



# How the good and the bad conspire to the ugly

Maria Rugenstein

Dirk Olonscheck, Shreya Dhame, Marc Alessi, Senne Van Loon

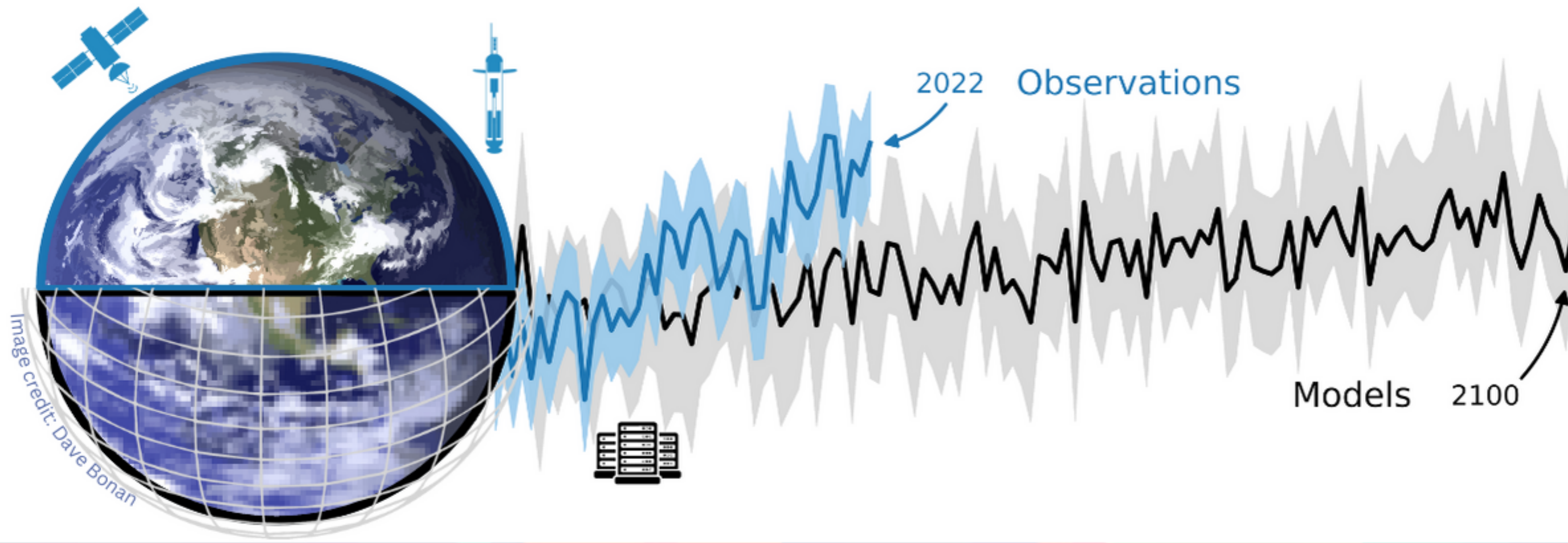
Robb Wills, Masahiro Watanabe, Richard Seager, Libby Barnes



# How the good and the bad conspire to the ugly

## US Clivar workshop **Confronting Earth System Model trends with observations: the good, the bad and the ugly**

200 attendees from 18 countries, 120 in-person, 62% early-career



**Confronting Earth system model trends with observations:**  
A new era in simulating and predicting climate

# How the good and the bad conspire to the ugly

1. TOA radiation trends last 20yrs
2. Surface temperature trends last 70yrs
3. Implications for projections next 40yrs

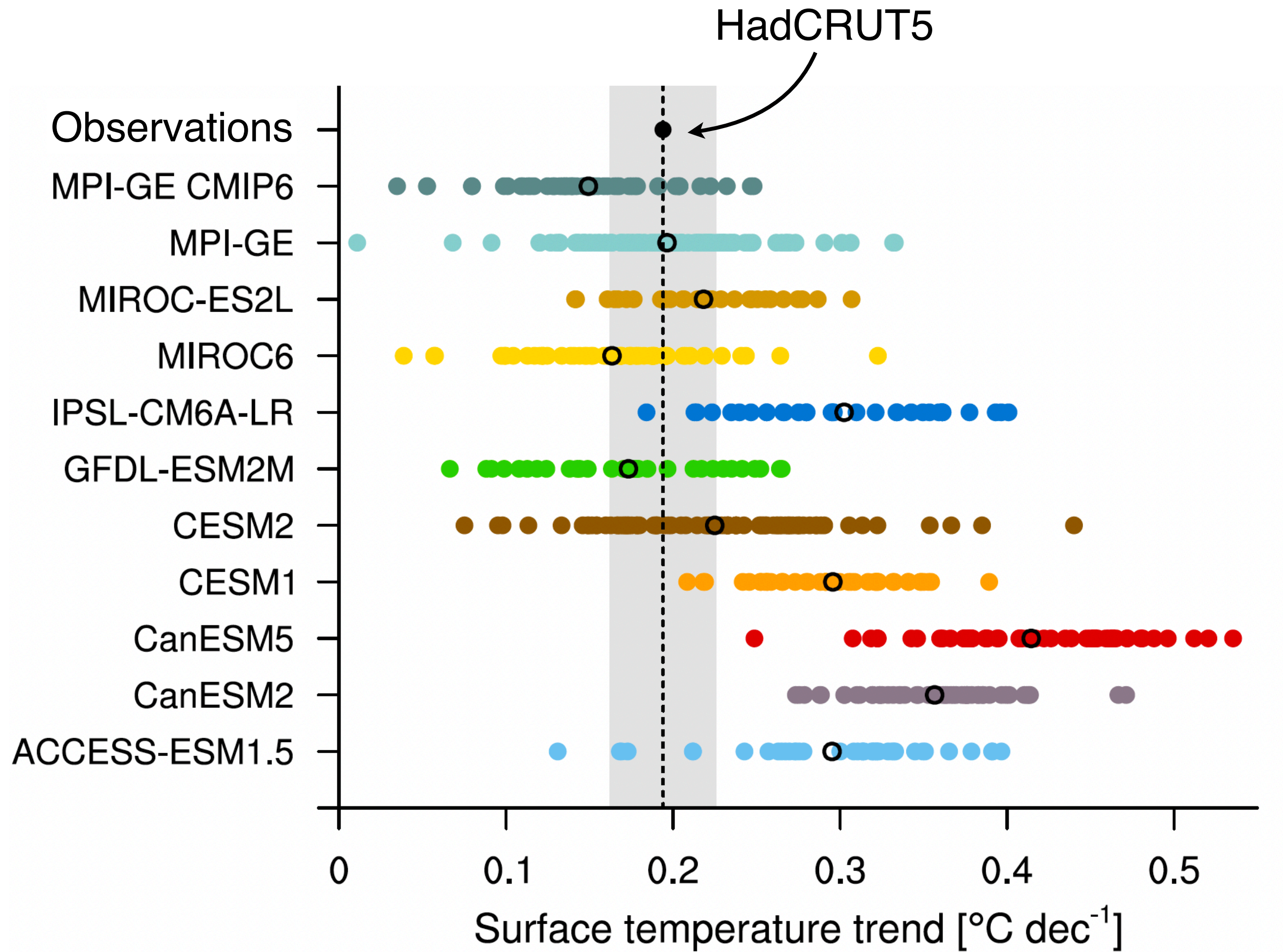
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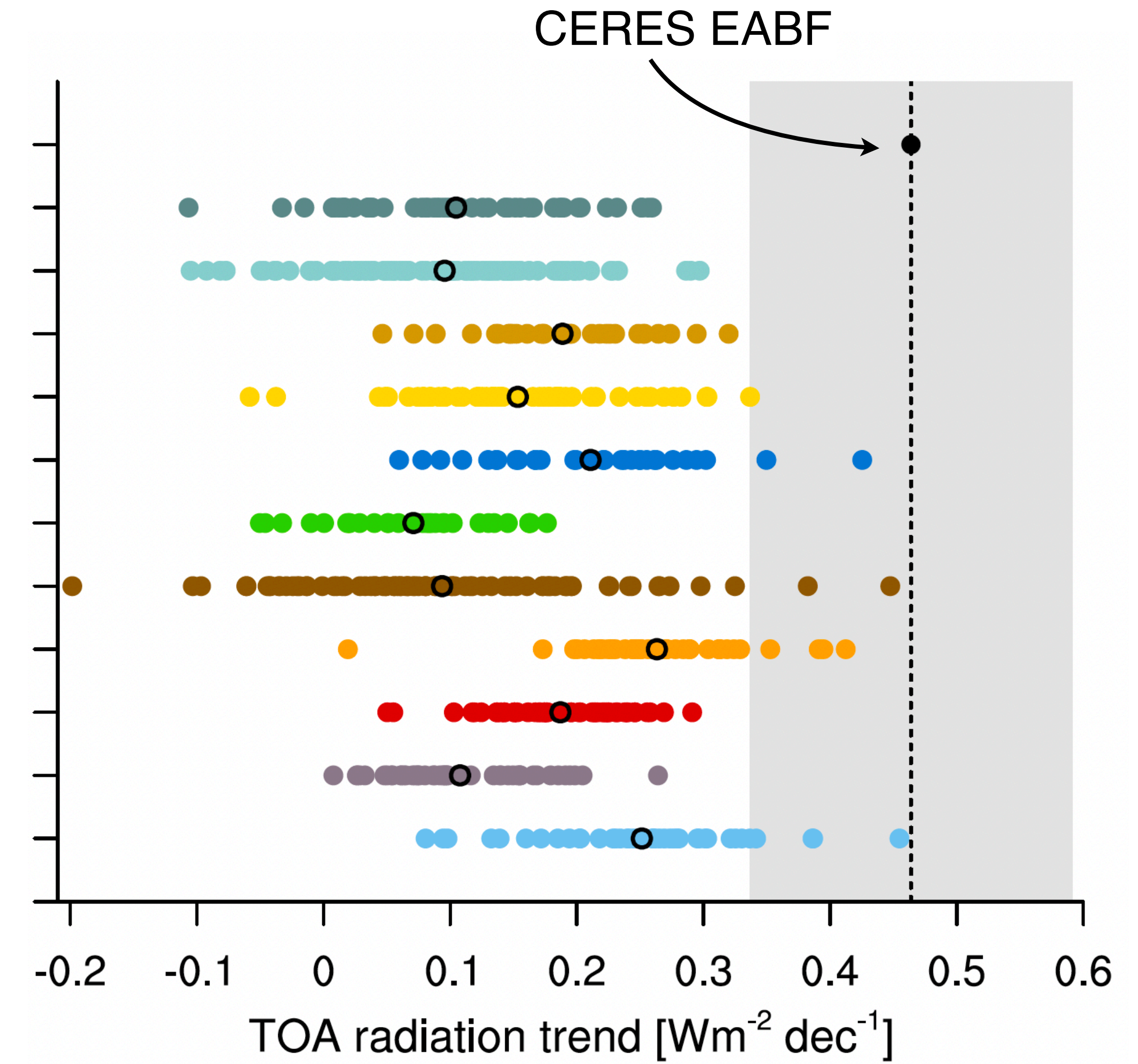
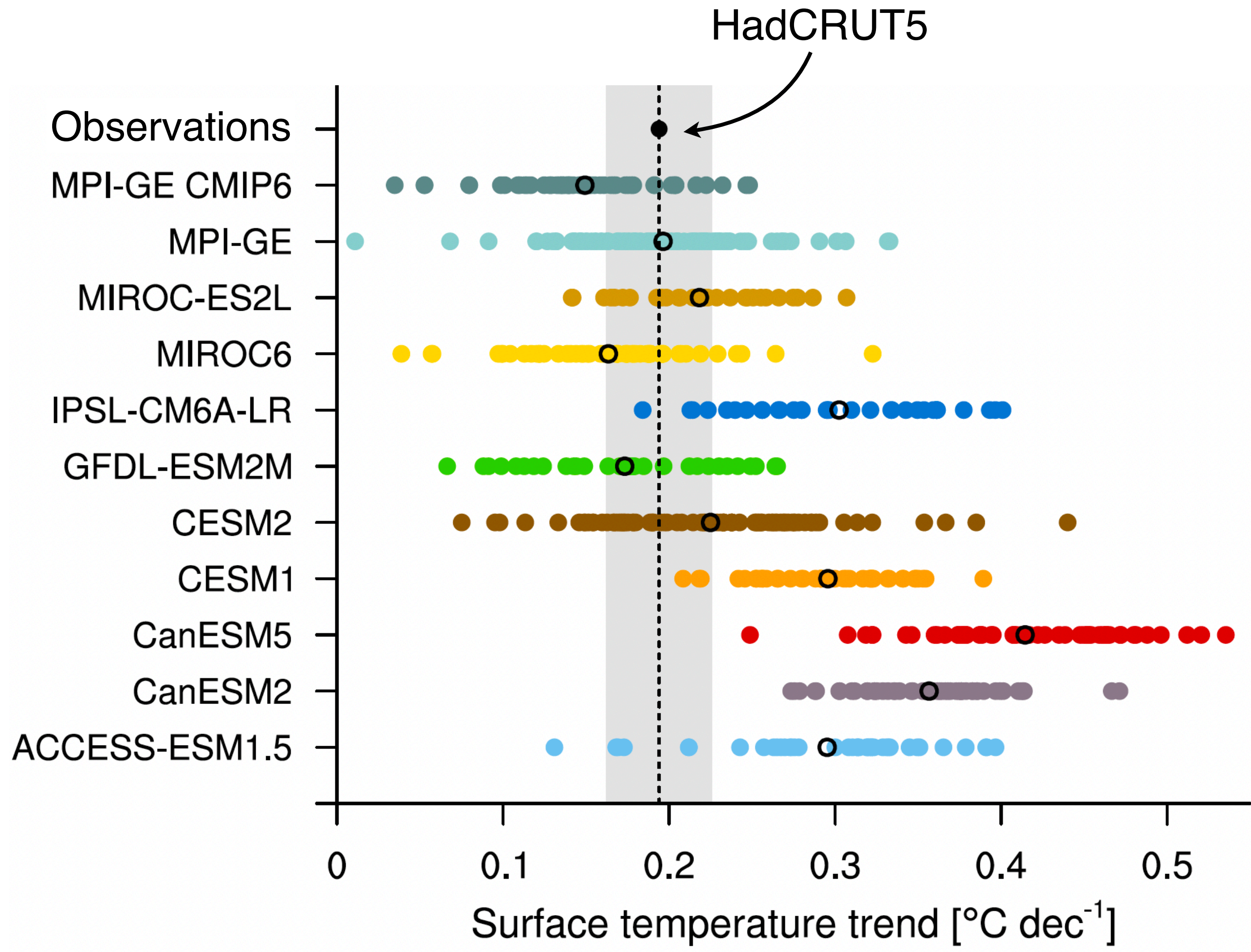
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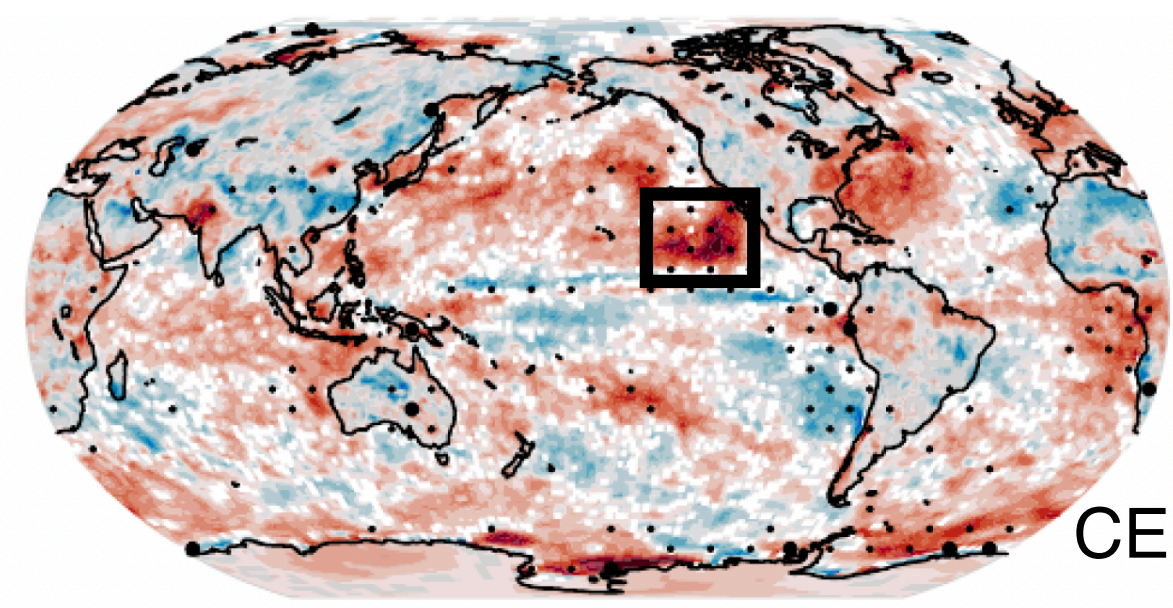
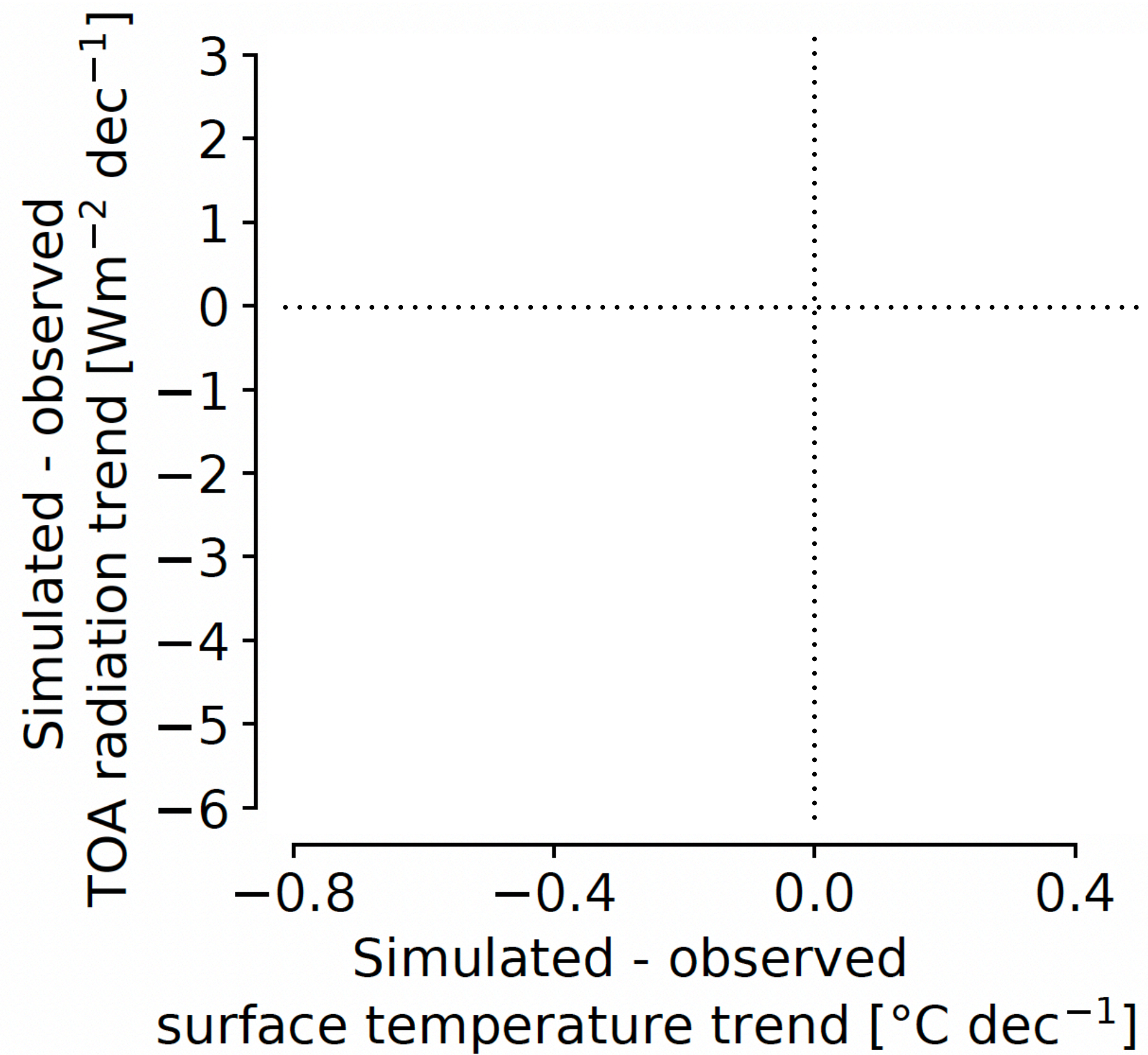
# 2000 - 2022 global-mean surface temperature is good



# Global-mean top of the atmosphere radiation is bad

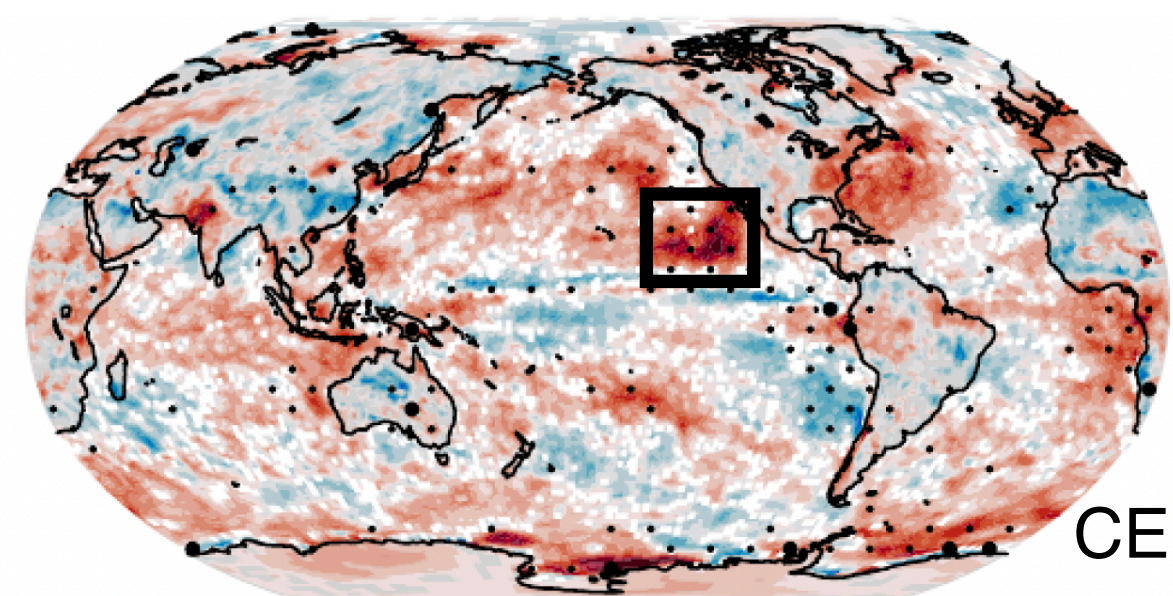
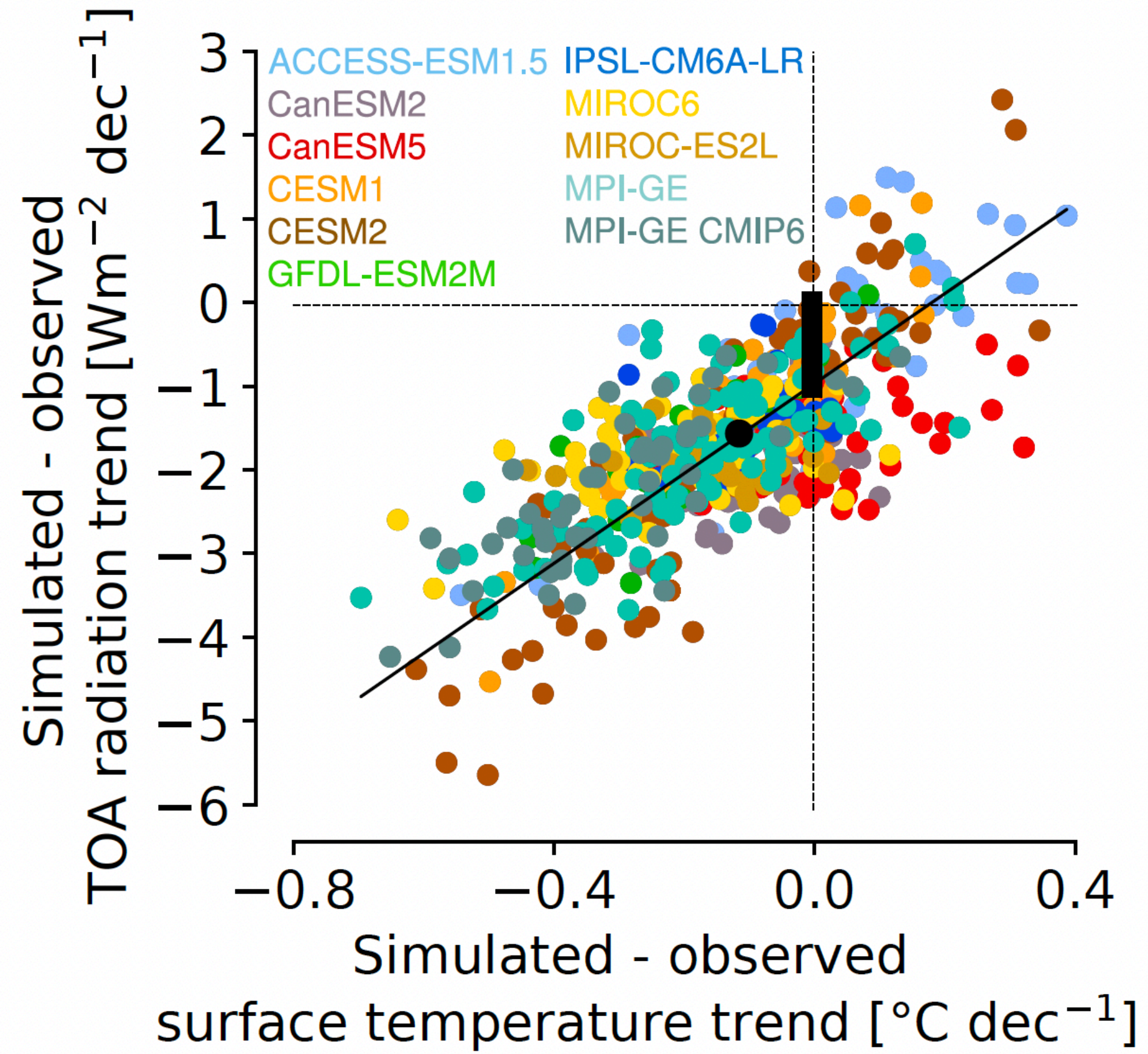


