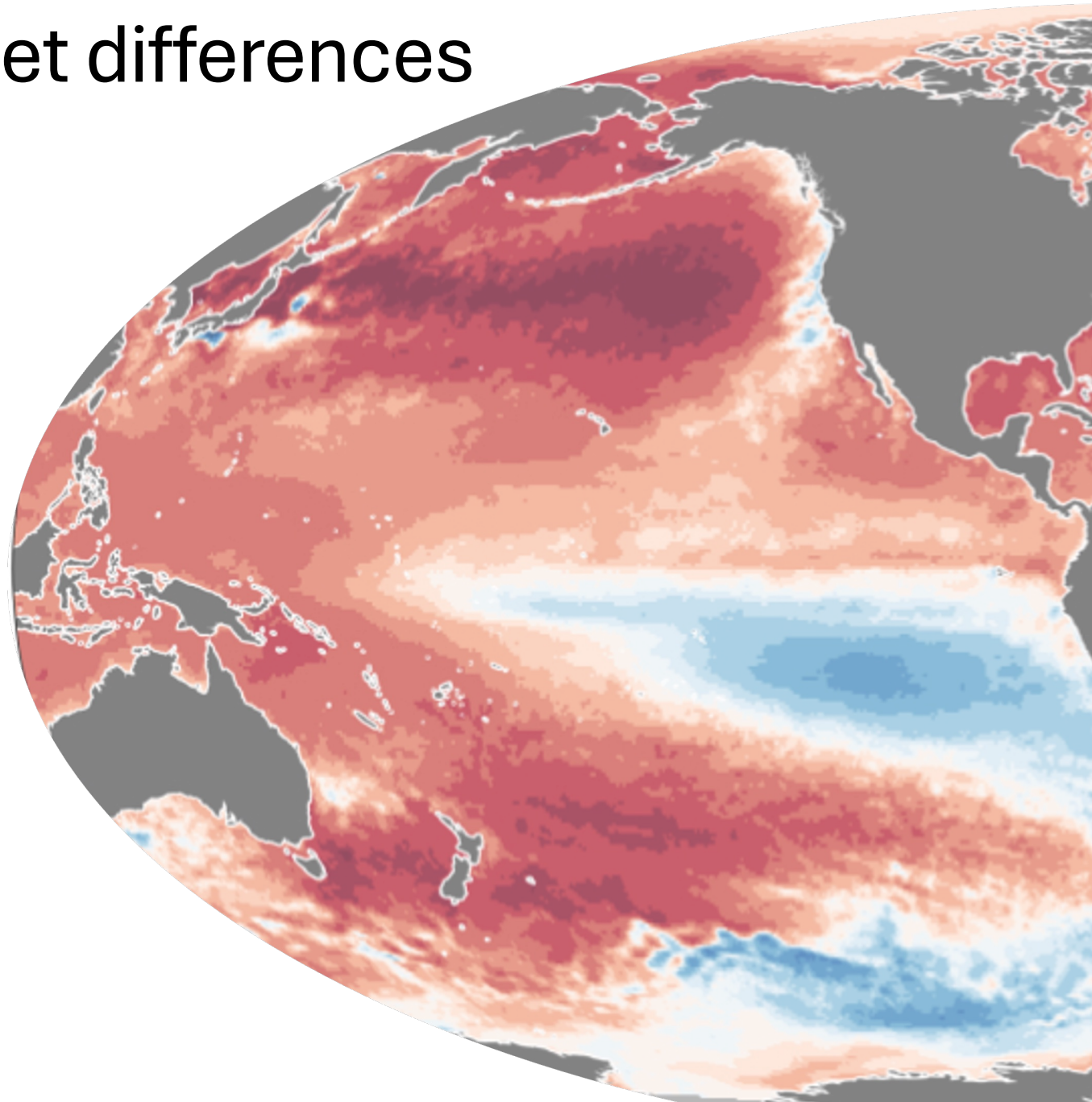
Implications of inter-dataset differences in sea surface warming for Earth's energy imbalance



Mark Zelinka[1], Paul Durack[1], Karl Taylor[1], Stephen Po-Chedley[1], Chen Zhou[2], Yue Dong[3], Chris Golaz[1], Wuyin Lin[4]

[1] Lawrence Livermore National Lab [2] Nanjing University
[3] University of Colorado [4] Brookhaven National Lab

CERES Science Team Meeting | Oct 2024

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Motivation – Several Threads

Scientific:

- TOA radiation trends during the CERES period
  - What's driving observed trends?
  - Why do models struggle to capture observed trends?

- The pattern effect
  - How different are recent observed warming patterns from those produced in models?
  - How different are recent observed warming patterns from future projections from models?
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Practical:

- The input for PCMDI's post-1981 AMIP SST boundary conditions (NOAA –OISST-v2.0) has been discontinued as of Jan 2023.
  - Need to make some decisions about the path forward

Sea Surface Temperature Datasets

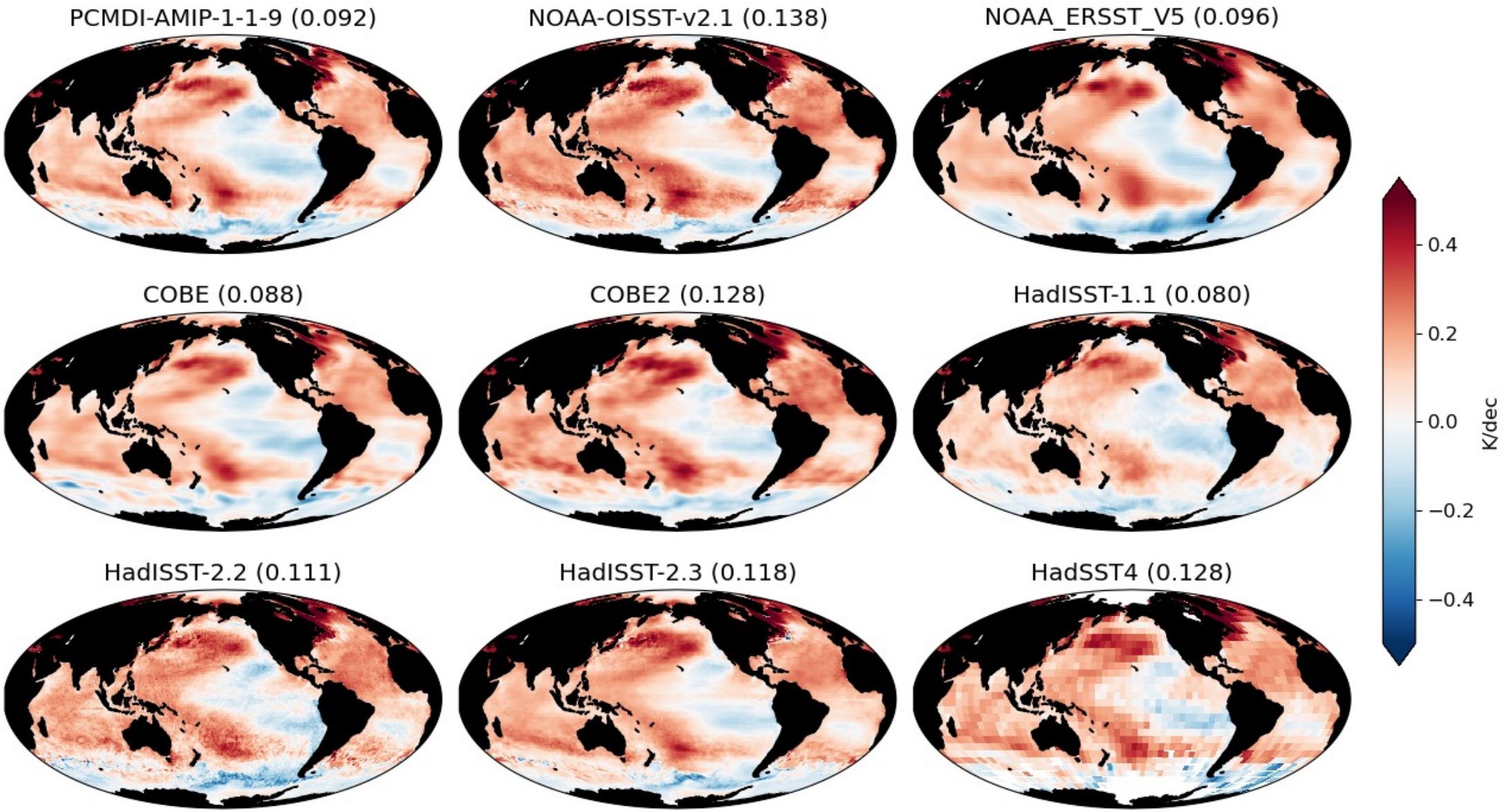
PCMDI-AMIP-1-1-9

Dataset	Start	End	Comments
NOAA-OISST-v2.0	1981-12	2023-01	discontinued Jan 2023
NOAA-OISST-v2.1	1981-09	2023-04	
NOAA_ERSST_V5	1854-01	2023-10	
COBE	1891-01	2023-04	
COBE2	1850-01	2019-12	
HadISST-1.1	1870-01	2023-09	
HadISST-2.2	1948-01	2015-12	used by E3SM for HighResMIP
HadISST-2.3	1850-01	2020-08	CERESMIP but vaporware
HadSST4	1850-01	2023-04	

