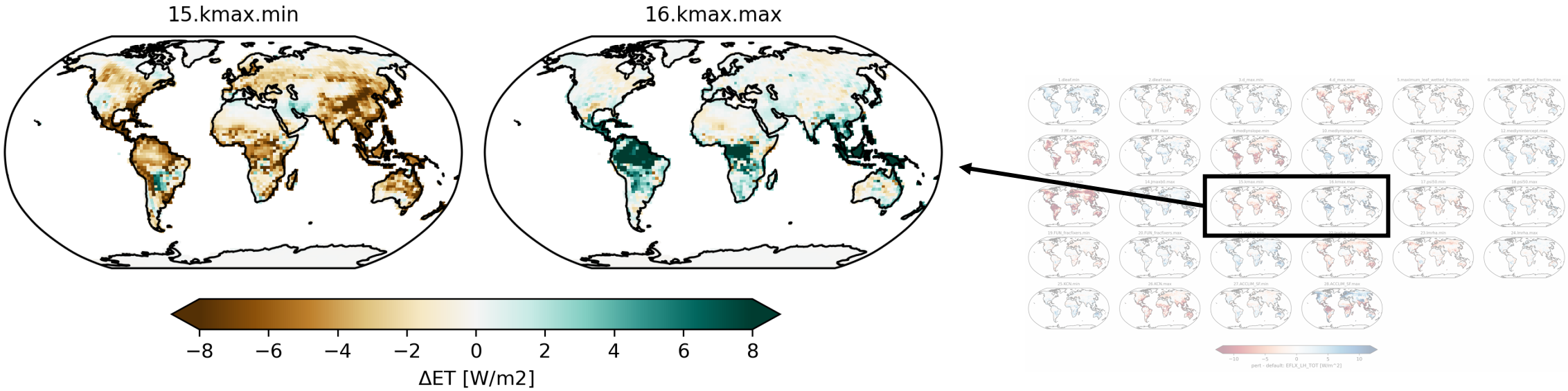
time mean from 1995-2014

Δ = (perturbed experiment) – (default experiment)

Where and how do parameter perturbations change ET?

Initial takeaways

- Nonlinear responses to min/max perturbations
- Strong compensation of ET components
- E.g., kmax (plant segment conductance) drives large changes in LAI, transpiration



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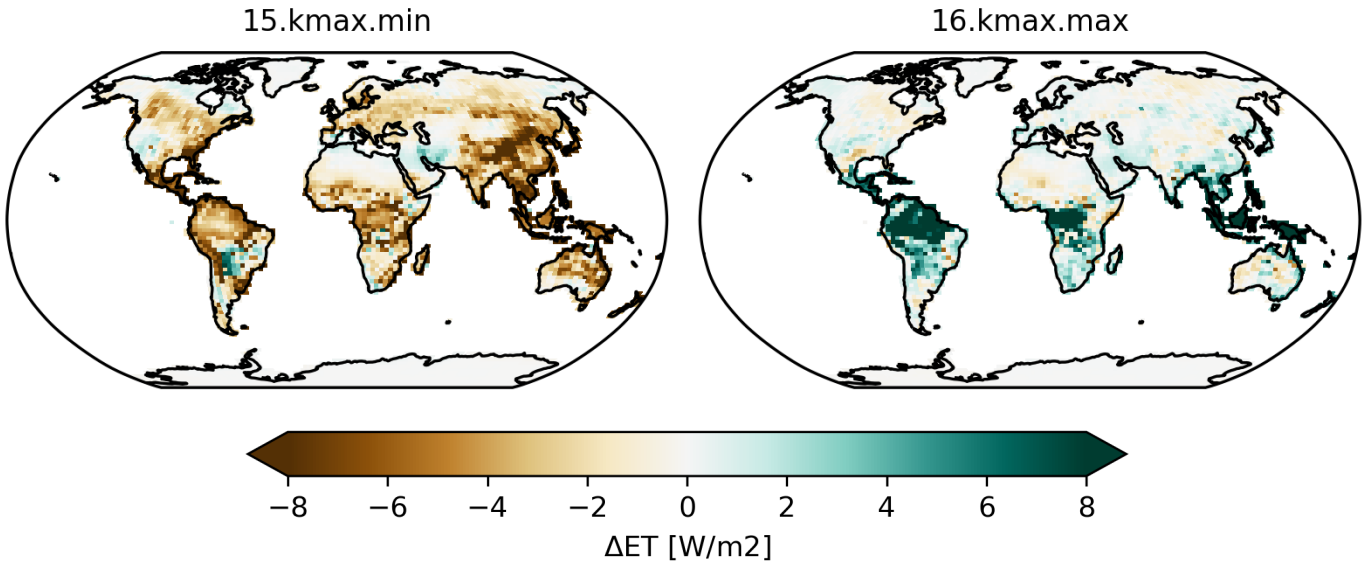


time mean from 1995-2014

Δ = (perturbed experiment) – (default experiment)

Difficult to compare across the ensemble…

Prior:

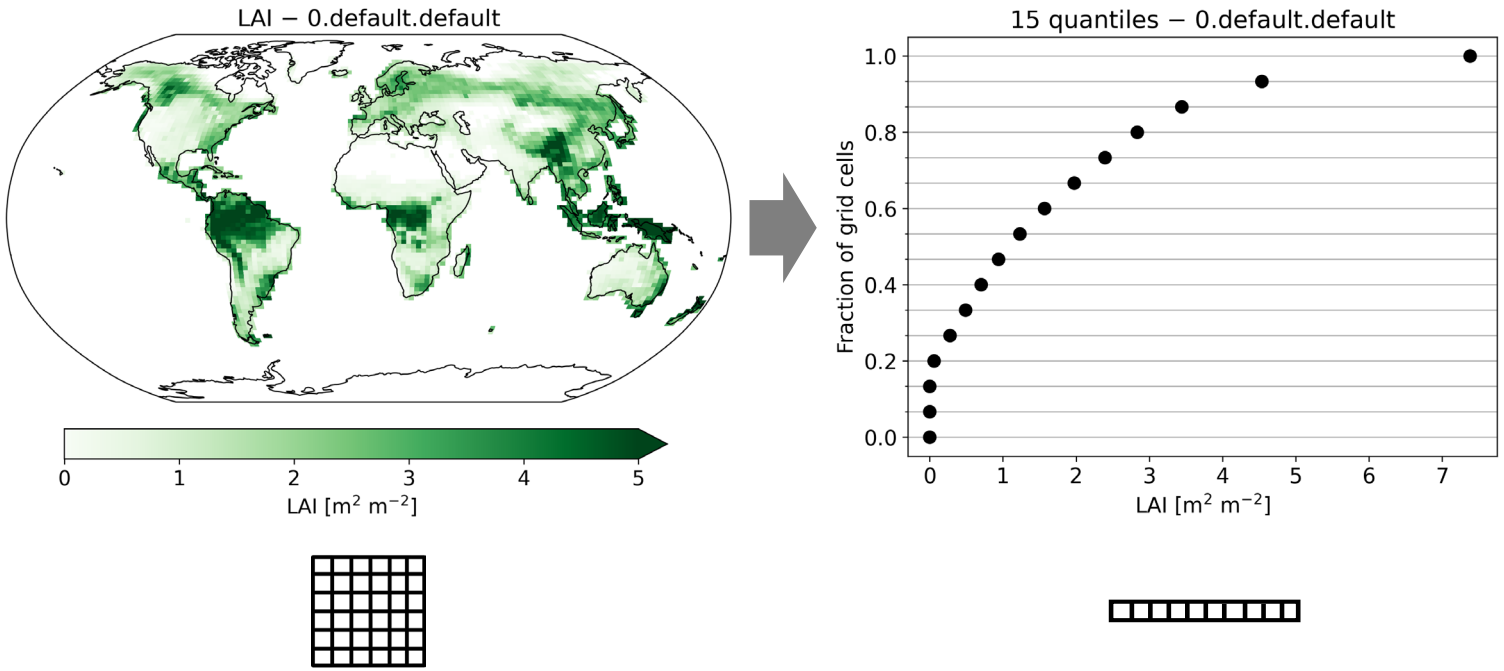
ET behaves differently depending on mean-state LAI and aridity

Transformation:

(lat-lon) ↦ (LAI-aridity)

climatological $\mathrm{AI} = R_{net}/L_v P$

Transforming from lat-lon to LAI-aridity space



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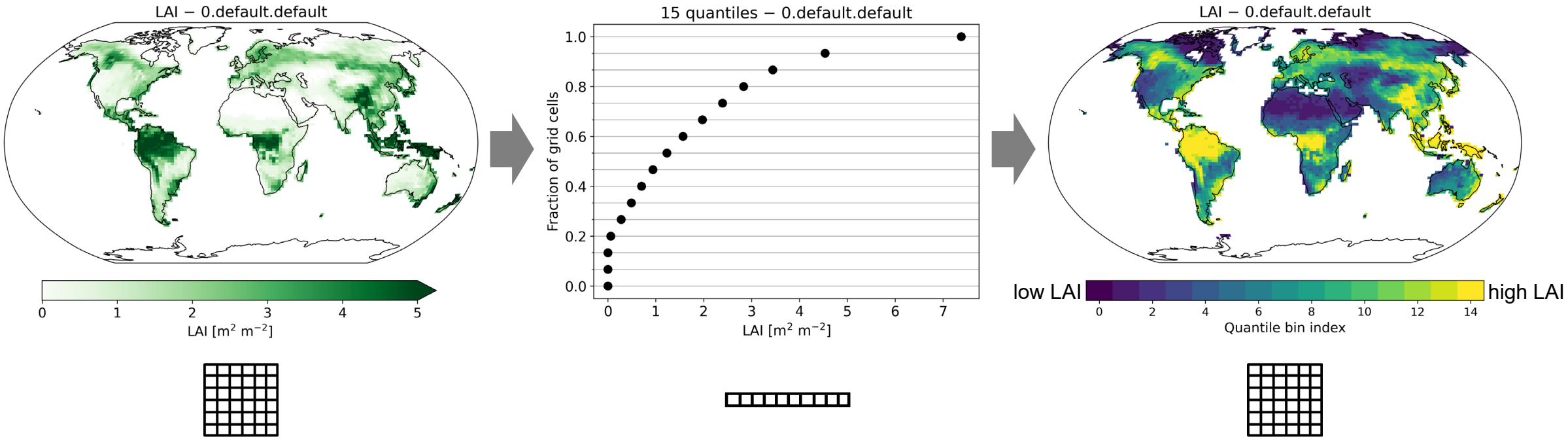

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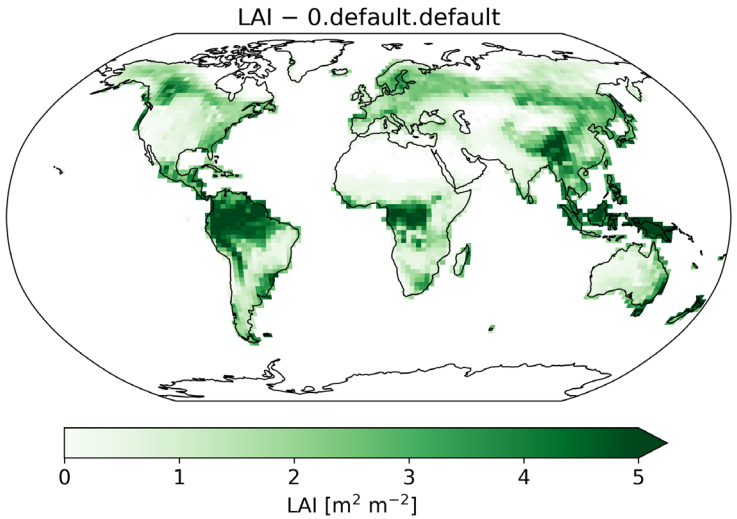

