Global Impacts of Recent Southern Ocean Cooling

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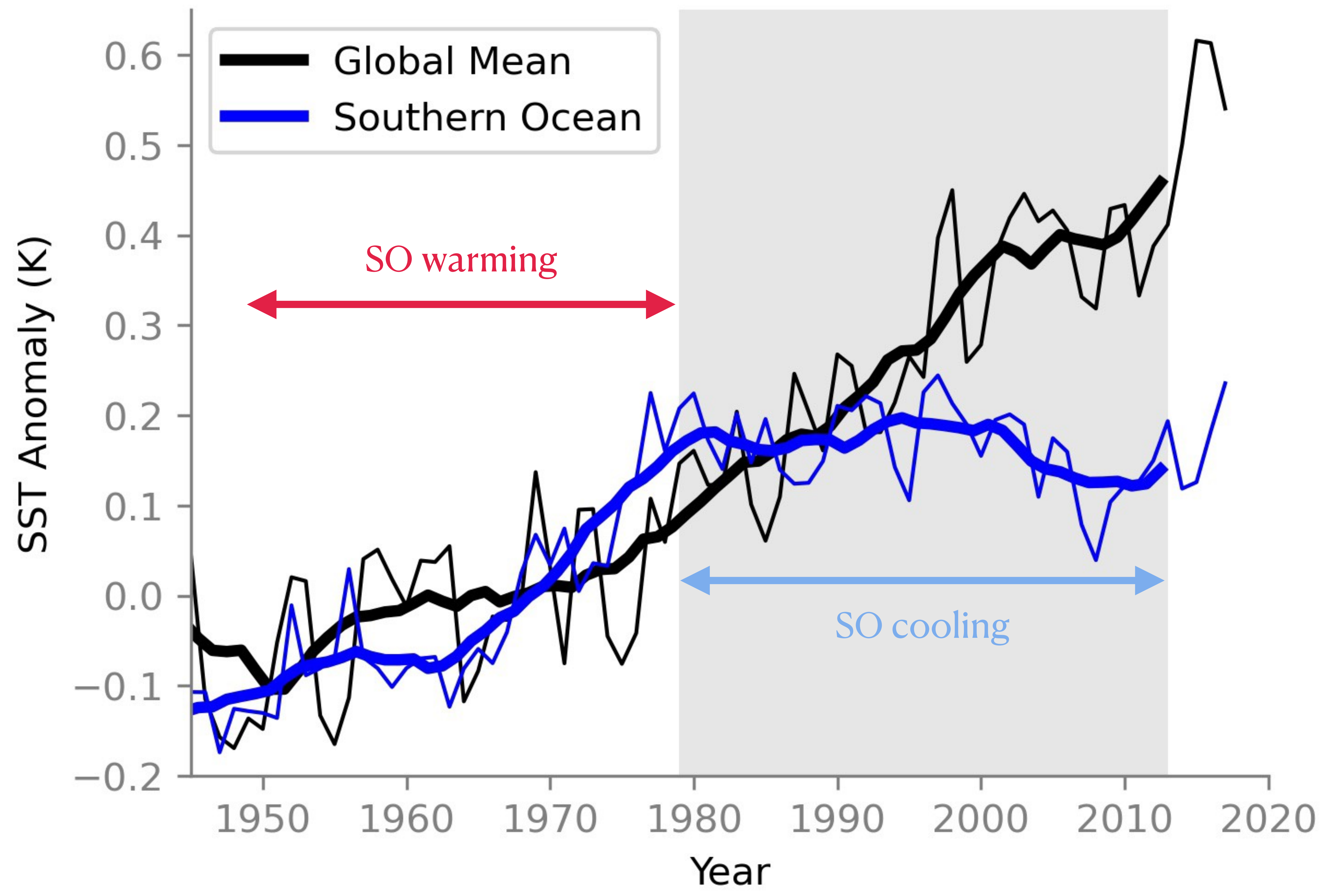
US CLIVAR Summit July 31, 2023