This motivates my choice to show trends from 1982-2015

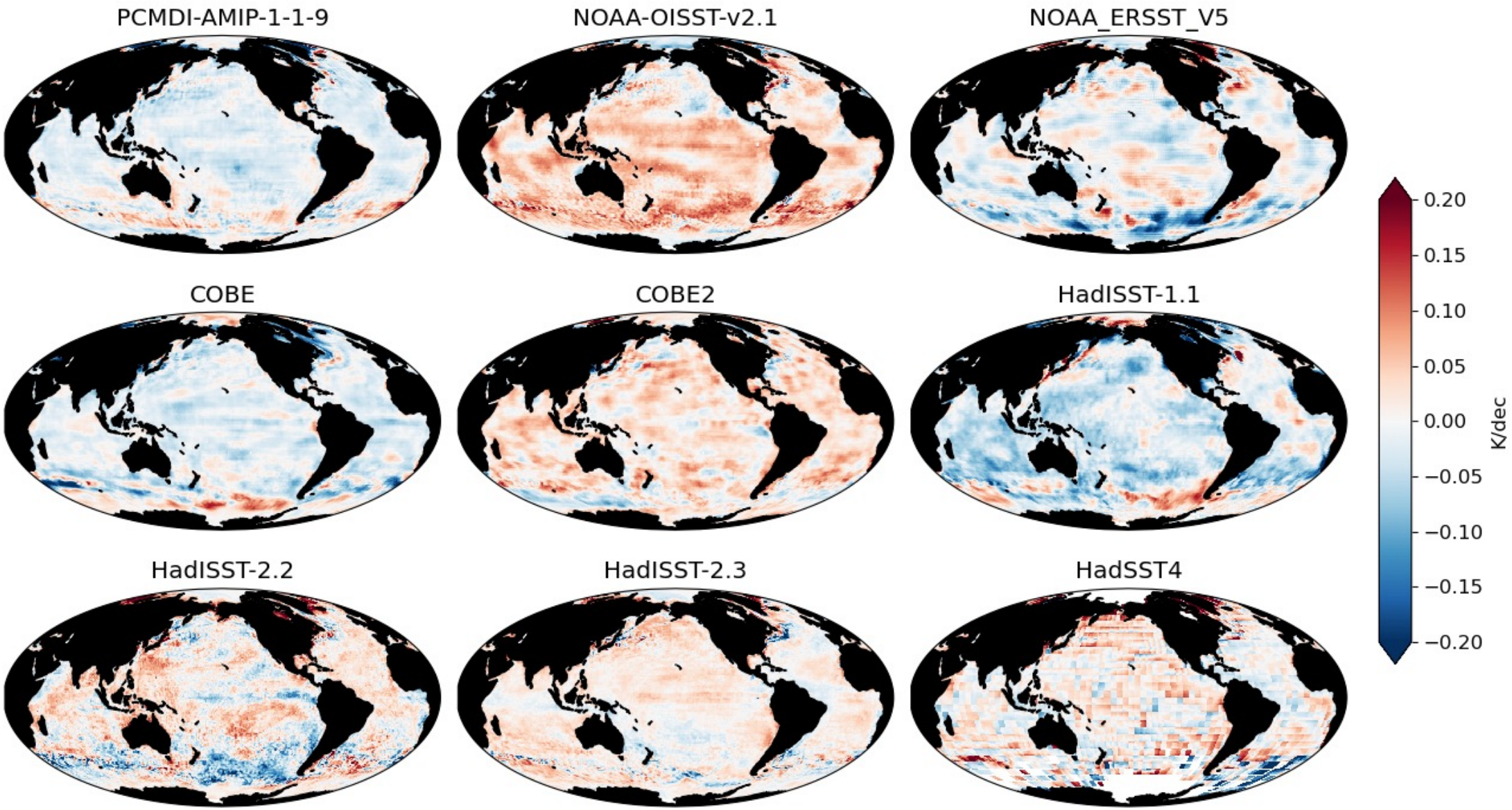
SST Trends

Jan 1982 – Dec 2015



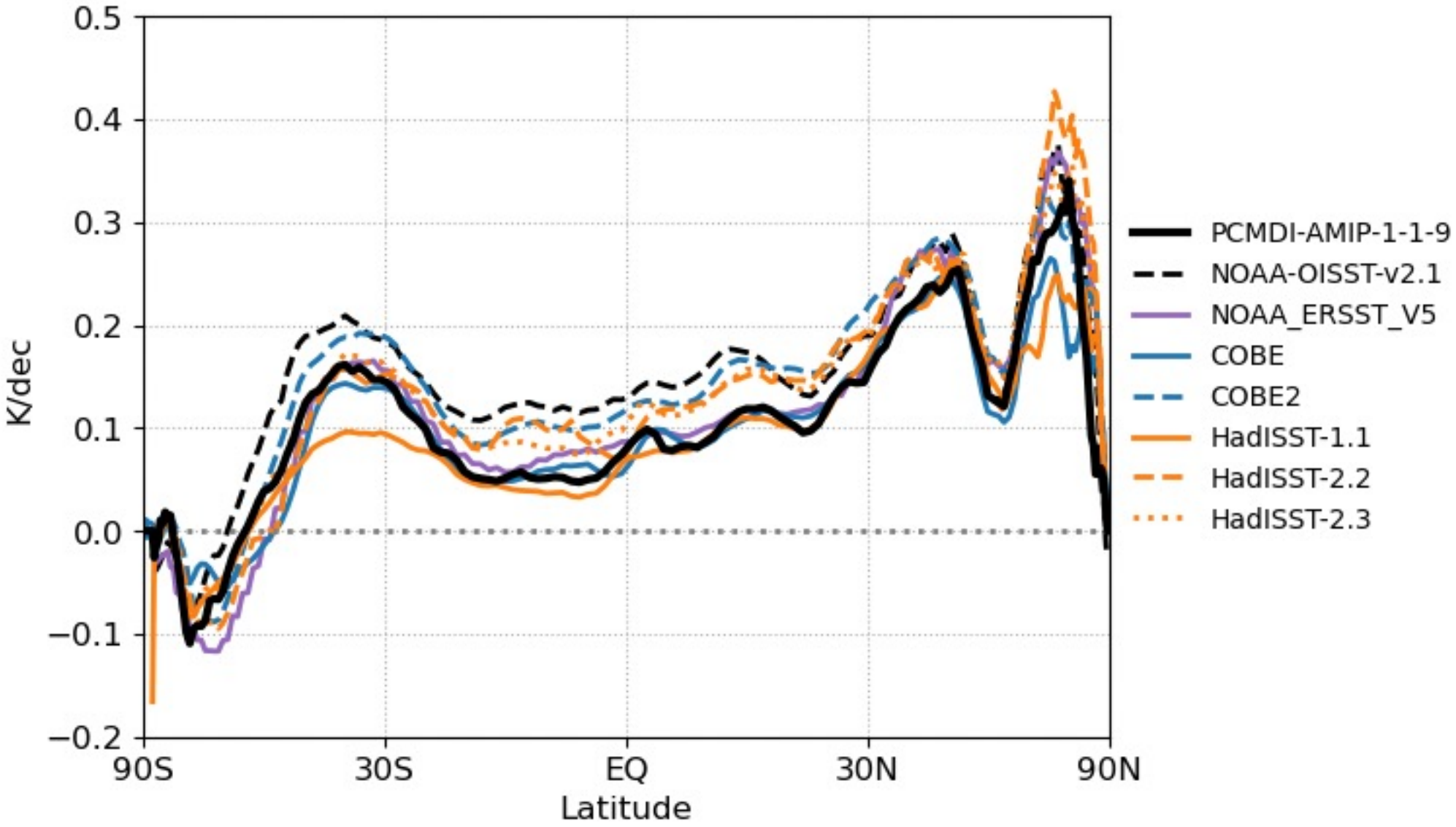
SST Trends relative to dataset mean

Jan 1982 – Dec 2015

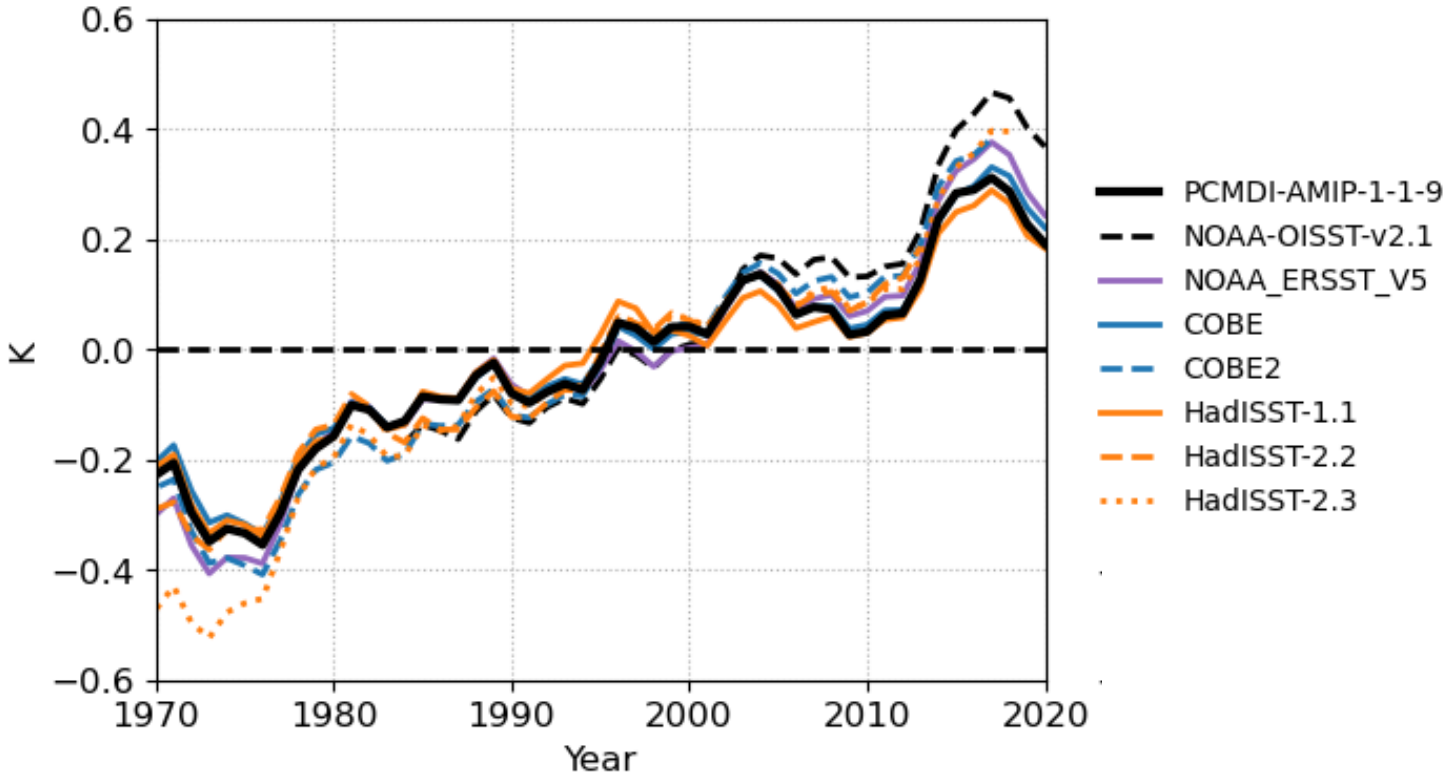


Zonal Mean SST Trends

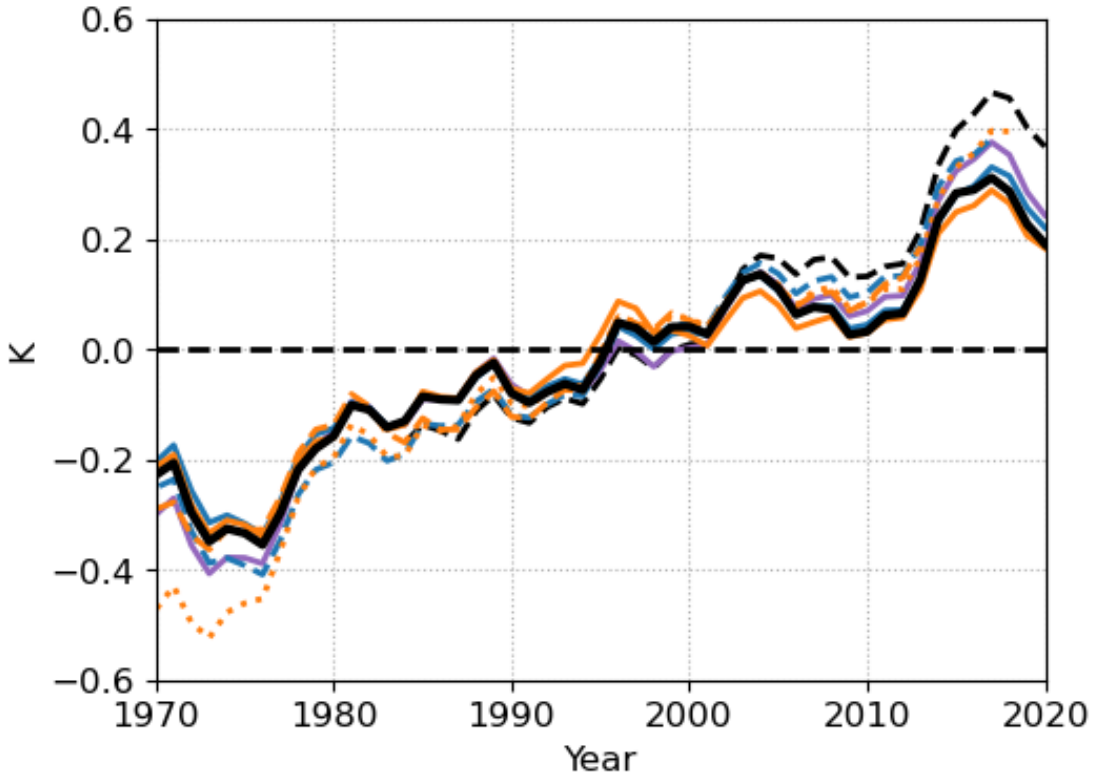
Jan 1982– Dec 2015



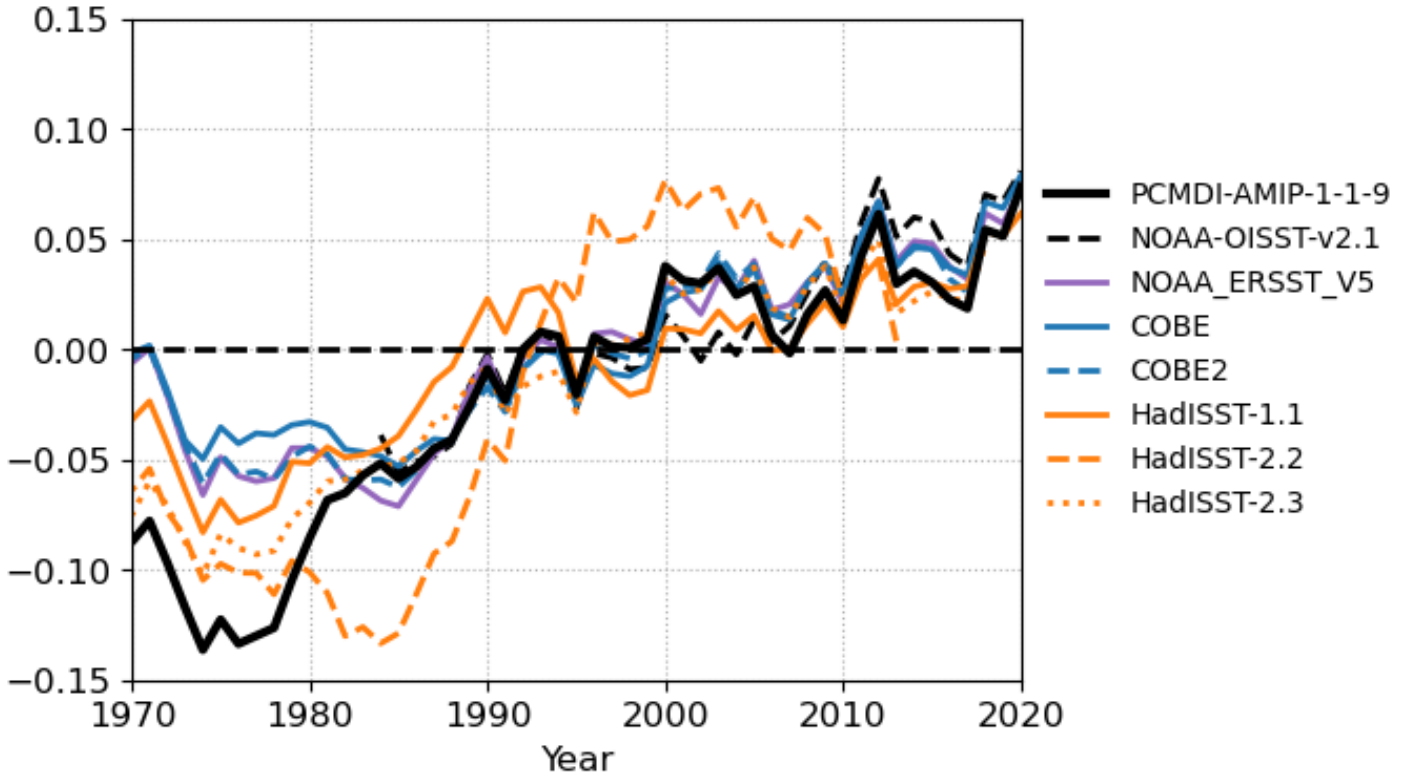
Tropical average SST



Tropical average SST

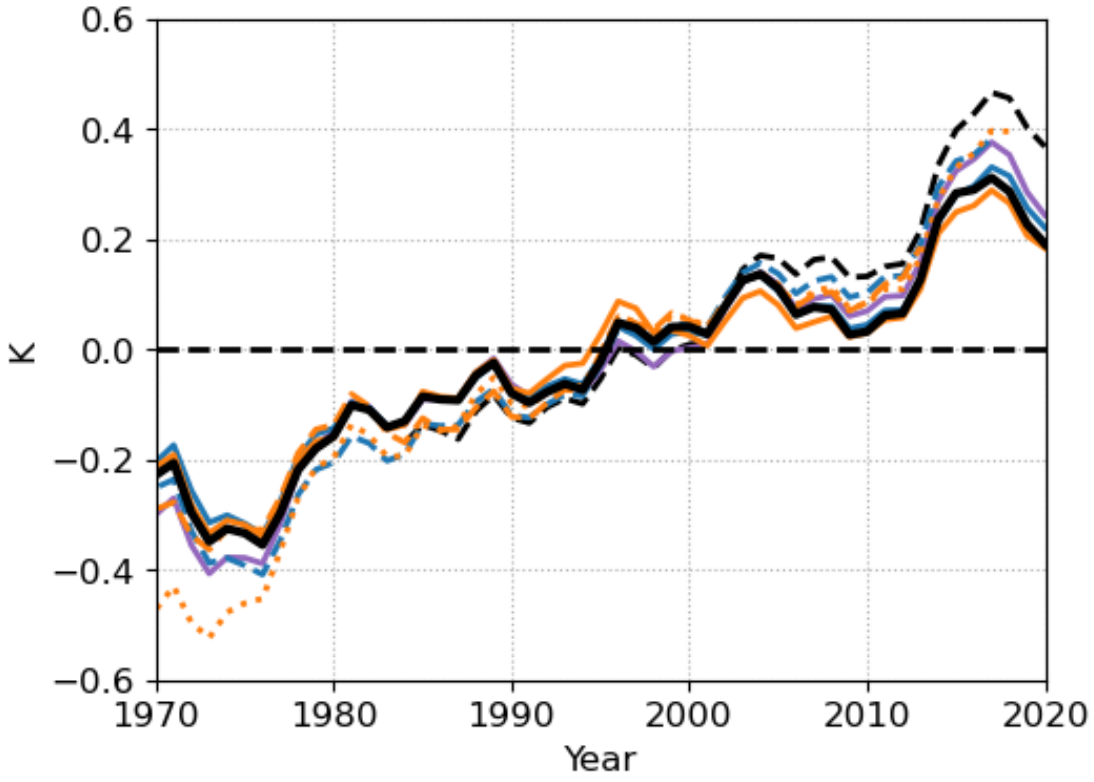


SST♯



SST♯ = the temperature of the warmest 30% minus the tropical average SST (Fueglistaler, 2019)

Tropical average SST



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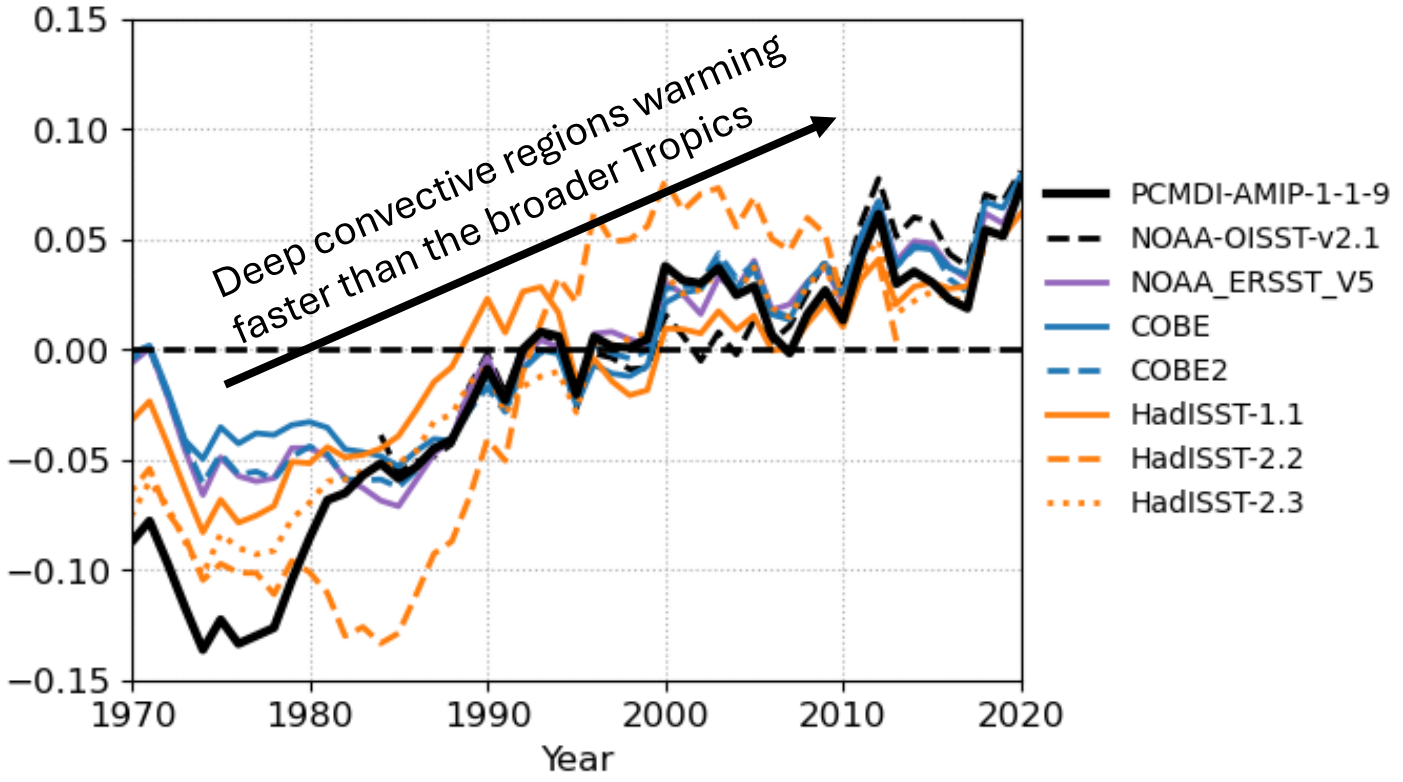