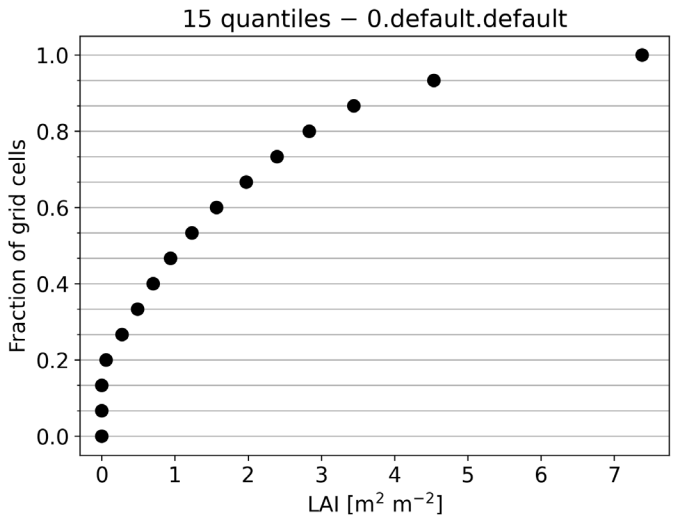

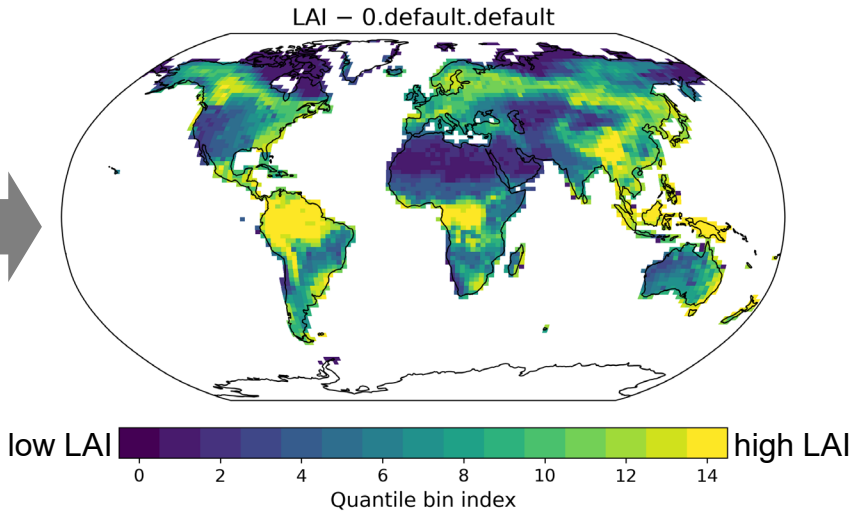

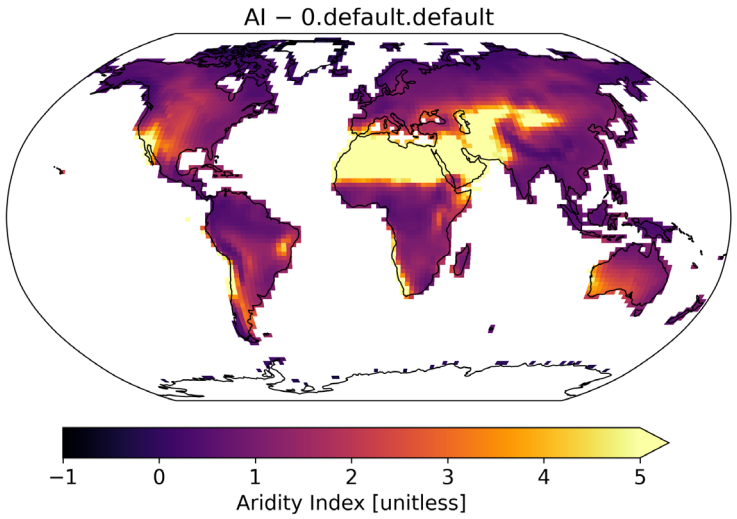

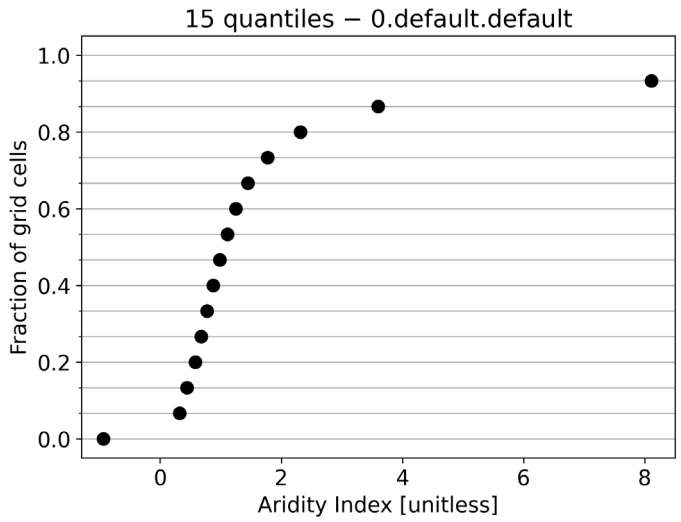

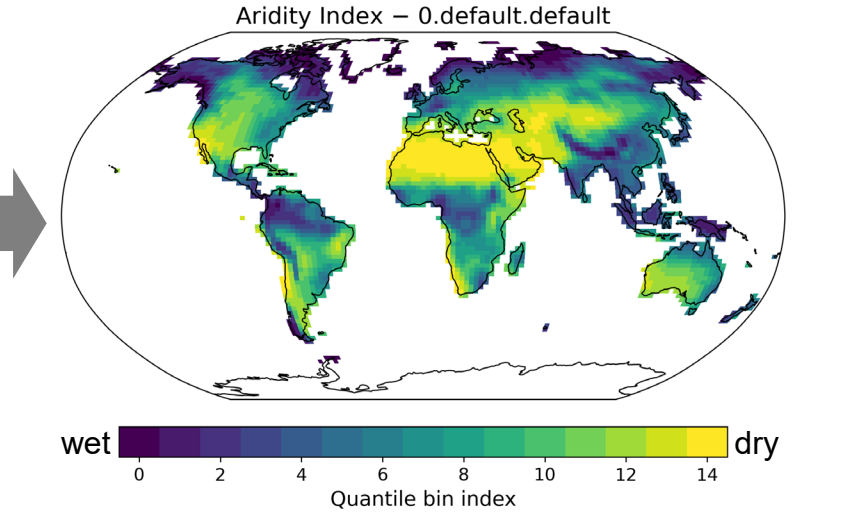

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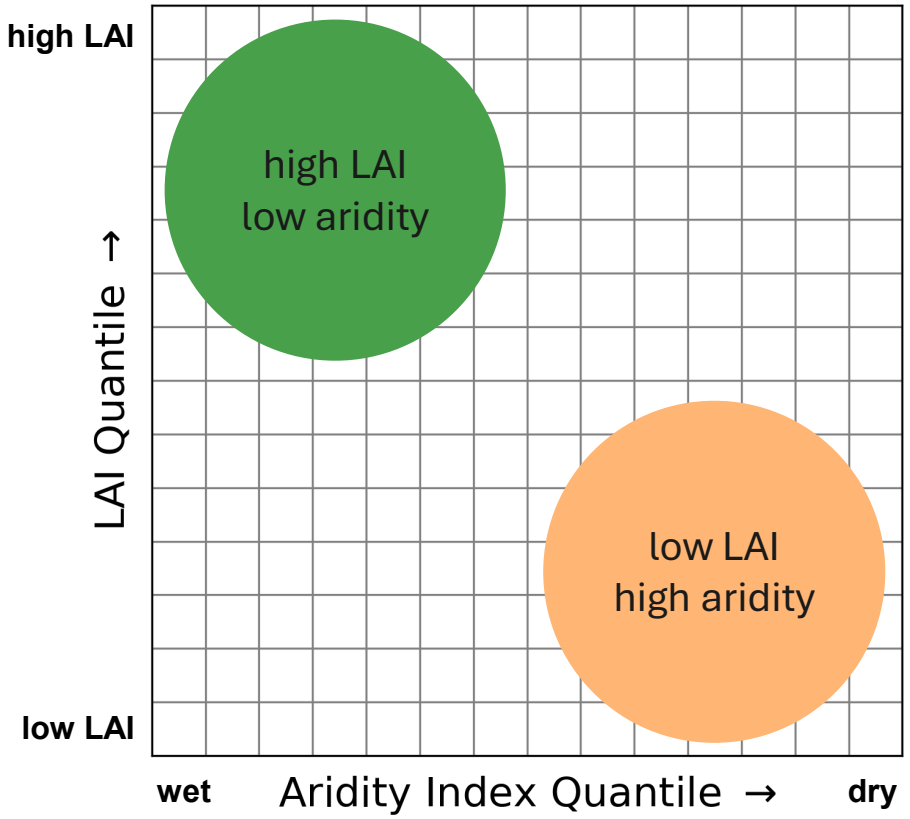