JOHNS HOPKINS UNIVERSITY

The Southern Ocean (SO) surface has cooled since late 1970s



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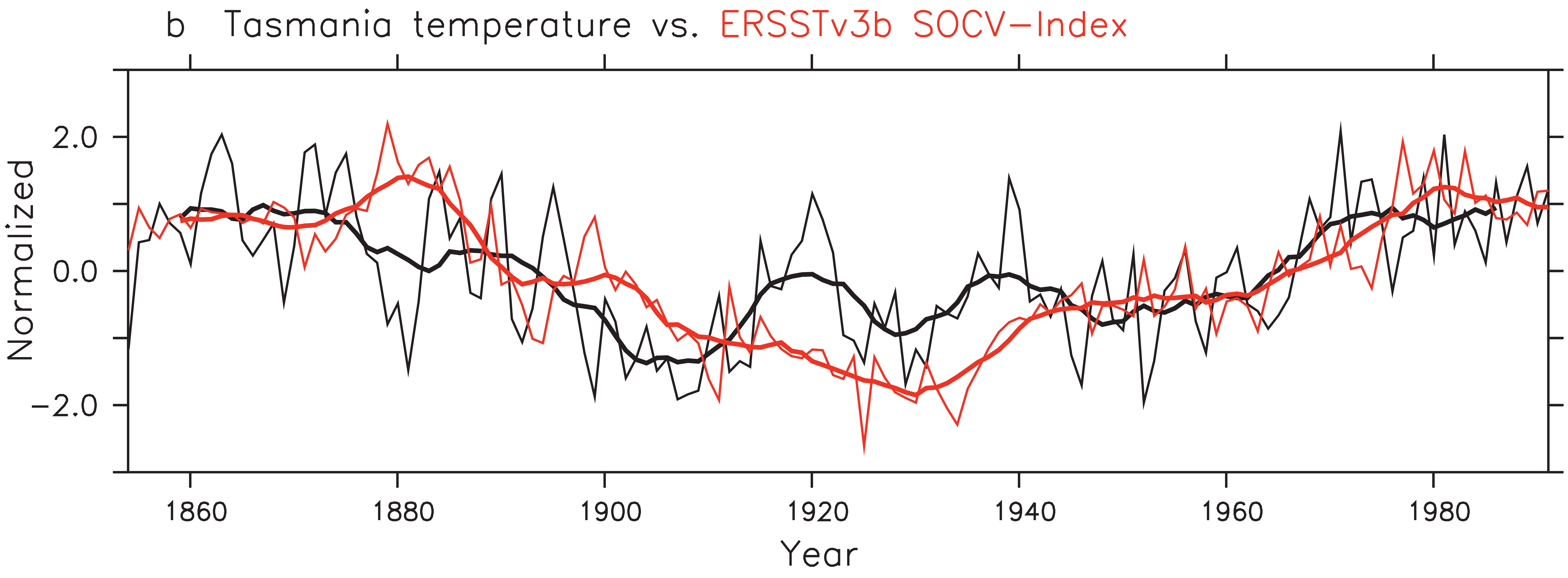
Zhang et al. (in prep)

Paleoclimate proxy shows SO SST multi-decadal variability

With tree ring records from Tasmania



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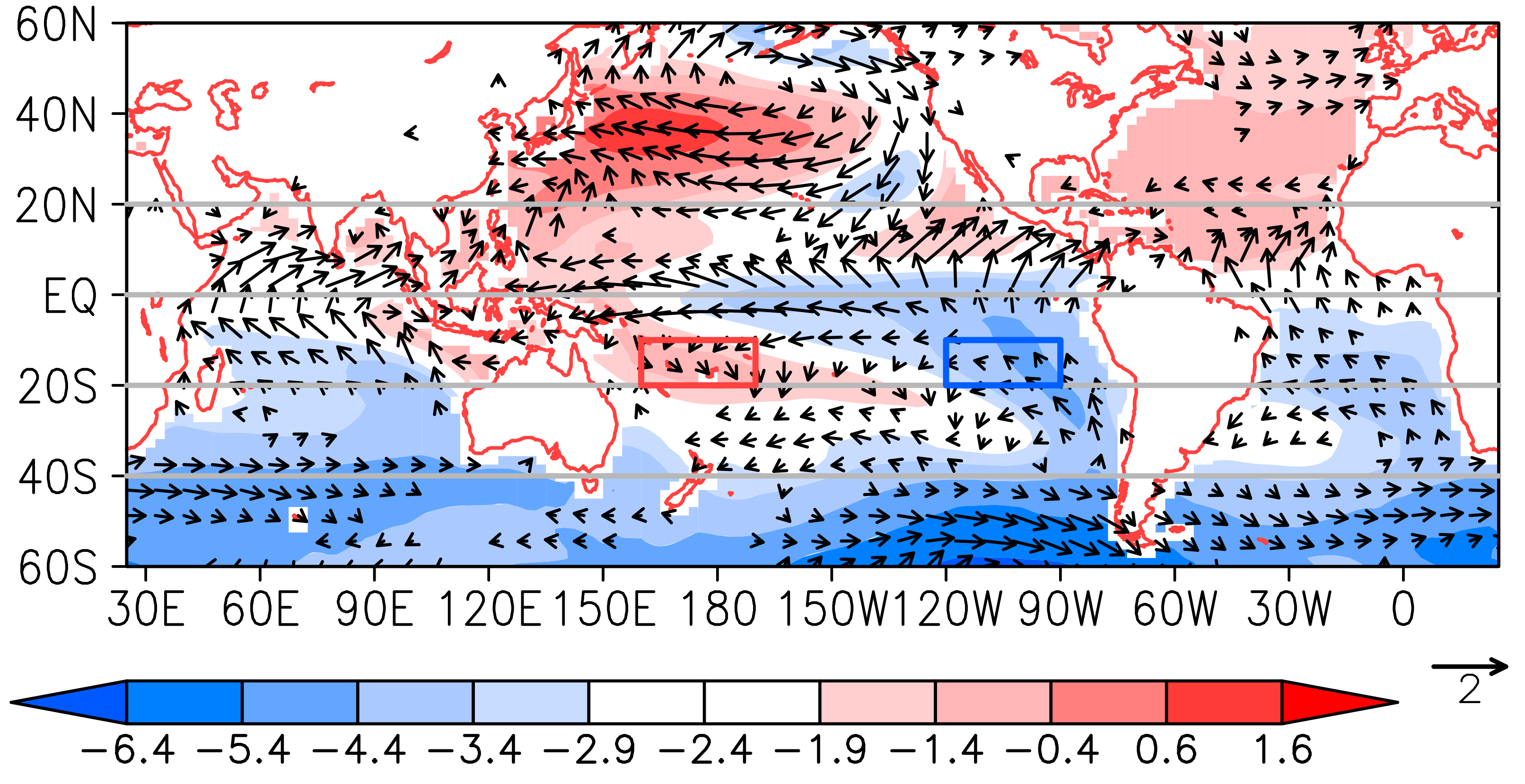
Latif et al. (2013)