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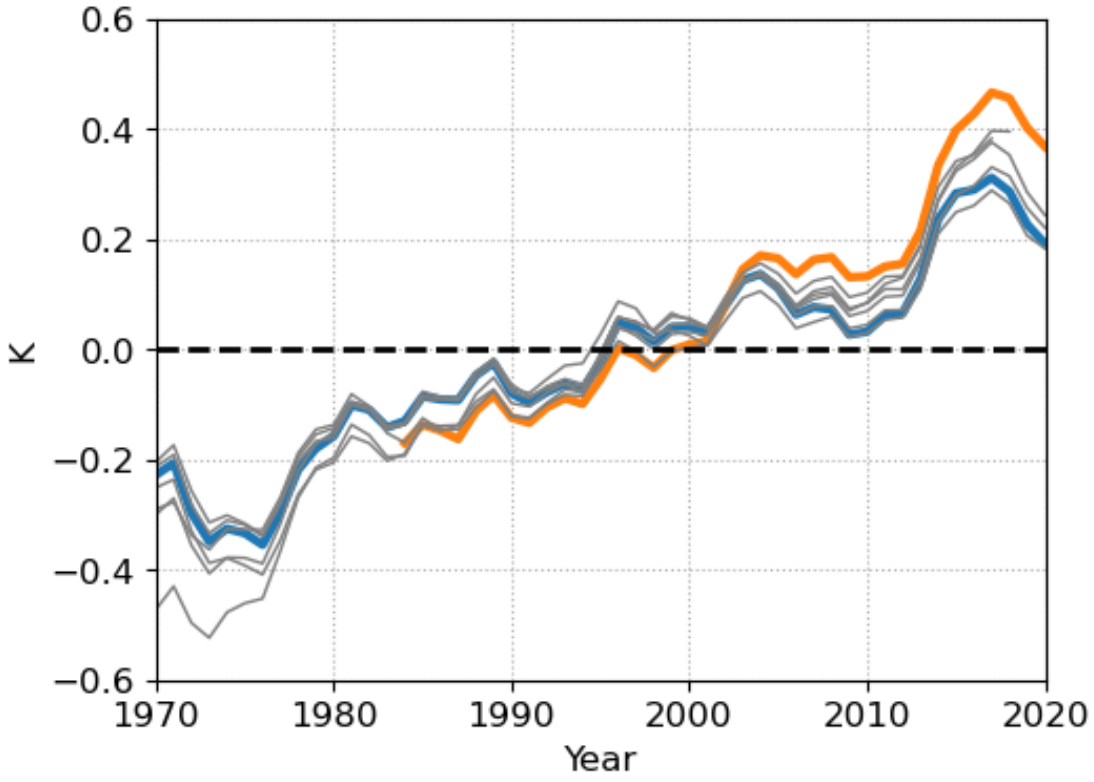

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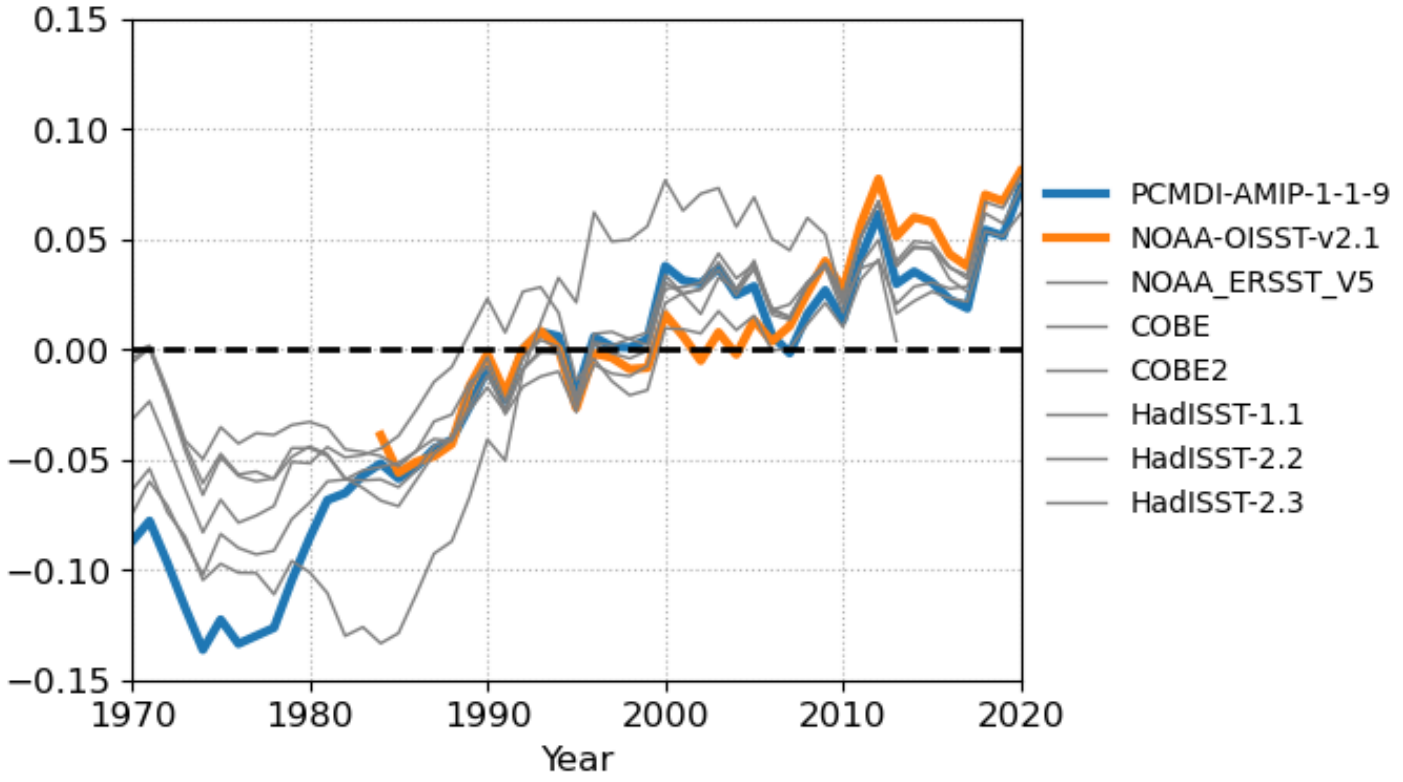

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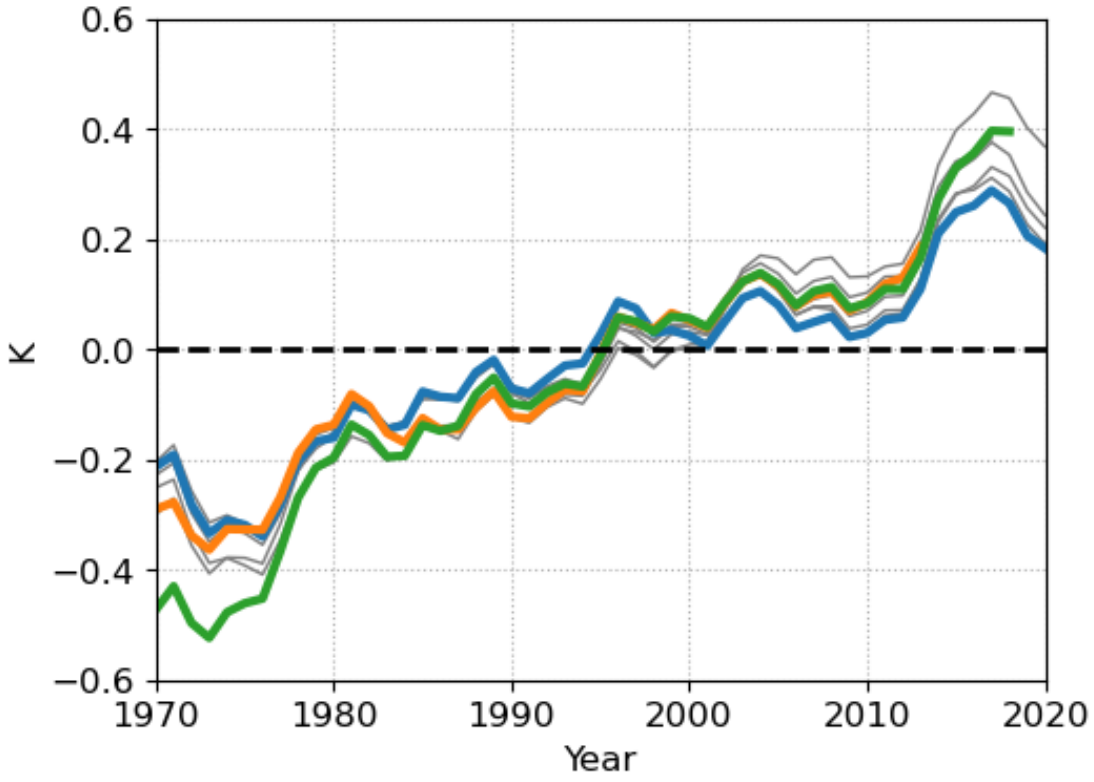

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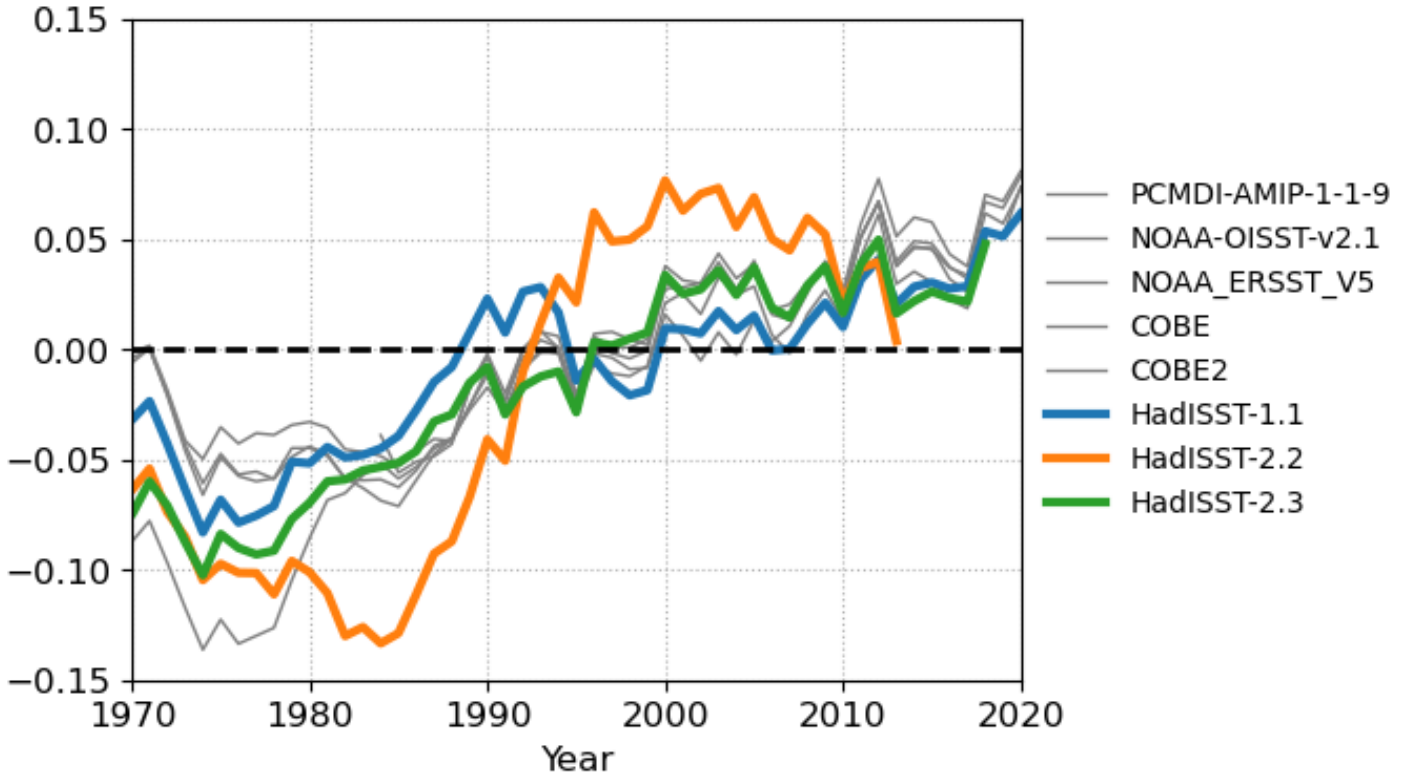

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Are these differences “big”?

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Two approaches:

- Green’s functions
- E3SM AMIP simulations

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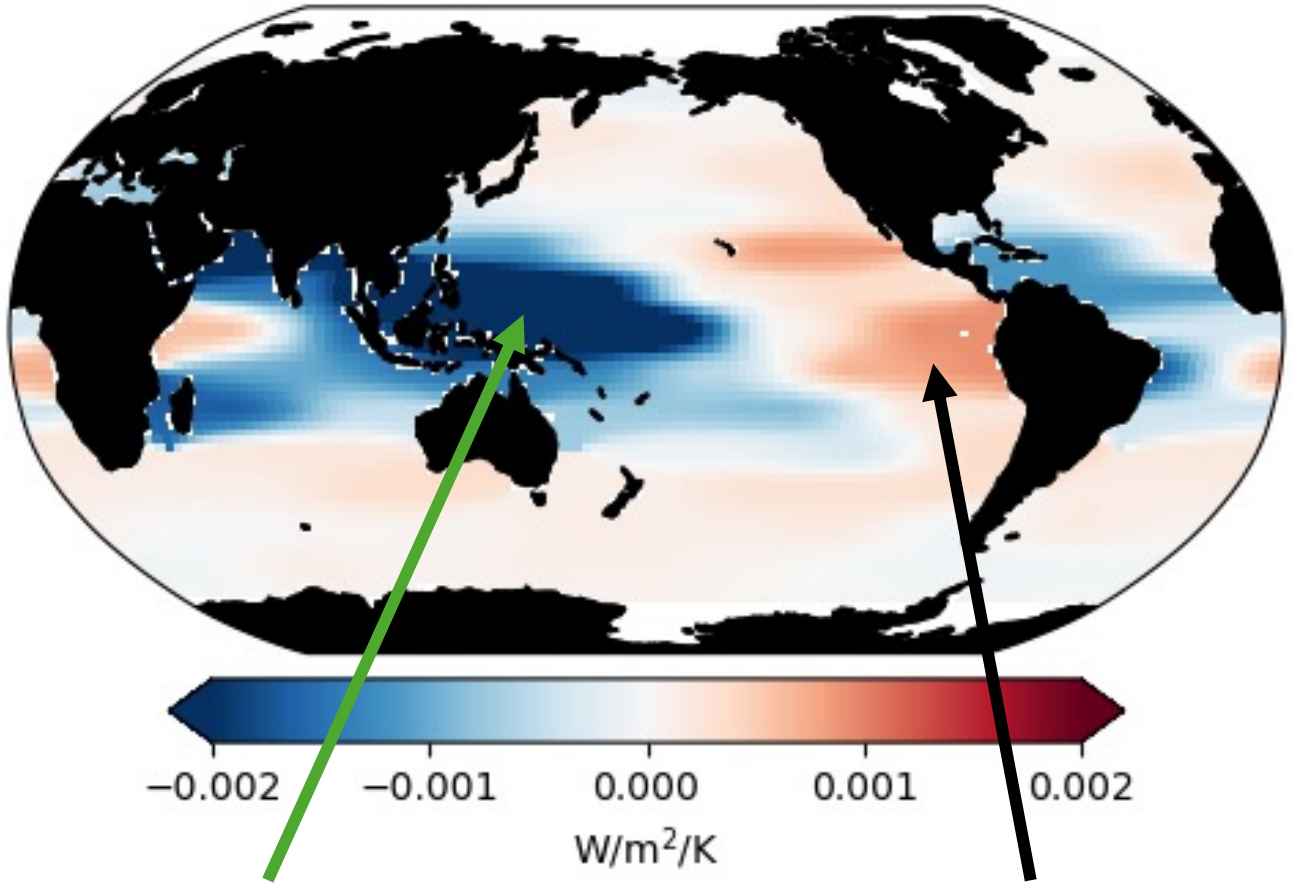
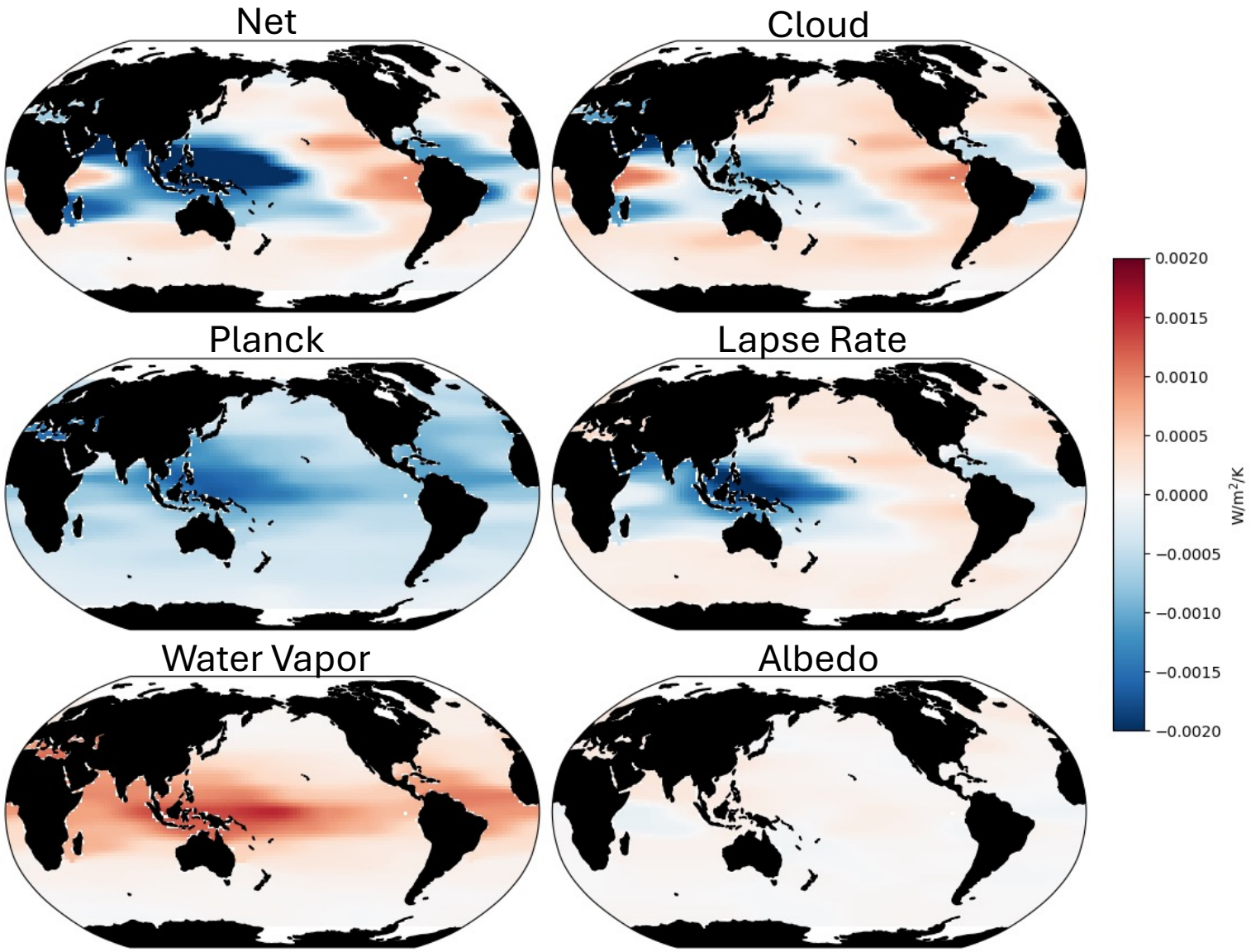
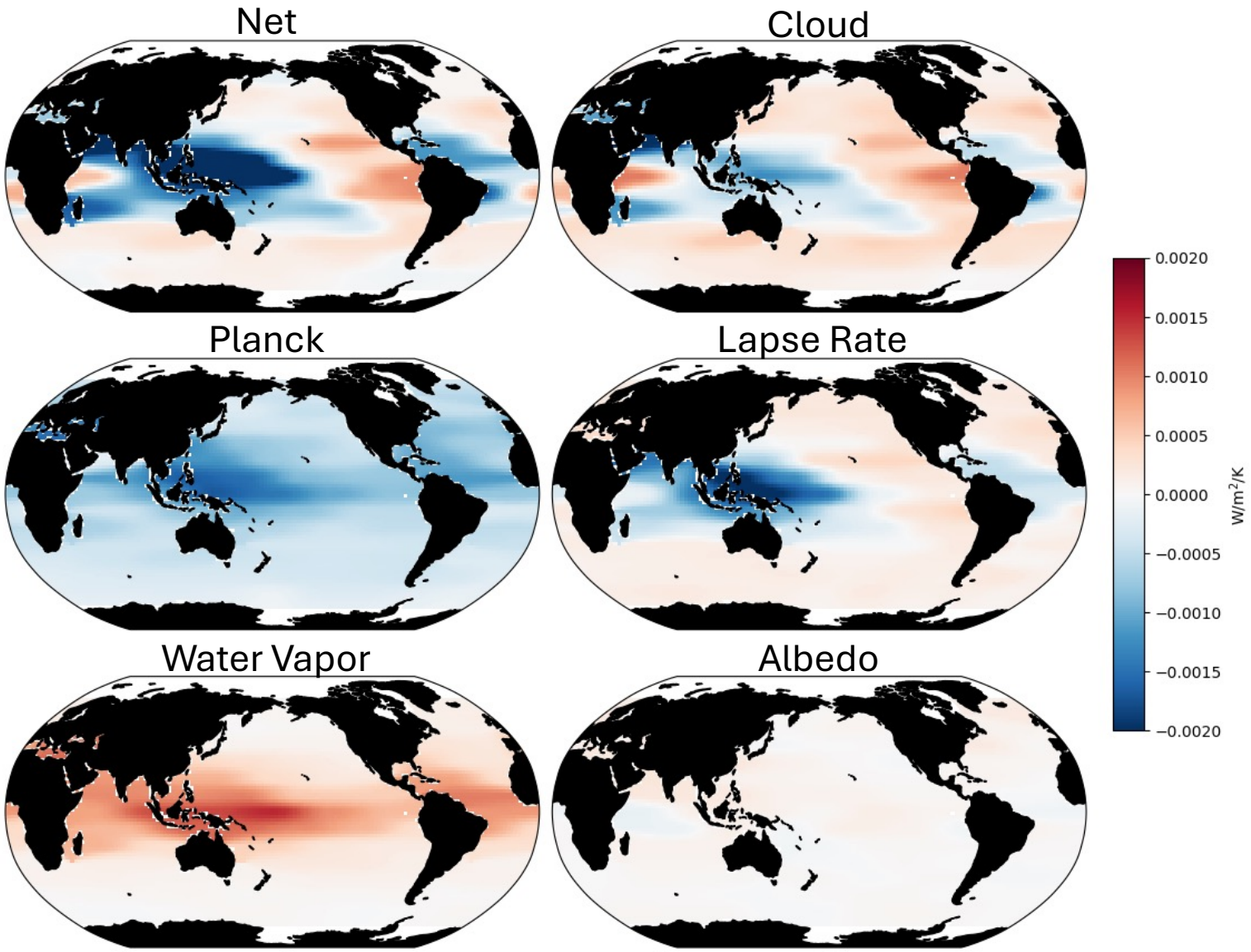
- **Green’s functions**
- E3SM AMIP simulations