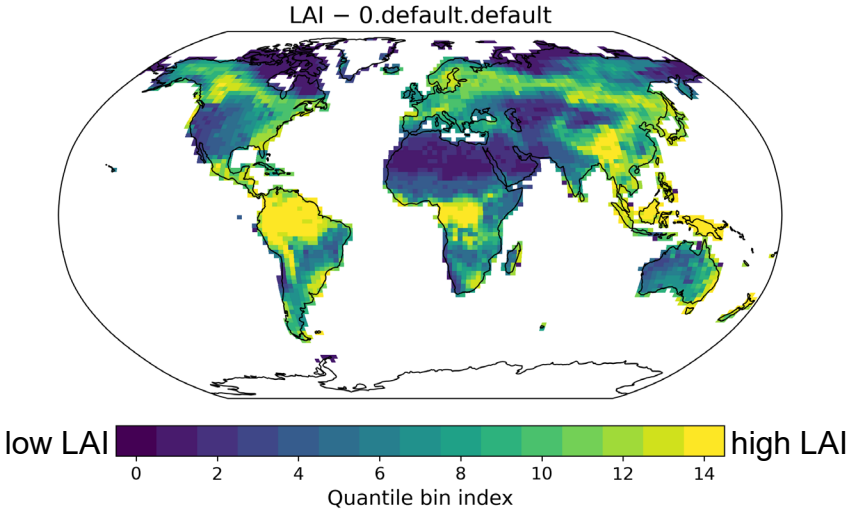

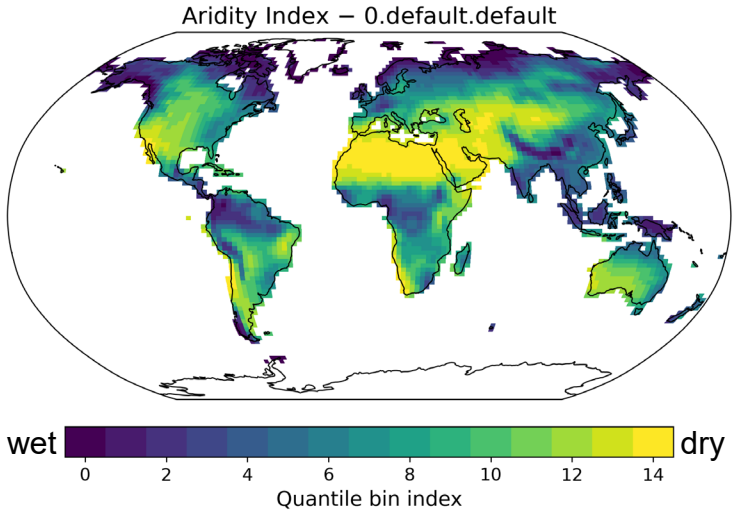

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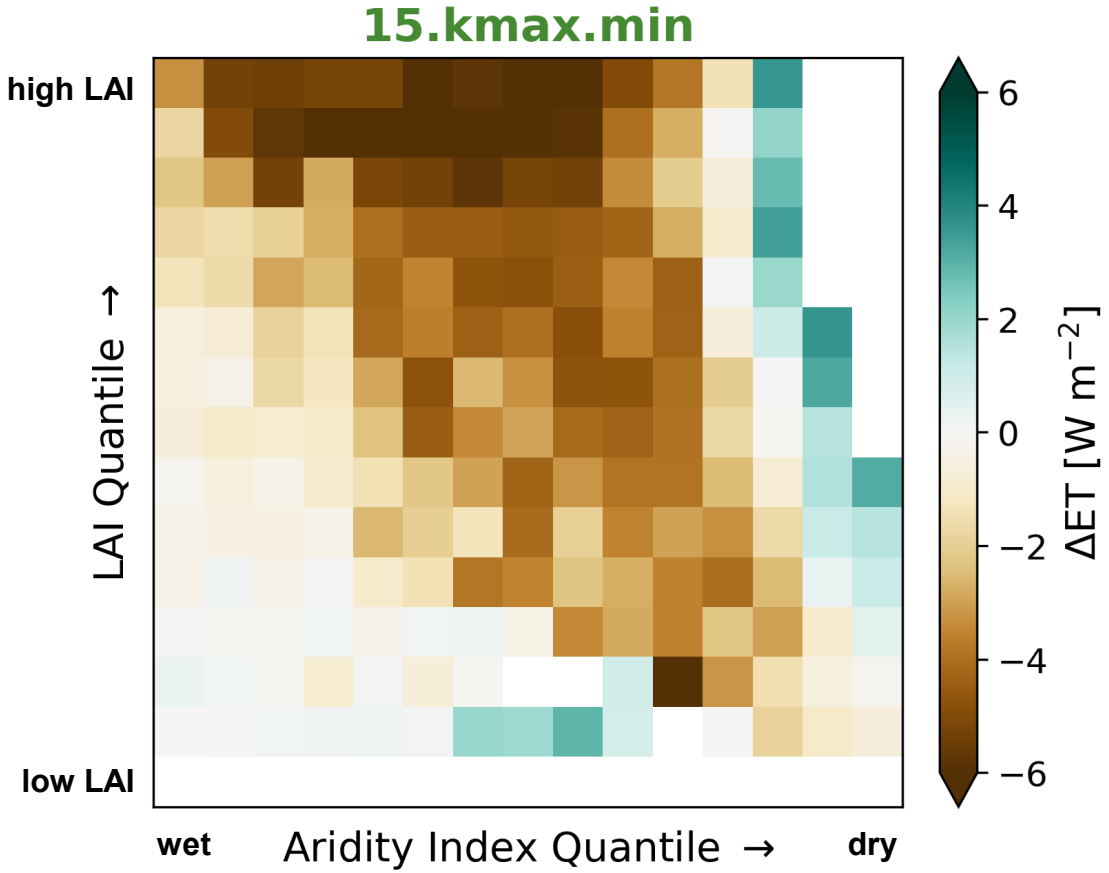
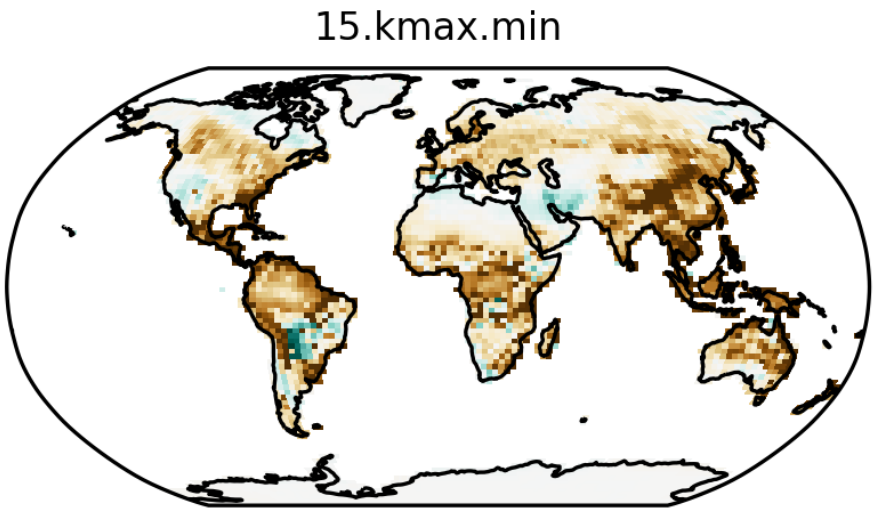
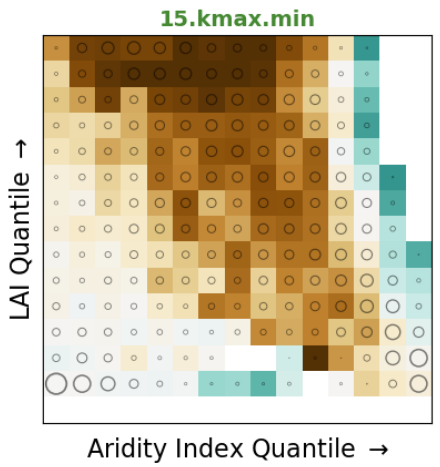
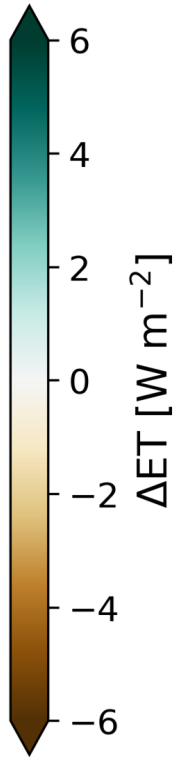




Different ΔET patterns emerge in LAI-aridity space





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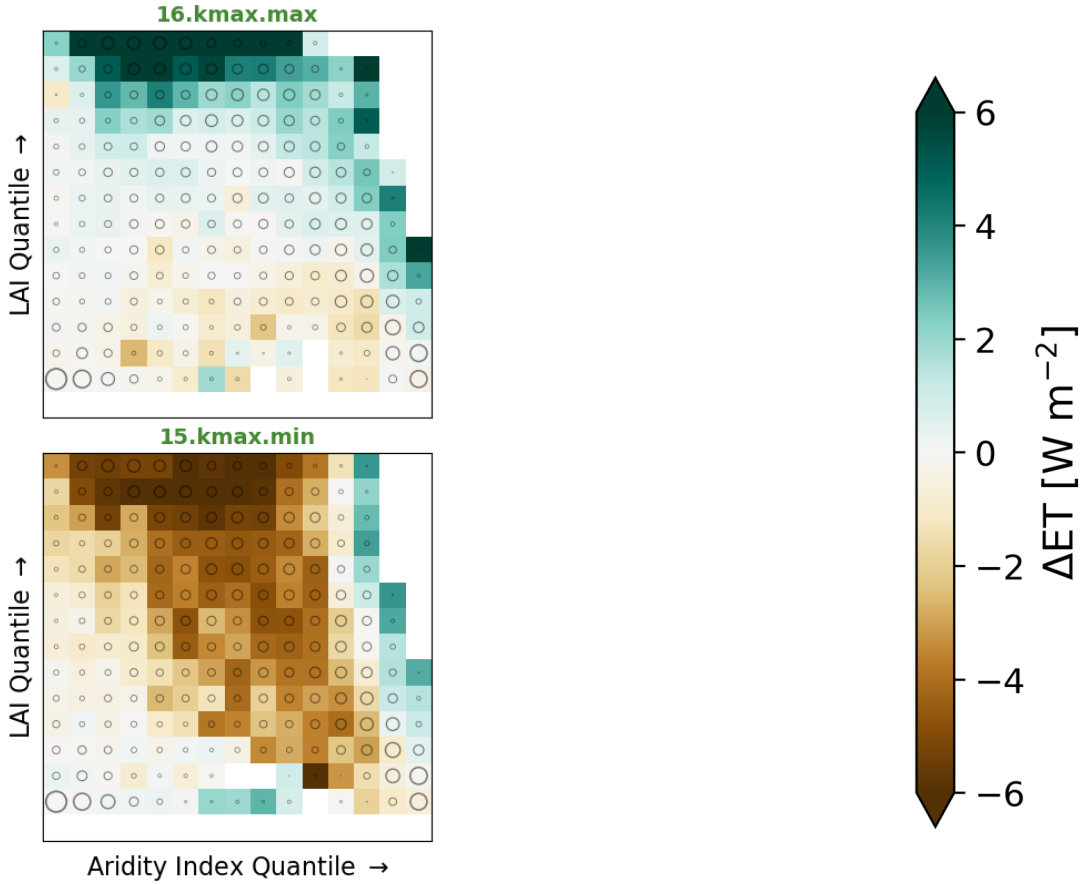

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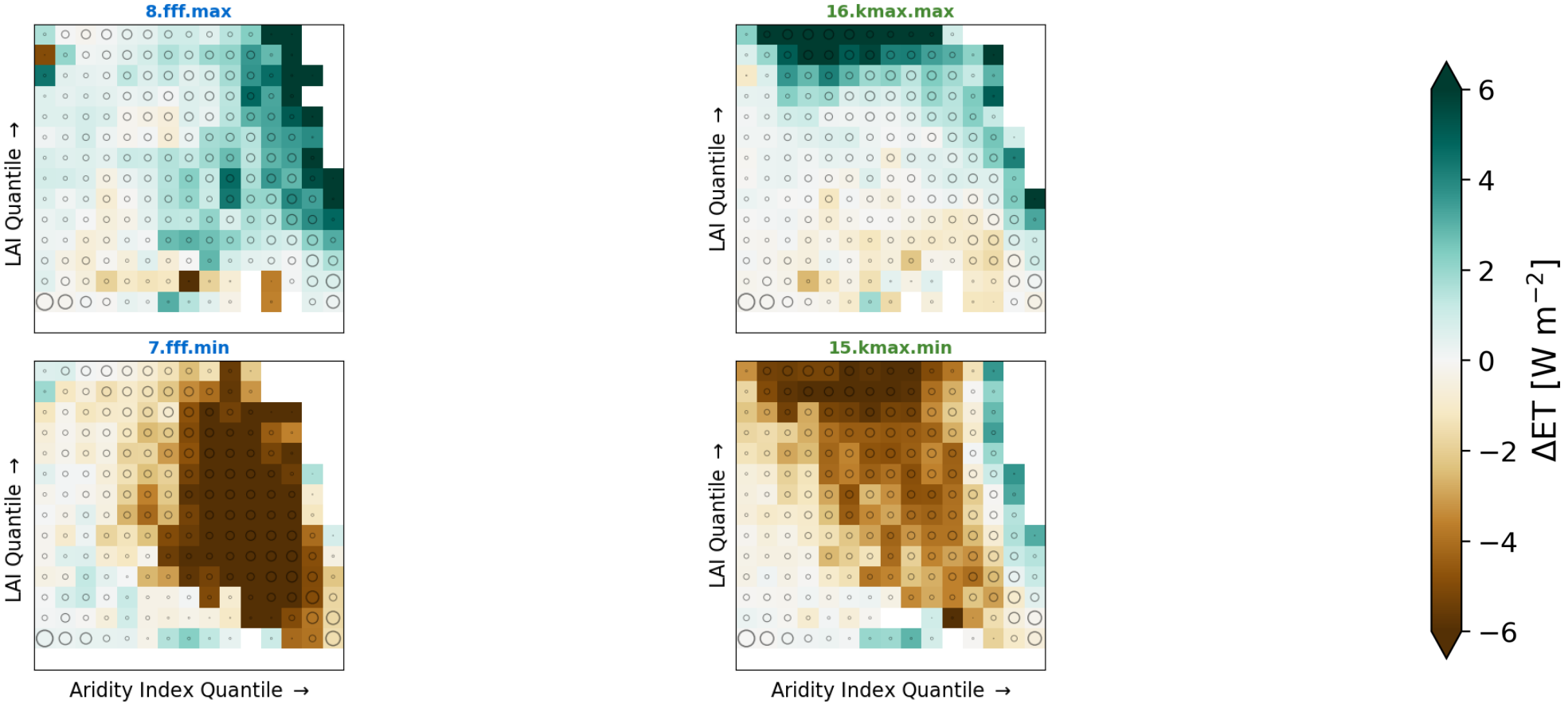