# Bias measure: if surface trend is correct, how off is radiation trend



CERES EABF 4.2

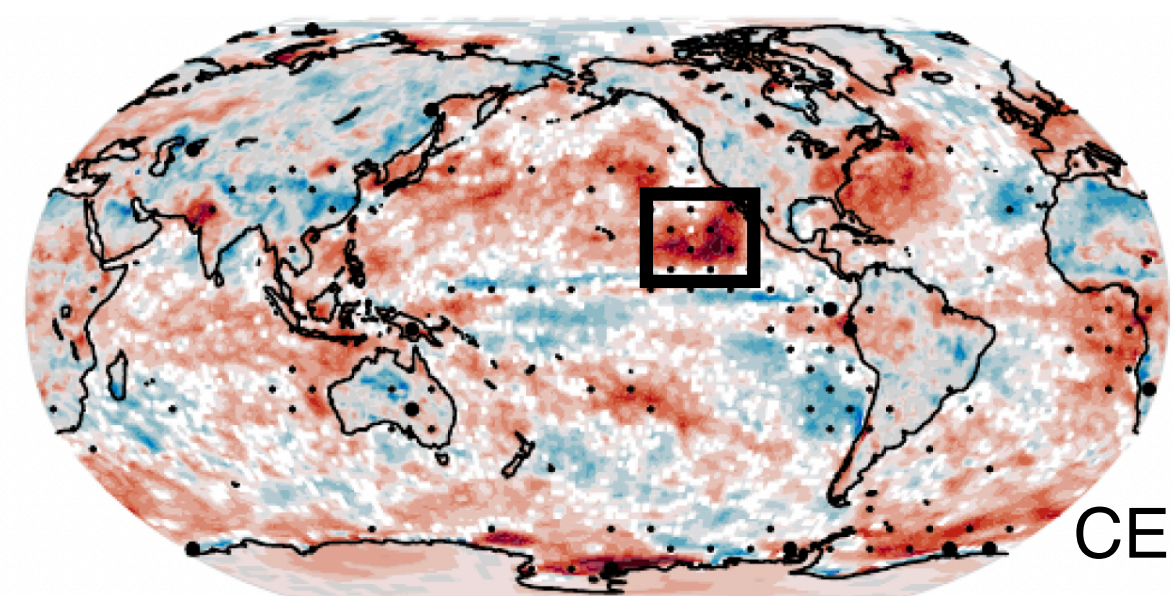
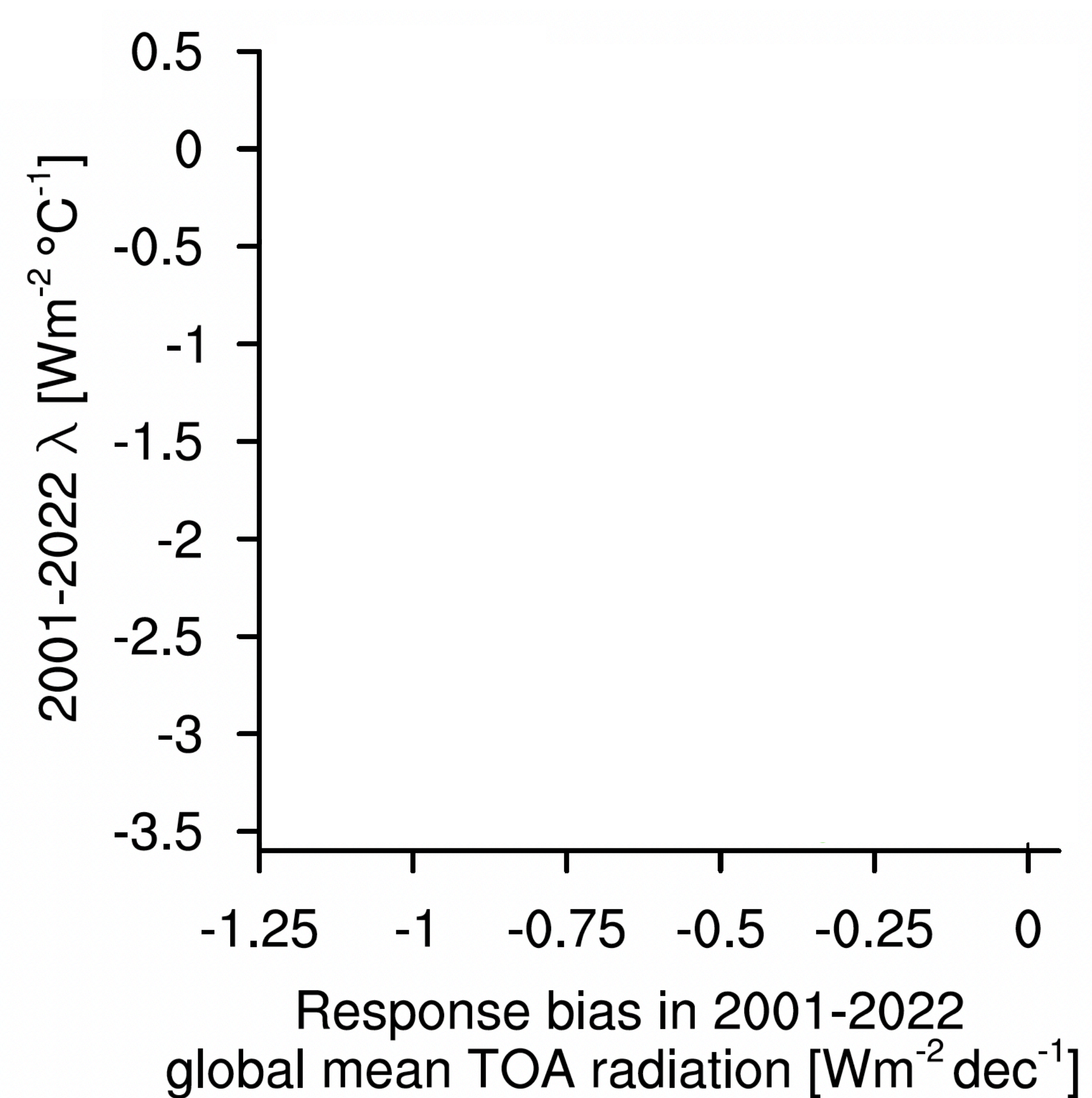
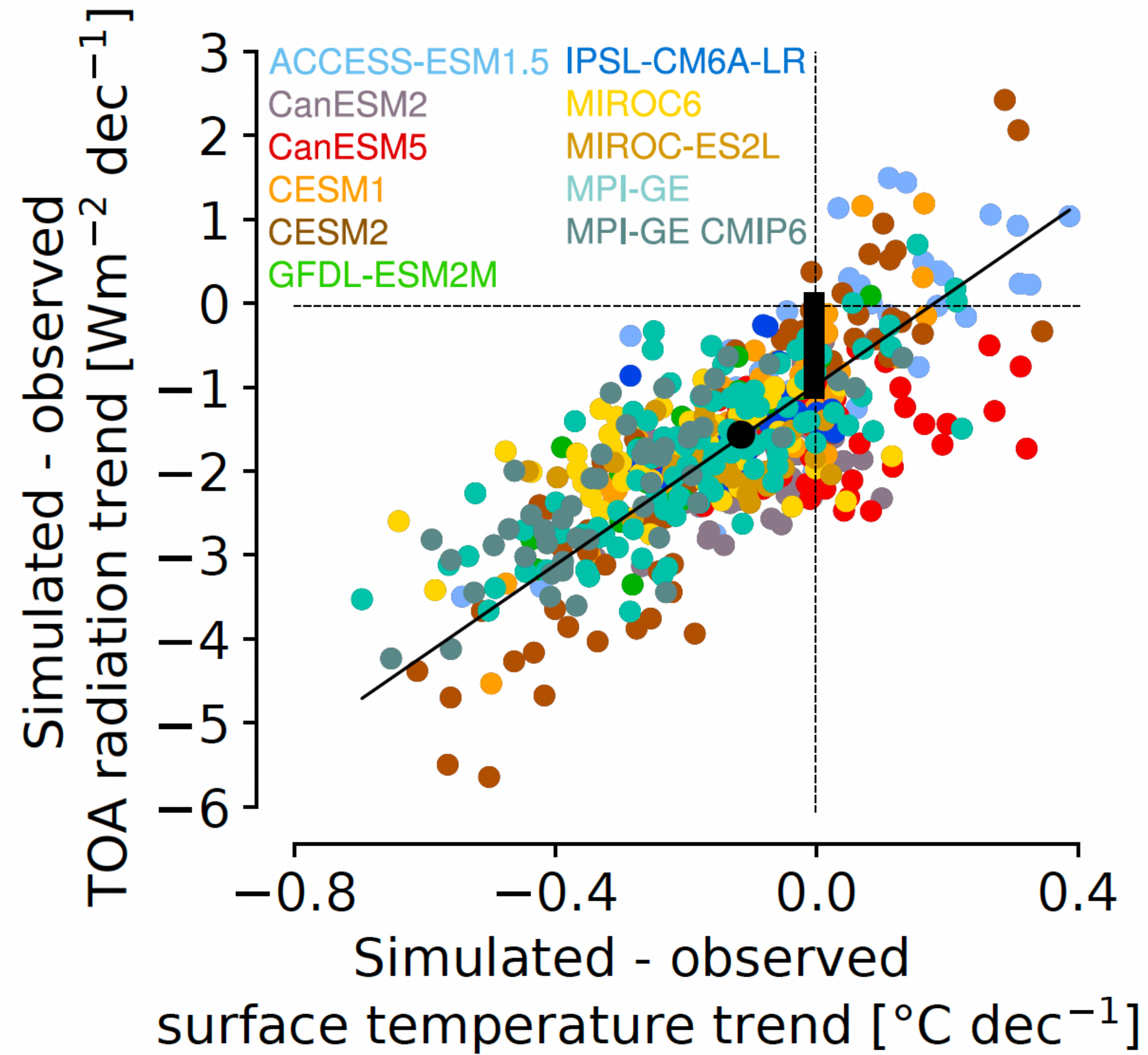
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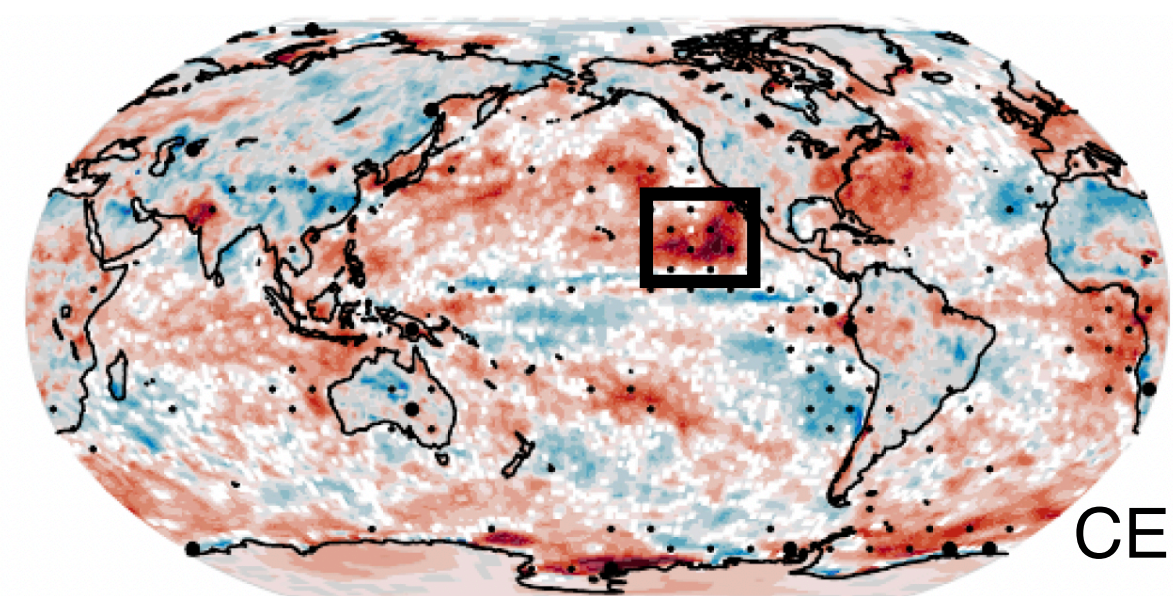
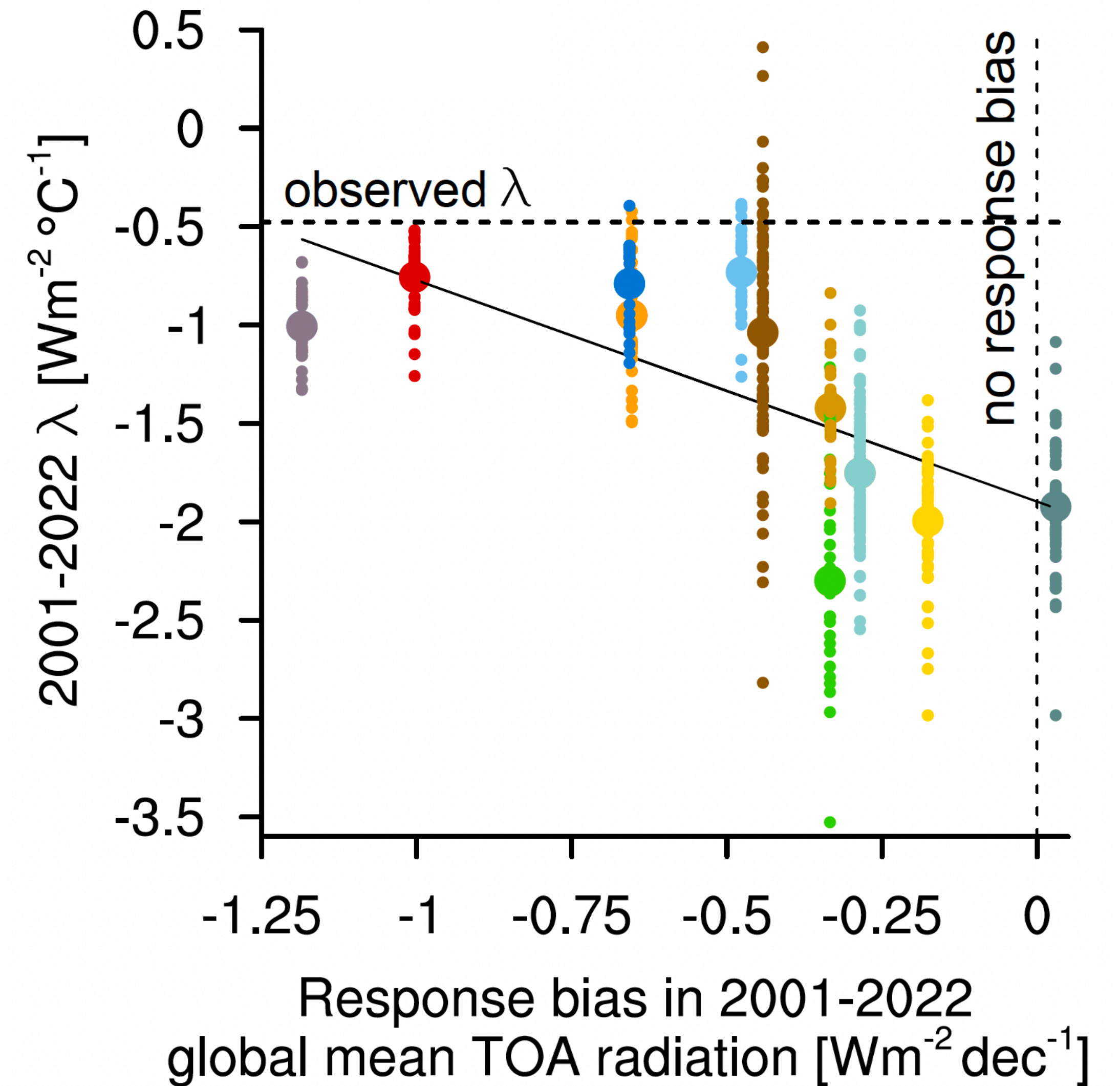
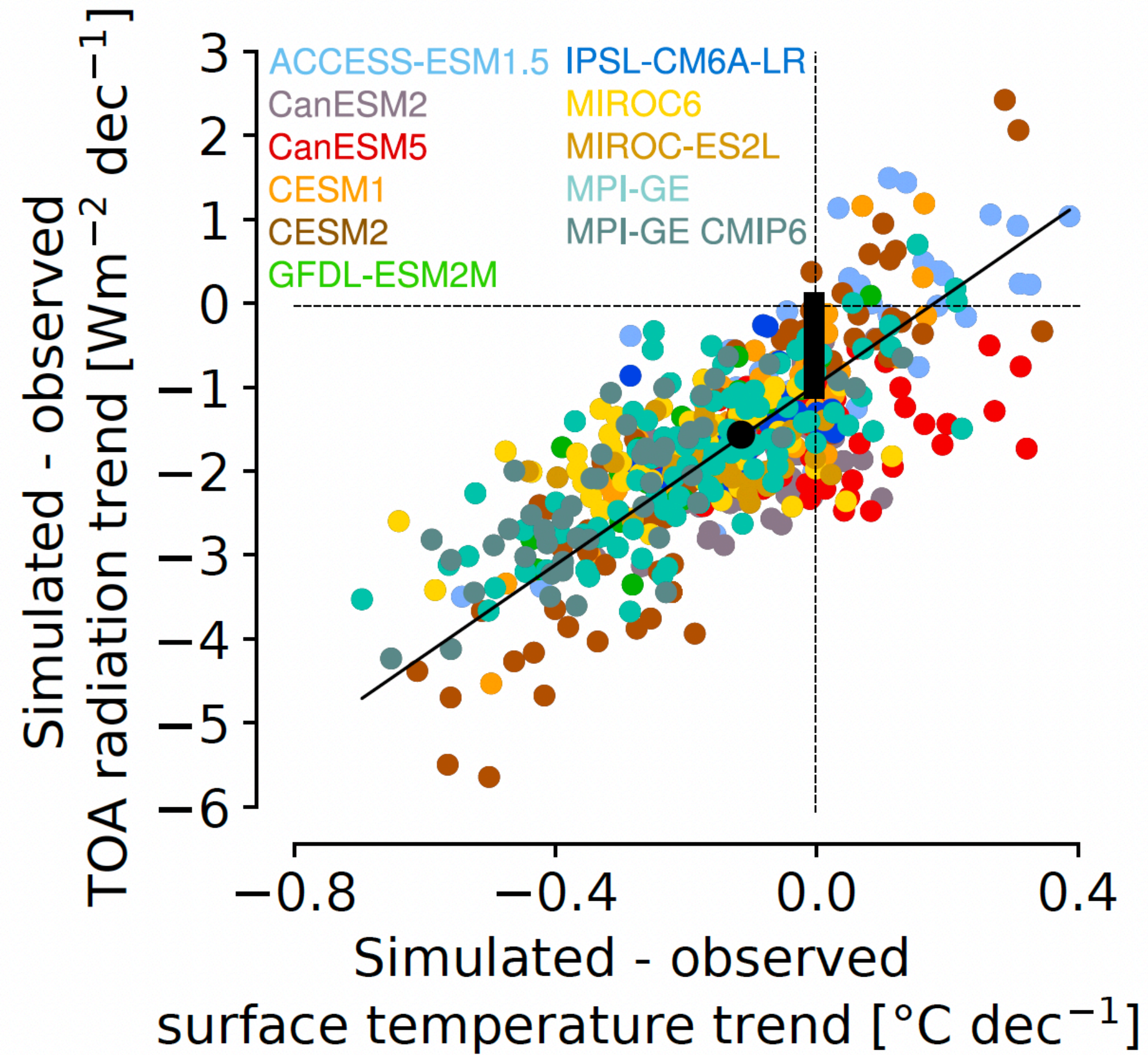


# Radiative feedbacks $d(N-F)/dT$ are pretty ugly



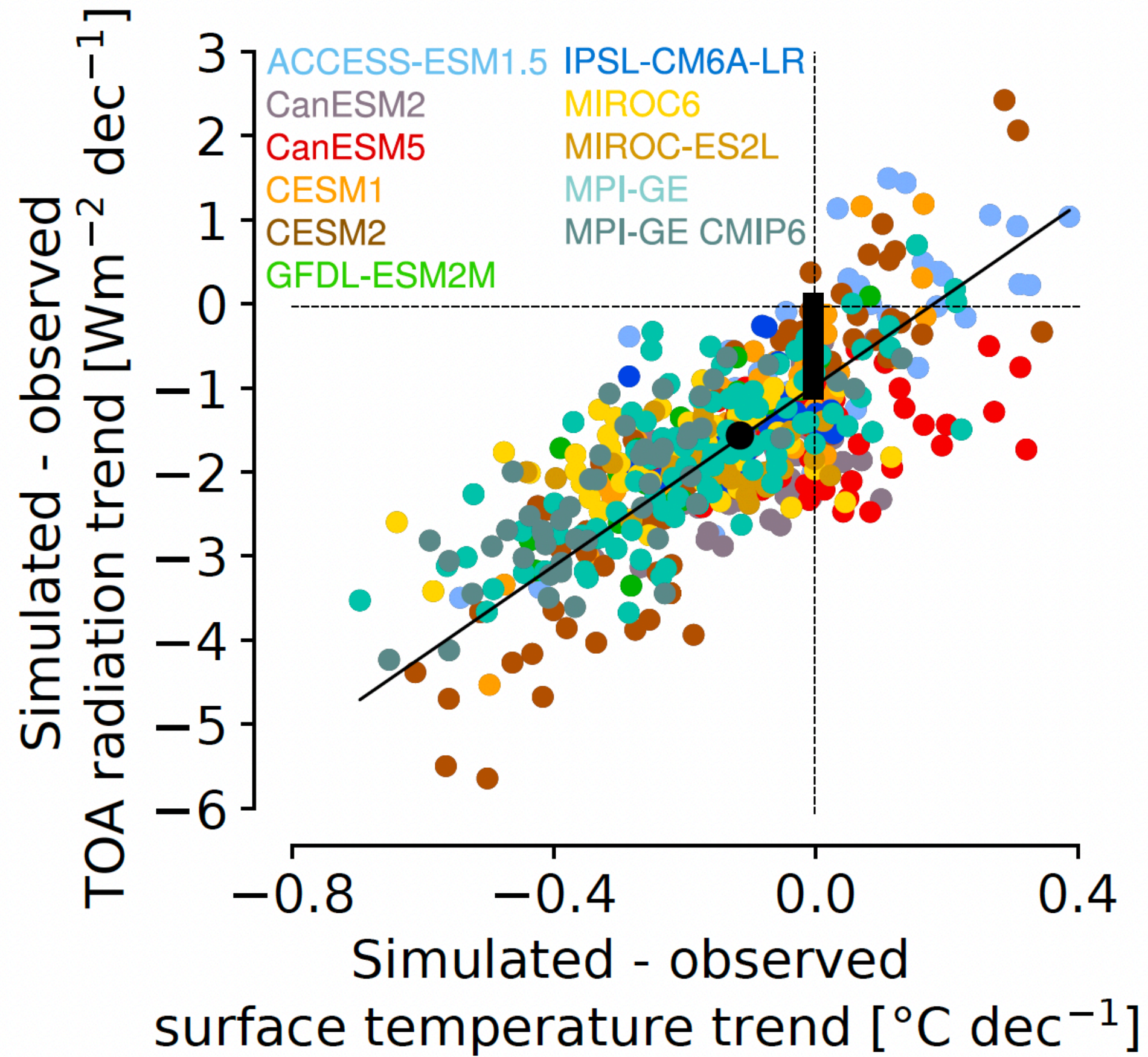
CERES EABF 4.2

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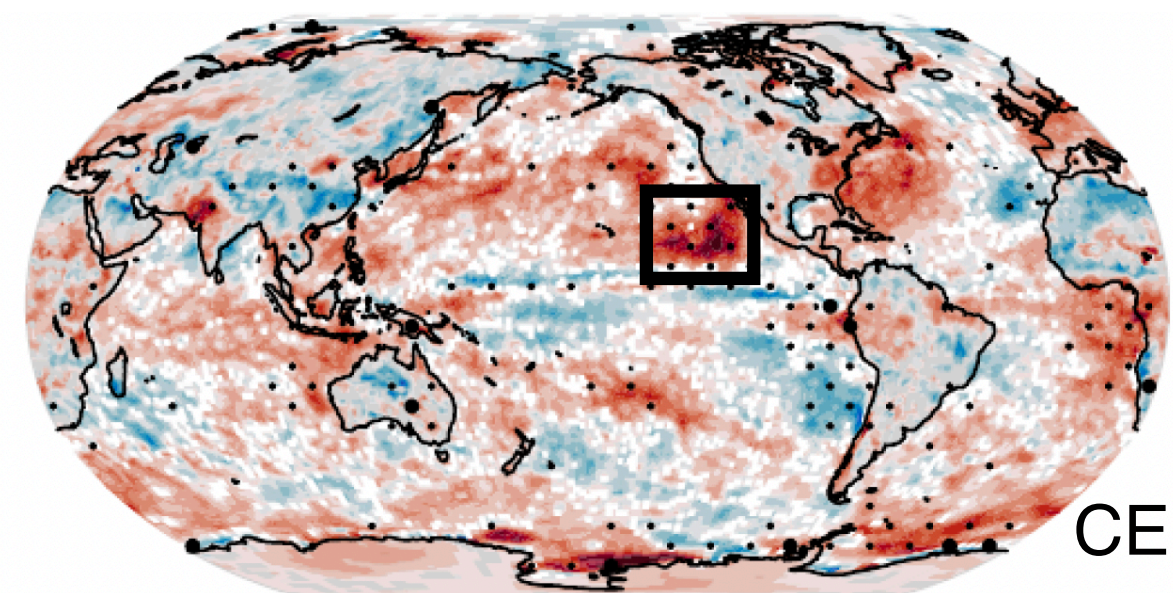
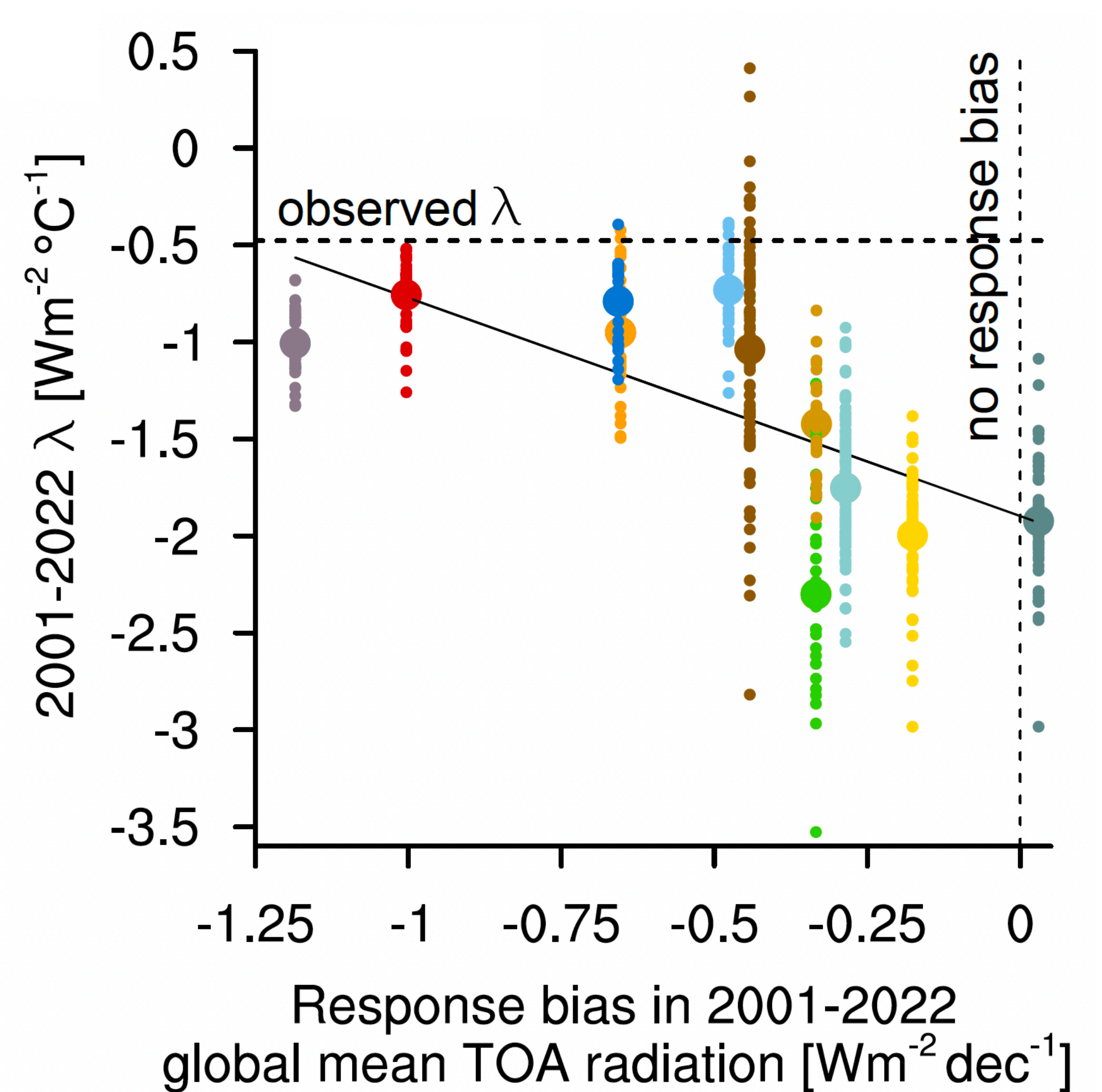