Green's functions quantify the sensitivity of global mean TOA radiative fluxes to local SST changes.
We convolve the SST trend maps with Green's functions to estimate the implied radiation trends.



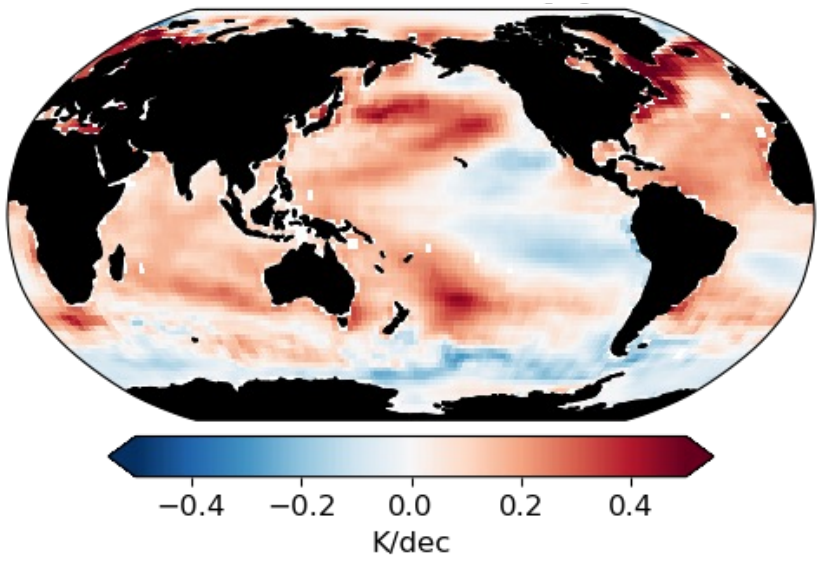
Approach 1: Green's Functions



Green's functions have been generated in several studies as part of GFMIP (Bloch-Johnson et al 2023). Here we use the following GFs:

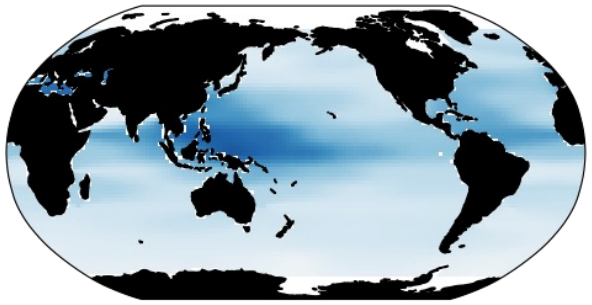
- **Zhou20**: 40-year patch exps in **CAM5**
- **Dong19**: 40-year patch exps in **CAM4**
- **Zhang23**: 10-year patch exps in **GFDL-AM4**

PCMDI-AMIP-1-1-9 SST Trend



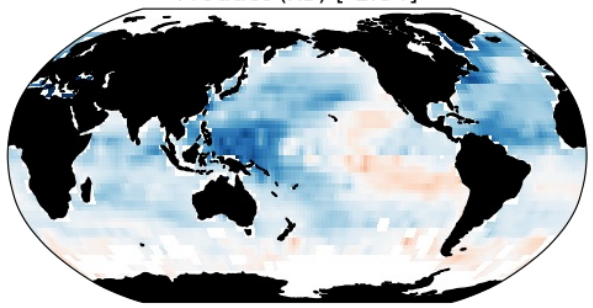
X

PL Green's Function



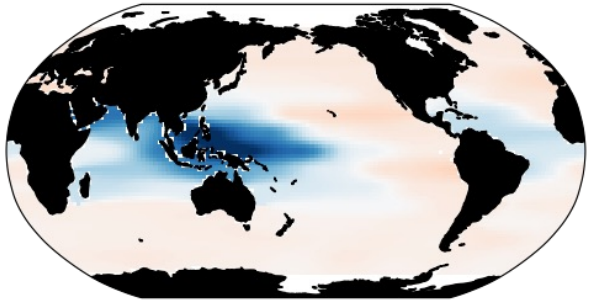
=

Product (x5) [-1.84]



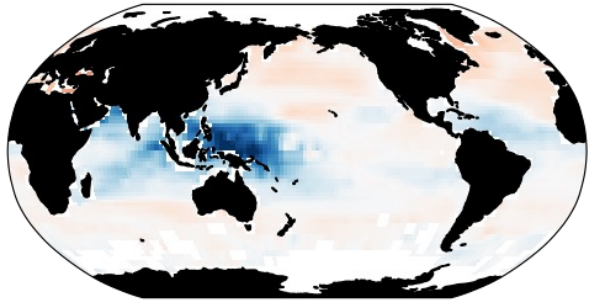
X

LR Green's Function



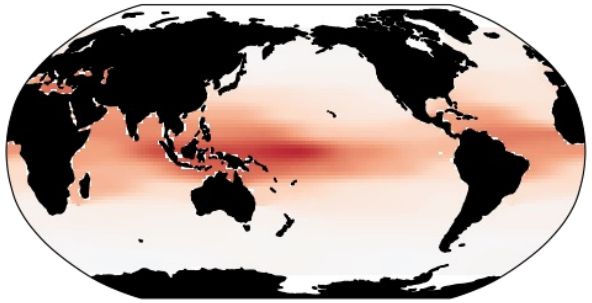
=

Product (x5) [-0.5]



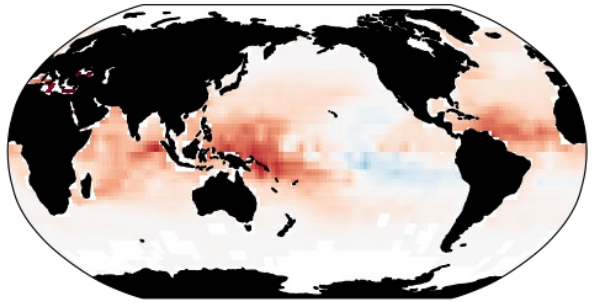
X

WV Green's Function



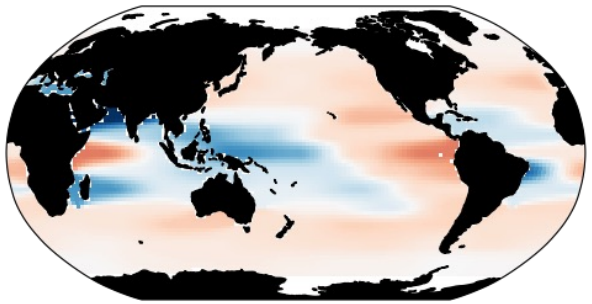
=

Product (x5) [1.11]



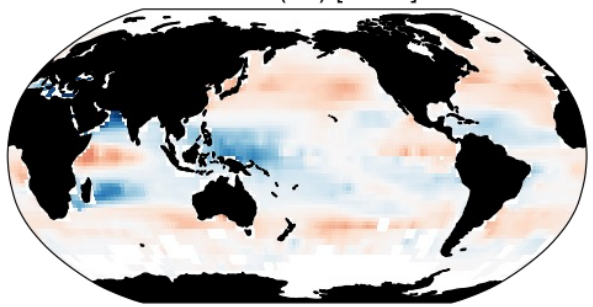
X

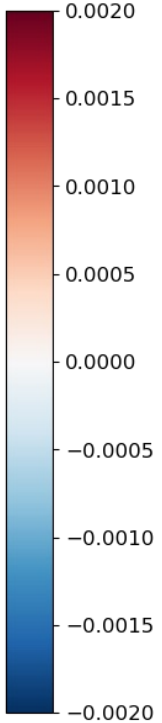
CLD Green's Function



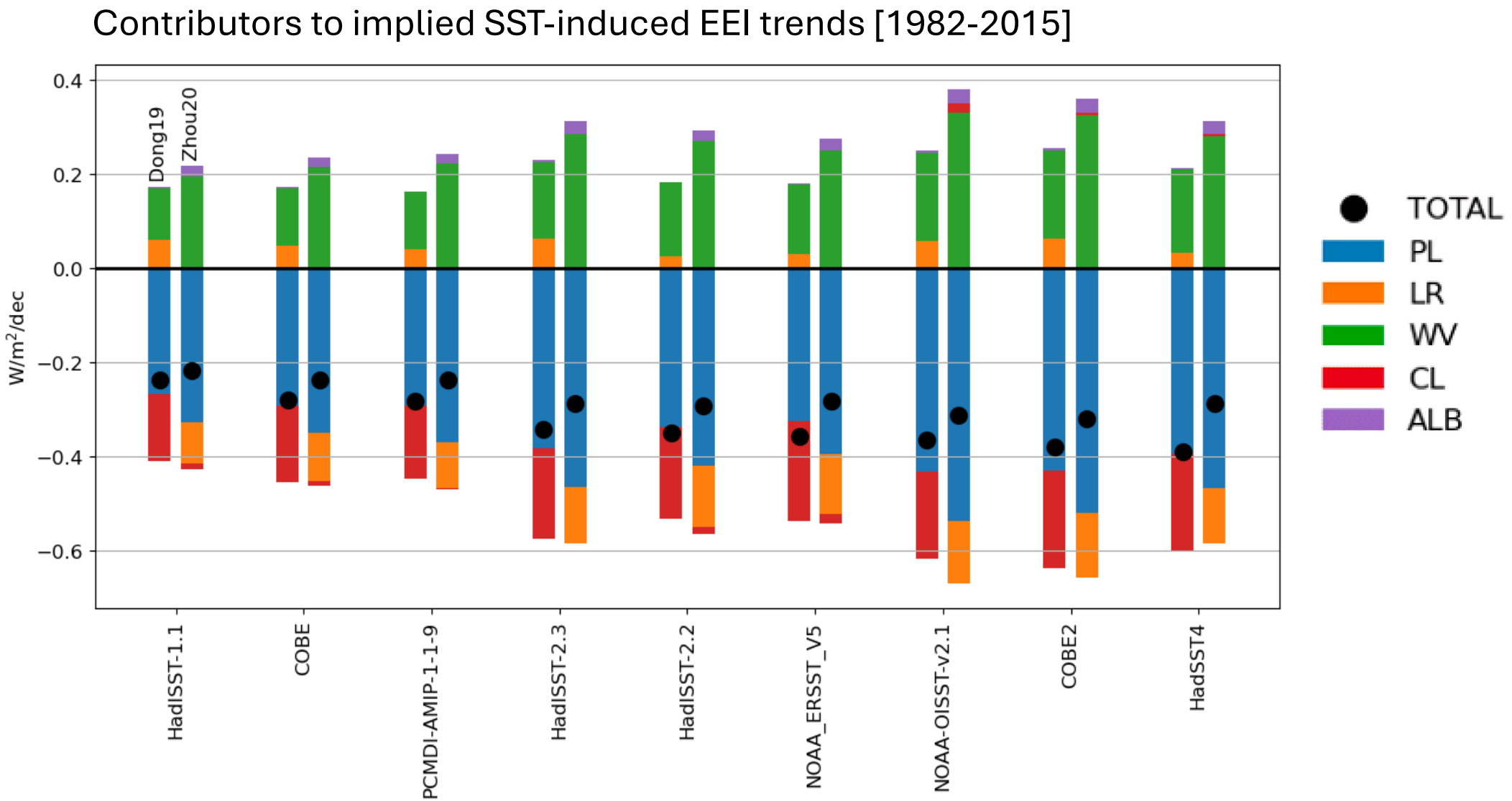
=

Product (x5) [-0.01]