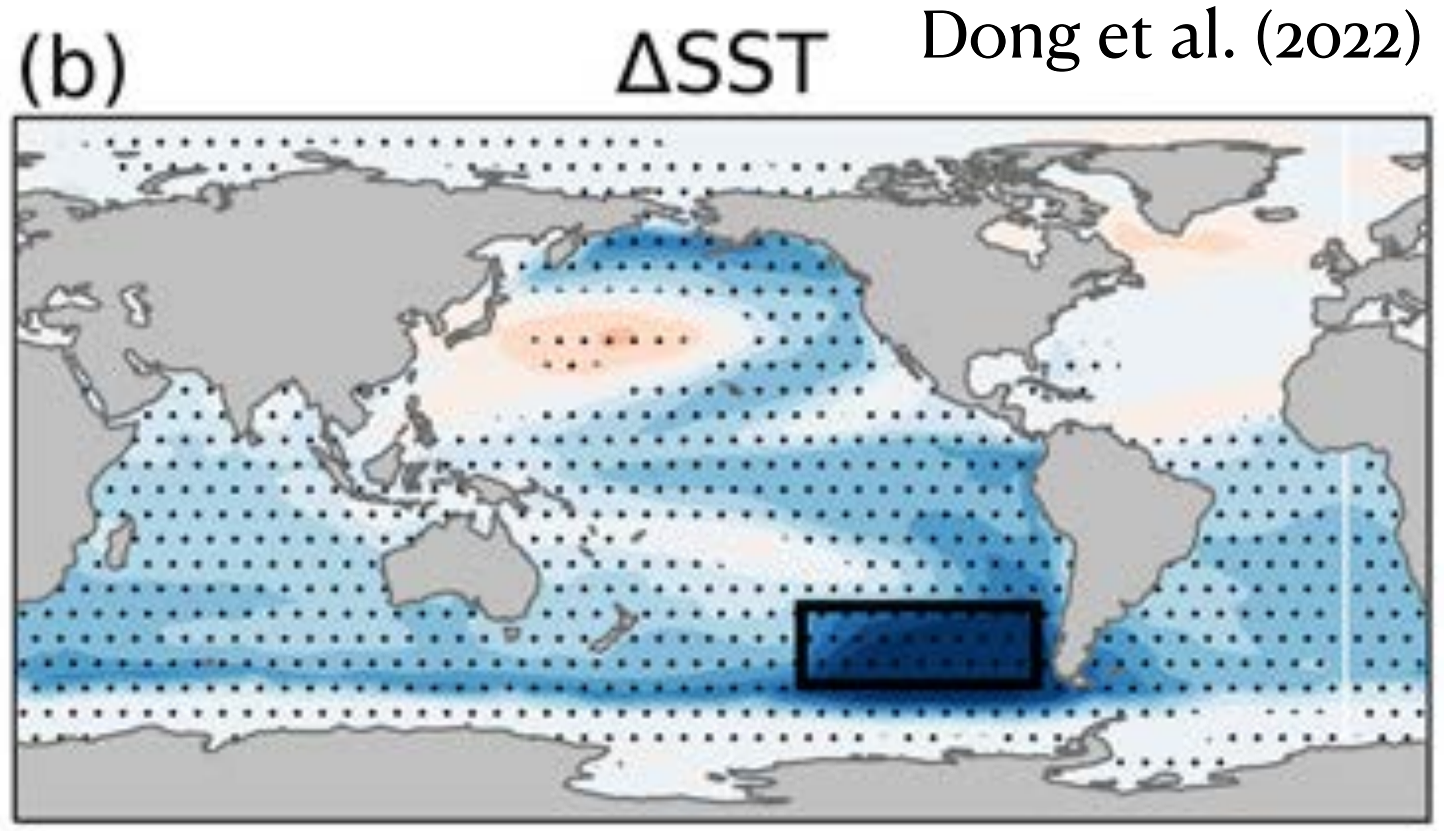
Previous studies suggest a robust response due to SH extratropical forcing