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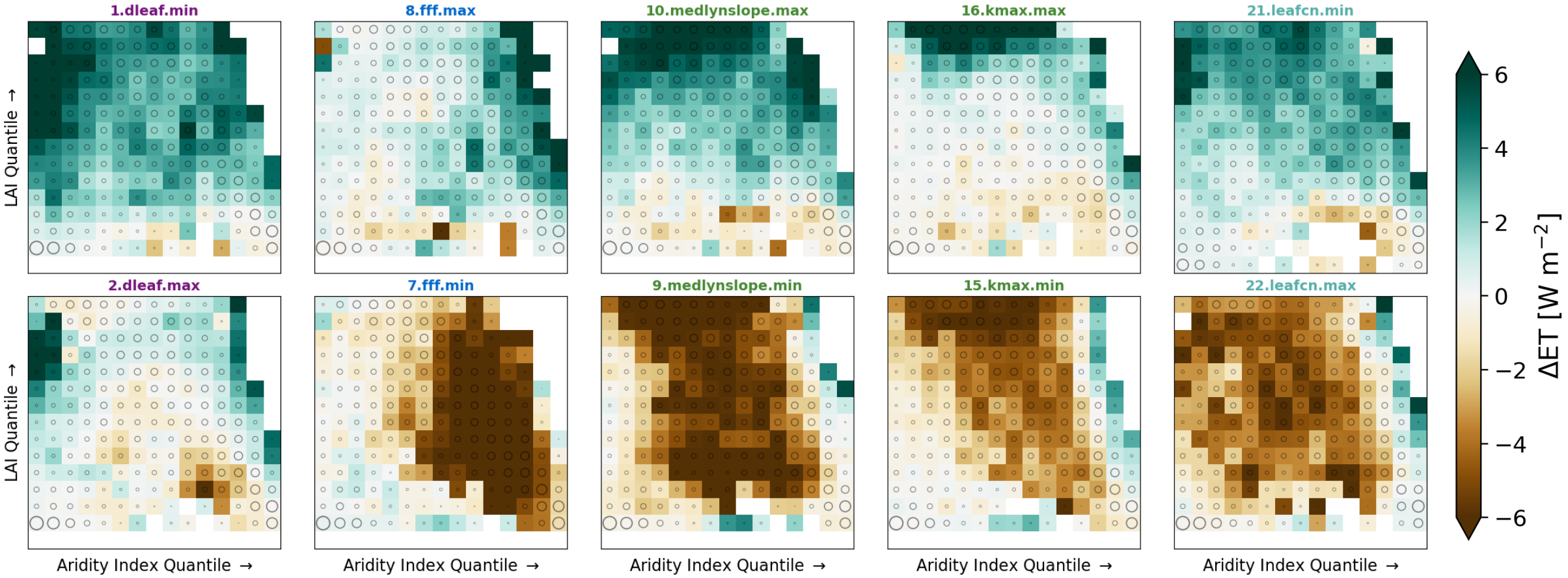
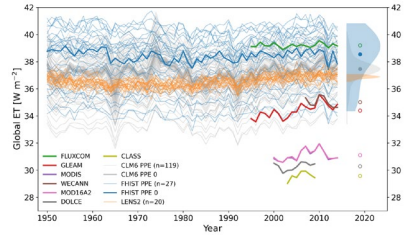
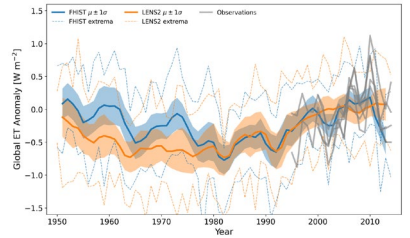


Key Takeaways

- Performed coupled historical PPE with prescribed SSTs
  - Large spread in mean land climate
  - No meaningful difference in global-mean trends





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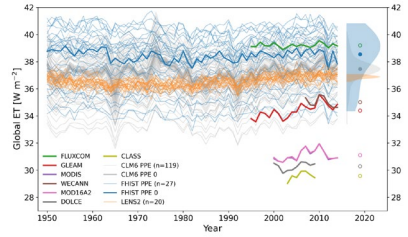
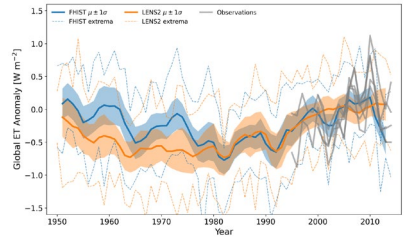
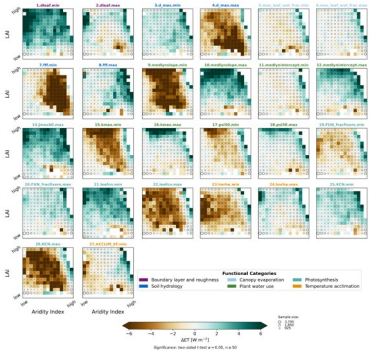
- Performed coupled historical PPE with prescribed SSTs
  - Large spread in mean land climate
  - No meaningful difference in global-mean trends
- Transforming lat-lon into LAI-aridity space reveals distinct patterns of parameter-driven ET change
  - Suggests diverse mechanisms
  - Maybe useful for model tuning

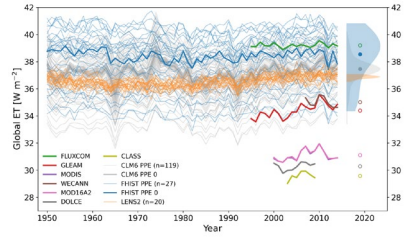


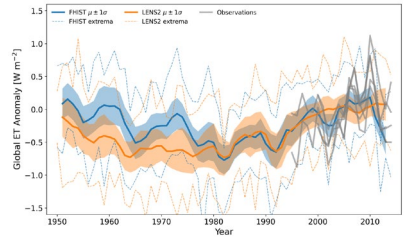


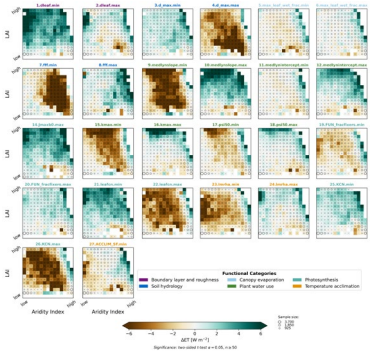


Key Takeaways

- Performed coupled historical PPE with prescribed SSTs
  - Large spread in mean land climate
  - No meaningful difference in global-mean trends
- Transforming lat-lon into LAI-aridity space reveals distinct patterns of parameter-driven ET change
  - Suggests diverse mechanisms
  - Maybe useful for model tuning
- *Moving forward:*
  - How do these patterns evolve seasonally? Arid vs. humid months?
  - Do future projections capture similar modes of ET variability in LAI-aridity space?
  - Where do regional ET trends differ? What mechanisms are responsible?







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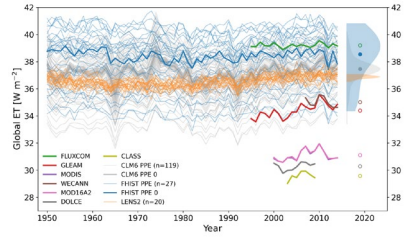
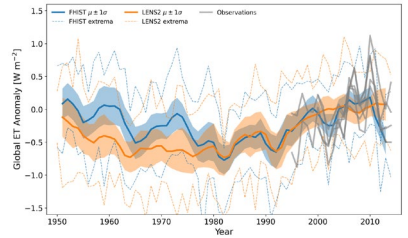
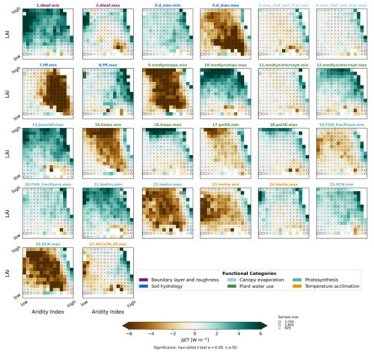






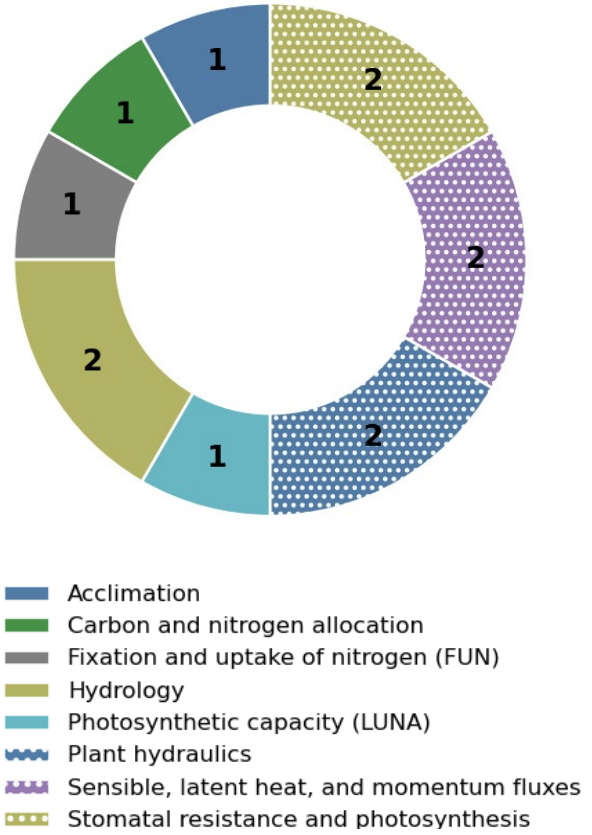
Thanks!