CERES EABF 4.2

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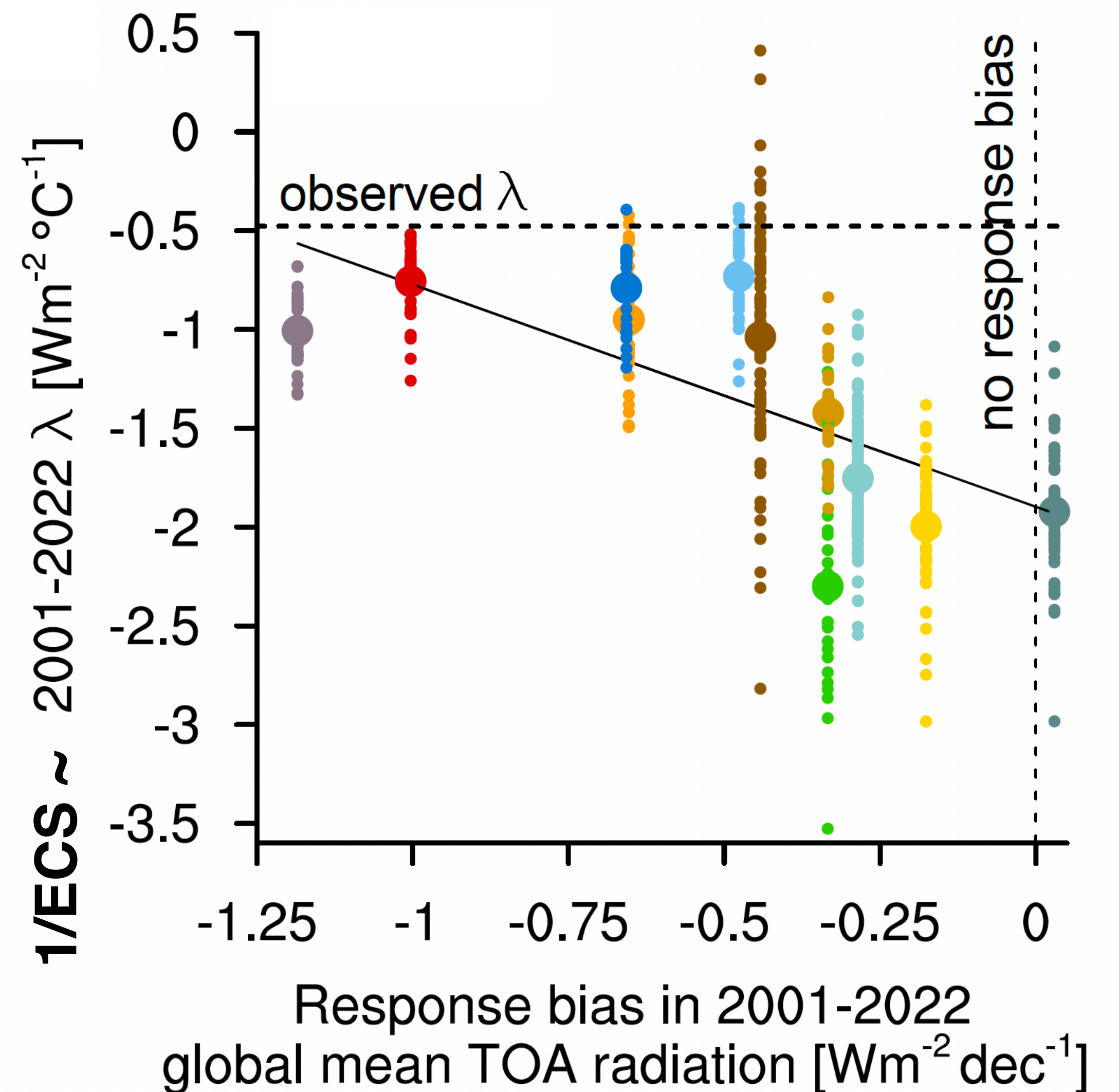
$1/\text{ECS} \sim$



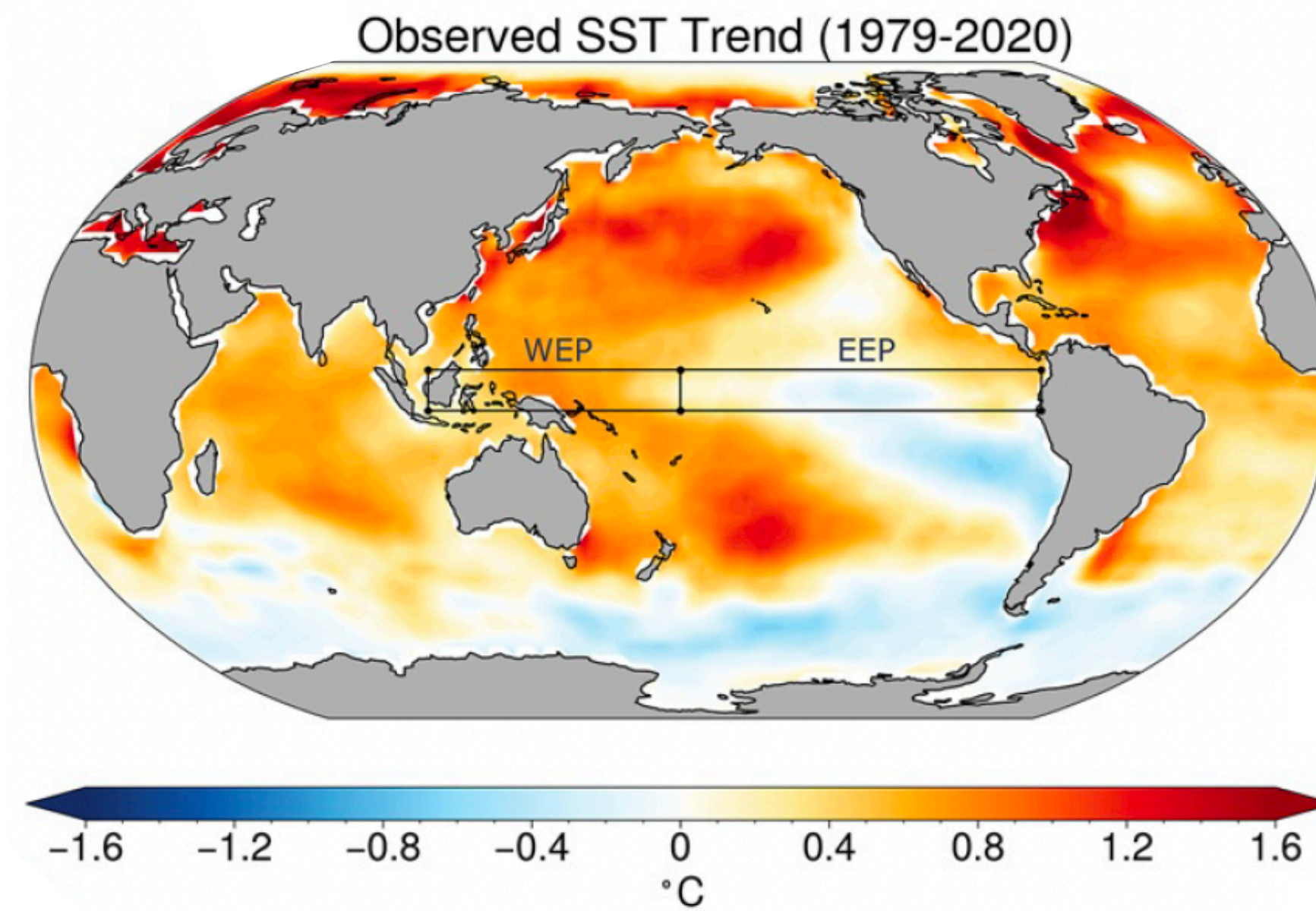
CERES EABF 4.2

# Radiative feedbacks $d(N-F)/dT$ are pretty ugly

- Surface temperature trends = good
- TOA radiation trends = bad
- Observed still too noisy to constrain models  
feedbacks = ugly
- Radiation response bias indicates models with a more negative, stabilizing, radiative feedback more readily reproduce observations
- Better models may have better SST patterns, better cloud physics, better forcing, or better compensating biases
- Implications for ocean heat uptake to follow



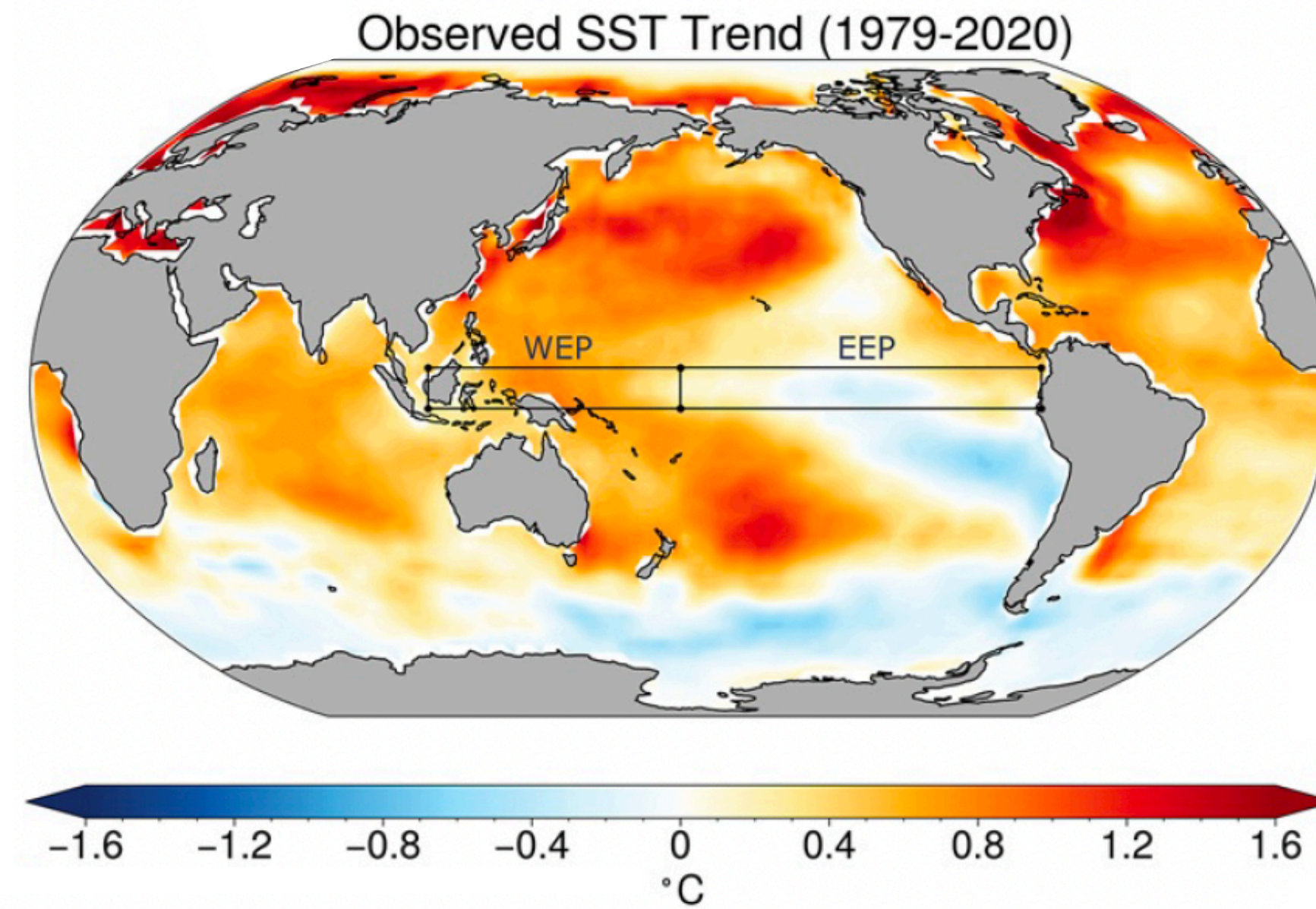
# Models do not reproduce swings in the Pacific SST patterns



Rugenstein, Dhame, Olonscheck, Wills, Watanabe, Seager, 2023  
Connecting the SST pattern problem and the hot model problem

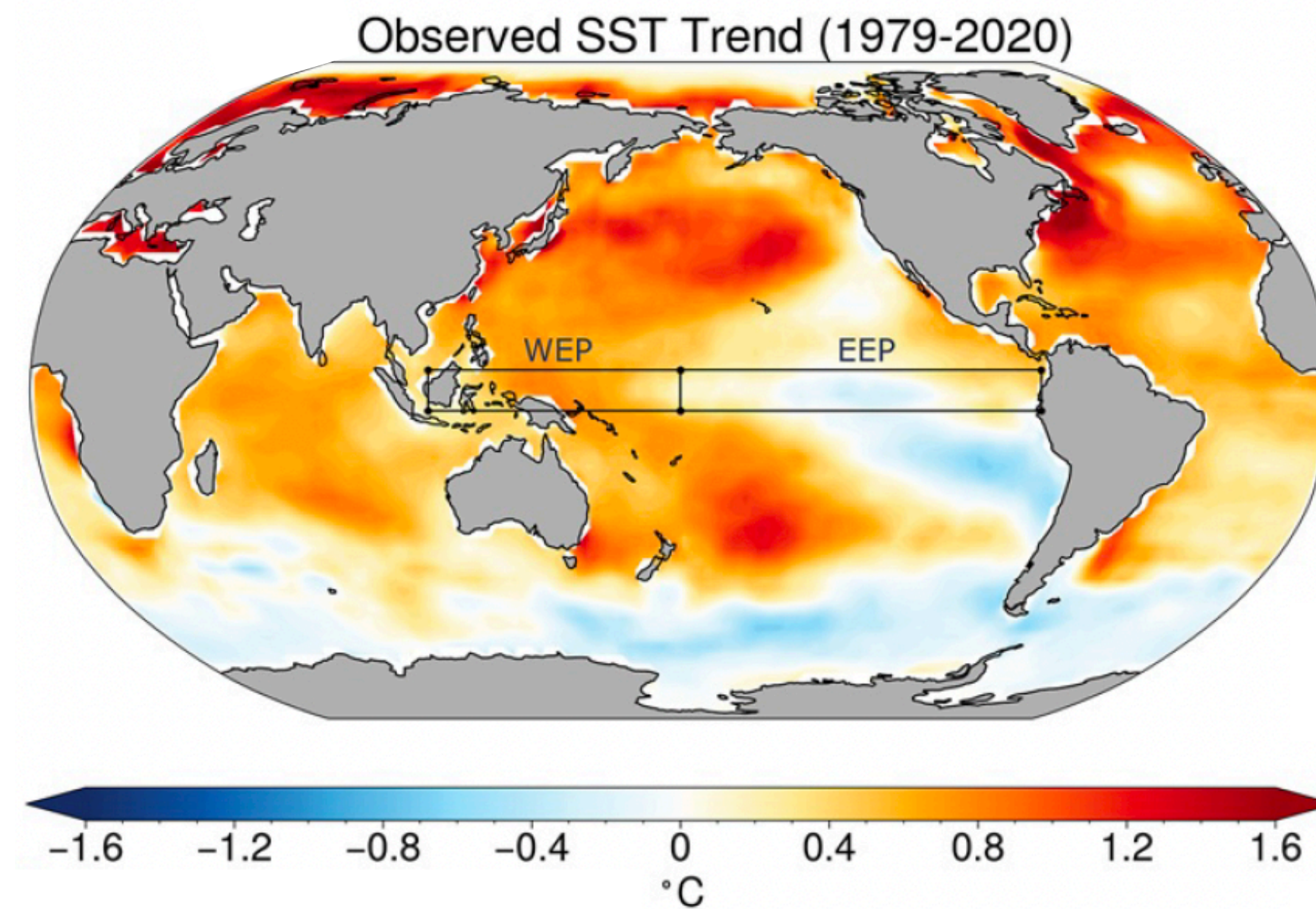


# Models do not reproduce swings in the Pacific SST patterns



last year

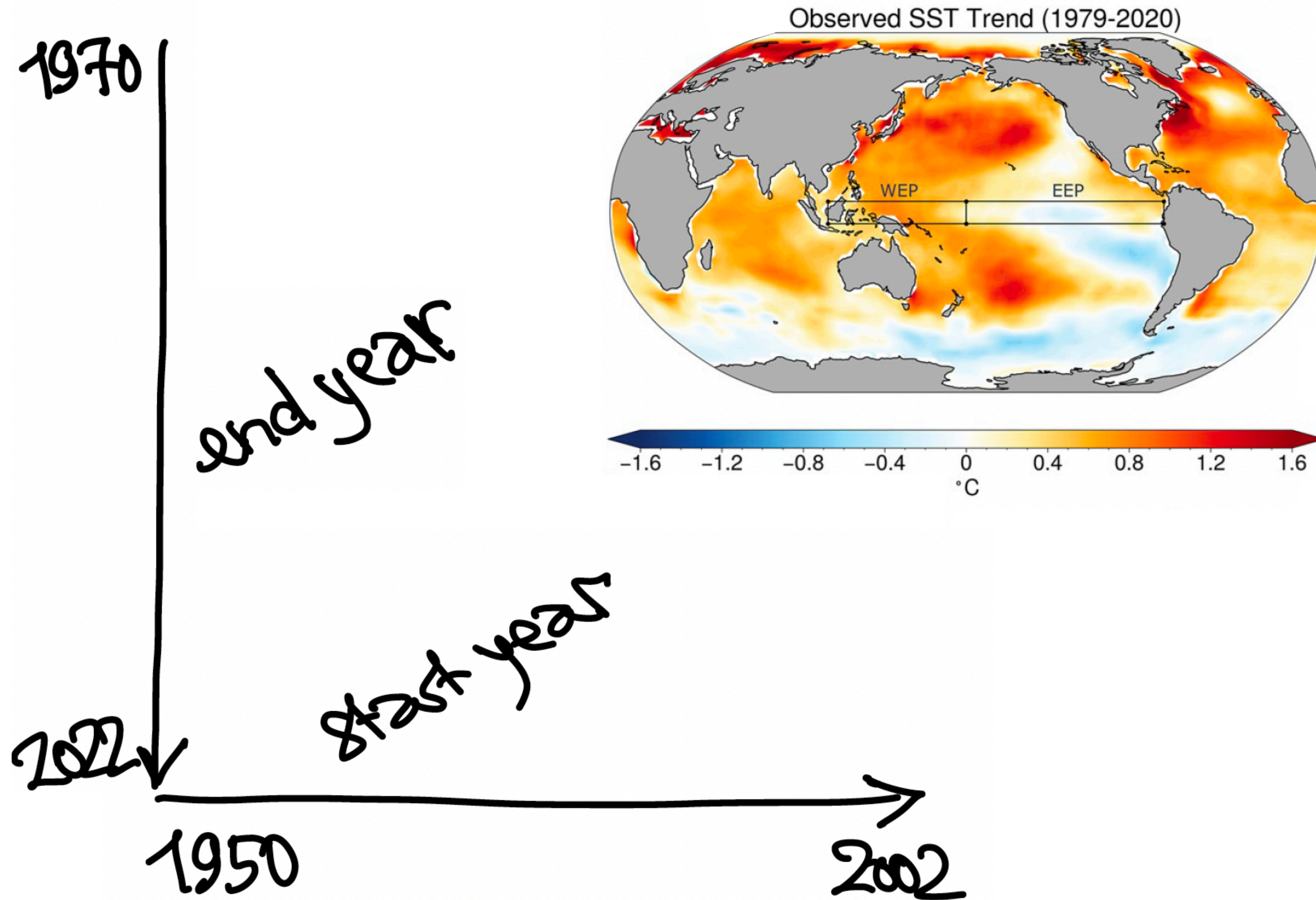
# Models do not reproduce swings in the Pacific SST patterns



*Start year*

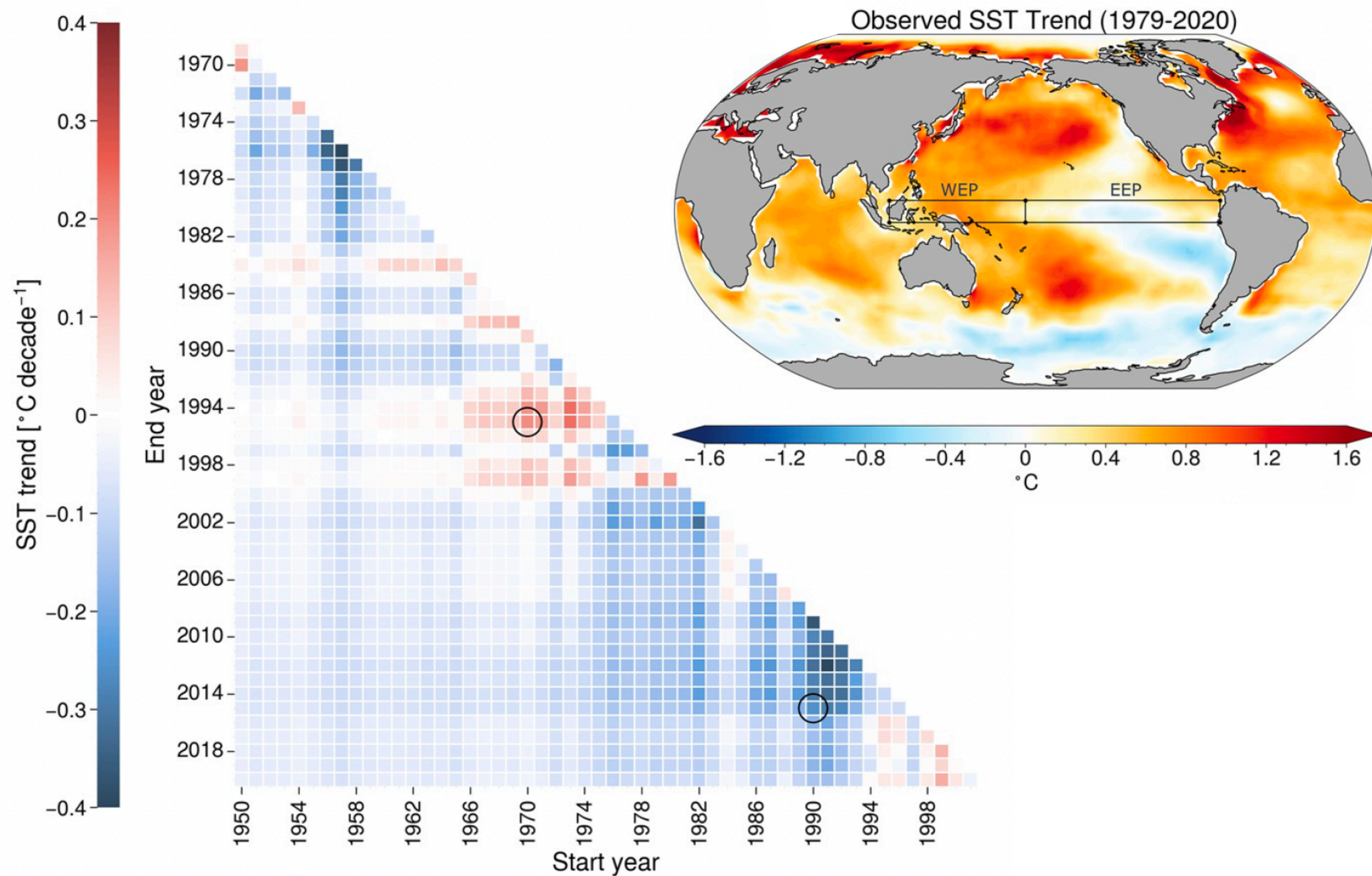
1950 → 2002

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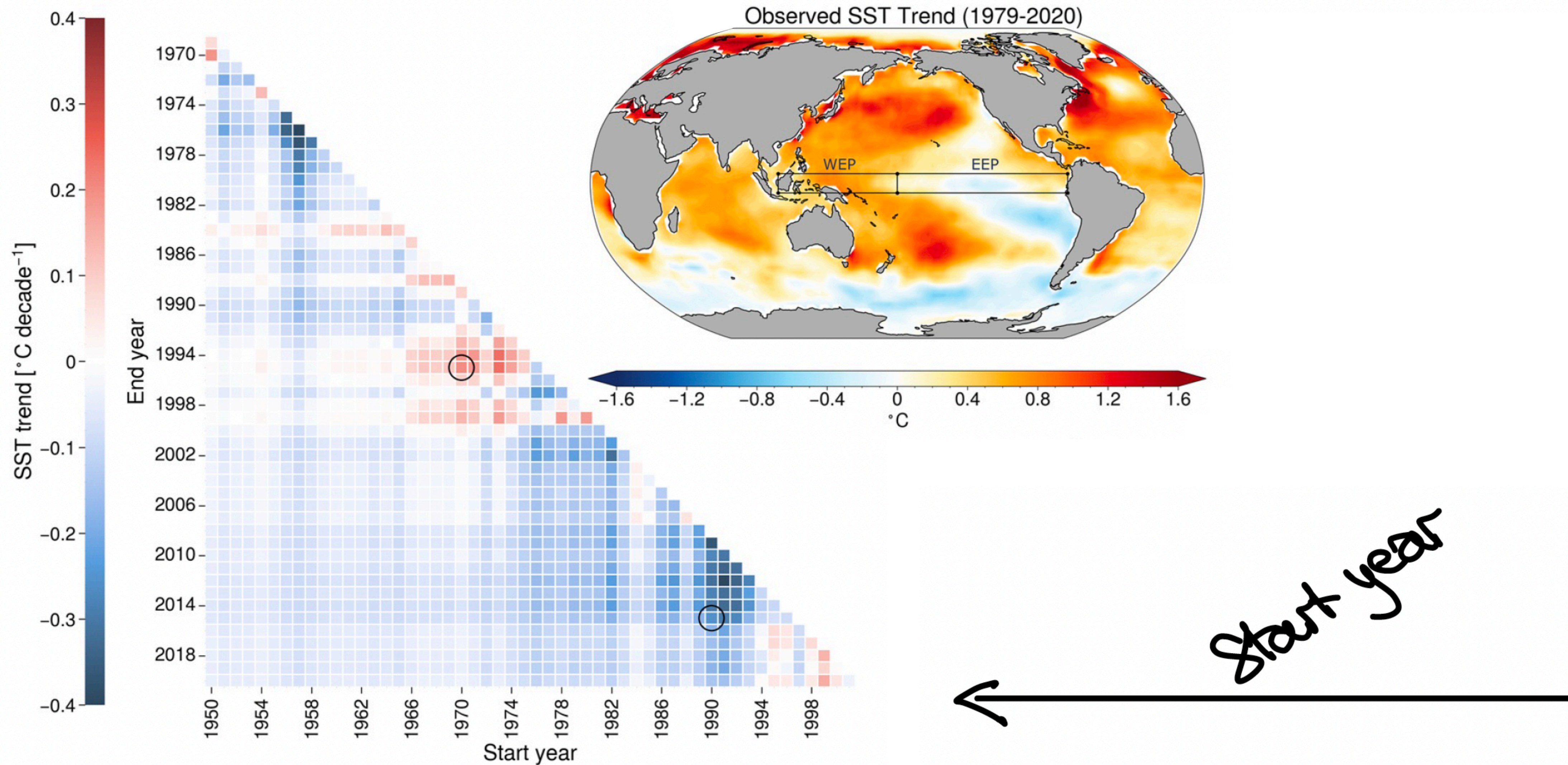