Approach 1: Green's Functions



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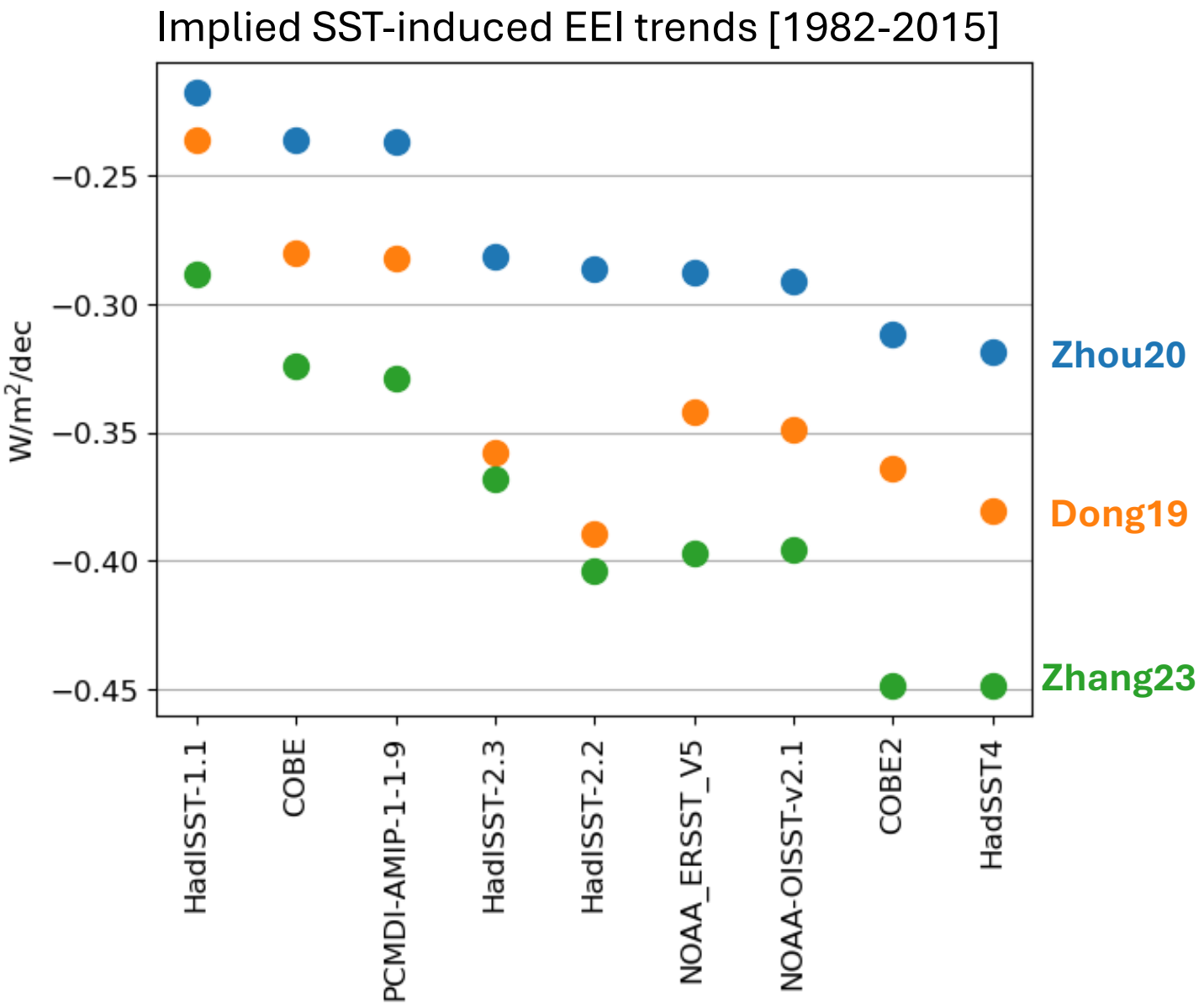


Approach 1: Green's Functions

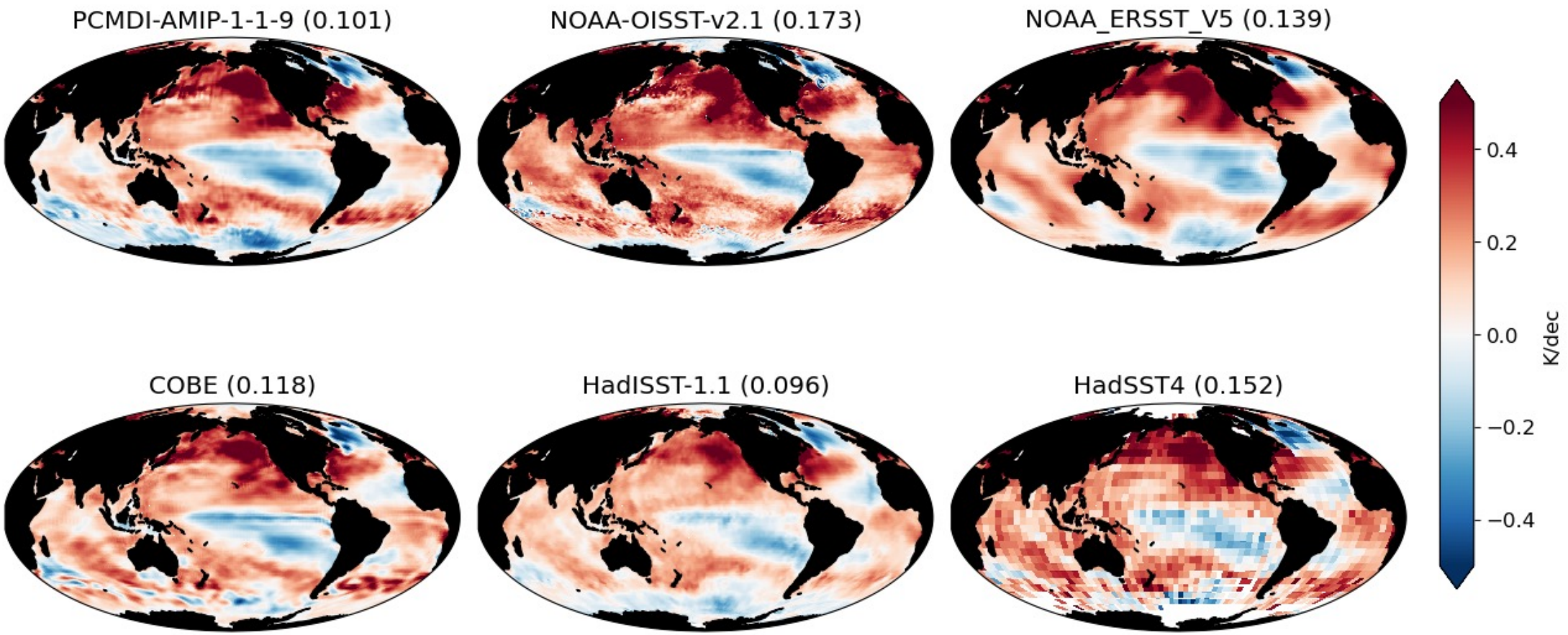
Are these differences “big”?

Two approaches:

- Green’s functions
- **E3SM AMIP simulations (focusing in on Jan 2001 – Dec 2022)**

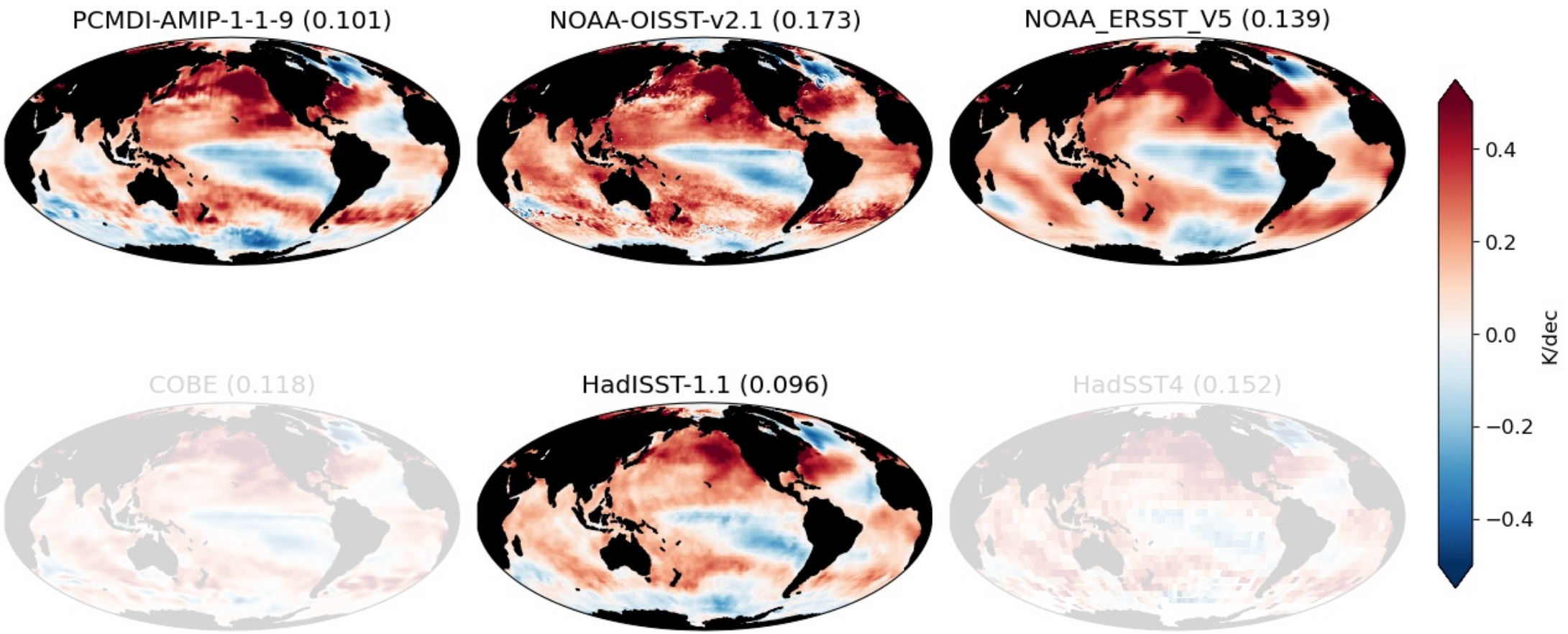
SST Trends

Jan 2001 – Dec 2022



SST Trends

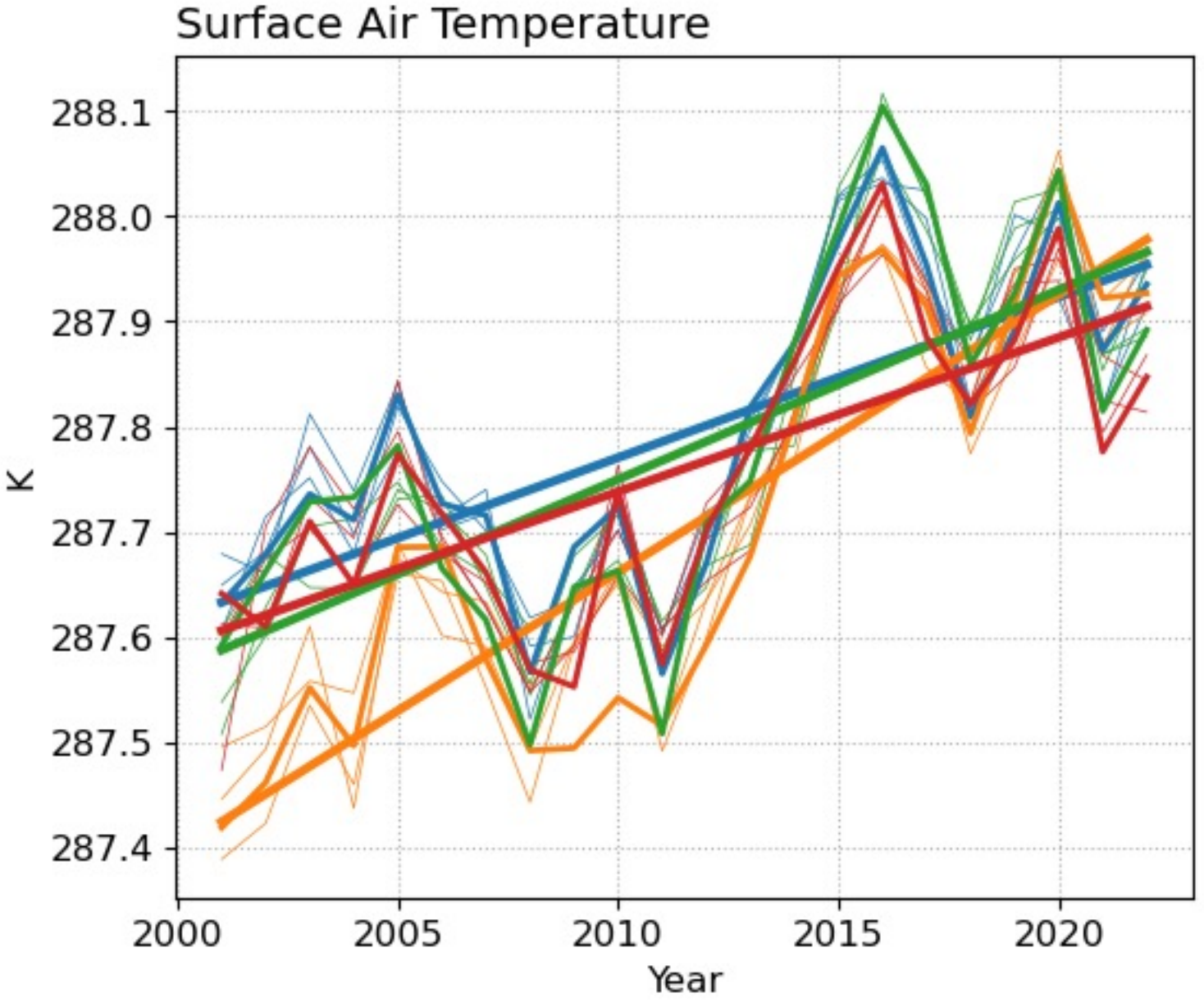
Jan 2001 – Dec 2022



AMIP Simulations

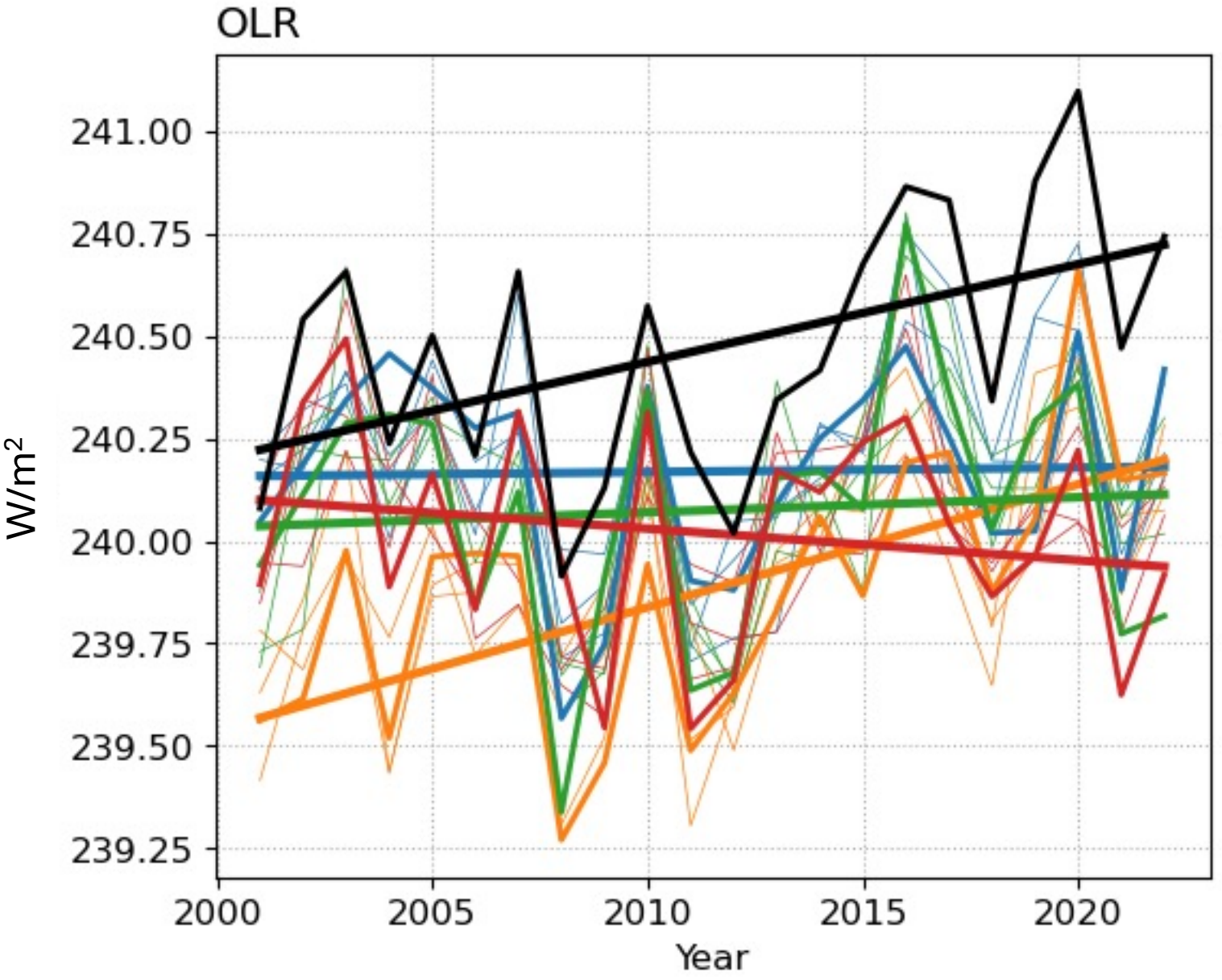
- E3SMv2 atmosphere-only simulations with prescribed historical SSTs, sea ice concentrations, and radiative forcings [1979-2022]
- Identical prescribed sea ice concentrations and radiative forcings in all simulations, but different SST boundary conditions:
  - PCMDI-AMIP-1-1-9 (= NOAA-OISST-2.0)
  - NOAA-OISST-2.1
  - NOAA-ERSST-v5
  - HadISST-1.1
- Post-2014 radiative forcings come from SSP-2.45
- Also conducted runs with radiative forcings fixed at 2010 levels