bbucho@uw.edu

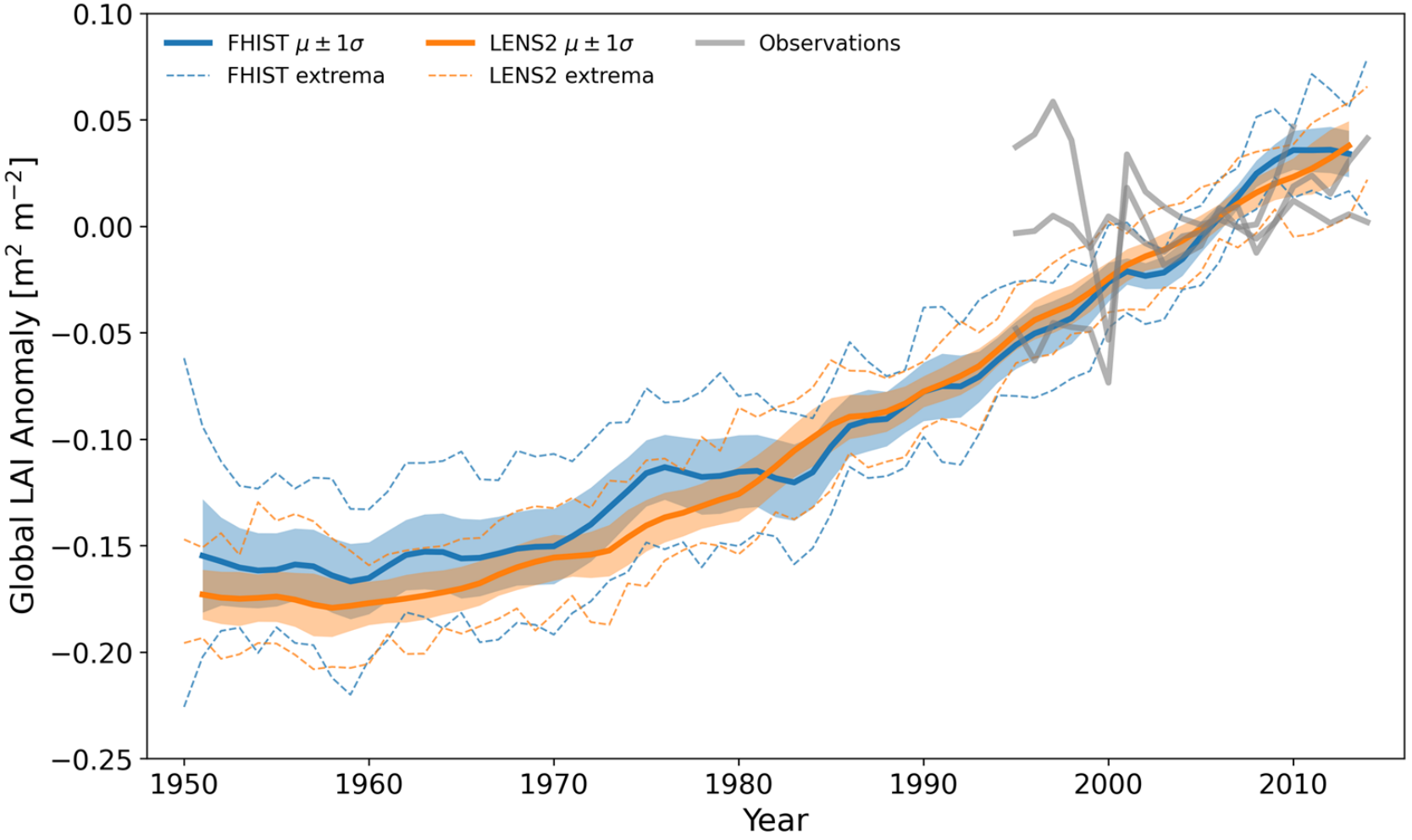
Supplemental Figures

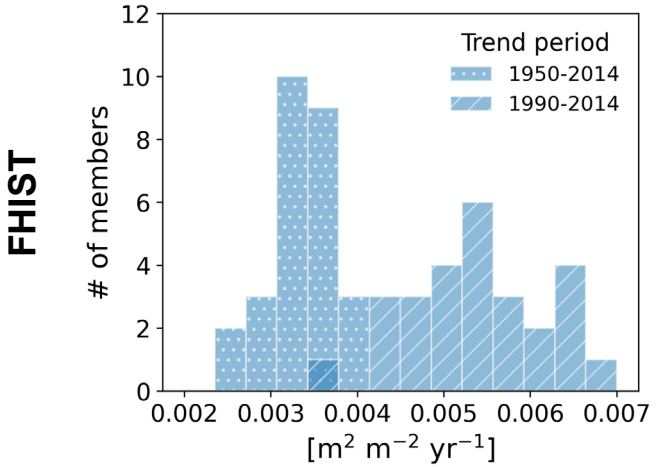
Perturbed parameters

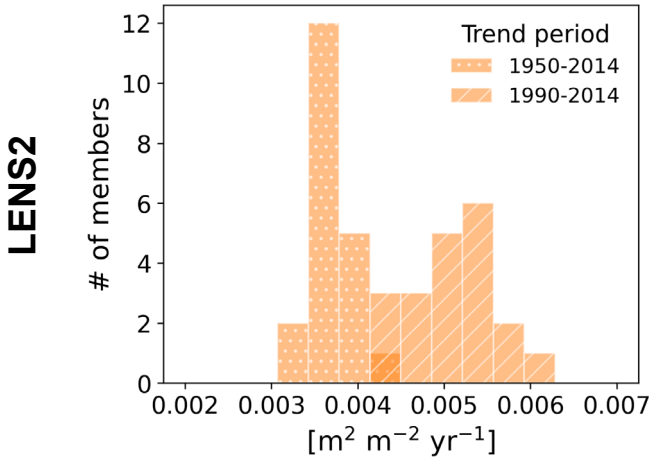
Name	Description	Category	Subcategory
fff	Decay factor for fractional saturated area	hydrology	soilwater
jmaxb0	the baseline proportion of nitrogen allocated for electron transport (J)	stomatal	luna
medlynslope	Medlyn slope of conductance-photosynthesis relationship	stomatal	vegwater
medlynintercept	Medlyn intercept of conductance-photosynthesis relationship	stomatal	vegwater
maximum_leaf_wetted_fraction	Maximum fraction of leaf that may be wet prior to drip occuring	biophysics	latent
kmax	Plant segment max conductance	stomatal	vegwater
leafcn	Leaf C:N	bgc	allocation
d_max	Dry surface layer (DSL) parameter	hydrology	soilwater
psi50	Water potential at 50% loss of conductance	stomatal	vegwater
dleaf		biophysics	latent
lmrha	activation energy for lmr	stomatal	acclimation
FUN_fracfixers	fraction of carbon available for N fixation	bgc	fun
KCN	kc_nonmyc, kn_nonmyc , akc_active, akn_active, ekc_active, akn_active	bgc	fun
ACCLIM_SF	vcmaxse_sf, jmaxse_sf, tpuse_sf	stomatal	acclimation