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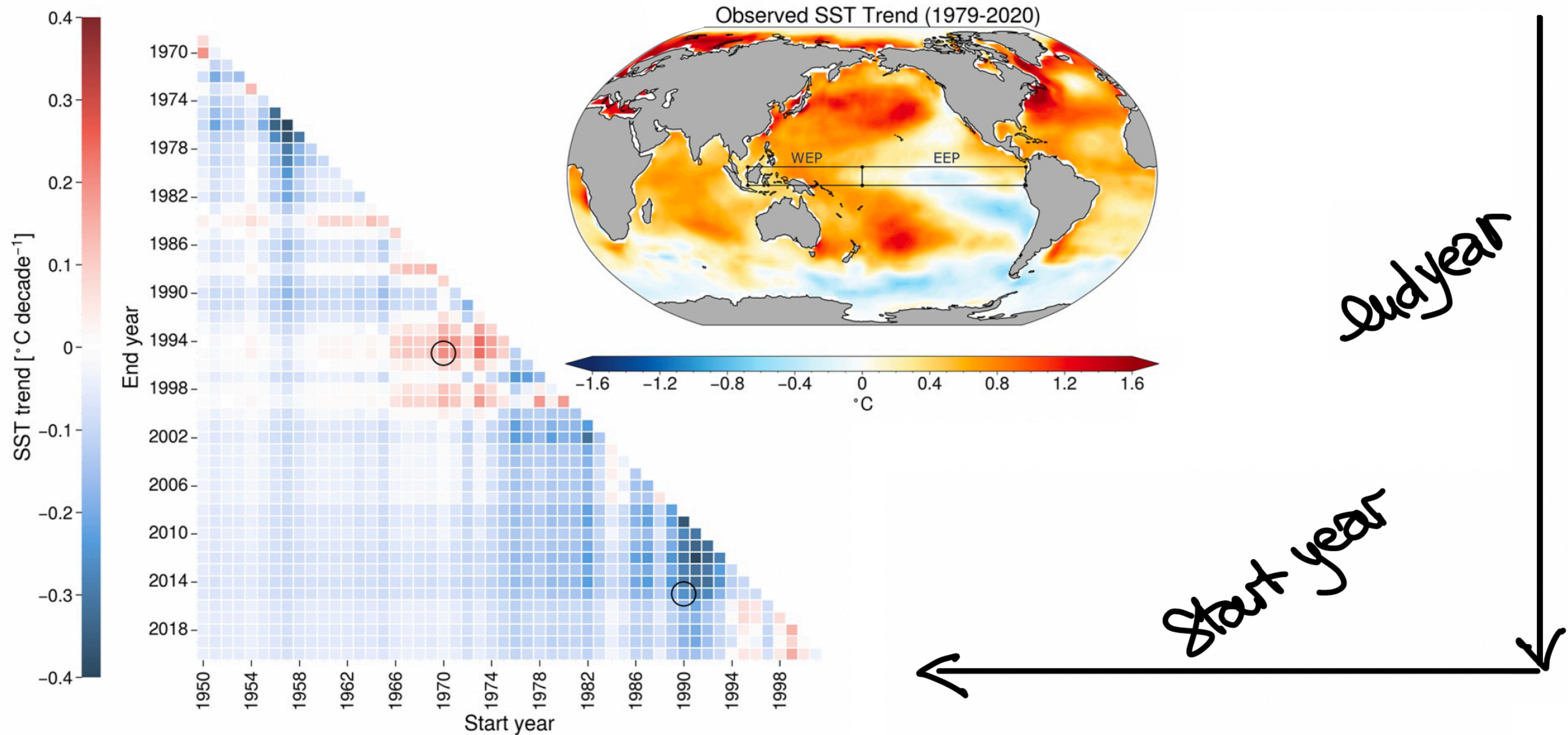
(b) East-West Pacific gradient in observations

# Models do not reproduce swings in the Pacific SST patterns



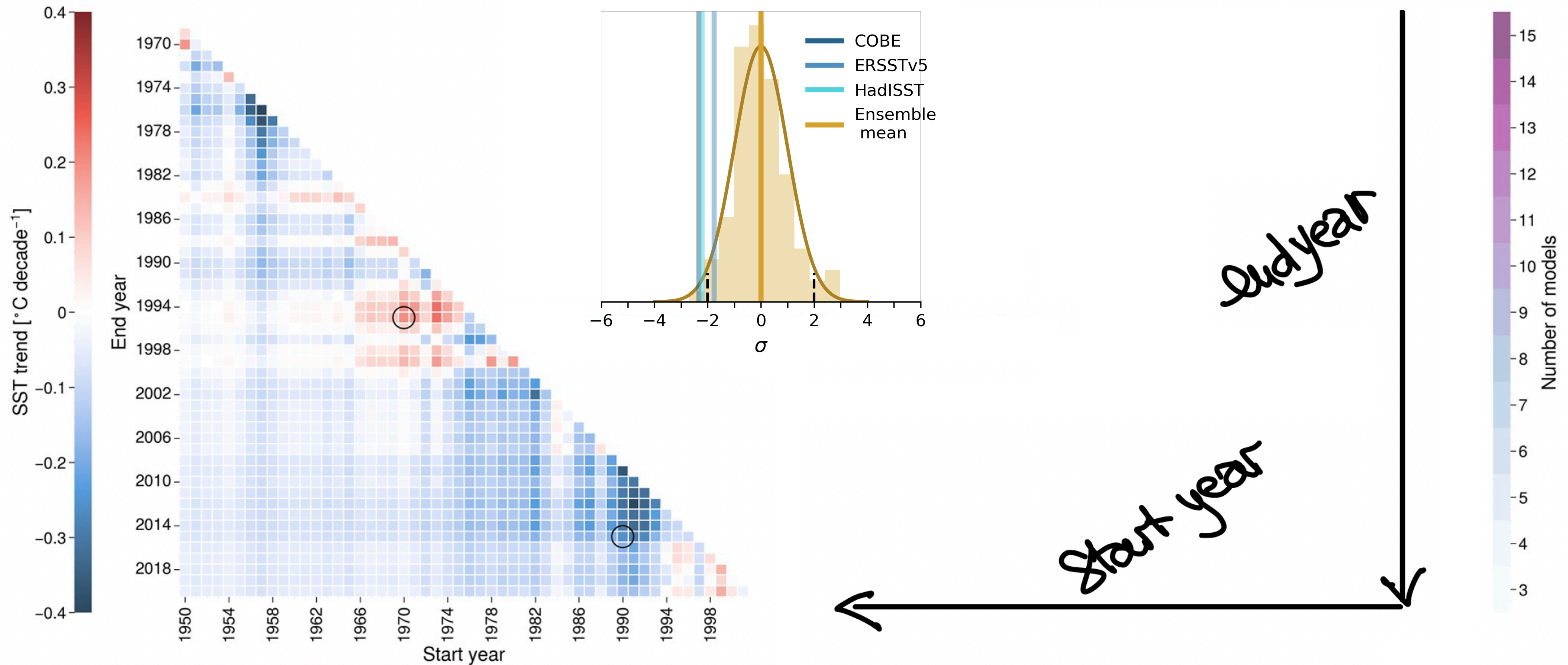
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# Models do not reproduce swings in the Pacific SST patterns



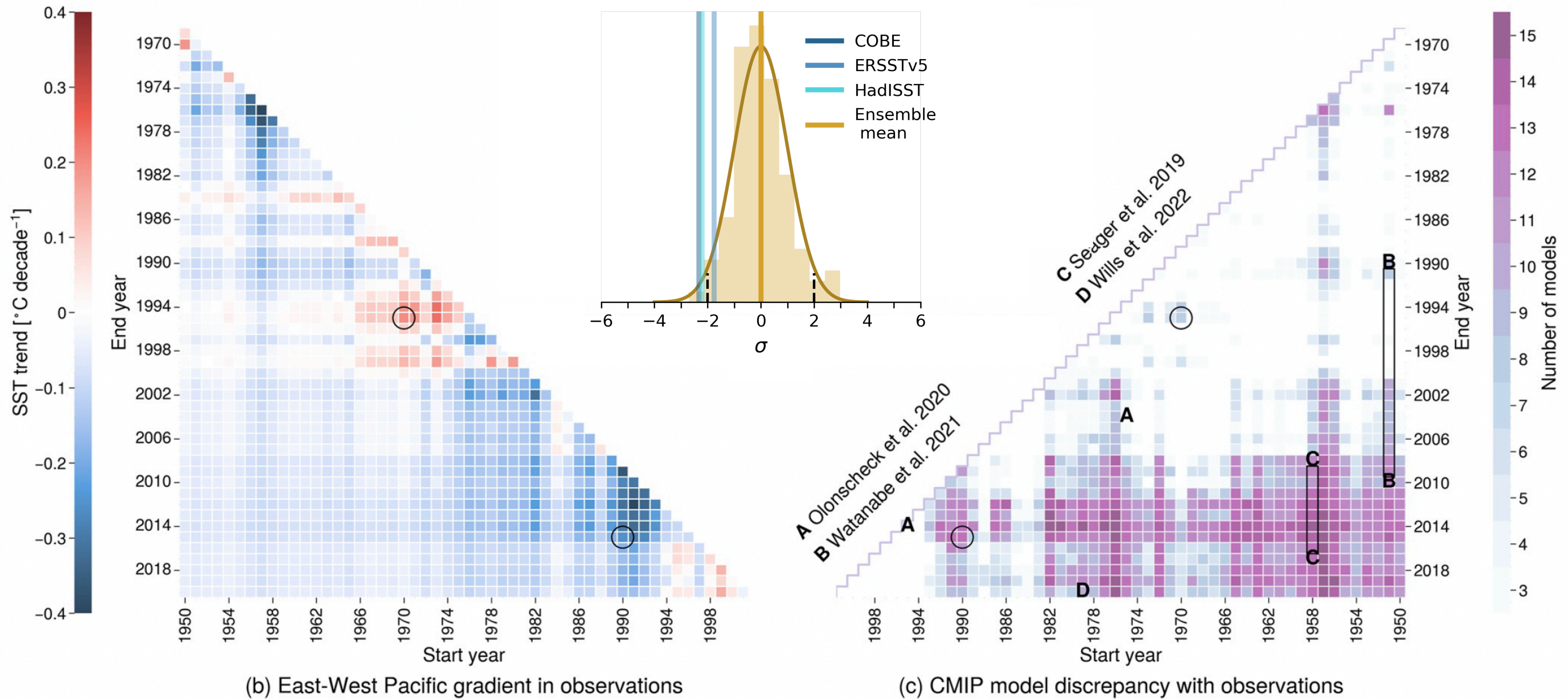
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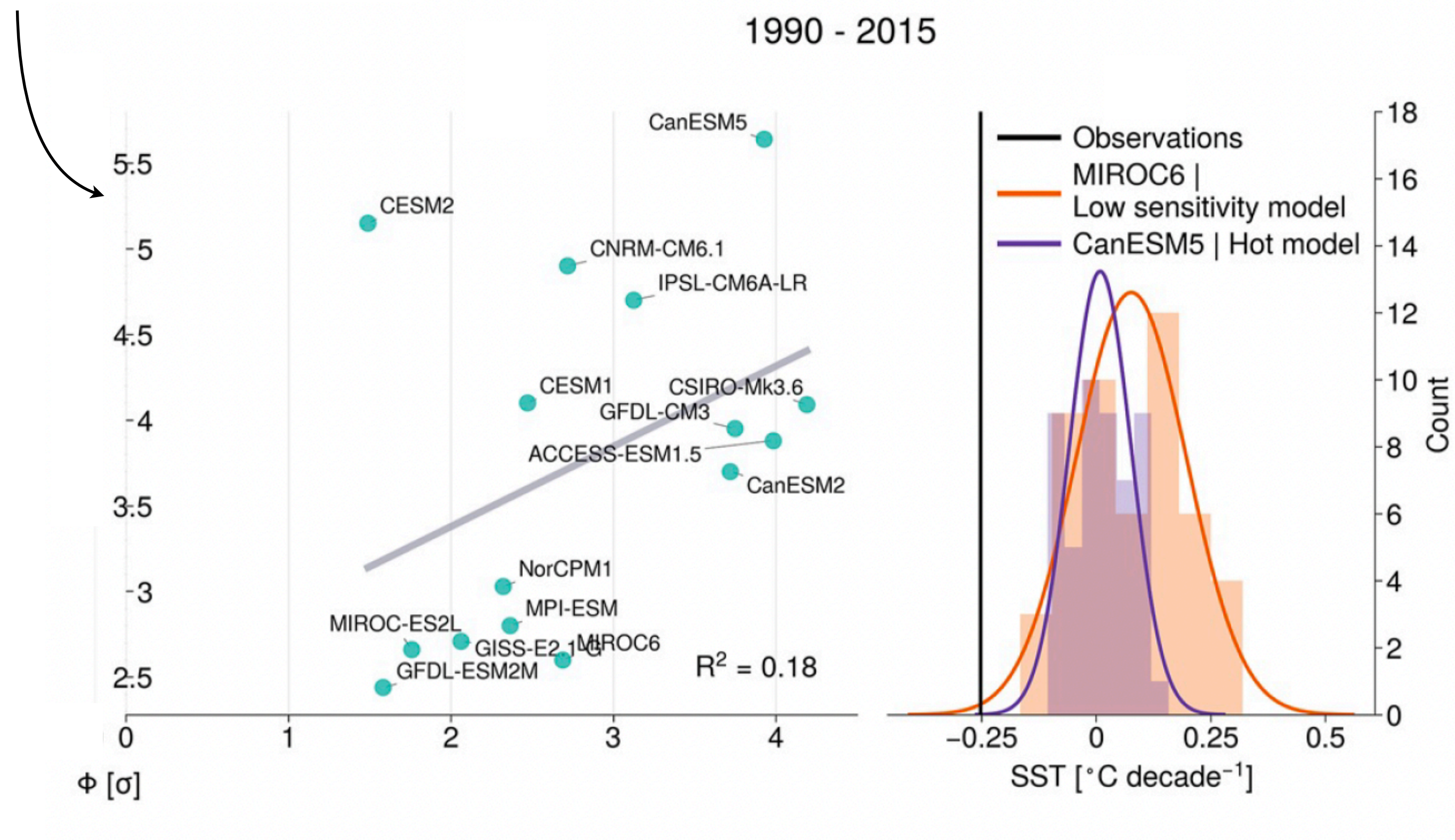


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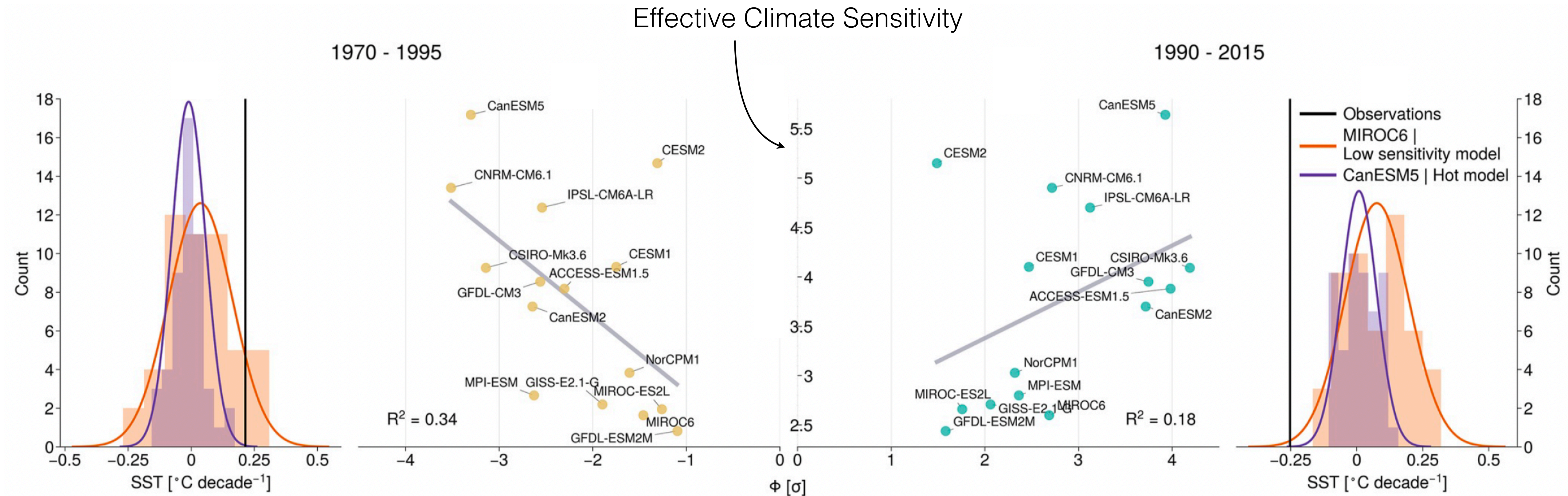
(c) CMIP model discrepancy with observations

# Models which cannot reproduce swings tend to have very high ECS

Effective Climate Sensitivity

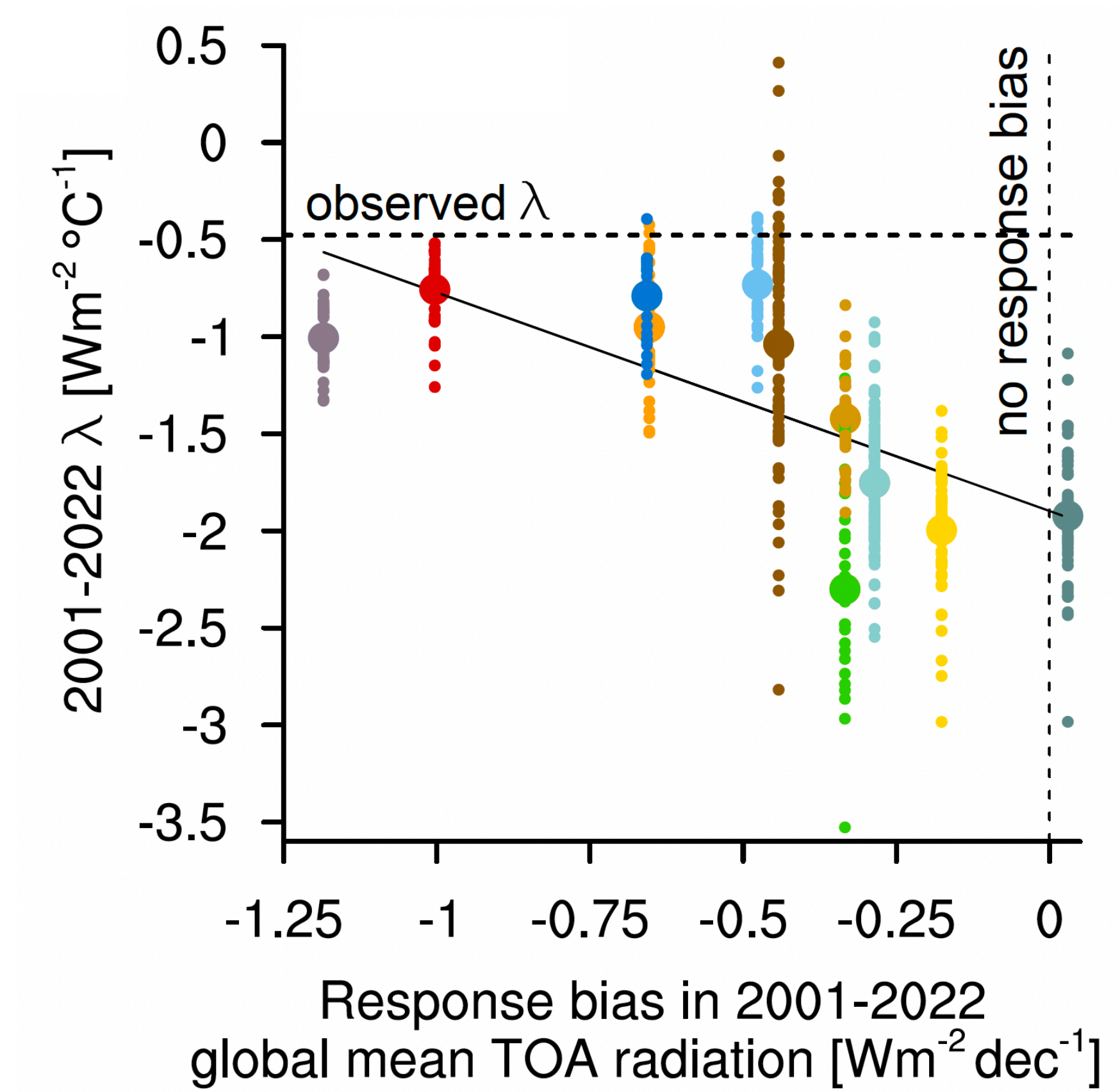


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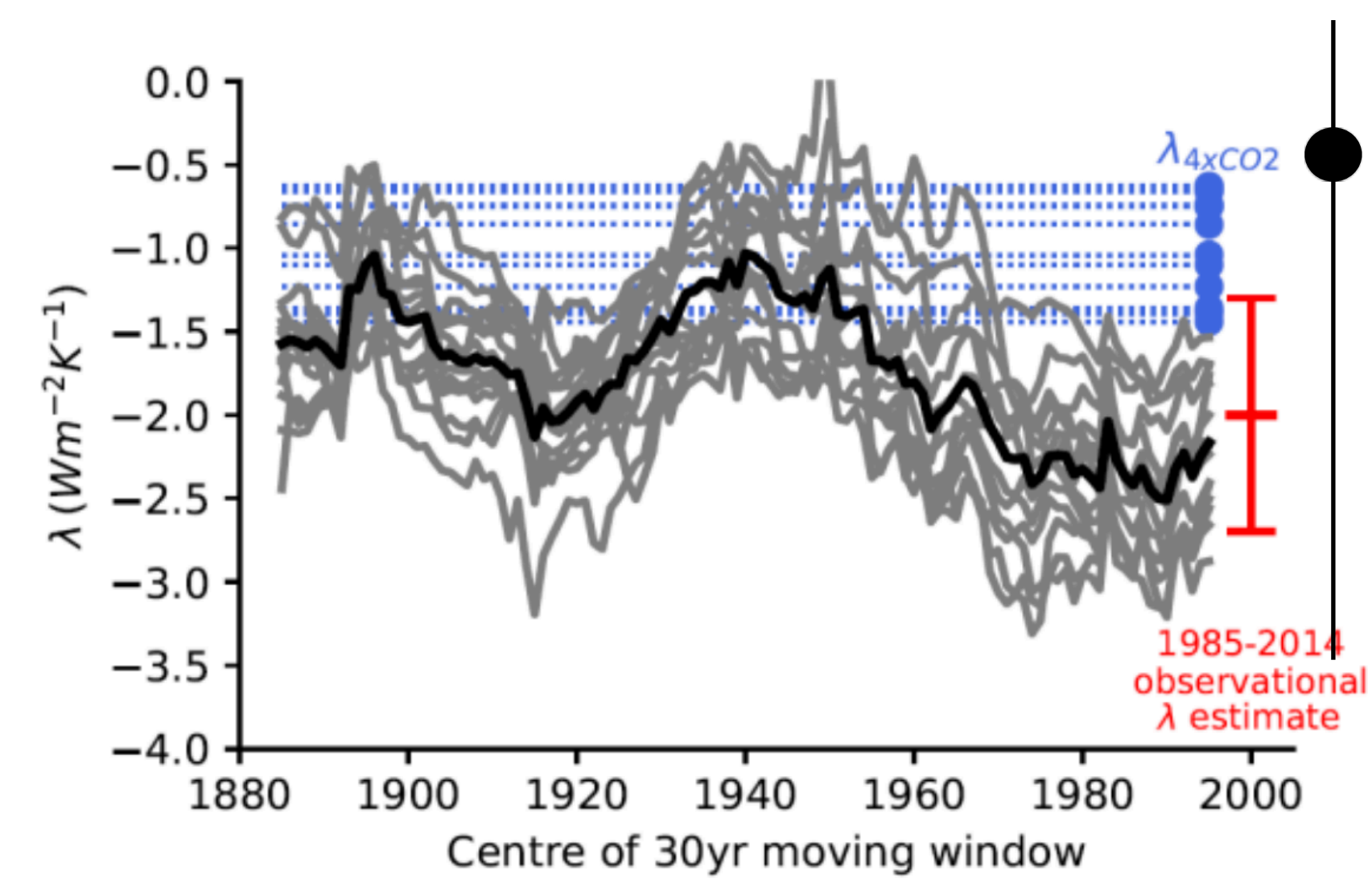
- Models all underestimate the slightly negative equatorial SST gradient on long timescales
- Half of the models underestimate the decadal-scale positive and negative swings
- Models with low variability tend to have a high climate sensitivity possibly due to a mismatch between SST and EIS short-wave cloud feedback