See also: Loeb et al (2020); Raghuraman et al (2021); **Schmidt et al (2023)**; Hodnebrog et al (2024)



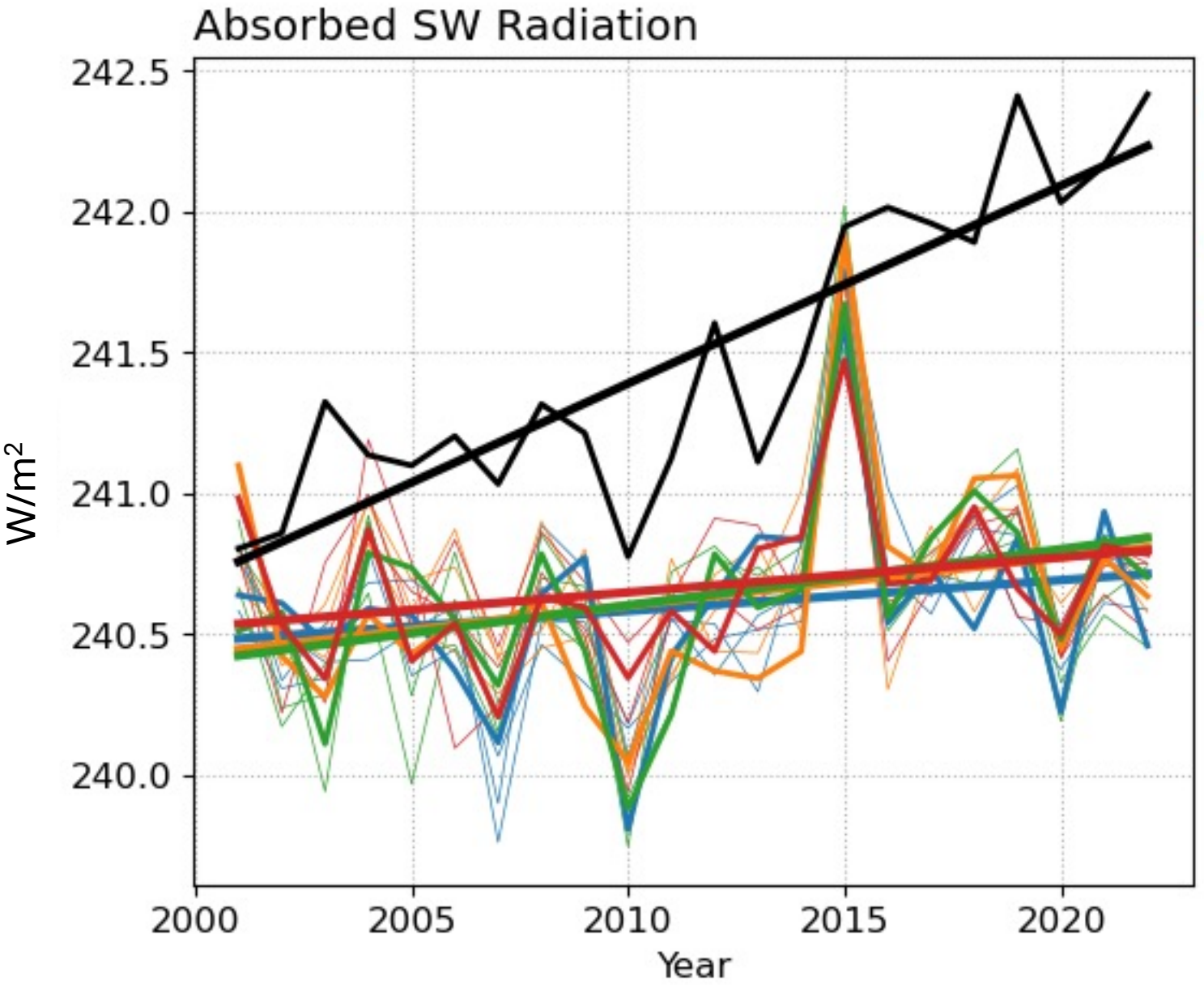
Dataset	Trend [K/dec]
PCMDI-AMIP-1-1-9	0.15 ± 0.03
NOAA-OISST-2.1	0.26 ± 0.04
NOAA-ERSST-v5	0.18 ± 0.04
HadISST-1.1	0.15 ± 0.03

Approach 2: E3SM AMIP Simulations



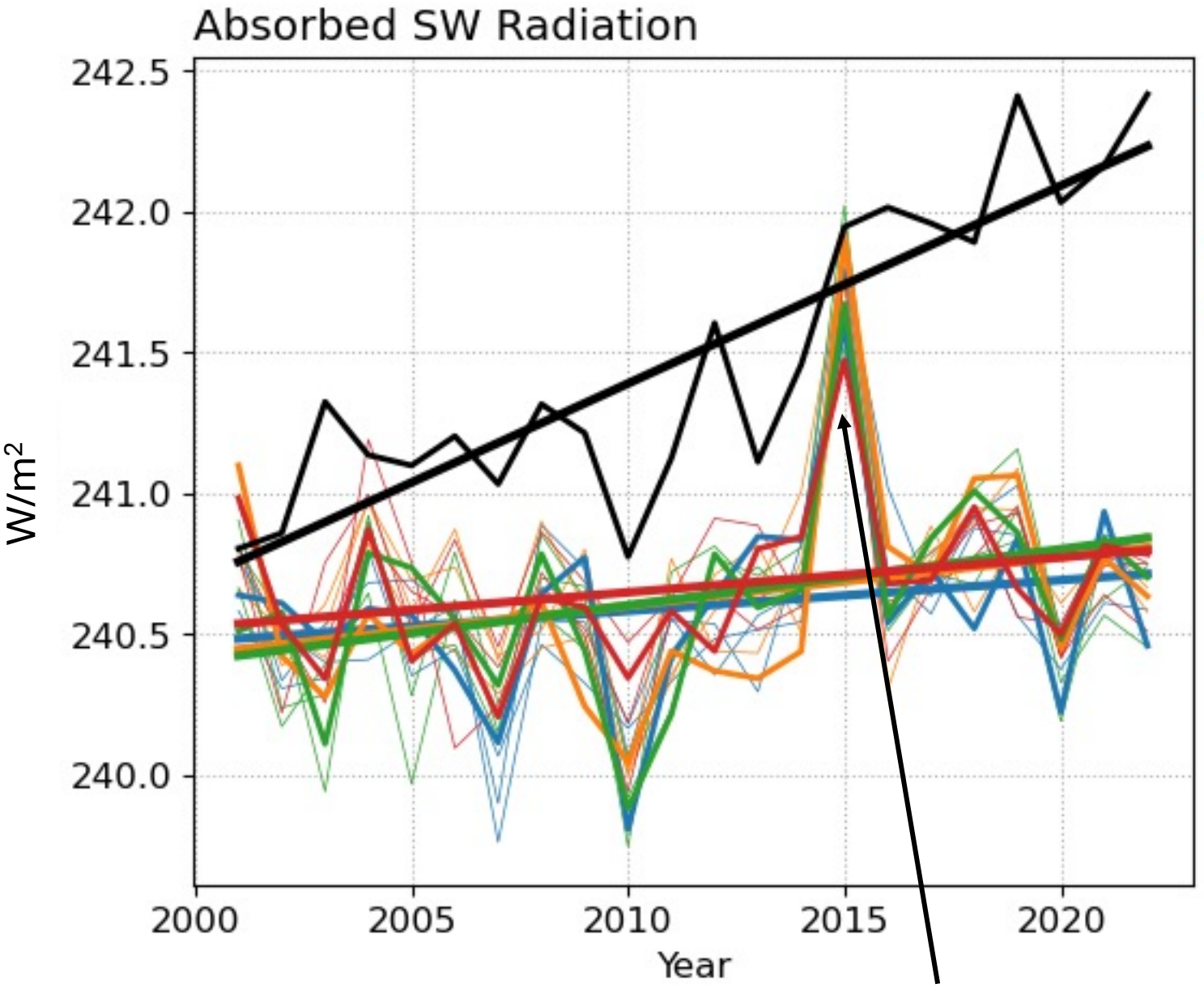
Dataset	Trend [W/m²/dec]
PCMDI-AMIP-1-1-9	0.01 ± 0.09
NOAA-OISST-2.1	0.30 ± 0.09
NOAA-ERSST-v5	0.04 ± 0.11
HadISST-1.1	-0.08 ± 0.09
CERES-EBAF-4.2	0.24 ± 0.09

Approach 2: E3SM AMIP Simulations



Dataset	Trend [W/m²/dec]
PCMDI-AMIP-1-1-9	0.11 ± 0.12
NOAA-OISST-2.1	0.17 ± 0.13
NOAA-ERSST-v5	0.20 ± 0.11
HadISST-1.1	0.12 ± 0.09
CERES-EBAF-4.2	0.70 ± 0.09

Approach 2: E3SM AMIP Simulations



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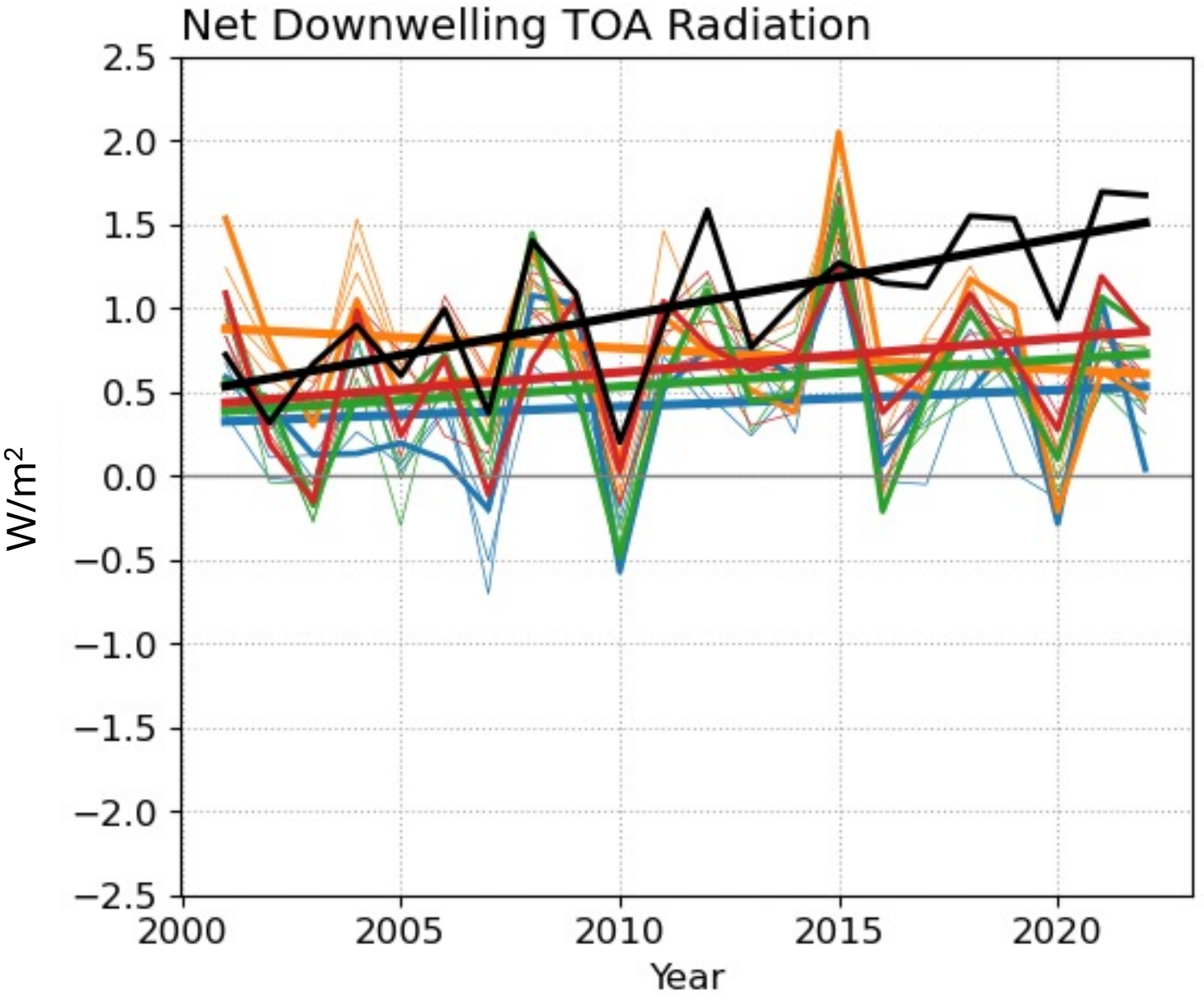
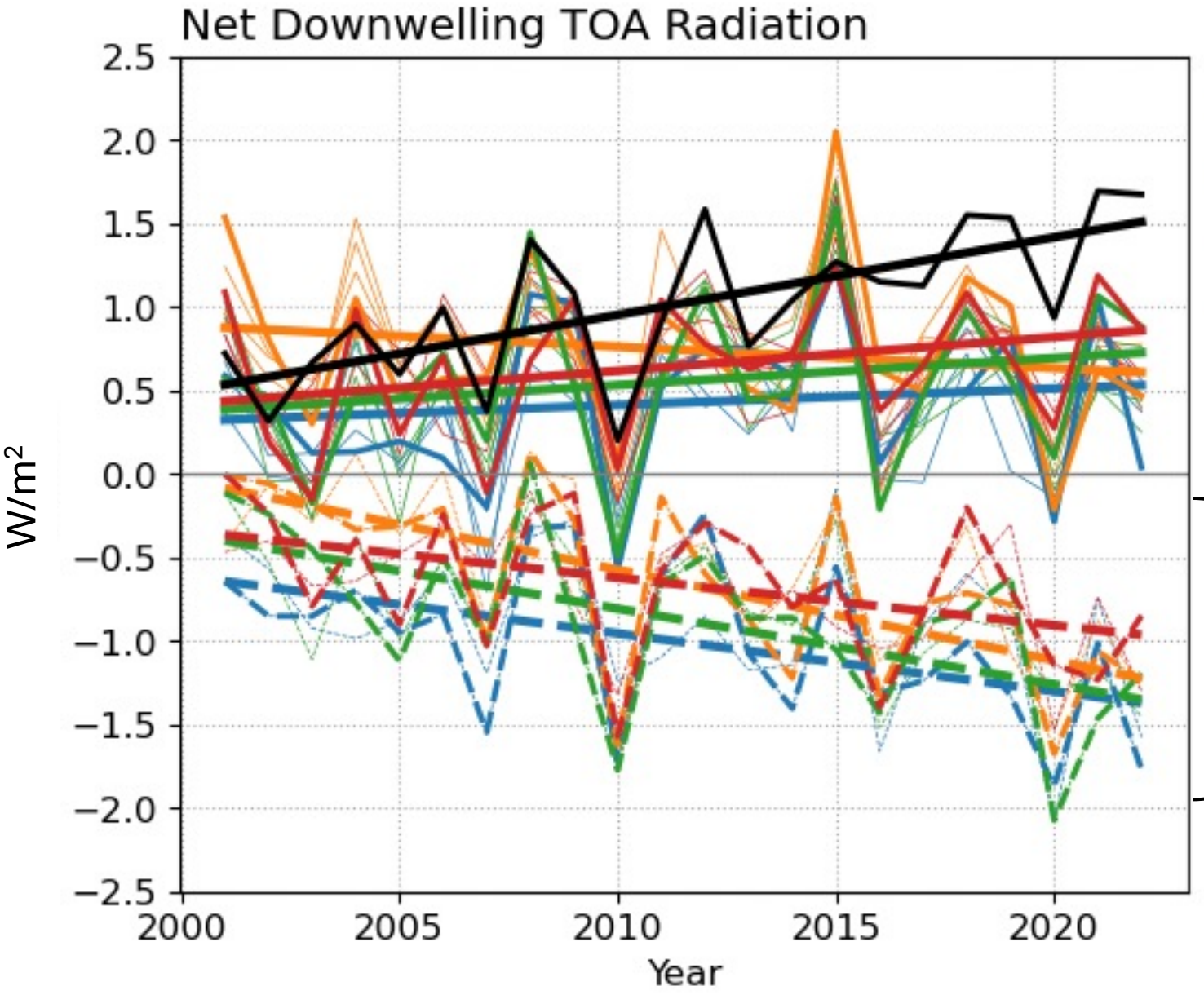
WTF (what the forcing)?!