No meaningful difference in global-mean LAI anomalies

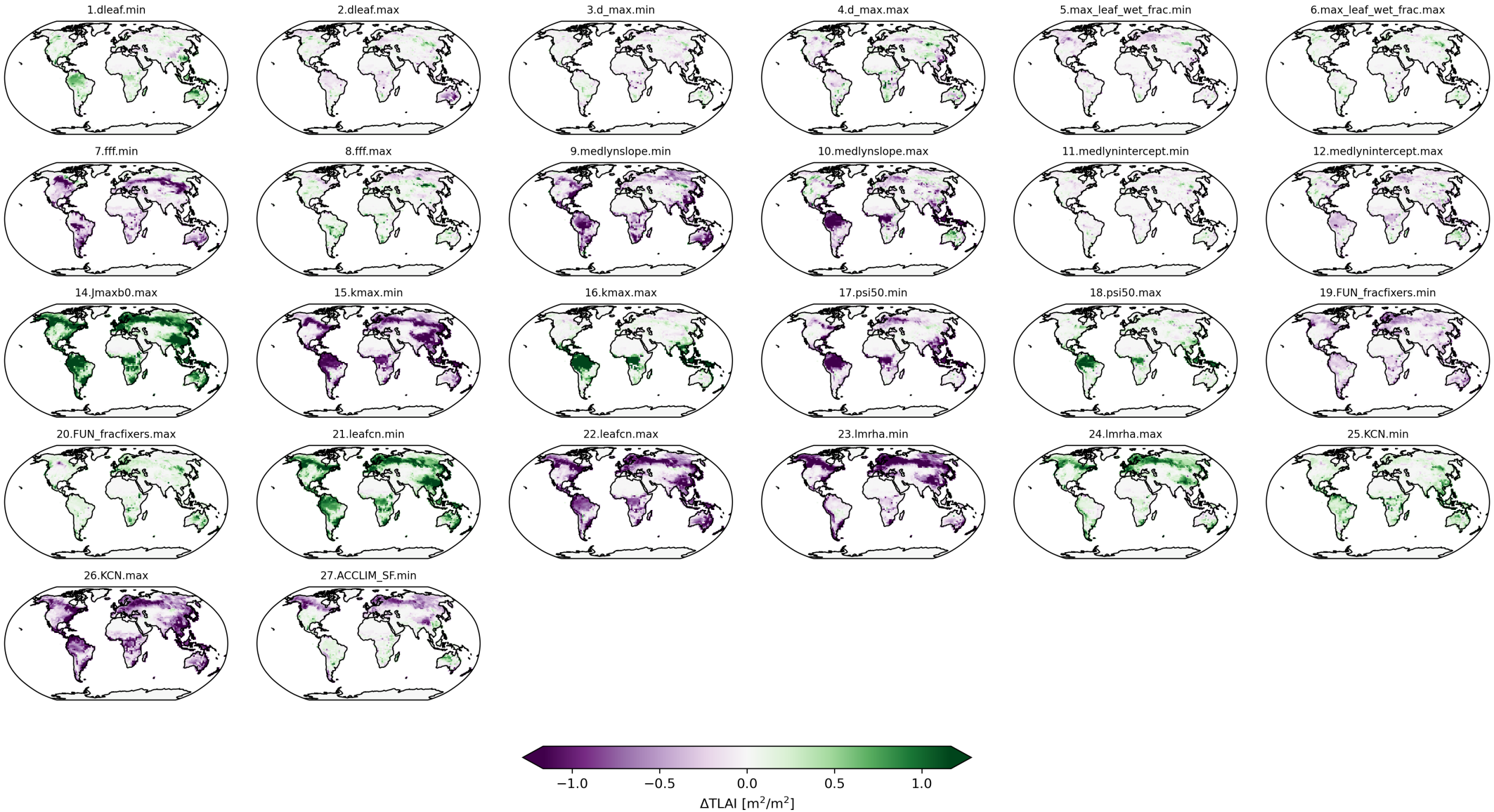




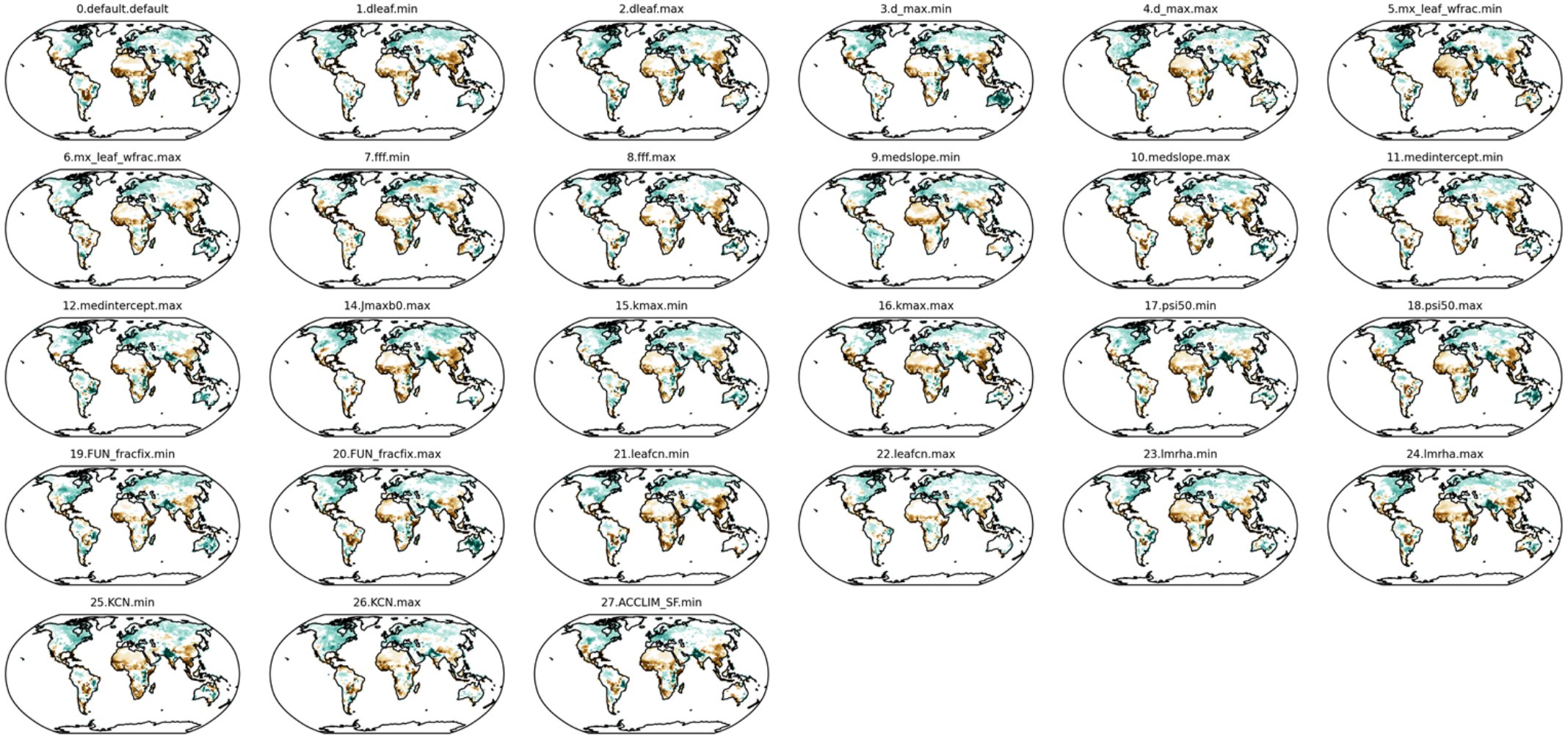


No significant difference in global-mean LAI trends

Time-mean 1995-2014 maps of ΔLAI

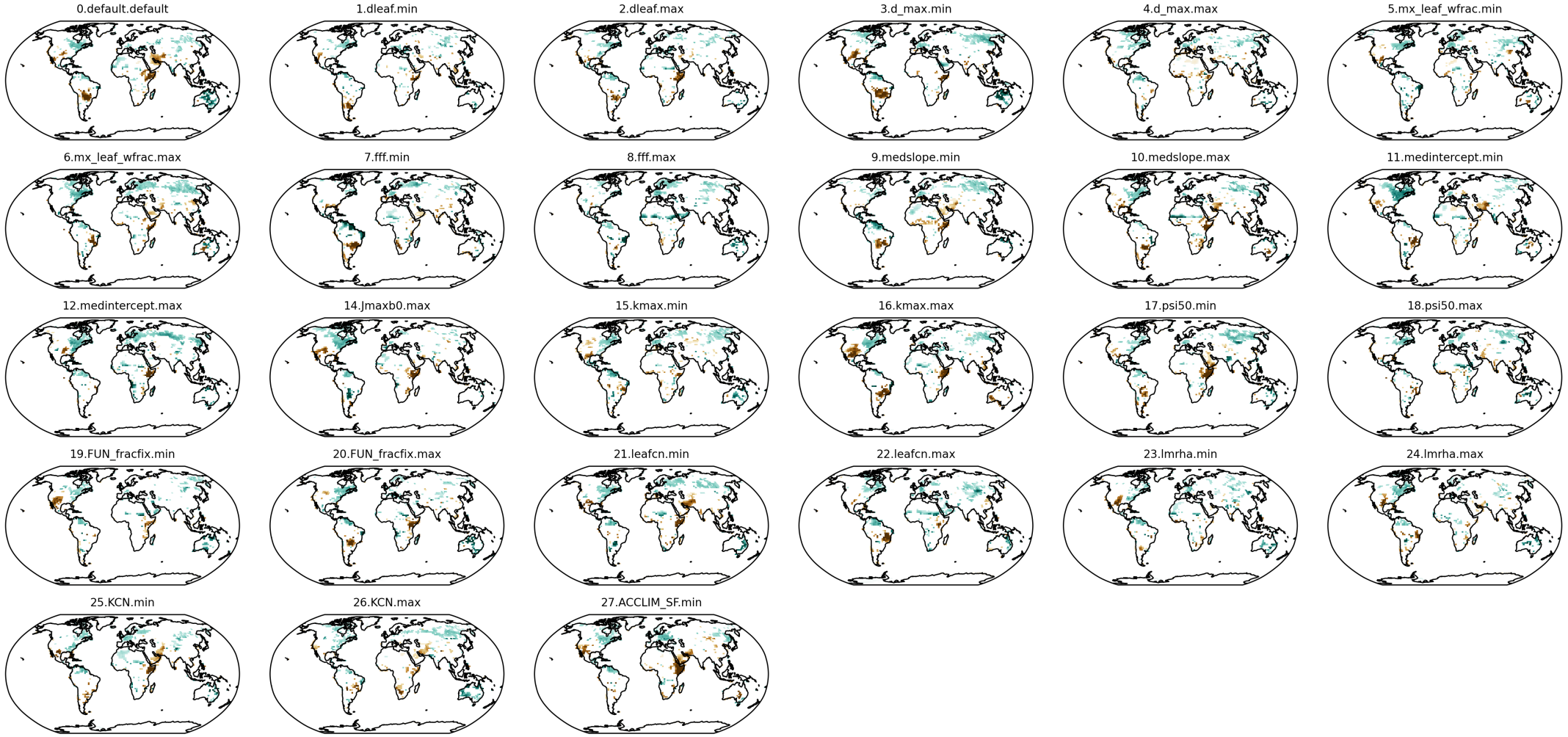


ET trend over **1950-2014**



$12.6\ \text{mm yr}^{-1} \approx 1\ \text{W m}^{-2}$

ET trend over **1990-2014**



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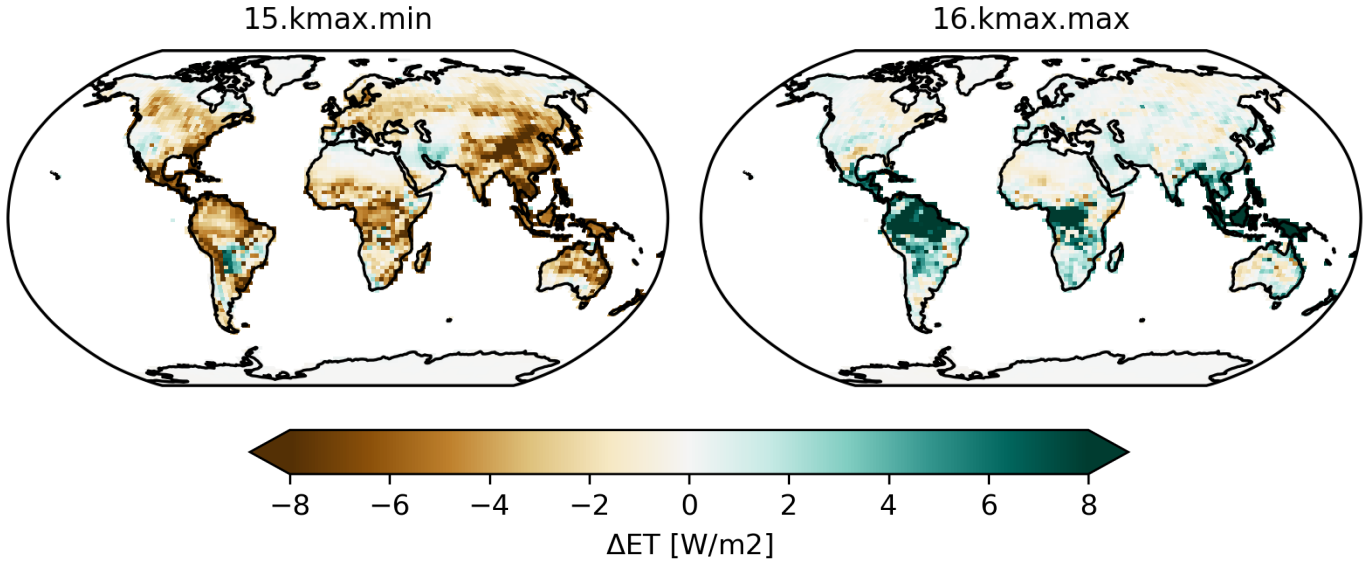
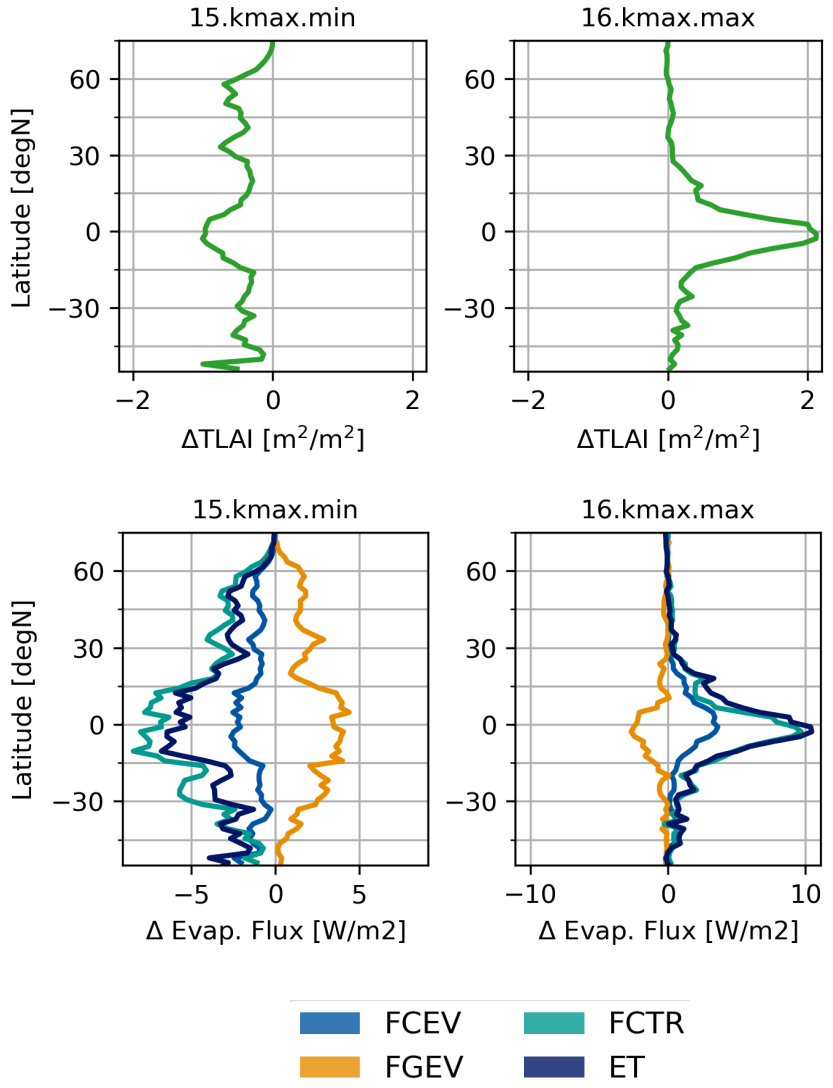
false discovery rate controlled at $\alpha = 0.05$