# Radiative feedbacks change in time (unverifiably though)

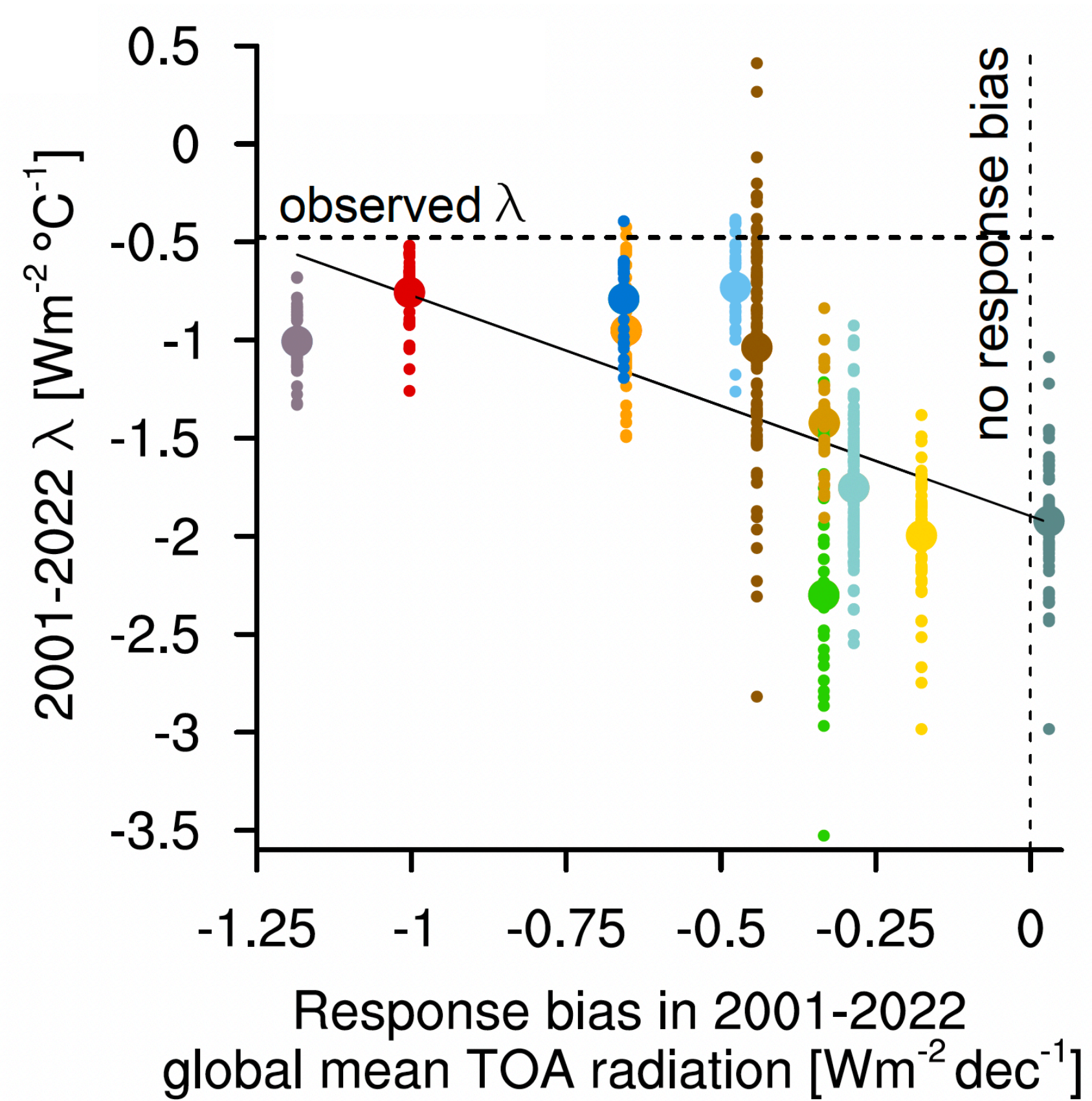




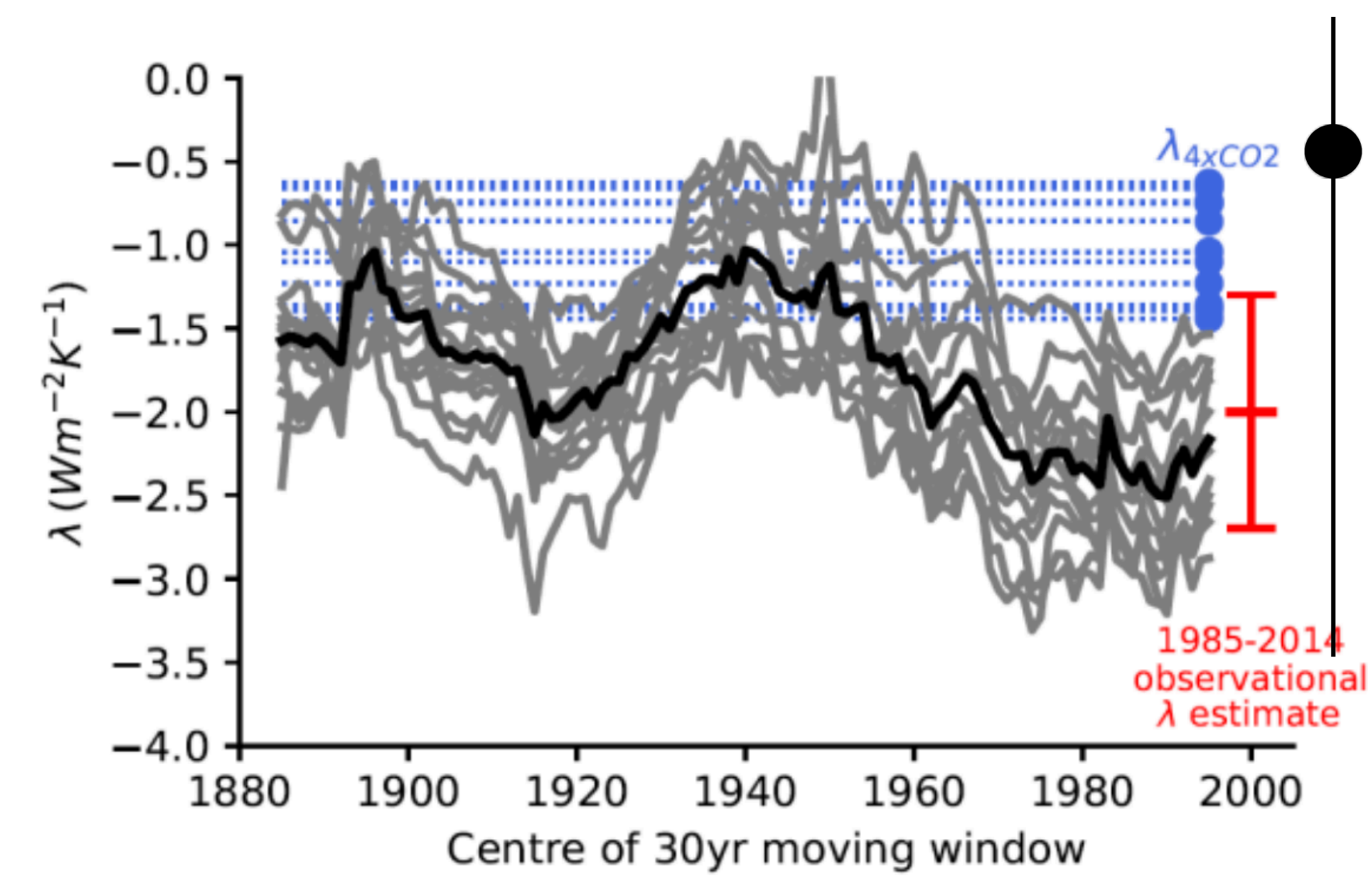
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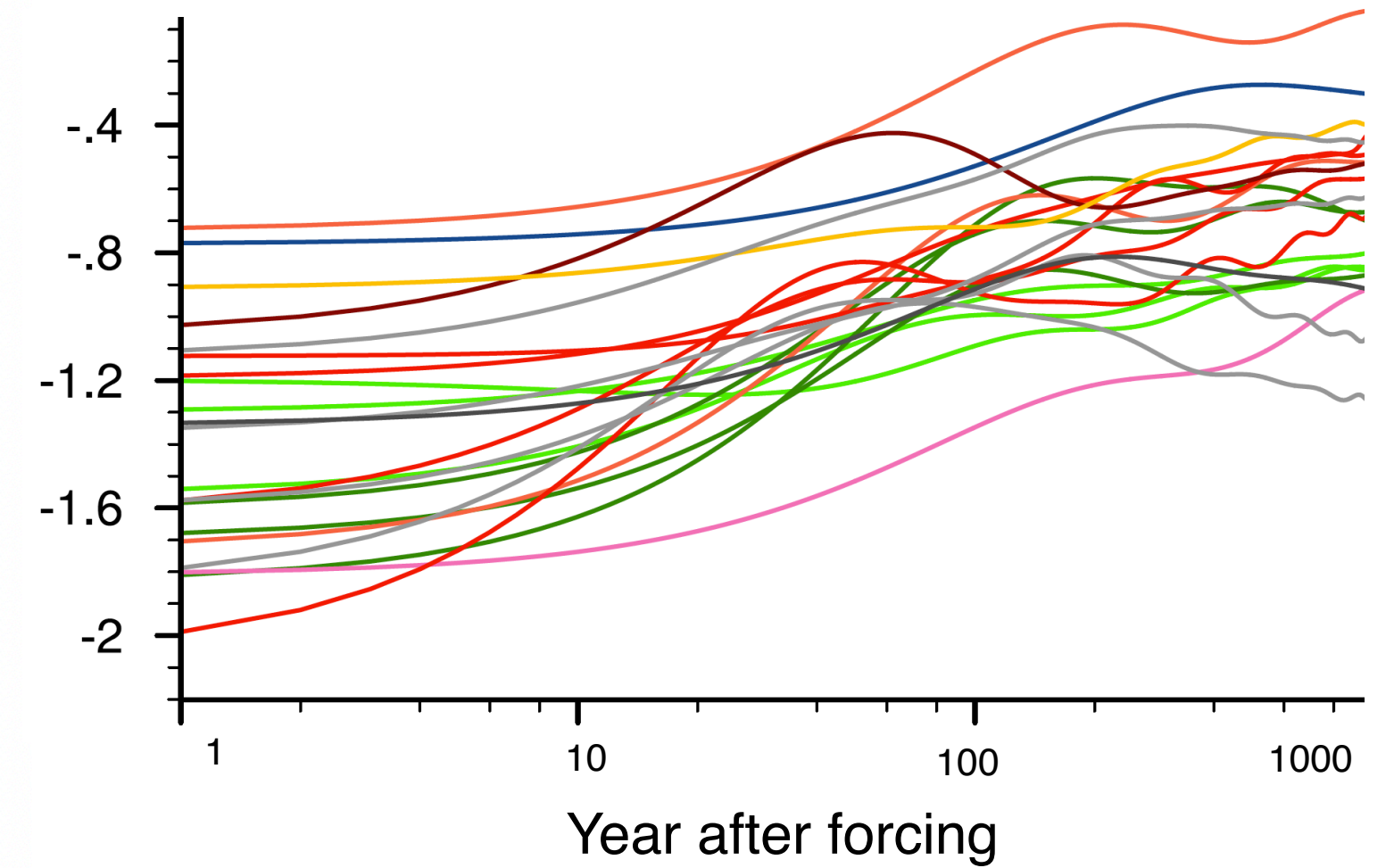
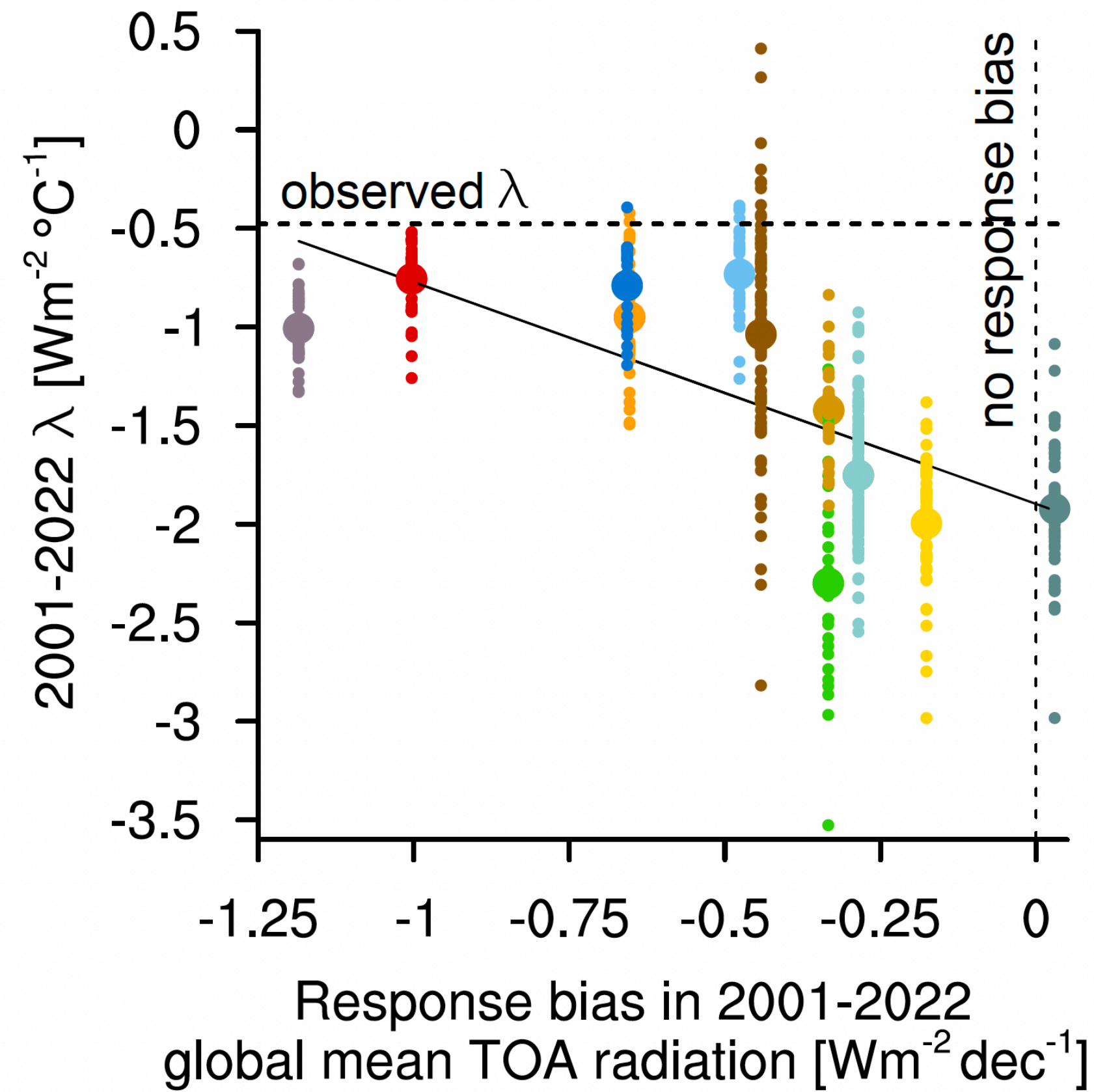
Andrews et al. 2022



# How will SST patterns and radiative feedbacks change in the future?

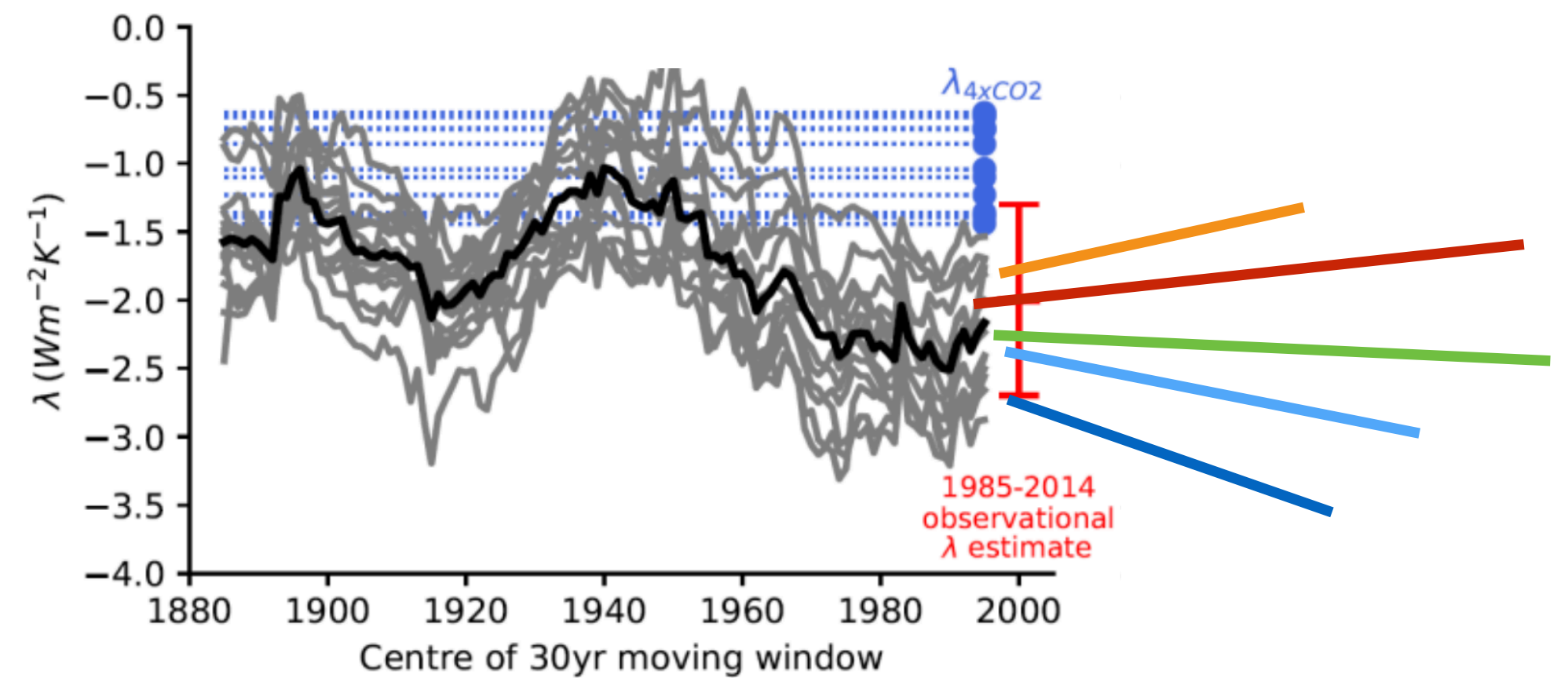


Andrews et al. 2022

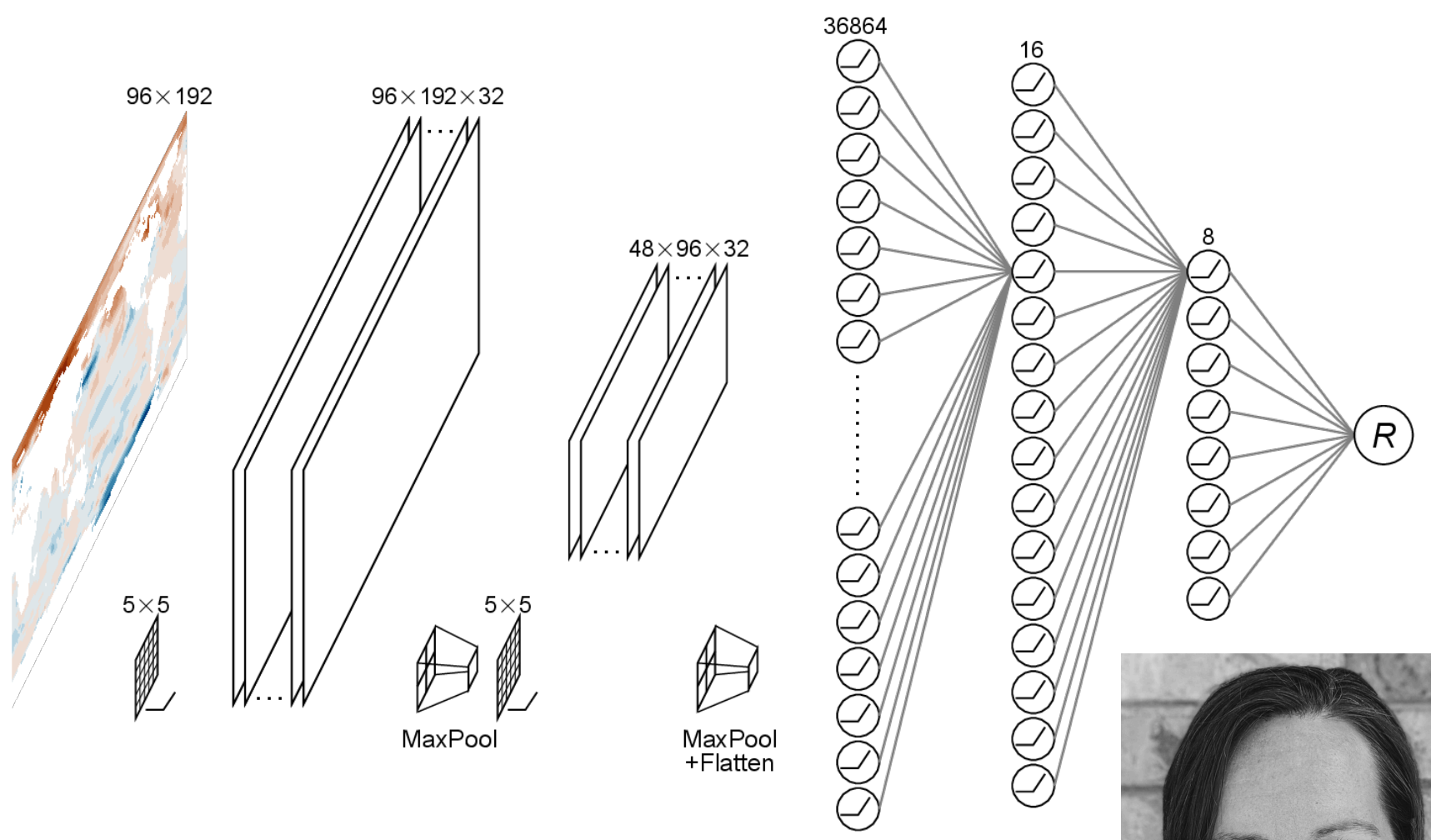


[LongRunMIP.org](http://LongRunMIP.org)

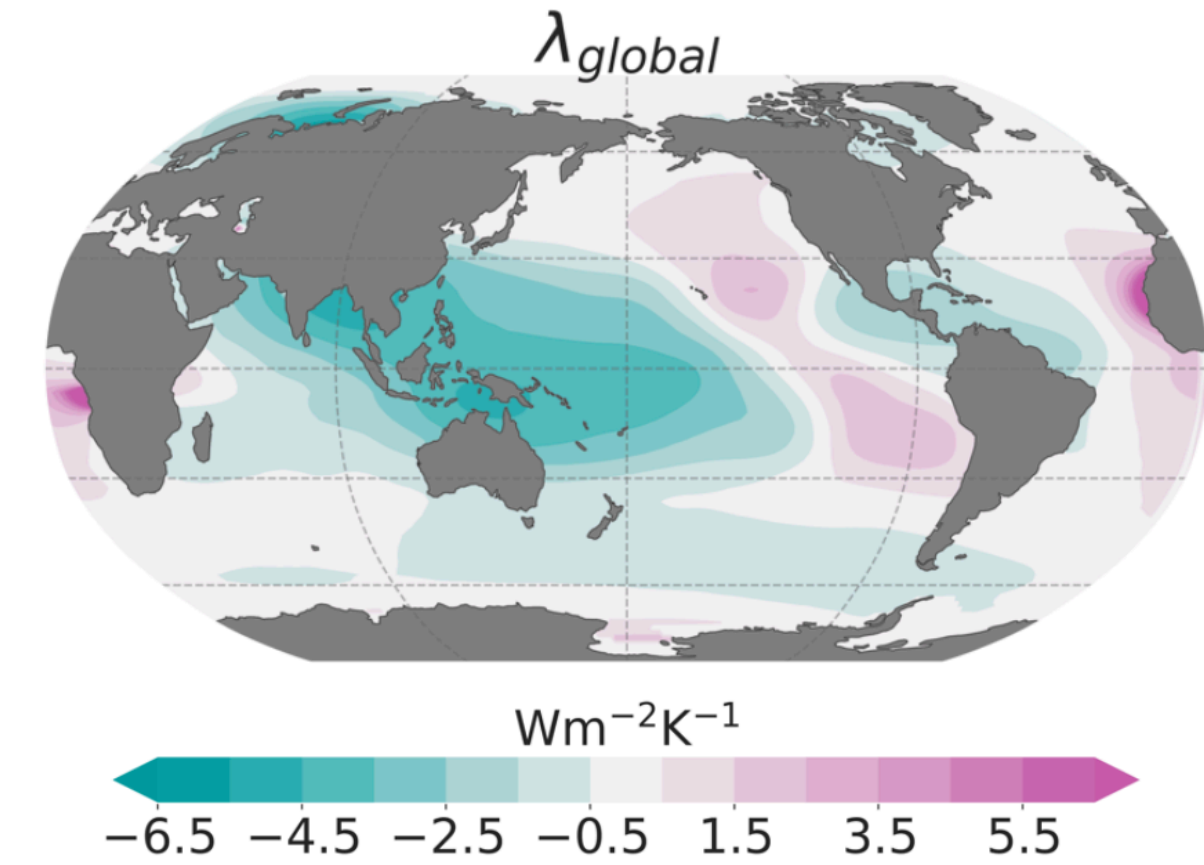
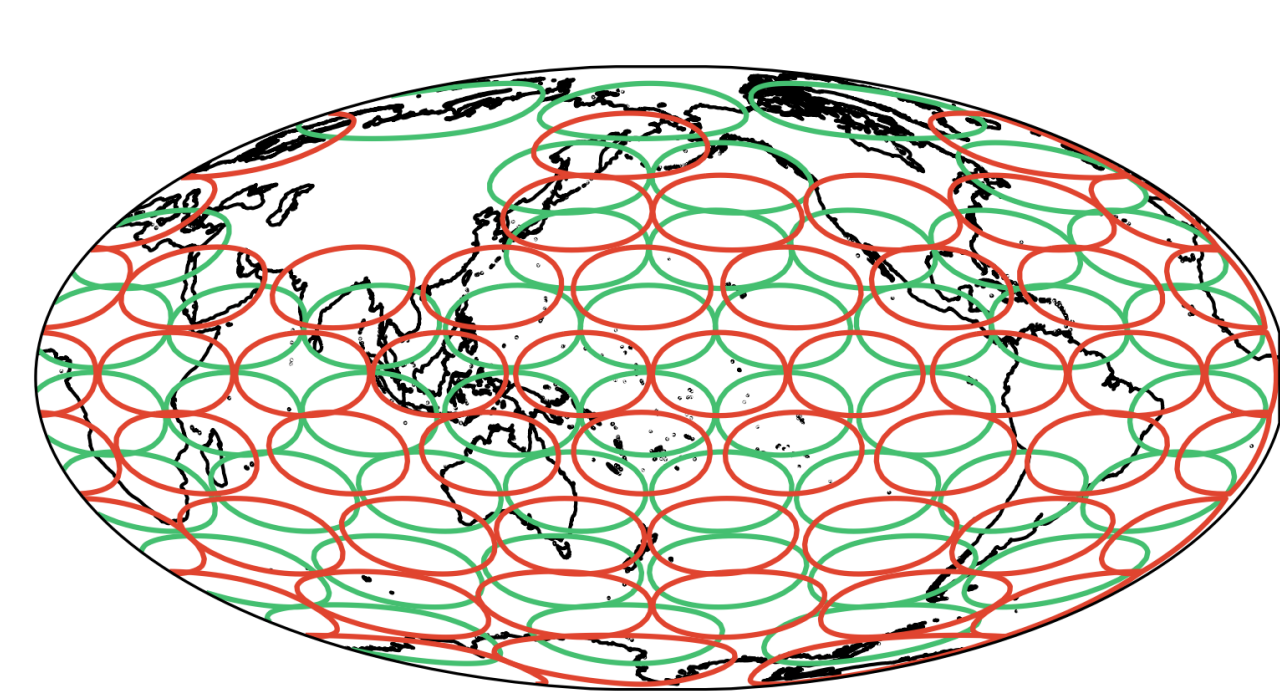
# How will SST patterns and radiative feedbacks change in the future?