Approach 2: E3SM AMIP Simulations



Dataset	Trend [W/m²/dec]
PCMDI-AMIP-1-1-9	0.10 ± 0.16
NOAA-OISST-2.1	-0.13 ± 0.17
NOAA-ERSST-v5	0.16 ± 0.17
HadISST-1.1	0.20 ± 0.14
CERES-EBAF-4.2	0.46 ± 0.11

Approach 2: E3SM AMIP Simulations



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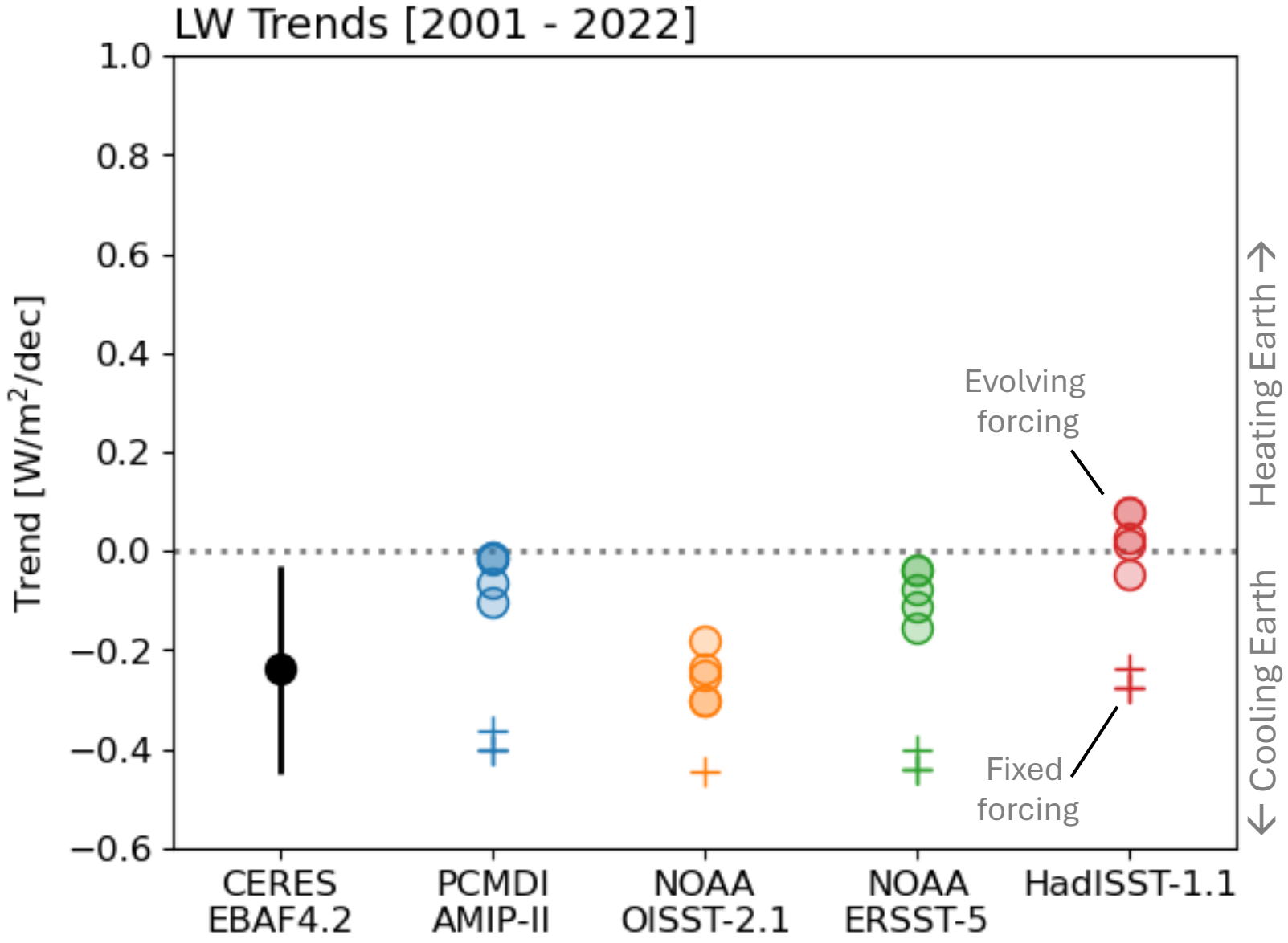
Forcing held fixed at 2010 levels

Approach 2: E3SM AMIP Simulations



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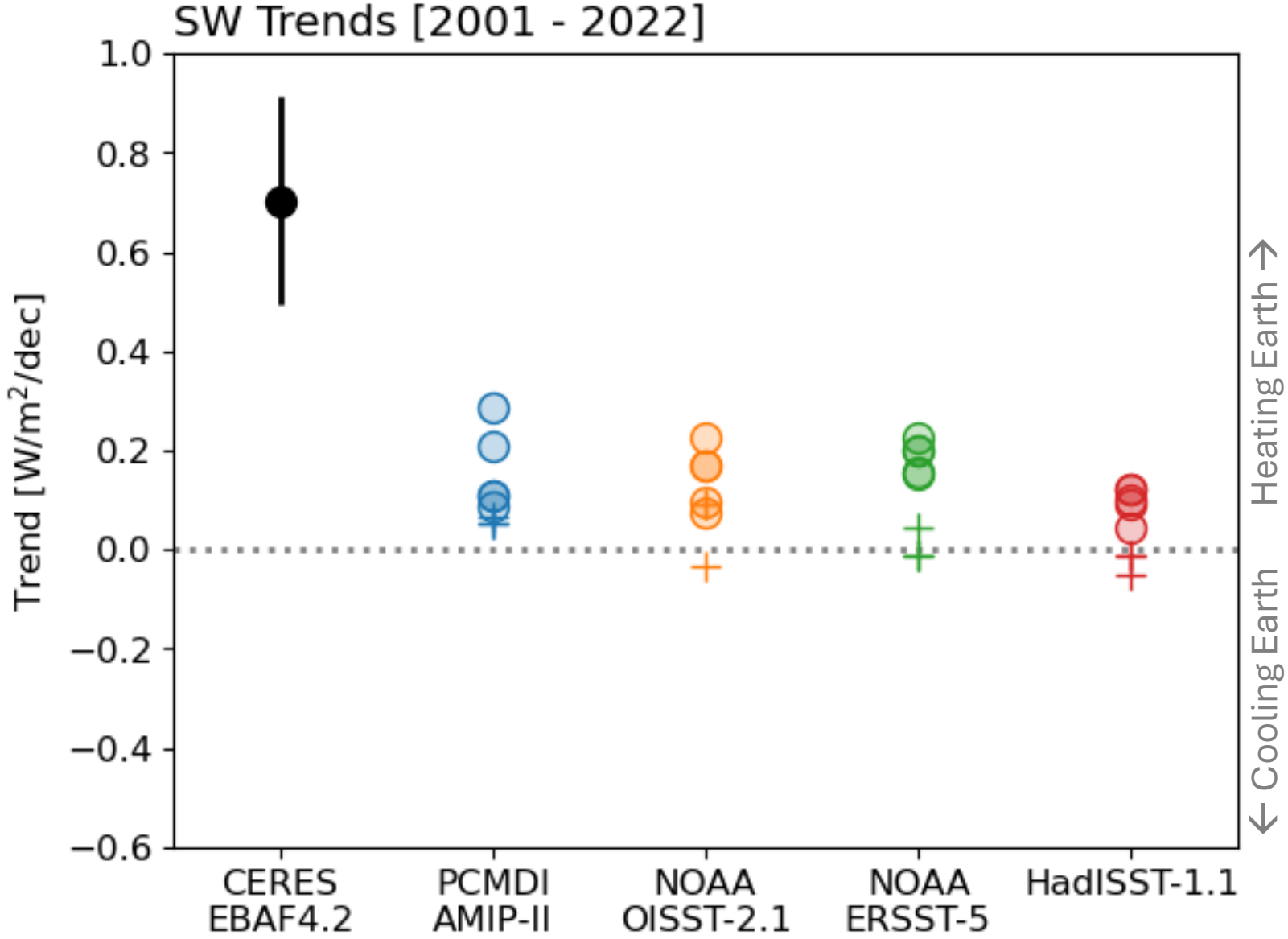

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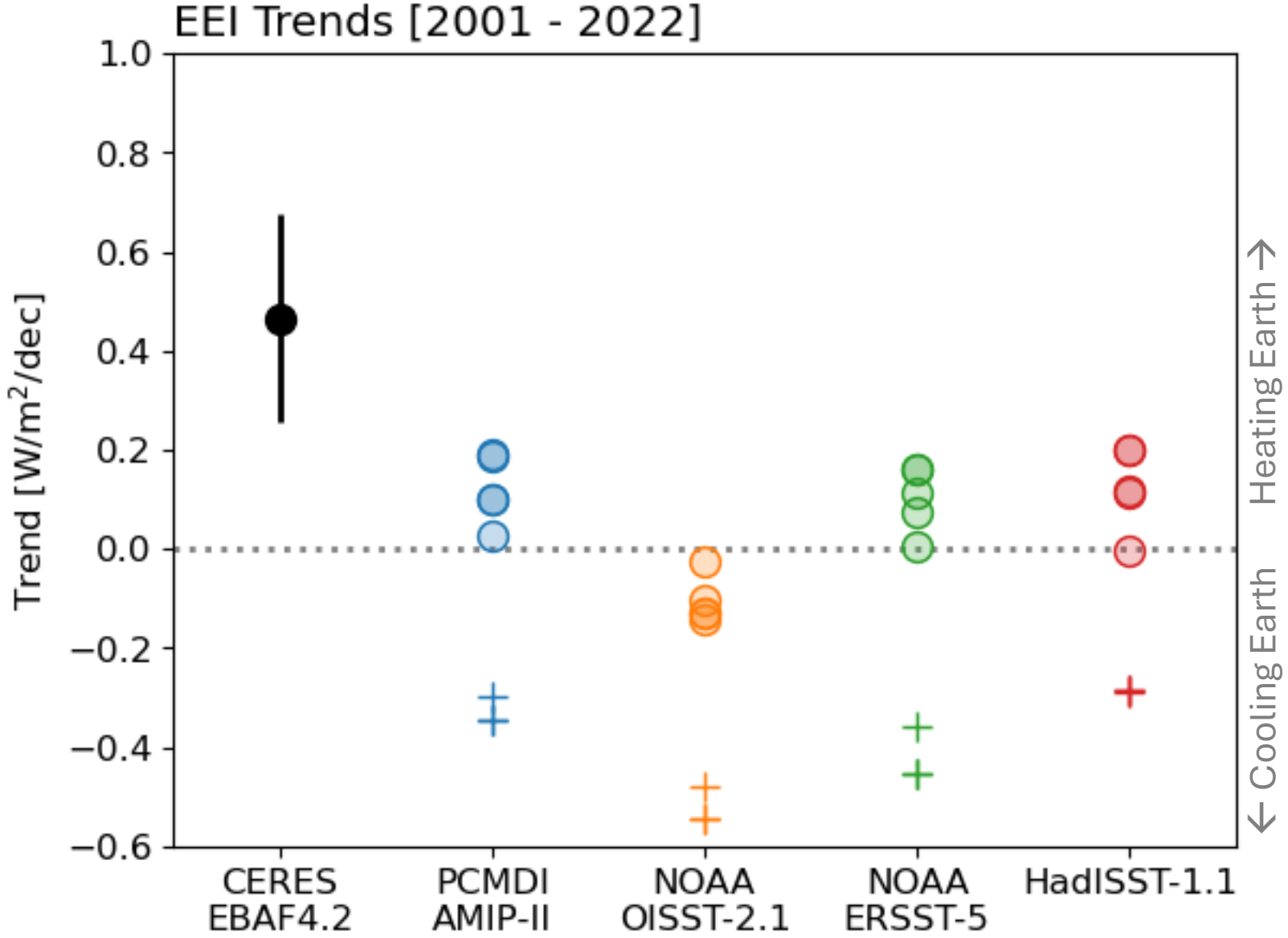

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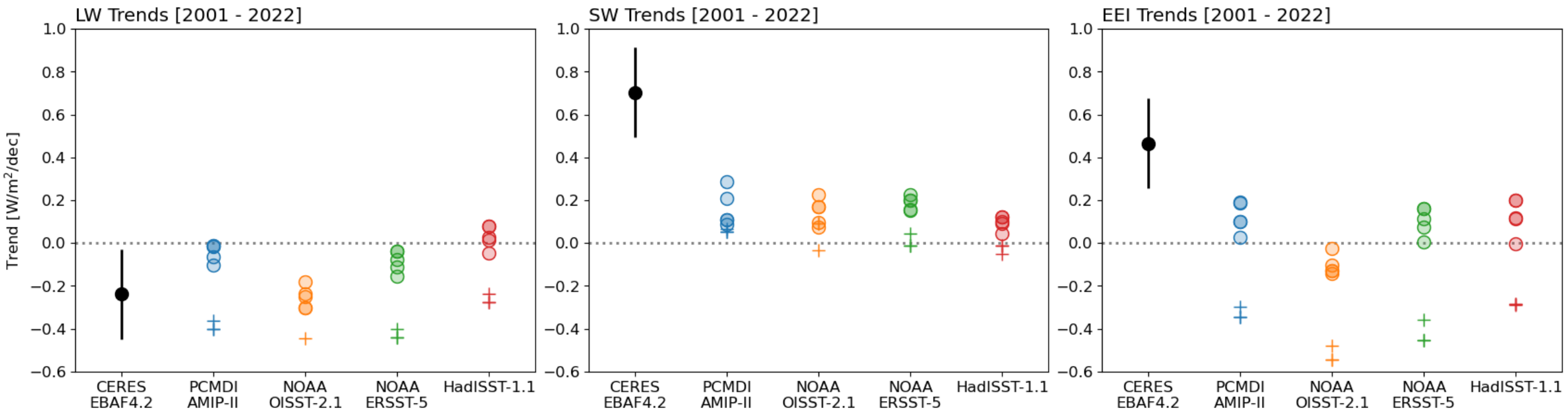