Large range of changes to ET partitioning





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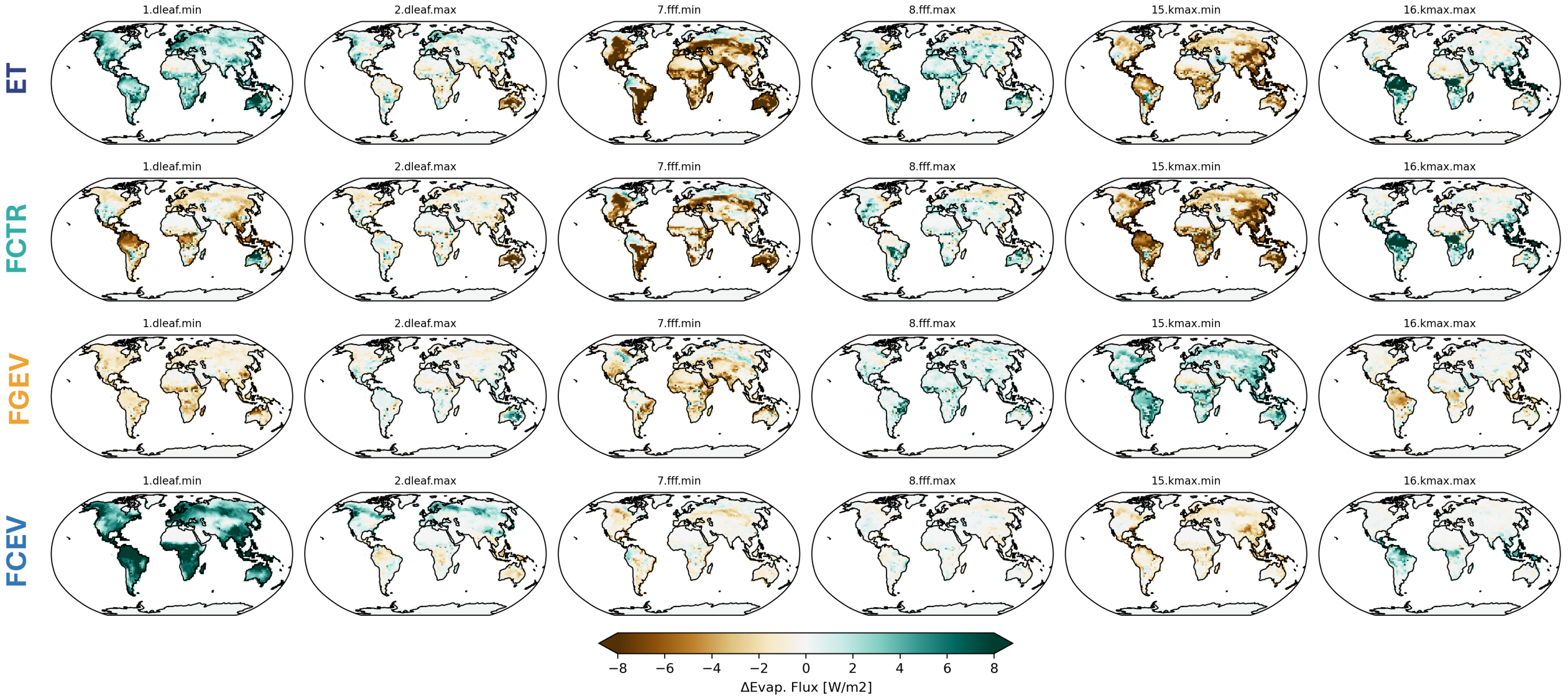

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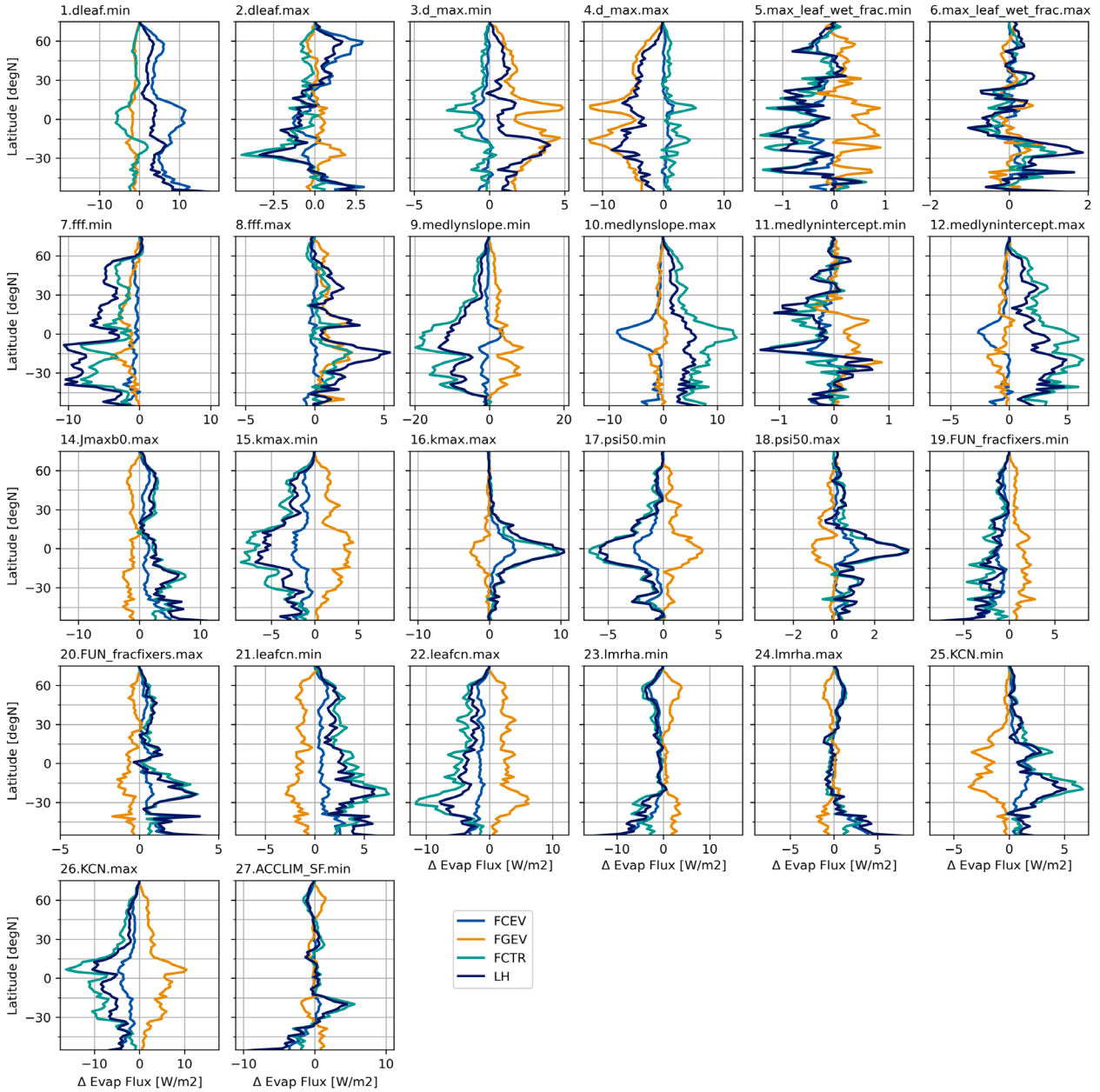