Convolutional Neural Networks *nonlinear*



Green's function ~ SST patch simulations *linear*

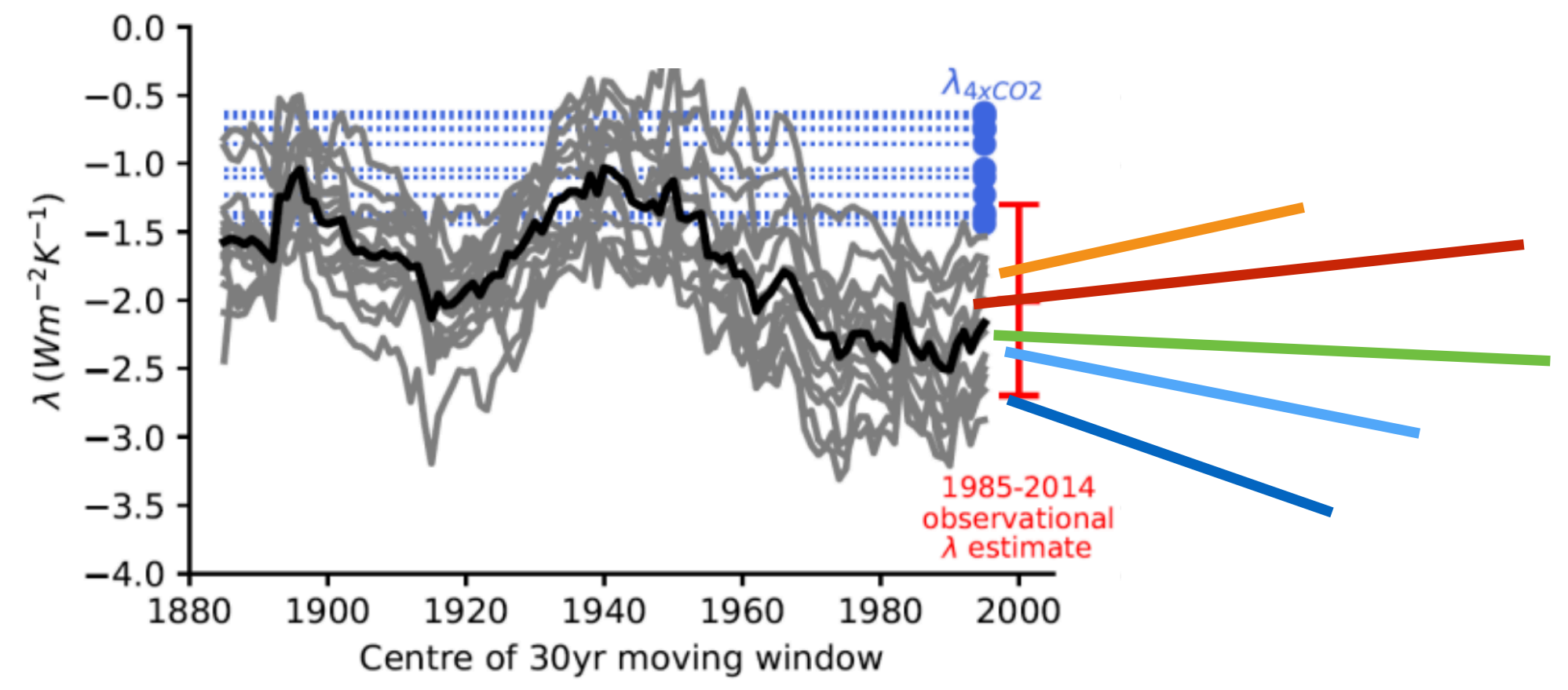
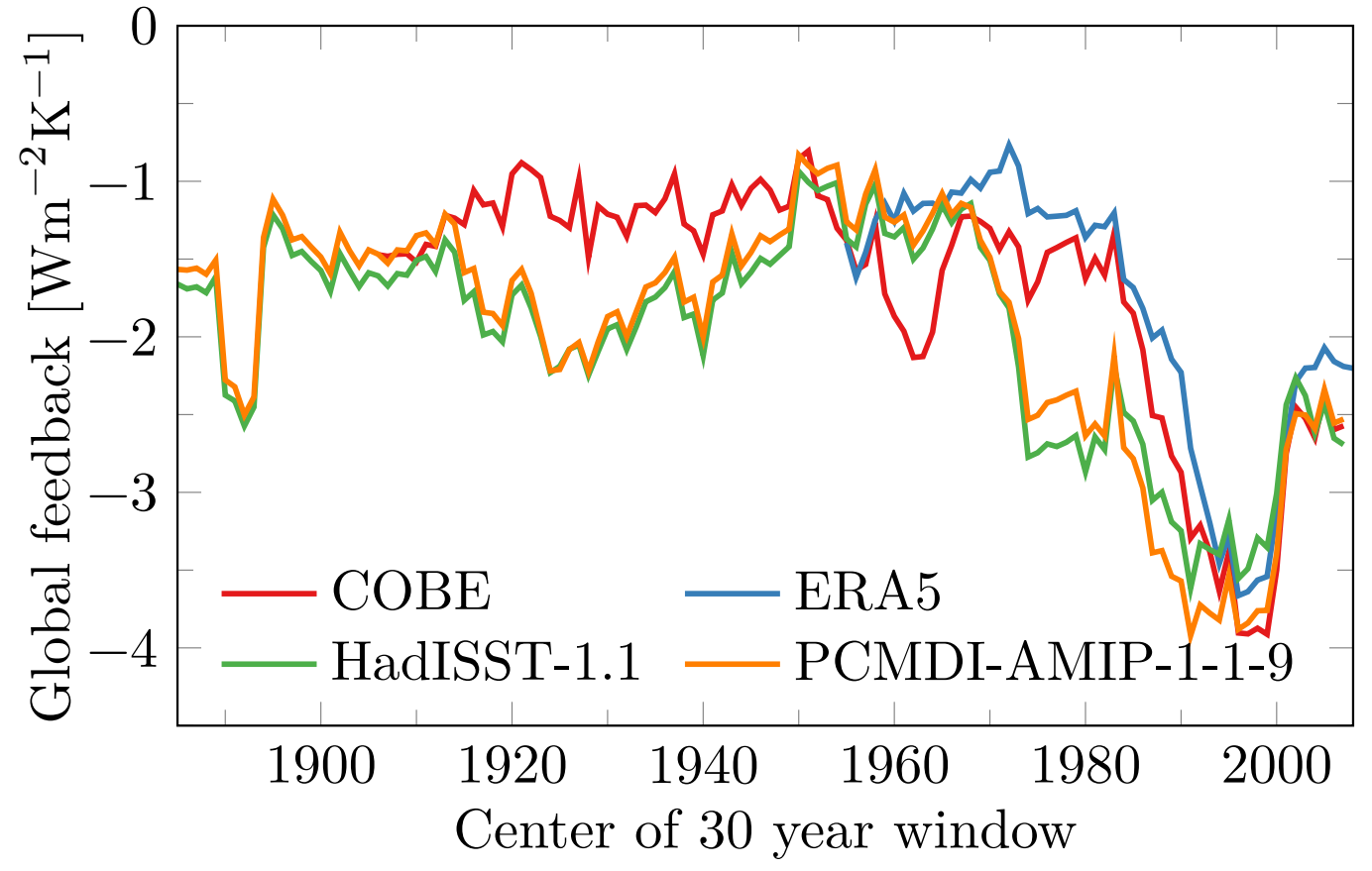


Rugenstein, Van Loon, Barnes, in rev.  
Van Loon, Rugenstein, Barnes, in prep

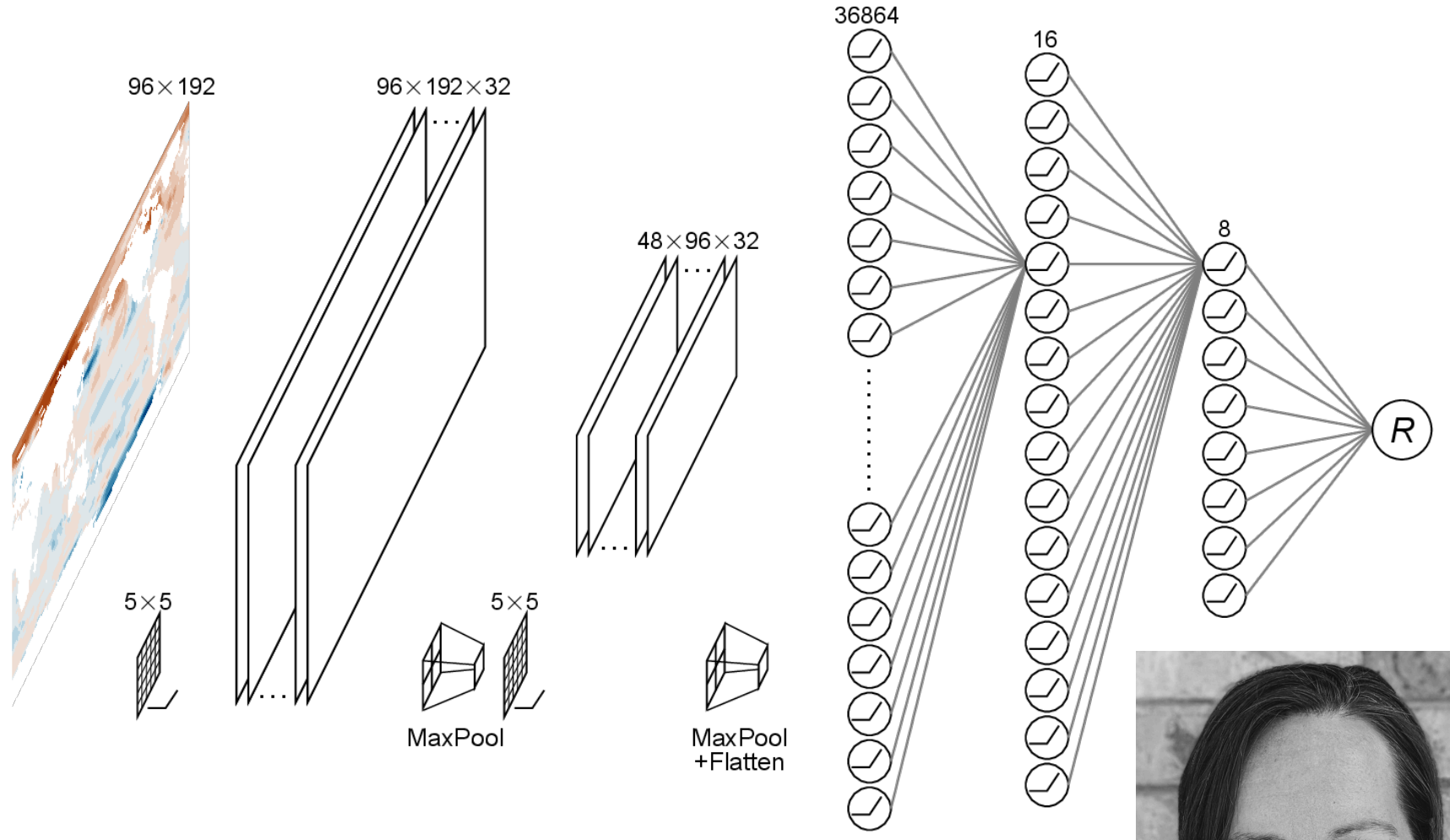
Alessi and Rugenstein, 2023: *Surface temperature pattern scenarios suggest higher warming rates than current projections*

Bloch-Johnson et al. 2024, GF-MIP

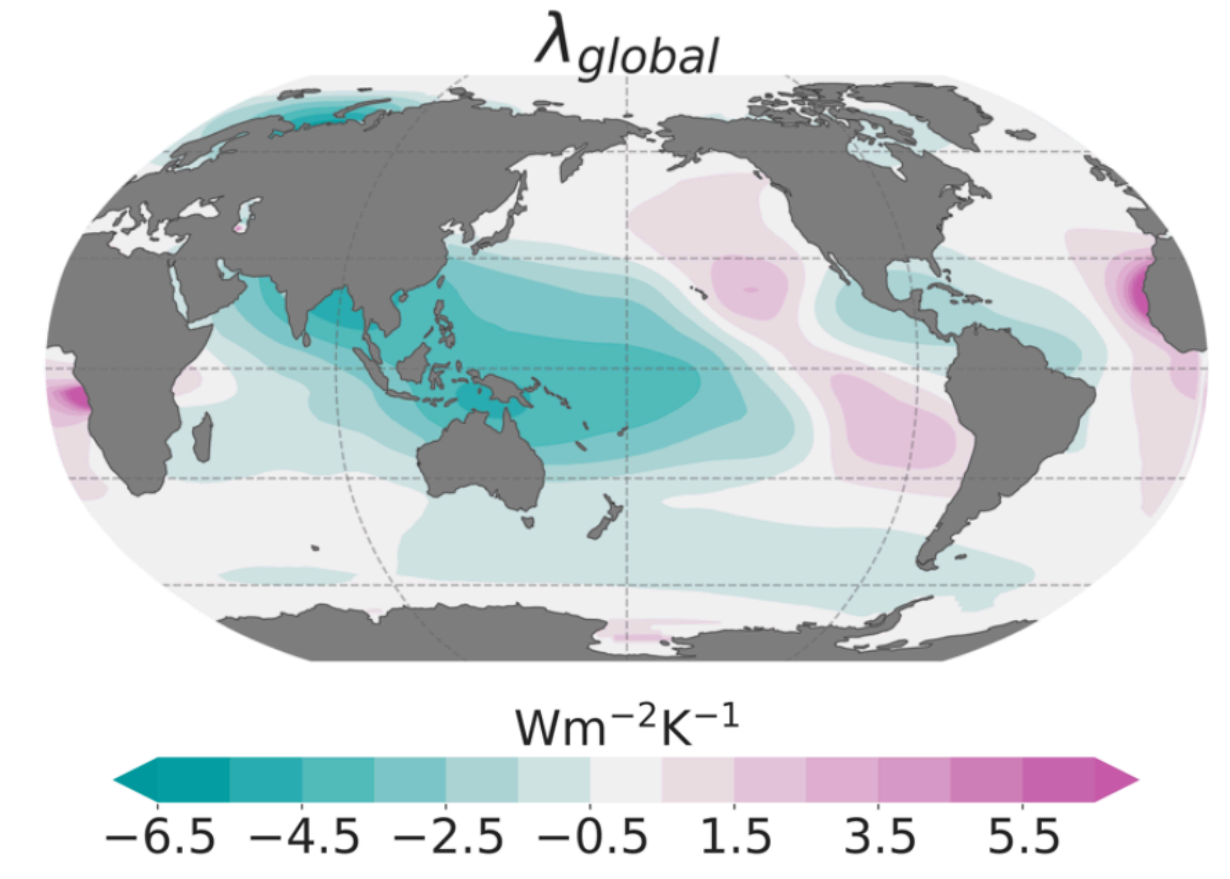
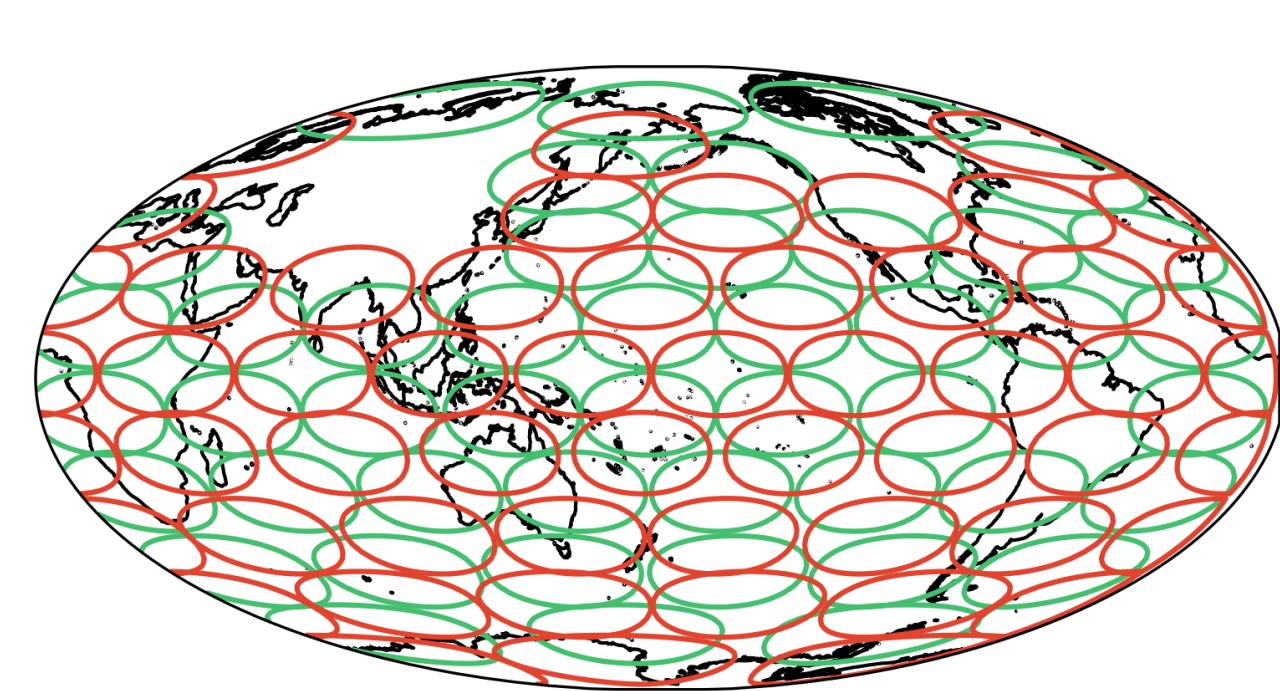
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Convolutional Neural Networks nonlinear



Green's function ~ SST patch simulations linear

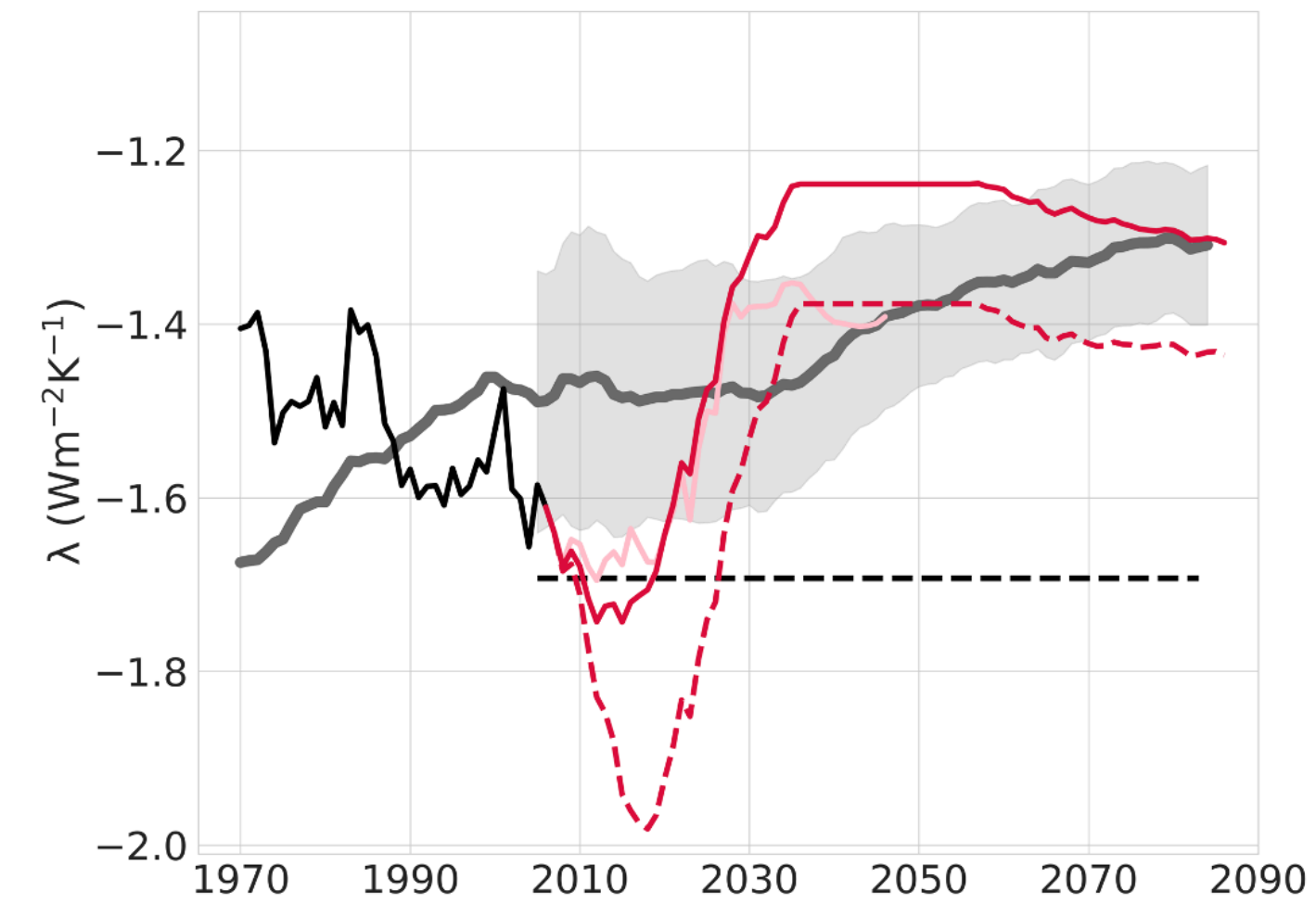
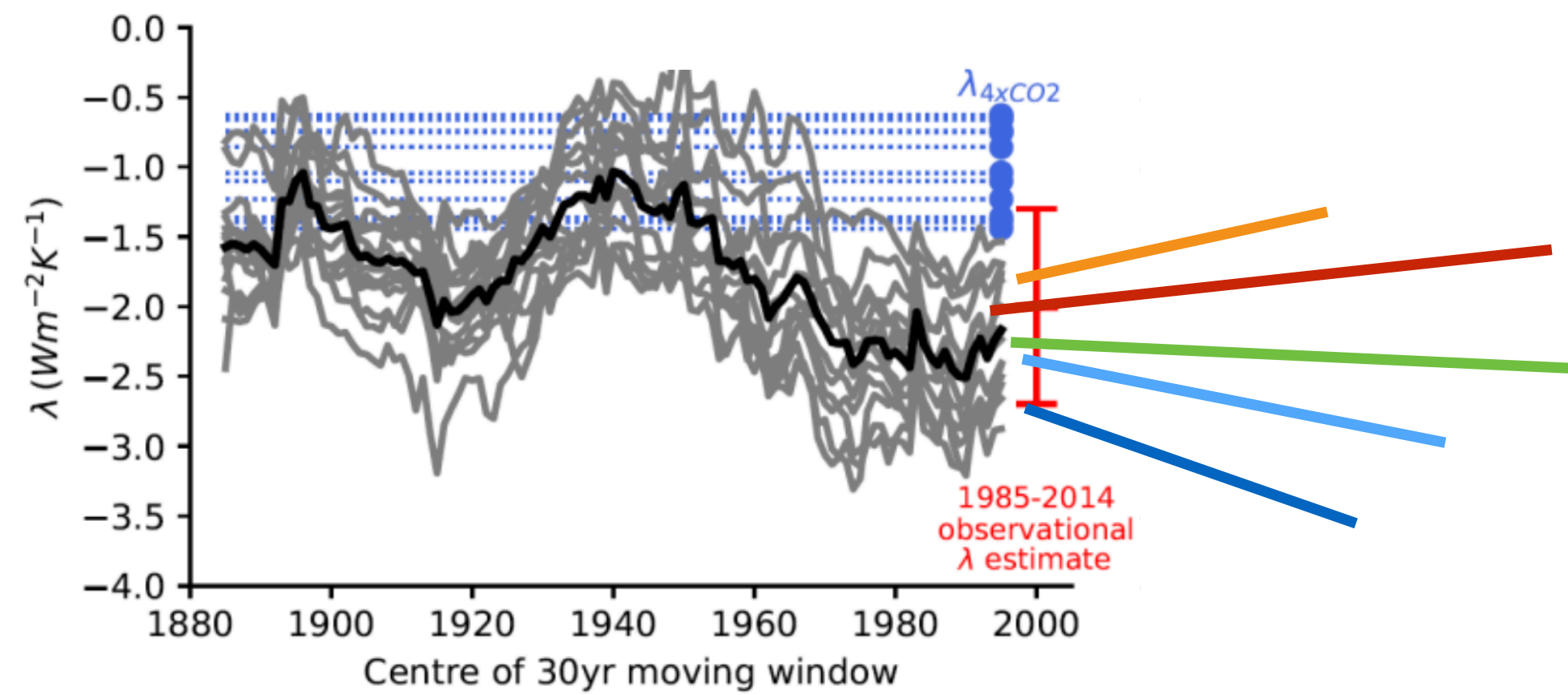
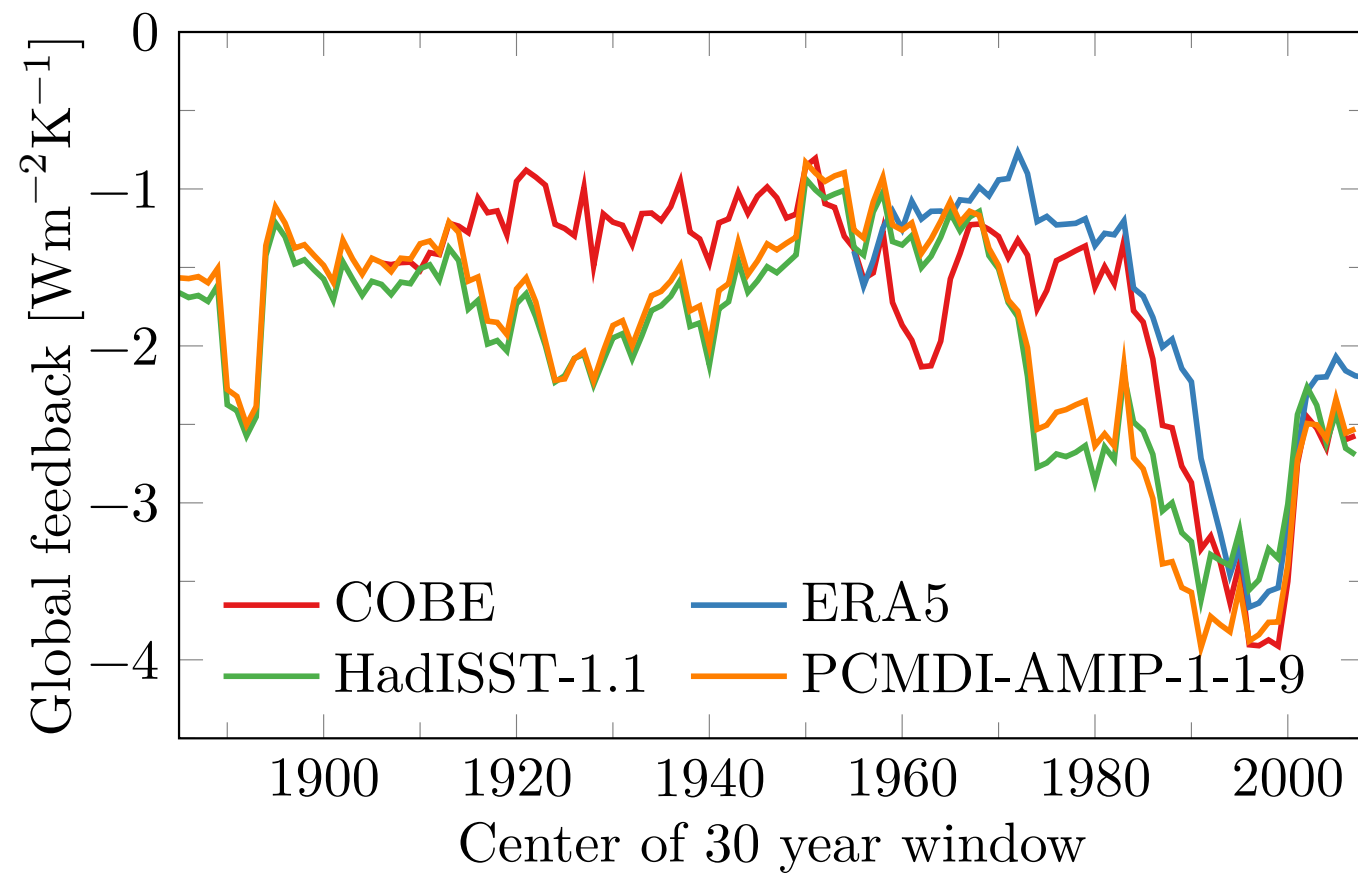