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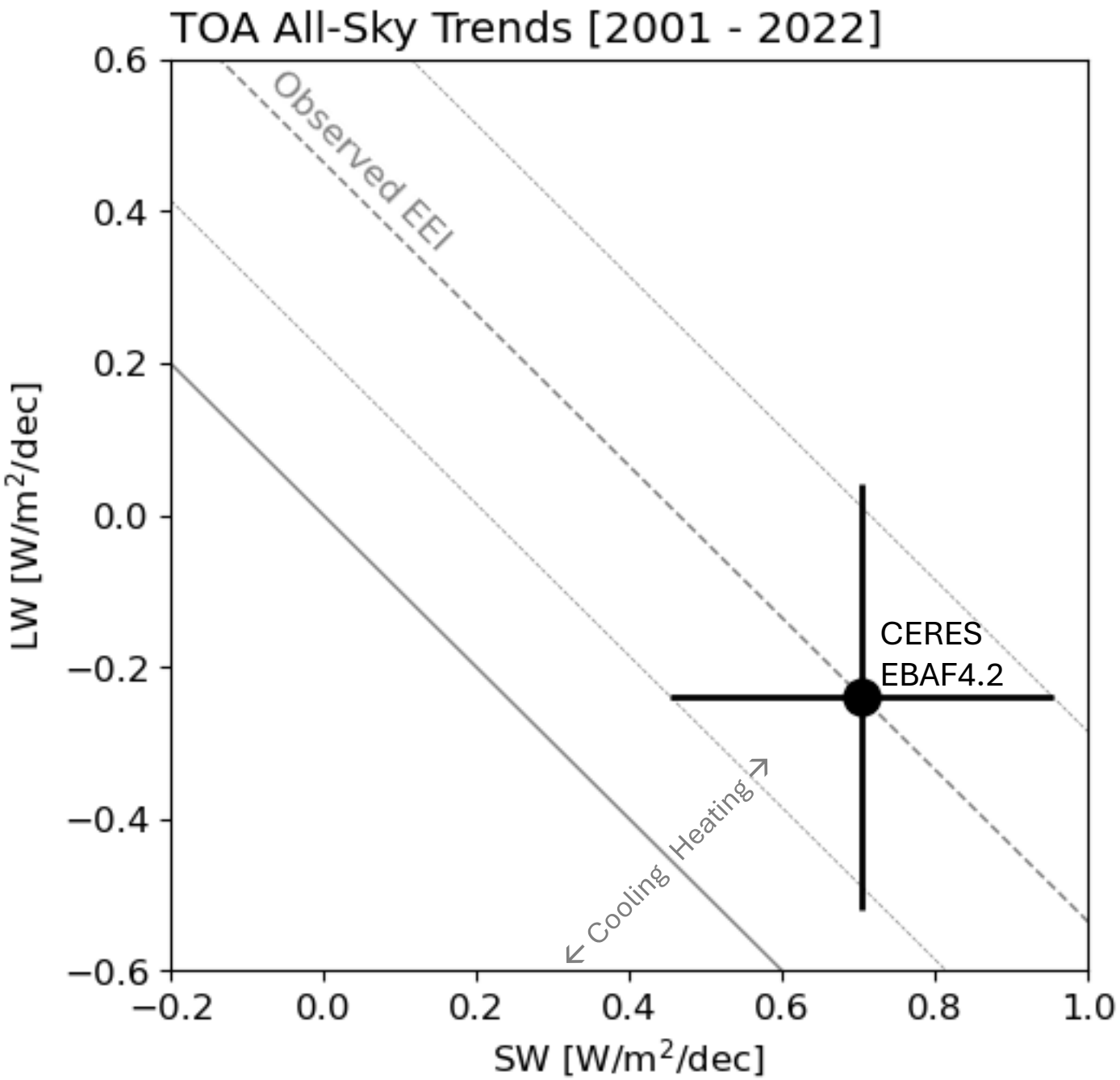
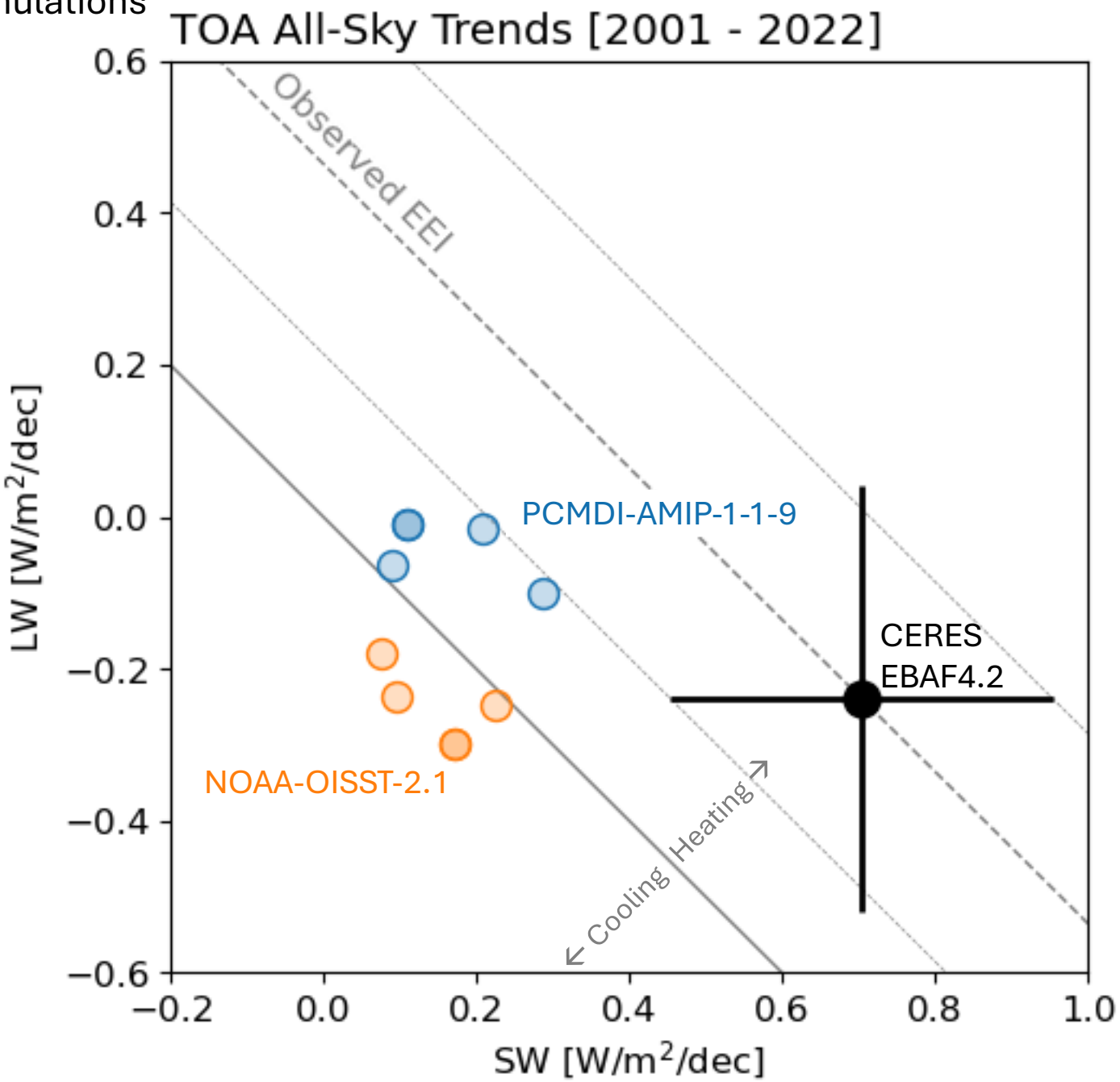


Approach 2: E3SM AMIP Simulations

Schmidt Diagram

Approach 2: E3SM AMIP Simulations



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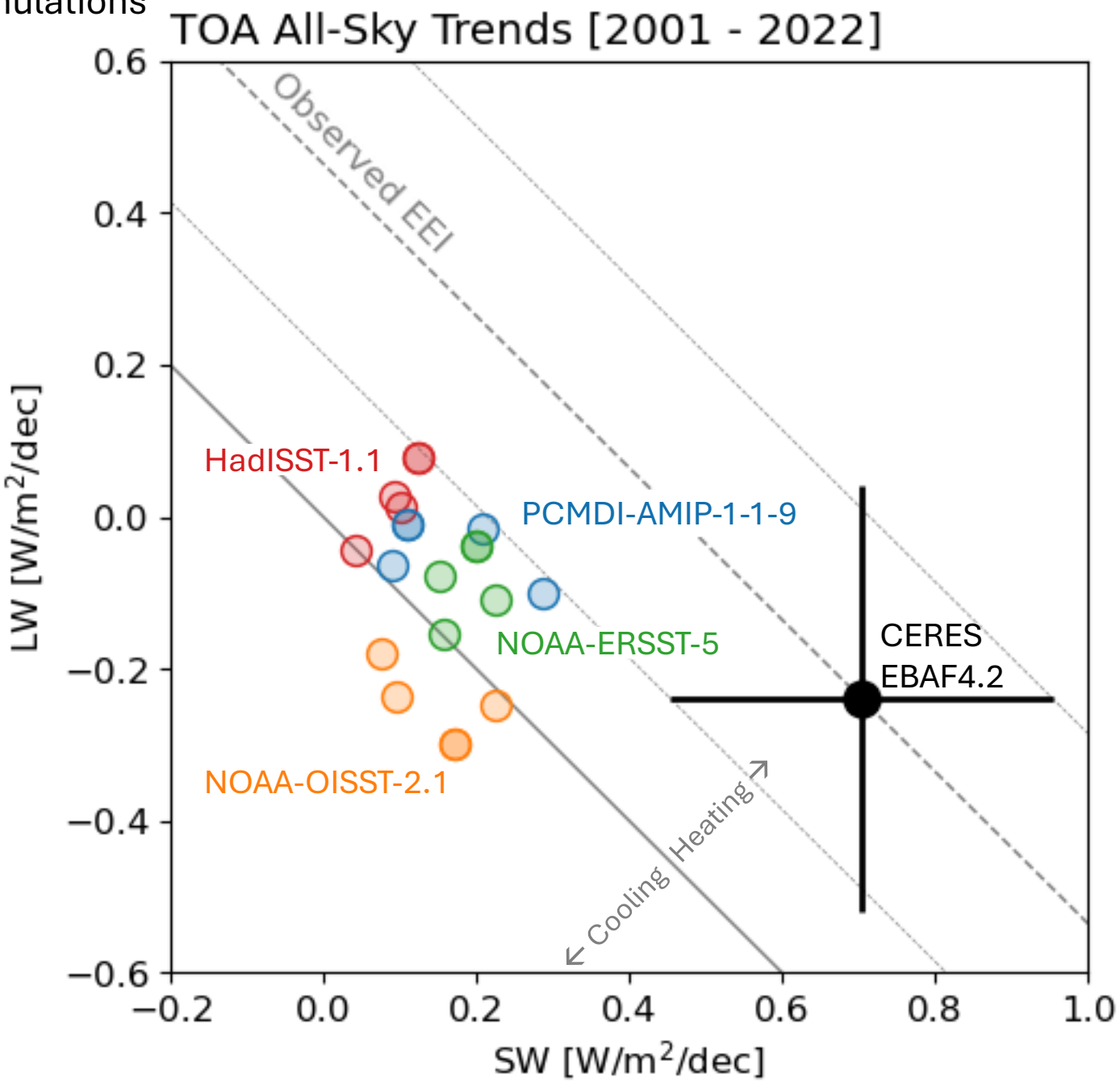

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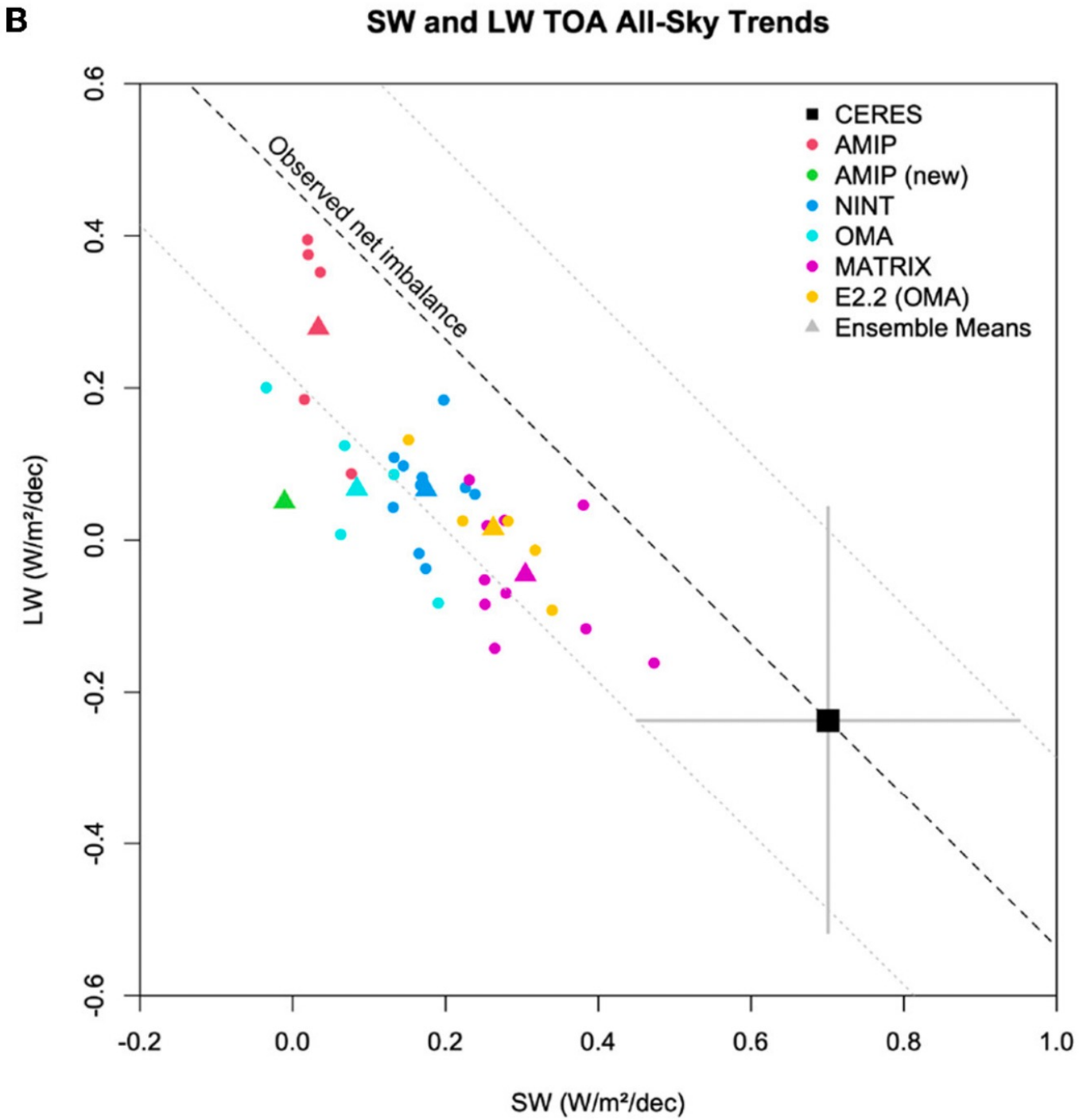


Schmidt et al (2023)

Future work

- Looking in more detail at radiative feedbacks induced by different SST datasets, including with COSP output
- Examining patterns of response rather than just global means, including fields other than TOA radiation
- Additional SST datasets
- Additional ensemble members
- Single-forcing runs to isolate causes of EEI trends
- **Updated real-world forcings**

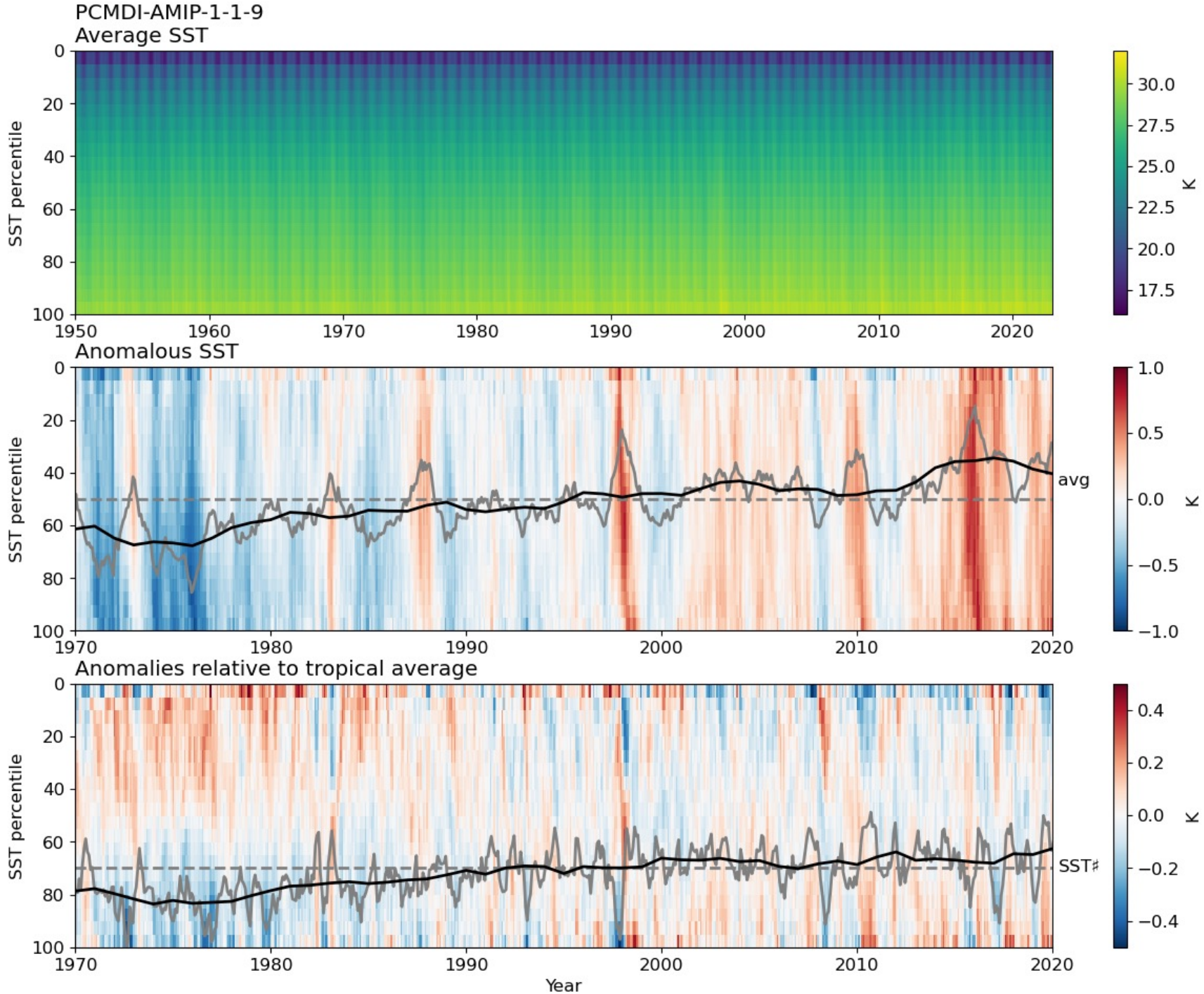
Take Home Points

- There are marked differences among SST datasets in both the global mean sea surface warming and its spatial pattern during recent periods.

- These differences are large enough to have discernible effects on EEI and its trends, as diagnosed via Green's functions & dedicated E3SM AMIP simulations.

- **Observational uncertainty – even during the recent "well-observed" period – cannot be ignored in studies of the pattern effect, CERESMIP, etc.**

- *Get in touch if you'd like to use output from these simulations and/or the SST boundary condition files for conducting your own AMIP simulations*


PCMDI-AMIP-1-1-9
Average SST
SST percentile
0
20
40
60
80
100
1950
1960
1970
1980
1990
2000
2010
2020
30.0
27.5
25.0
22.5
20.0
17.5
K
Anomalous SST
SST percentile
1970
1980
1990
2000
2010
2020
avg
1.0
0.5
0.0
−0.5
−1.0
K
Anomalies relative to tropical average
SST percentile
SST♯
0.4
0.2
0.0
−0.2
−0.4
K
Year