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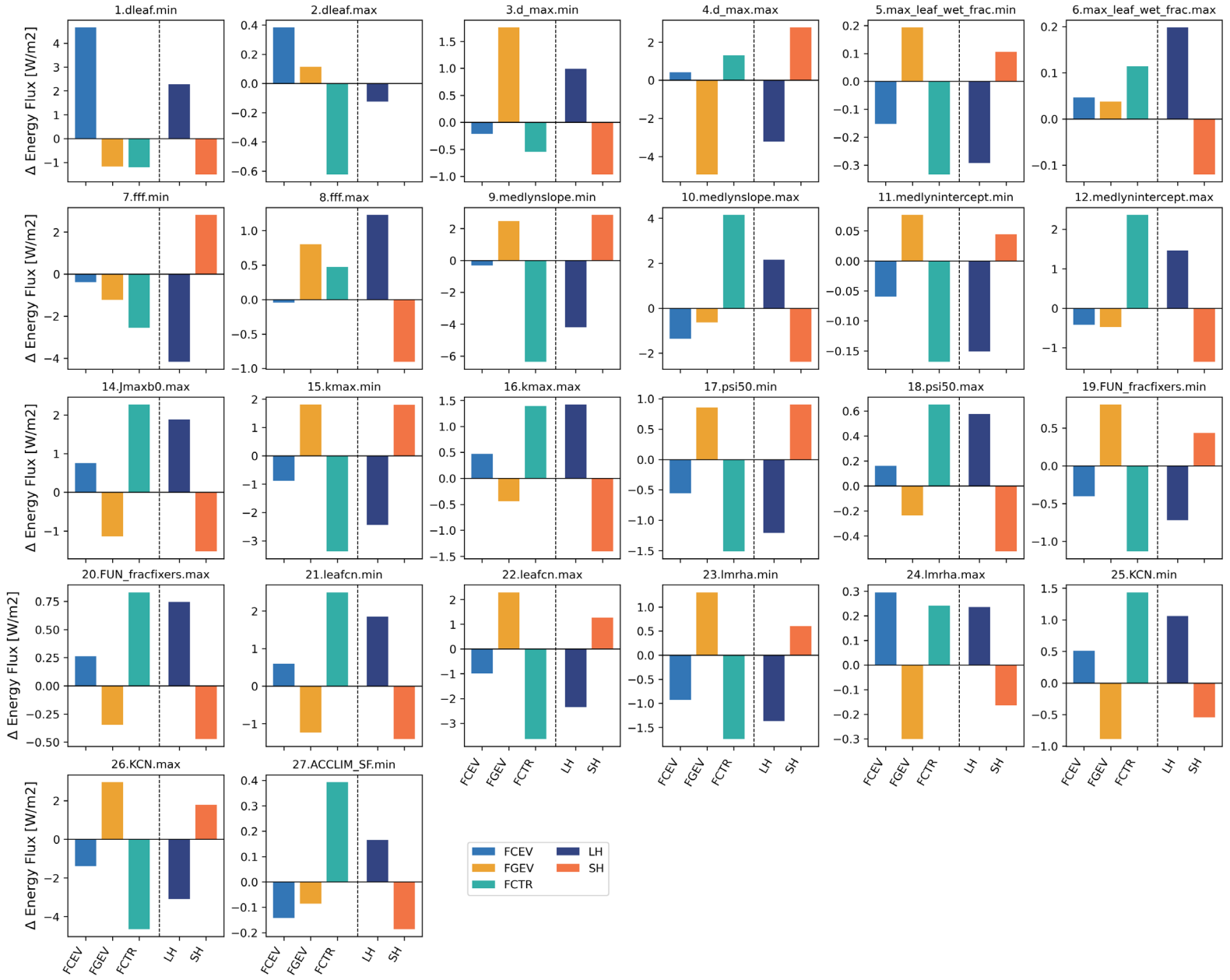
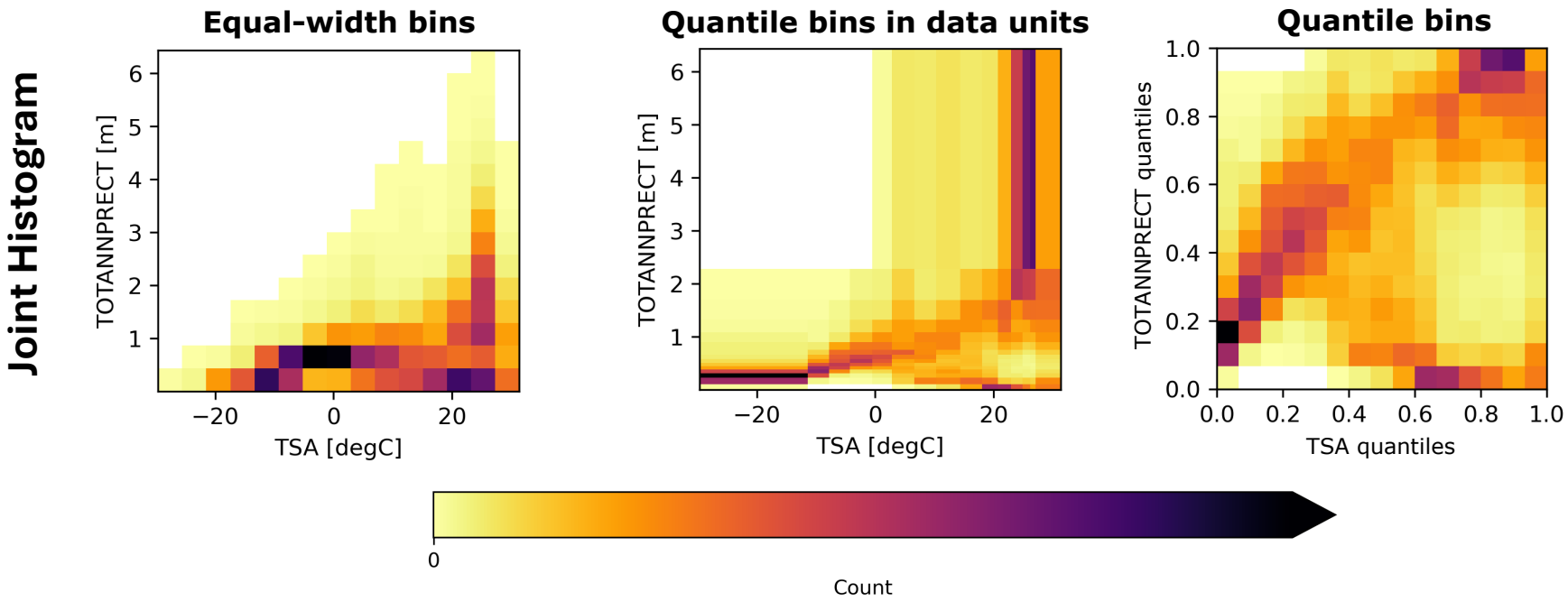
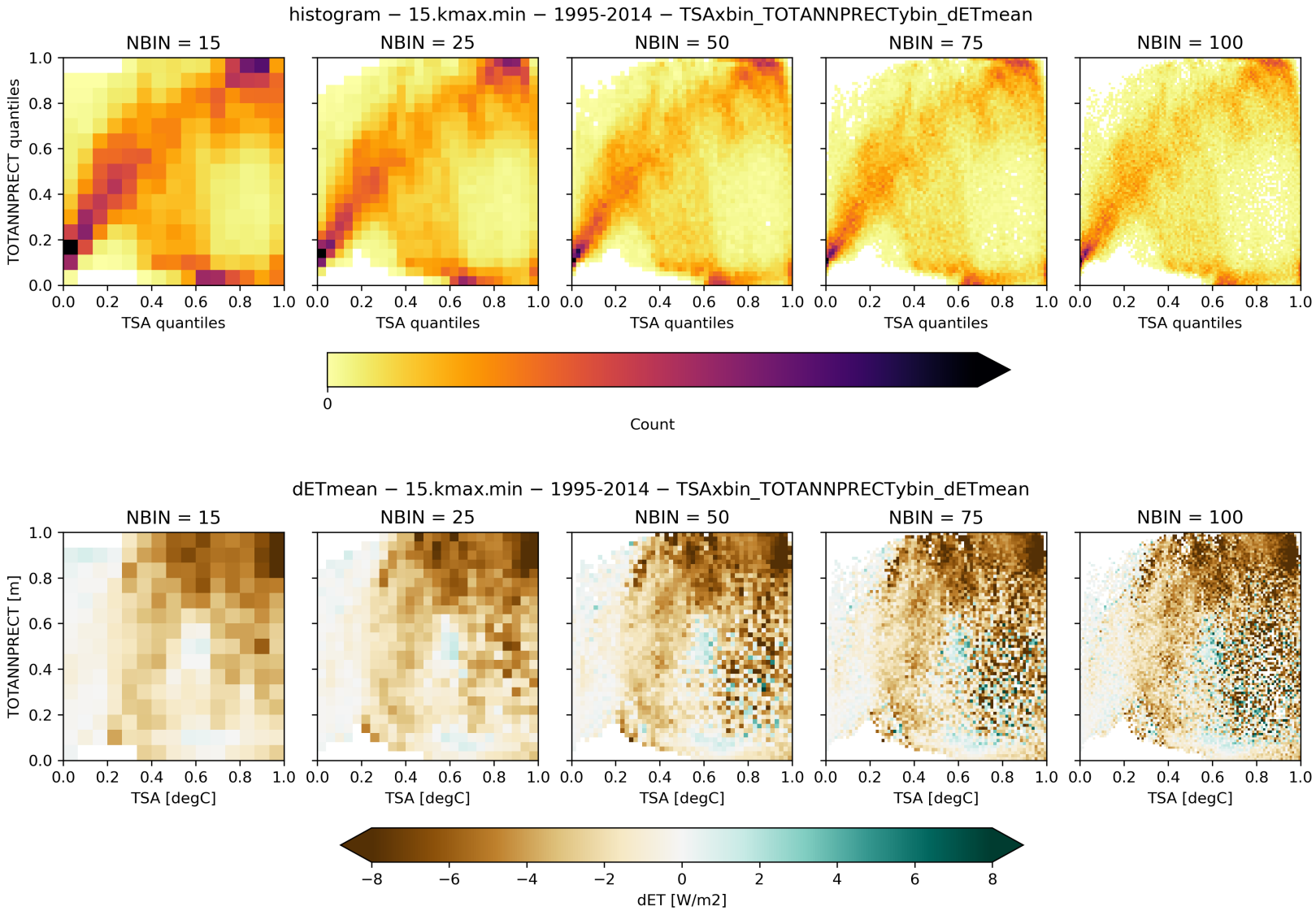


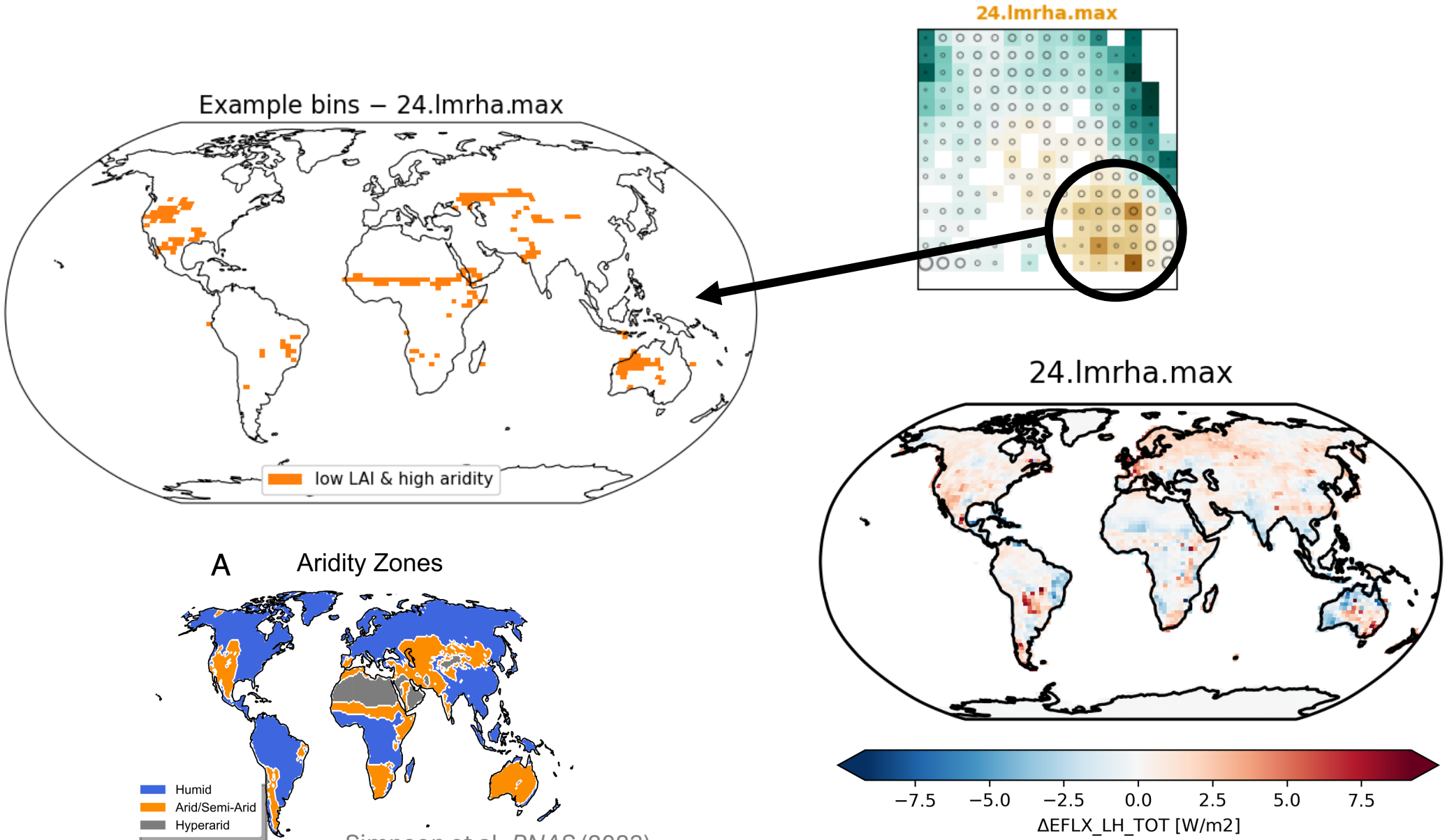
Transforming bins from equal-width to quantile bins



Sensitivity to number of quantile bins



Semi-arid regions with seasonally strong ET decreases



Simpson et al. *PNAS* (2023)