Rugenstein, Van Loon, Barnes, in rev.  
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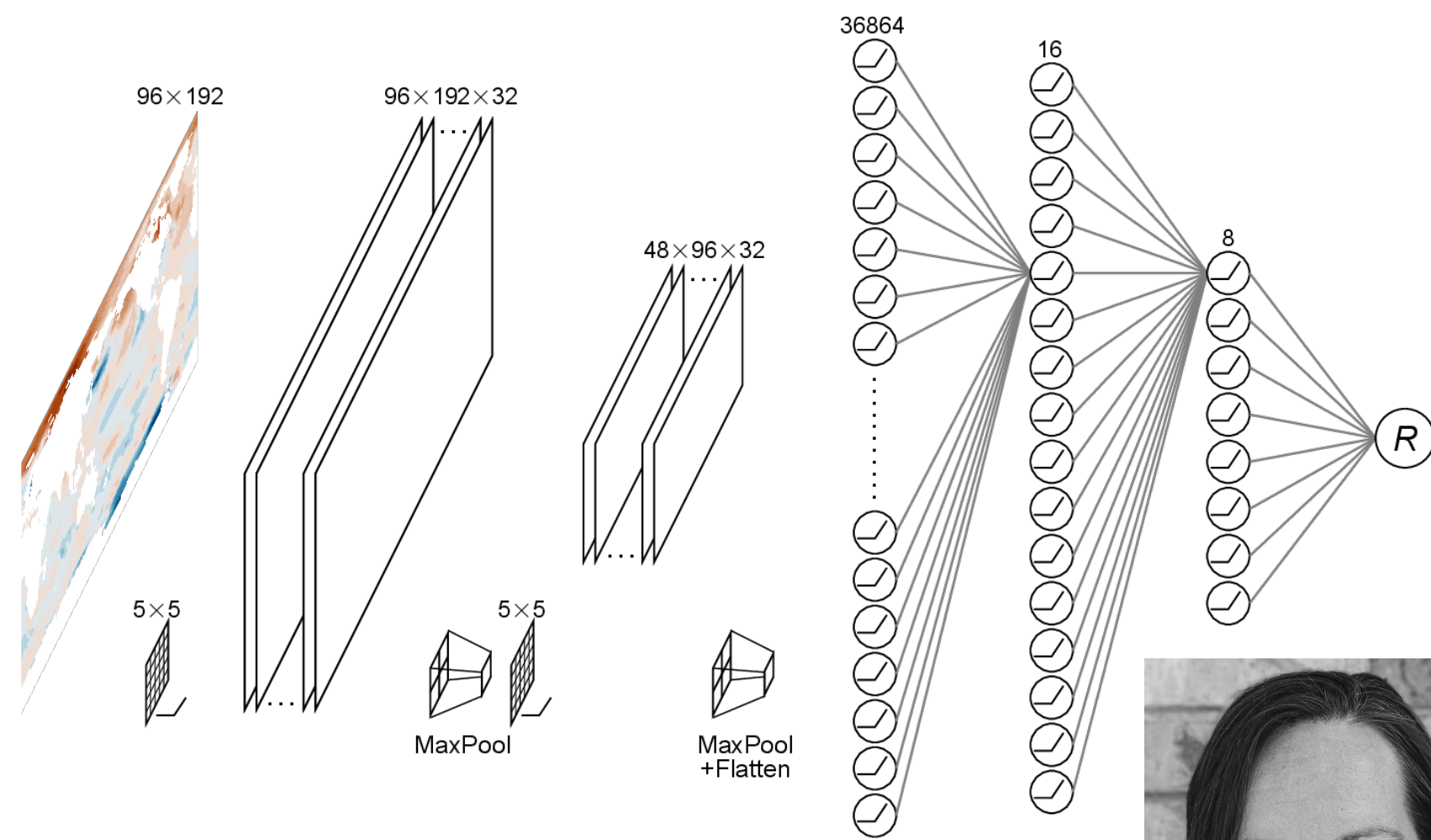
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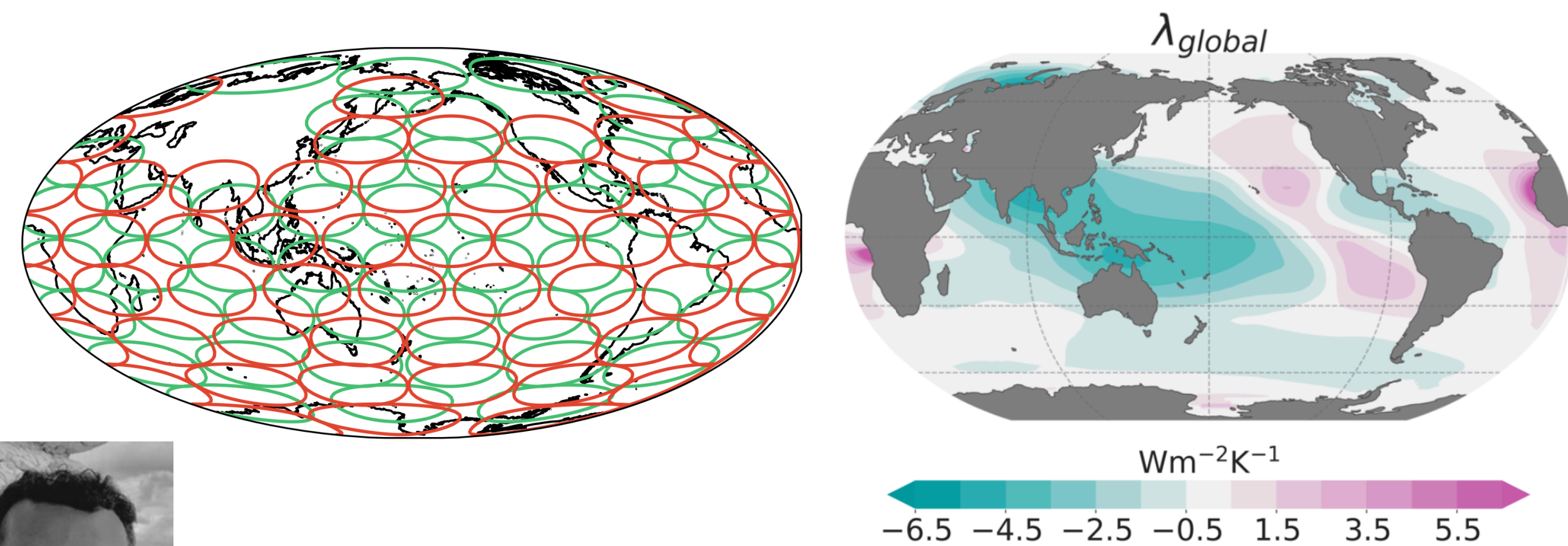
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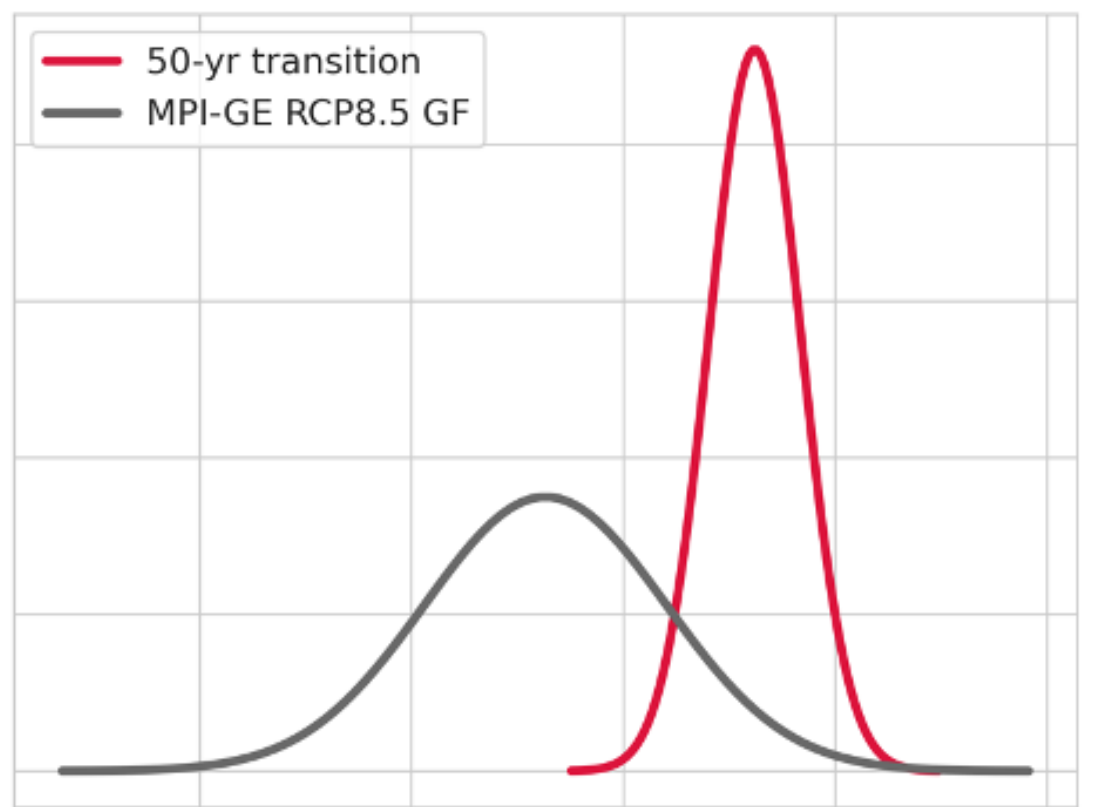


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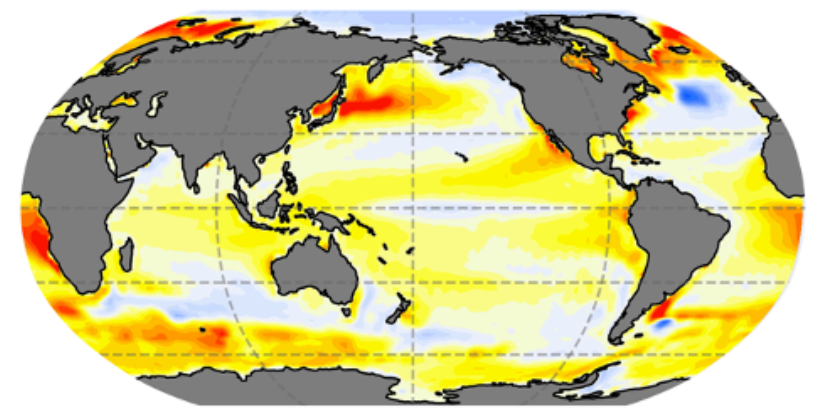
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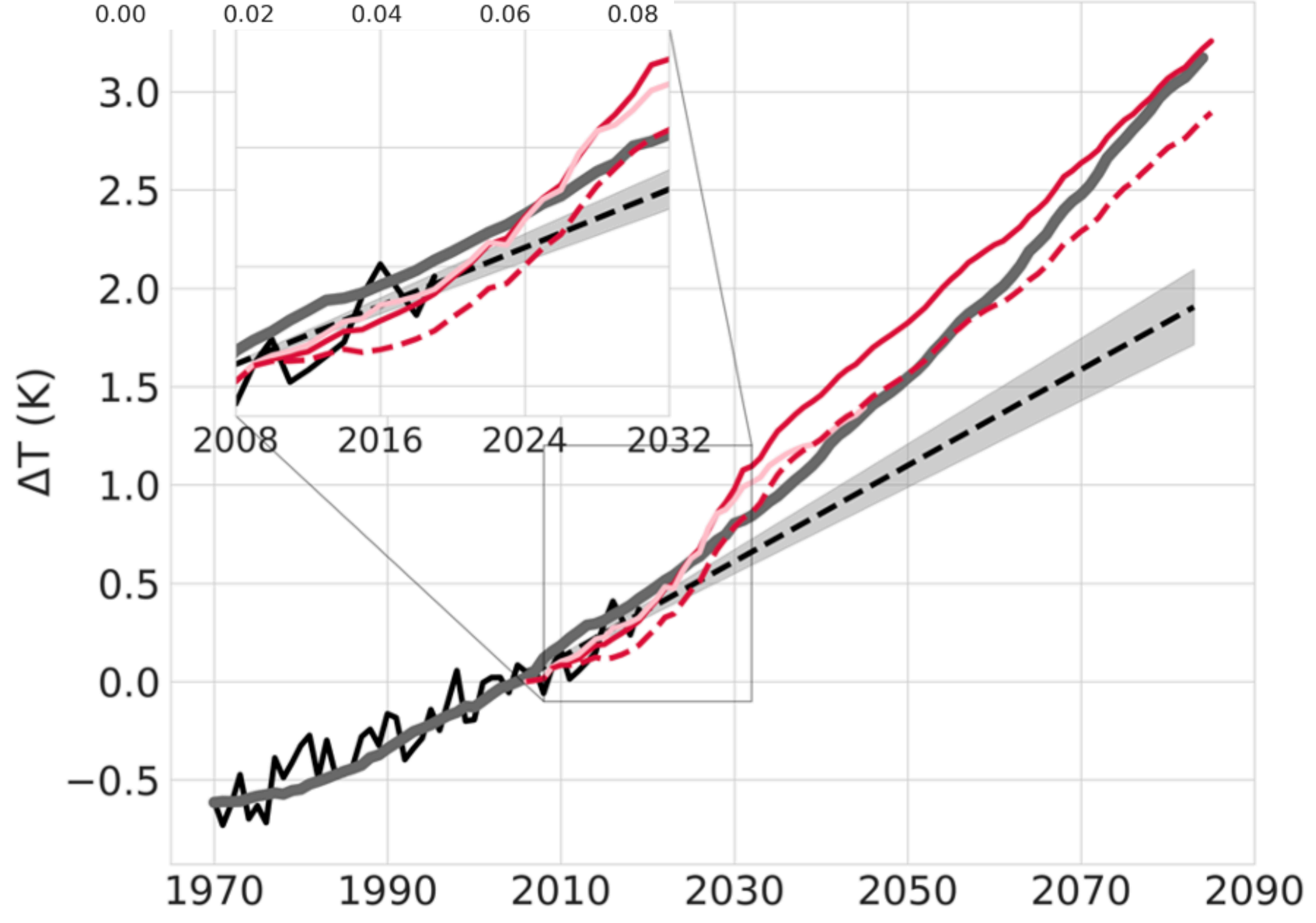
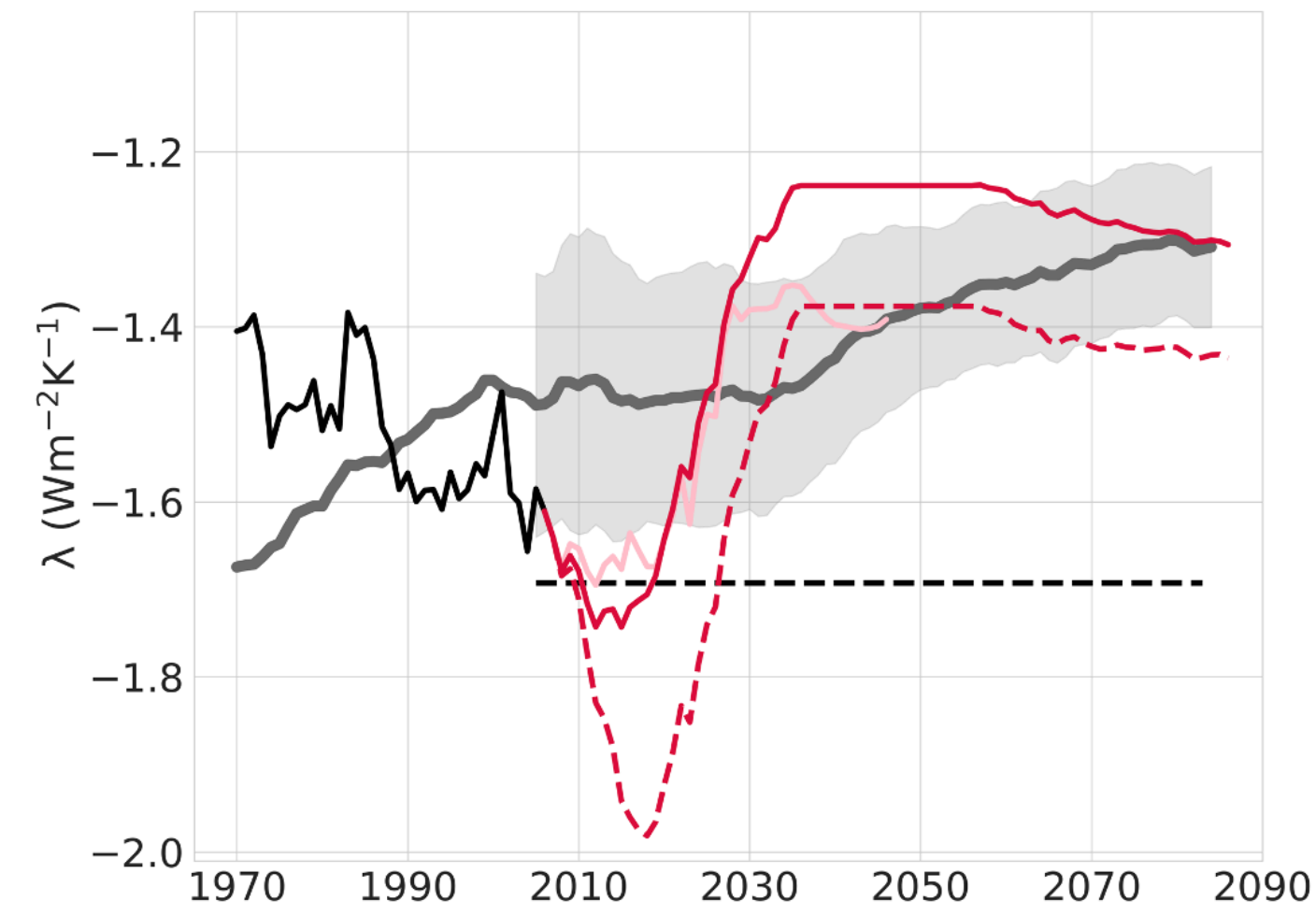
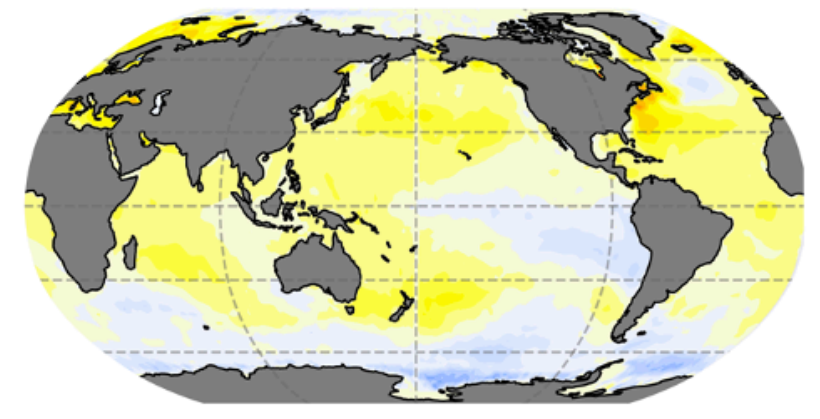
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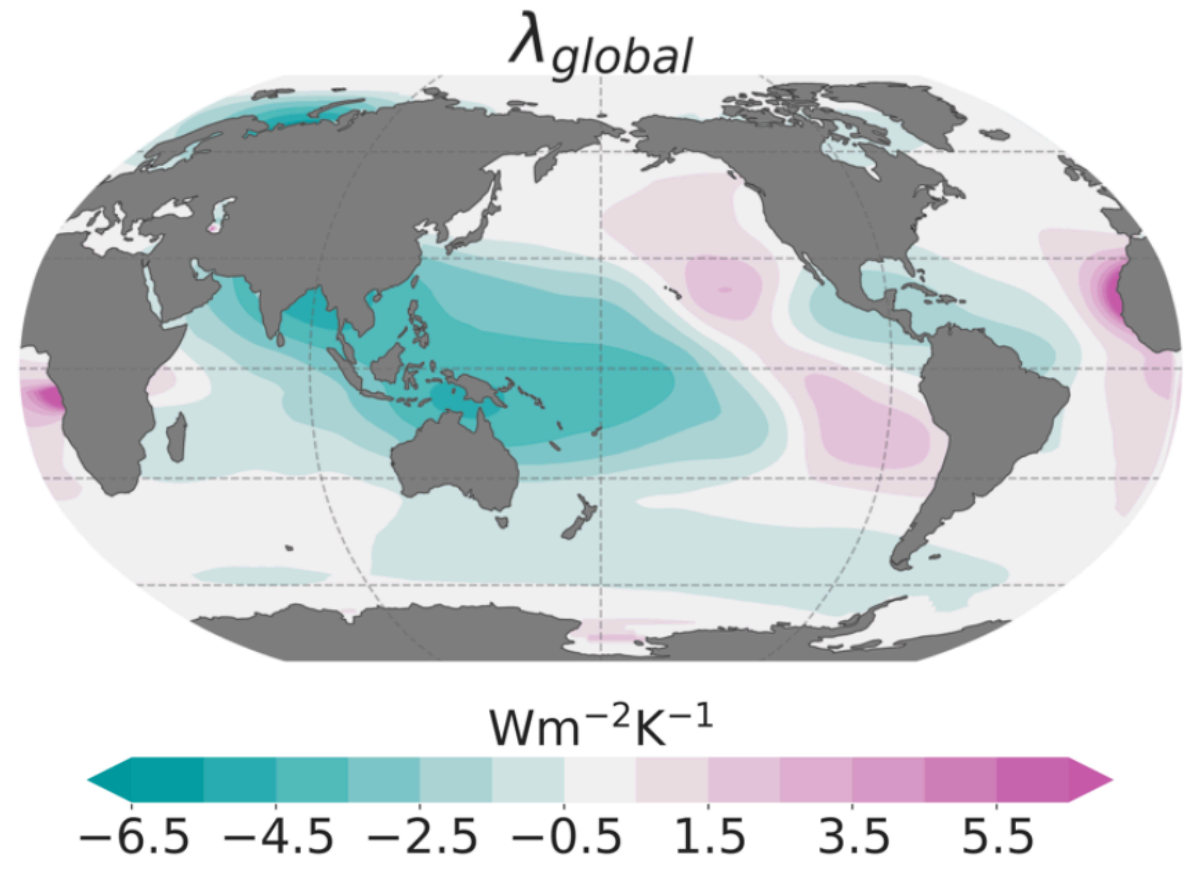
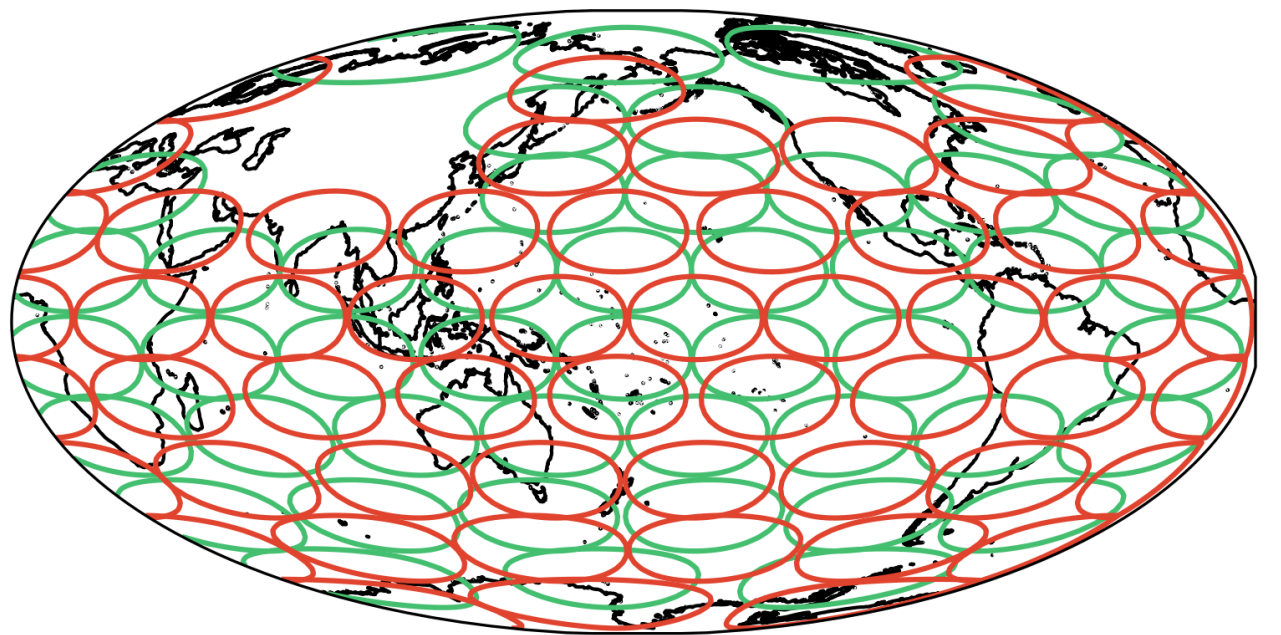
Interpolation observed to future



Observed SST trend 1990-2020



Green's function ~ SST patch simulations linear



Alessi and Rugenstein, 2023: *Surface temperature pattern scenarios suggest higher warming rates than current projections*

Bloch-Johnson et al. 2024, GF-MIP

# How the good and the bad conspire to the ugly

Observable TOA radiation trends

are seriously underestimated even though surface temperature is OK,  
feedbacks are unmeaningful

Observable surface temperature trends

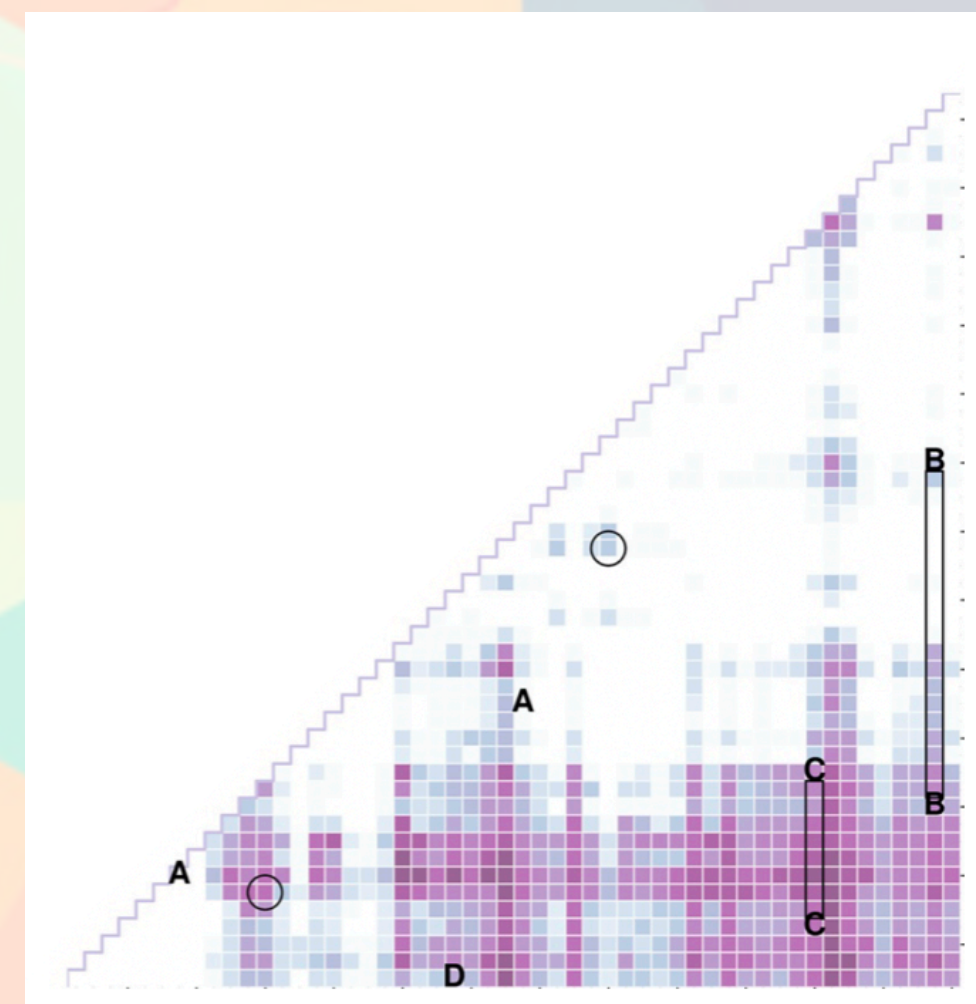
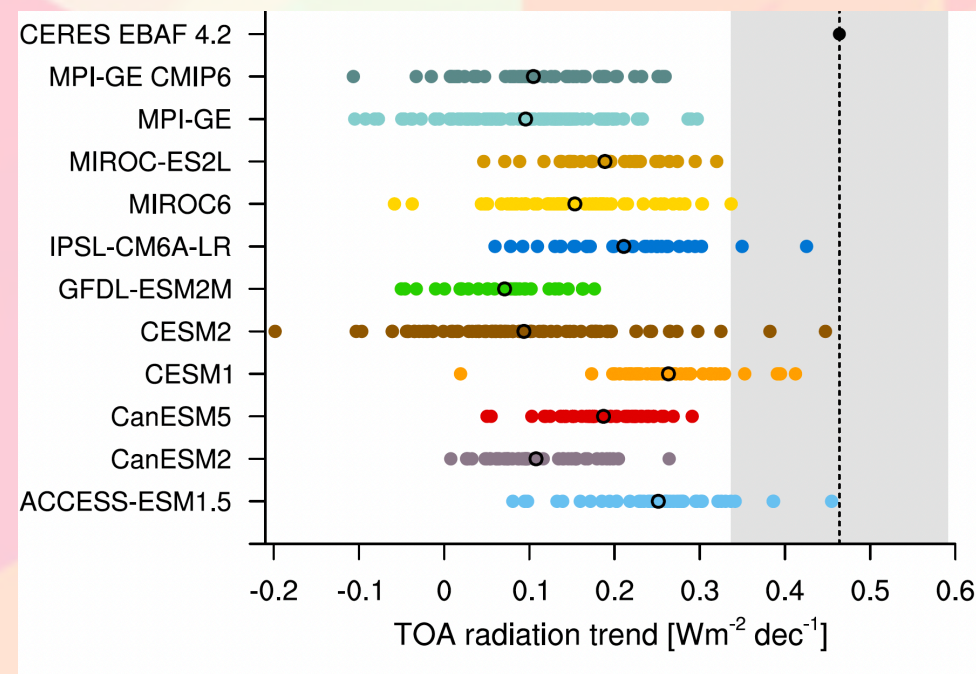
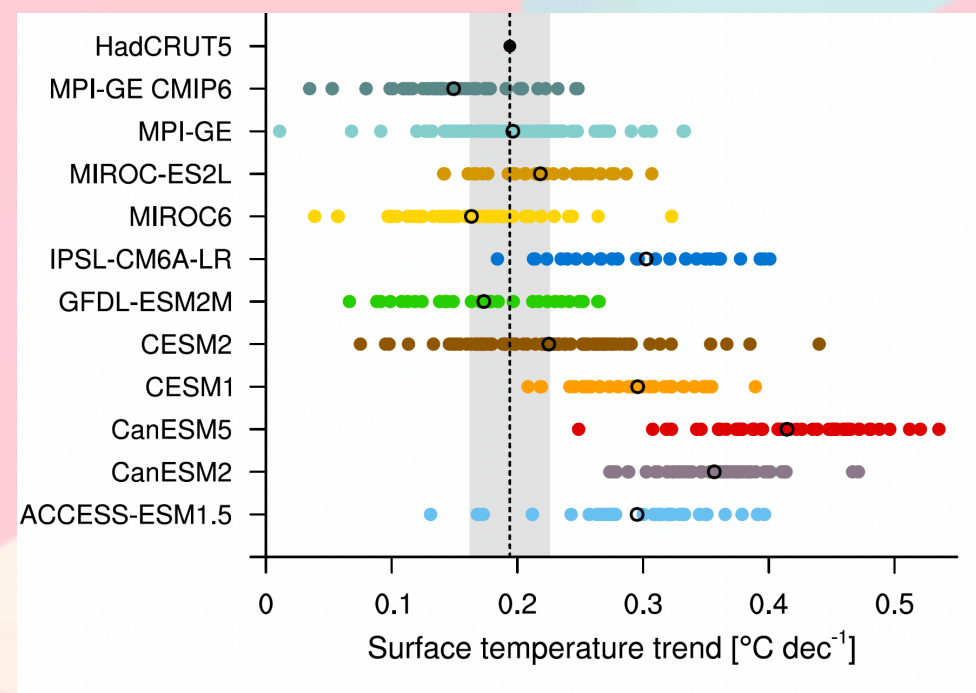
are locally and for certain timescales systematically off, radiation is  
unknown and feedbacks unverifiable

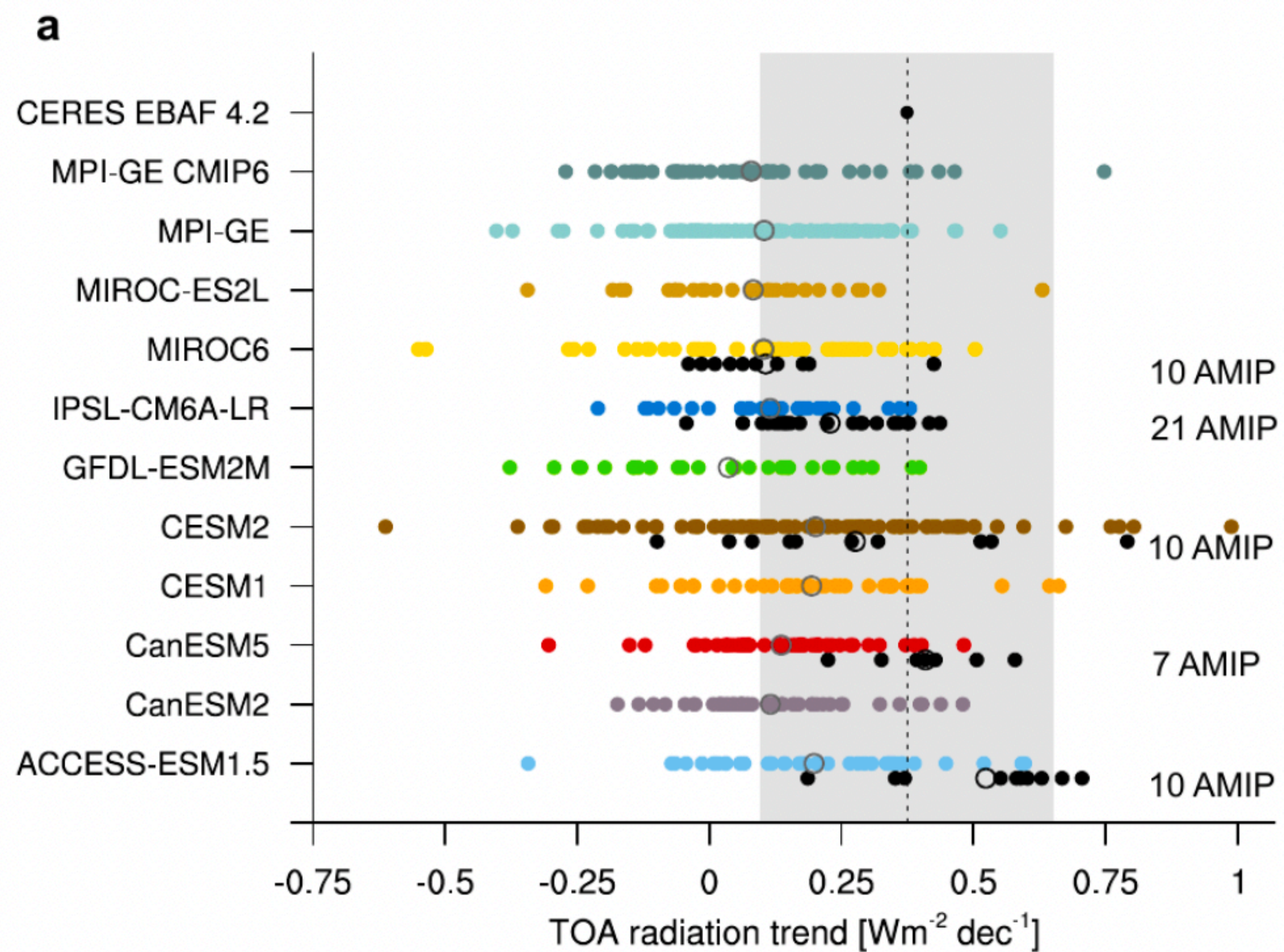
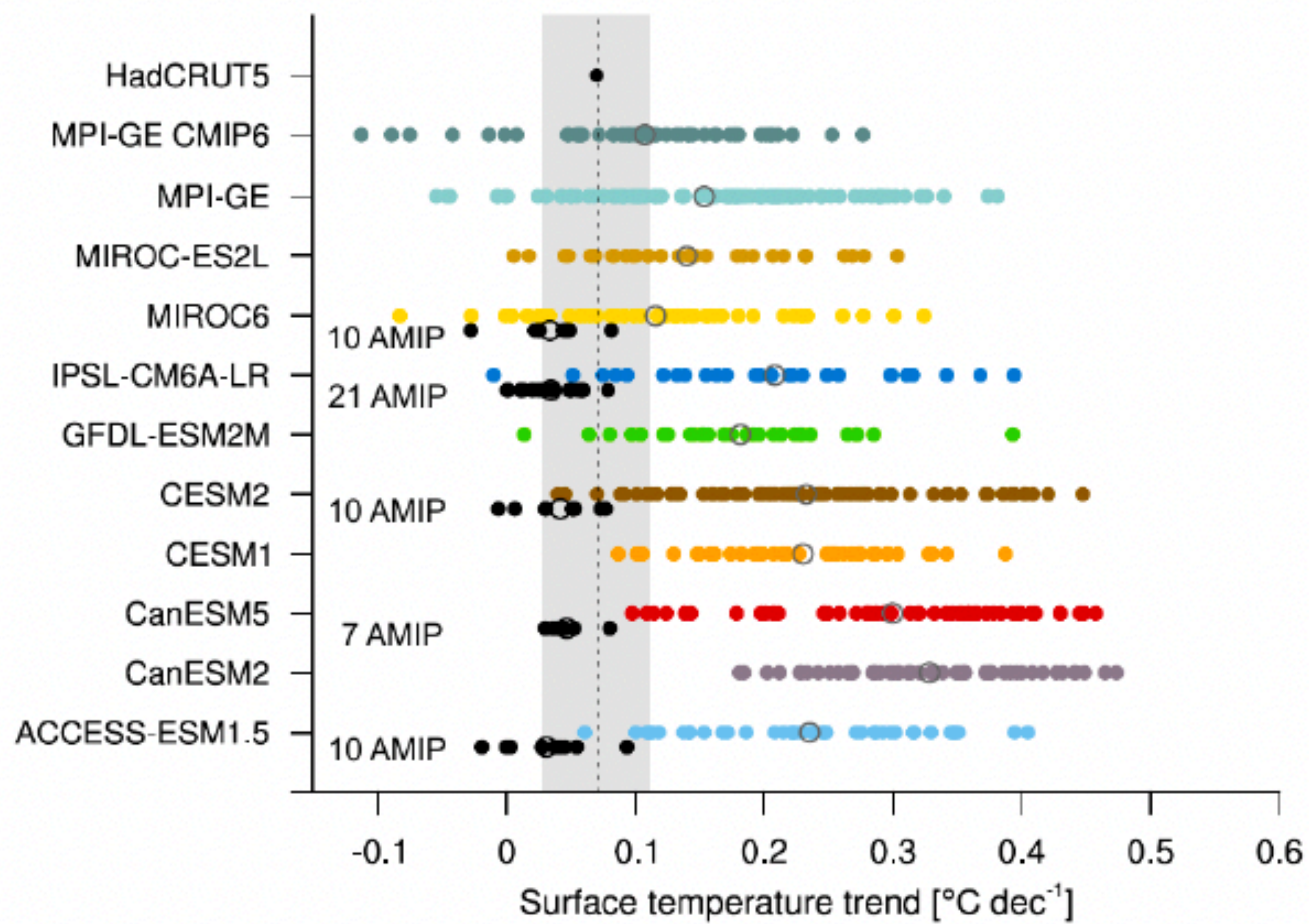
## Implications for projections of climate change

If the SST pattern problem and the heat uptake problem persist into the  
future projections of global-mean temperature might be seriously off

**Climate models: weak forcing & strong OHU balanced by too positive feedbacks**

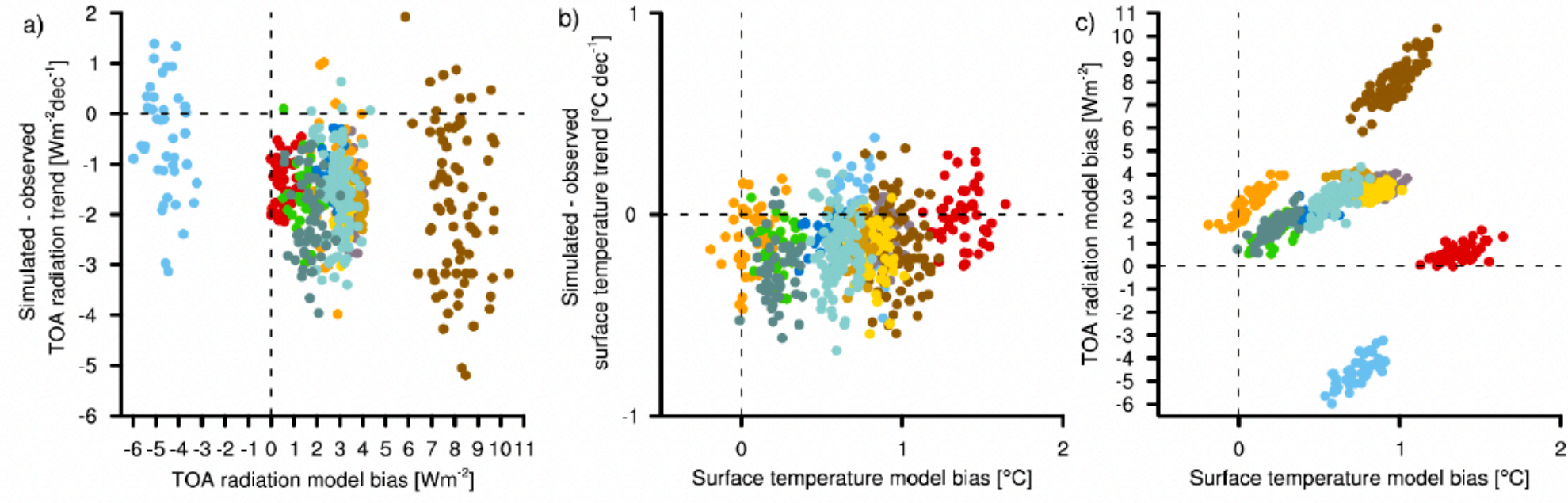
**Observations: strong forcing & weak OHU balanced by strongly restorative feedback**



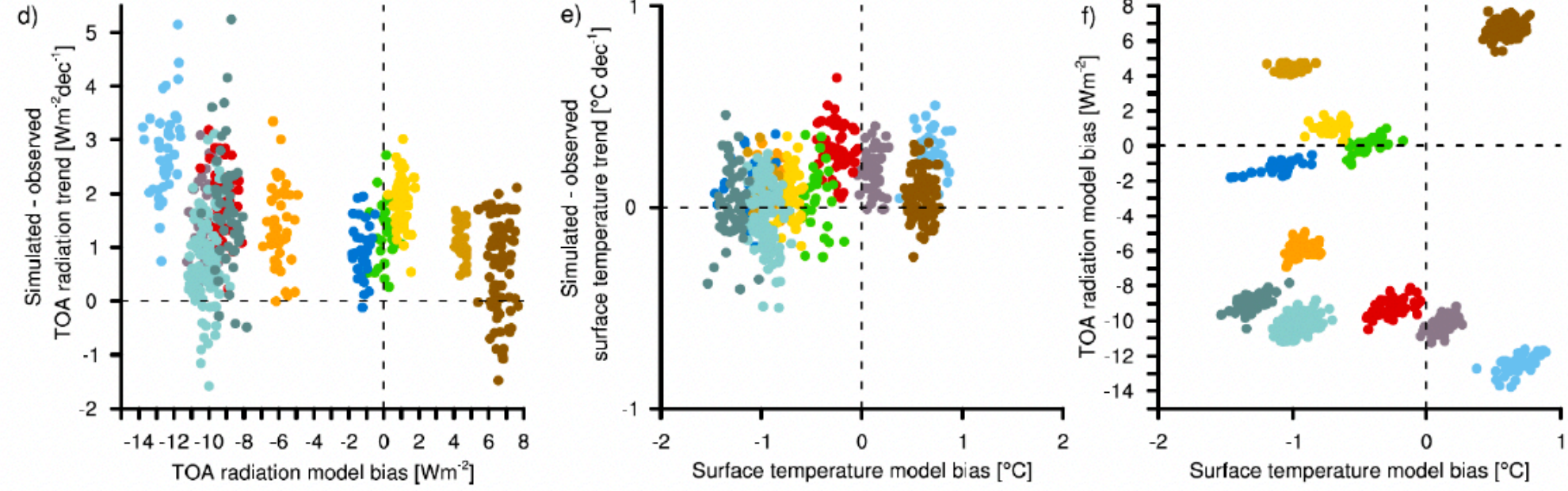




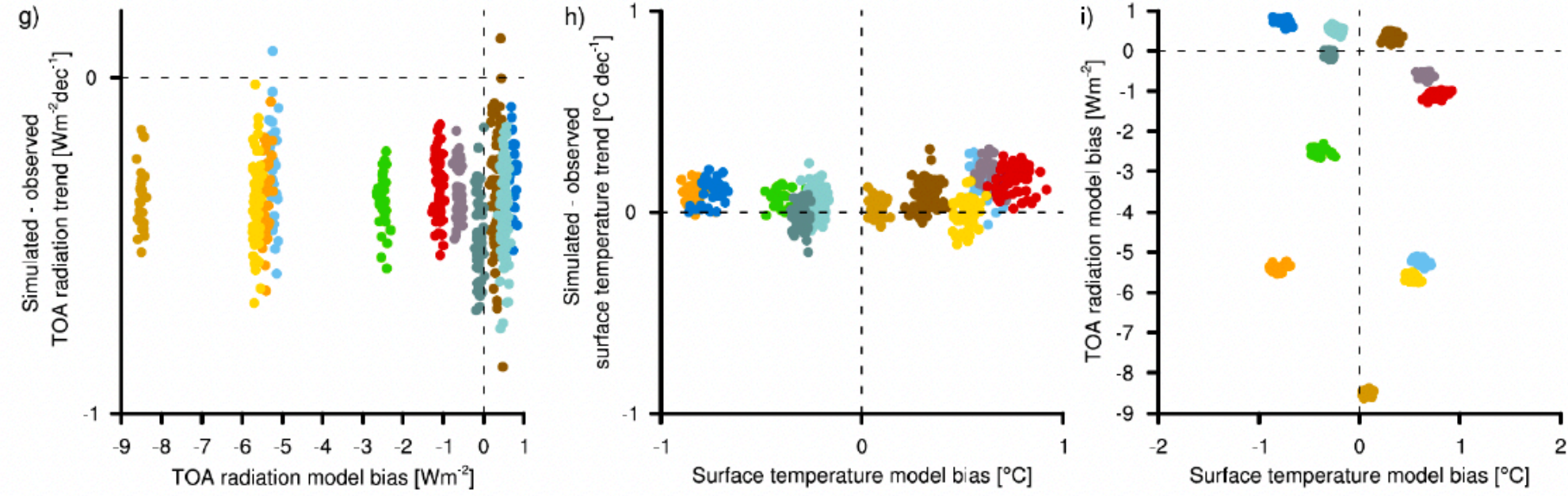
Subtropical eastern Pacific



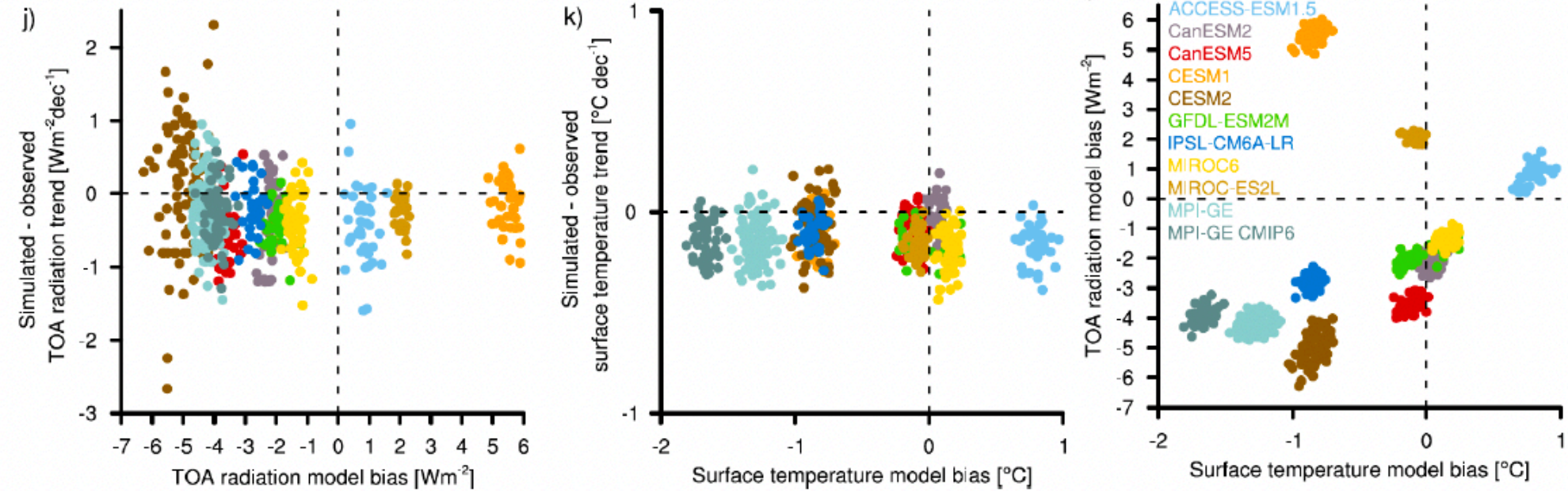
Subtropical east Atlantic



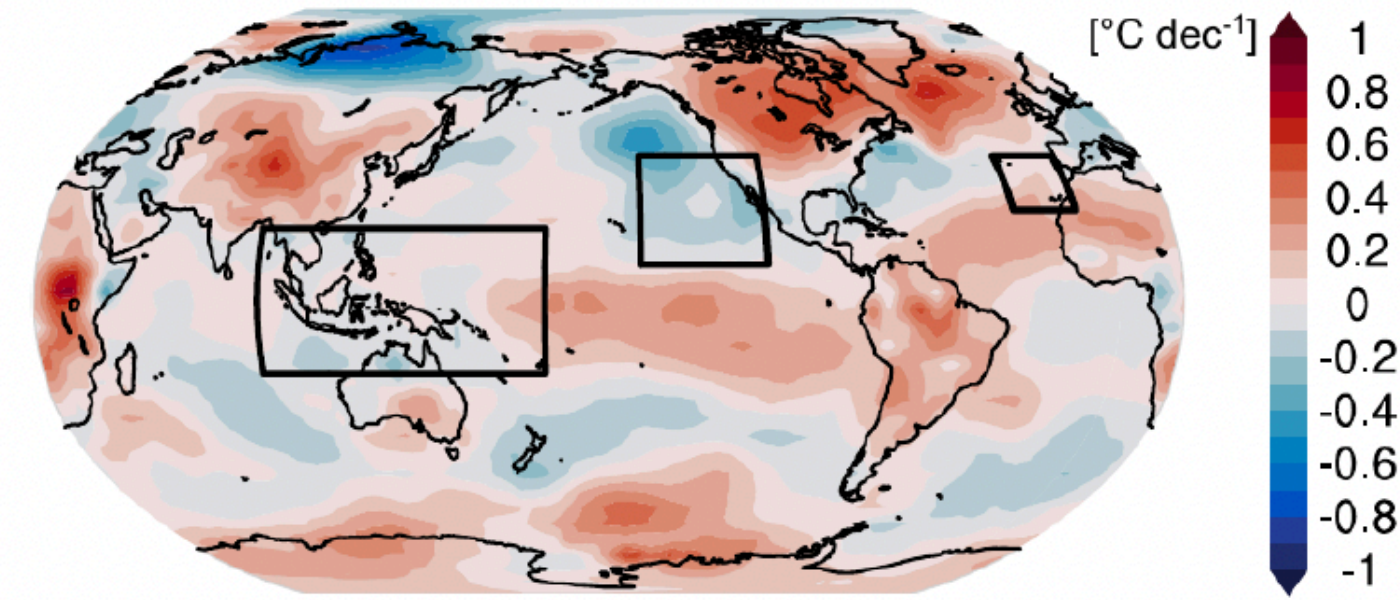
Tropics



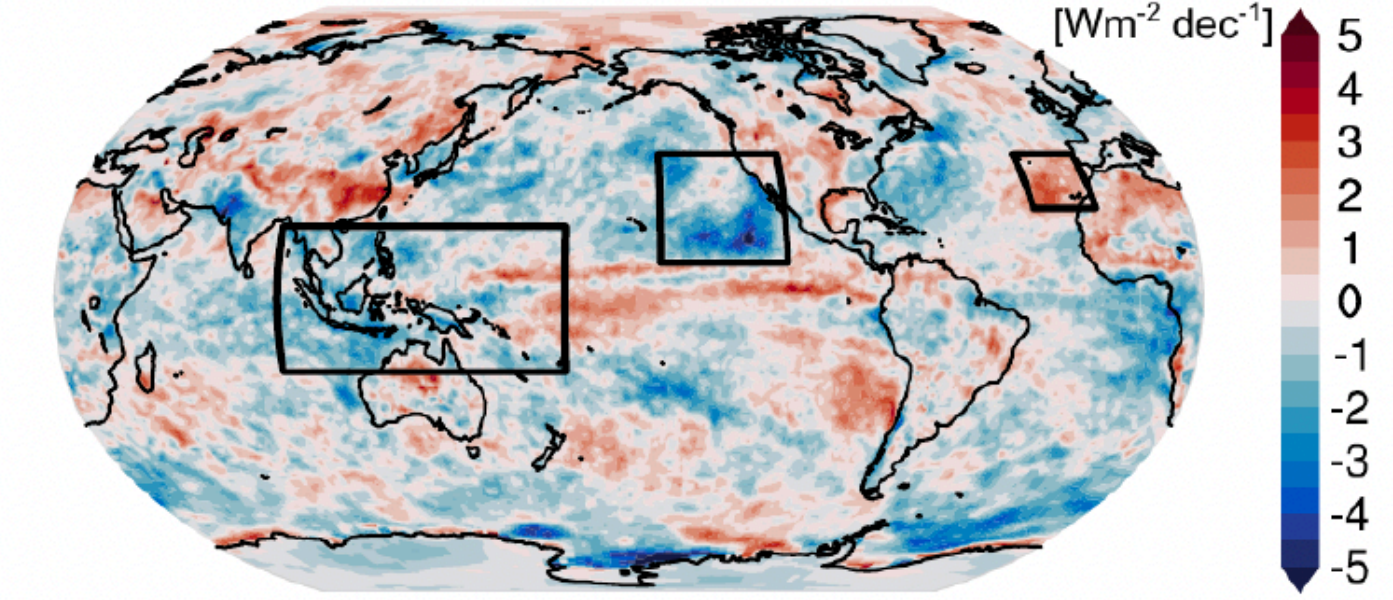
Southern Ocean



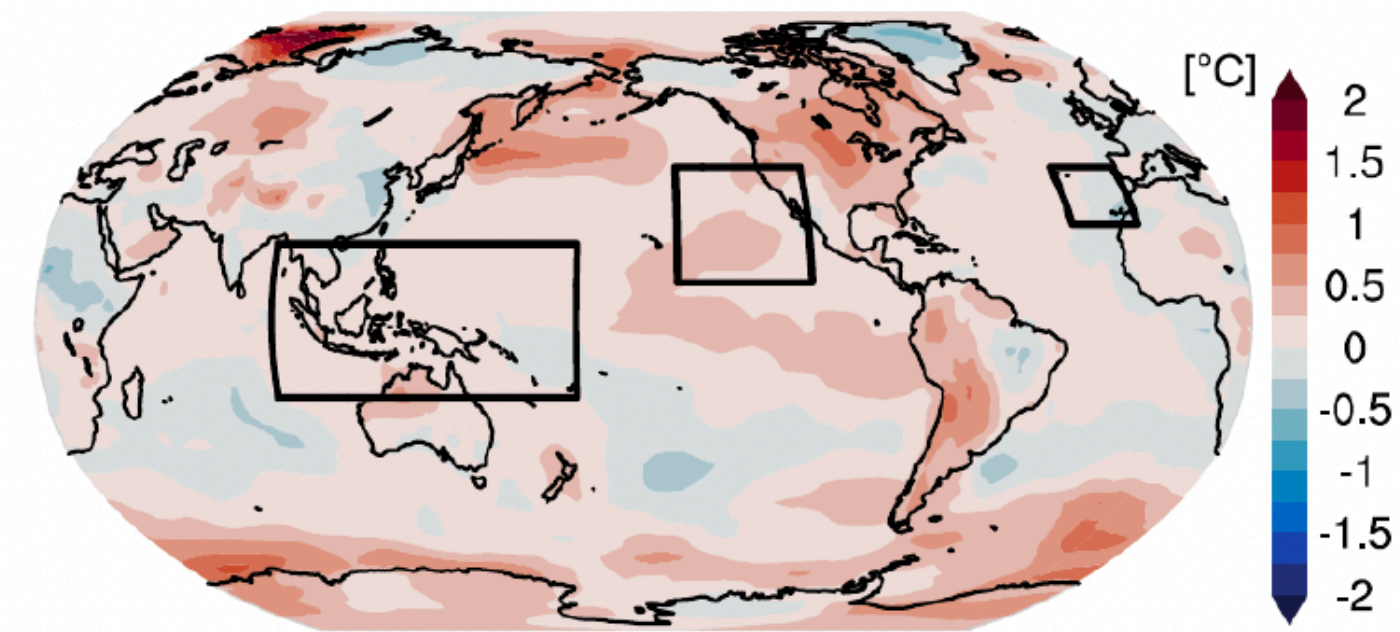
**a** Simulated - observed surface temperature trend



**b** Simulated - observed TOA radiation trend



**c** Surface temperature model bias across 2001-2022



**d** TOA radiation model bias across 2001-2022