Slab ocean

Hwang et al. (2017)



Dong et al. (2022)



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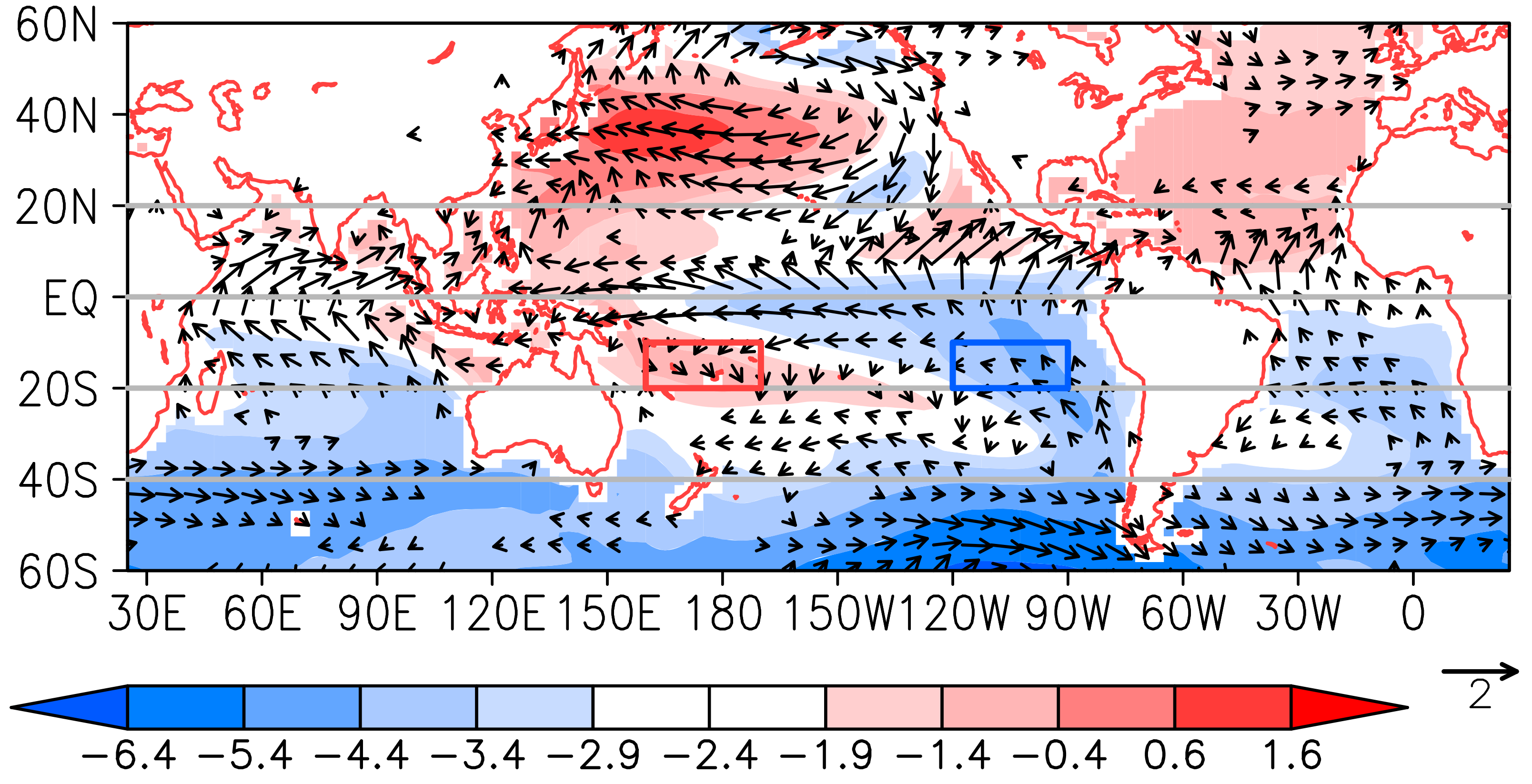

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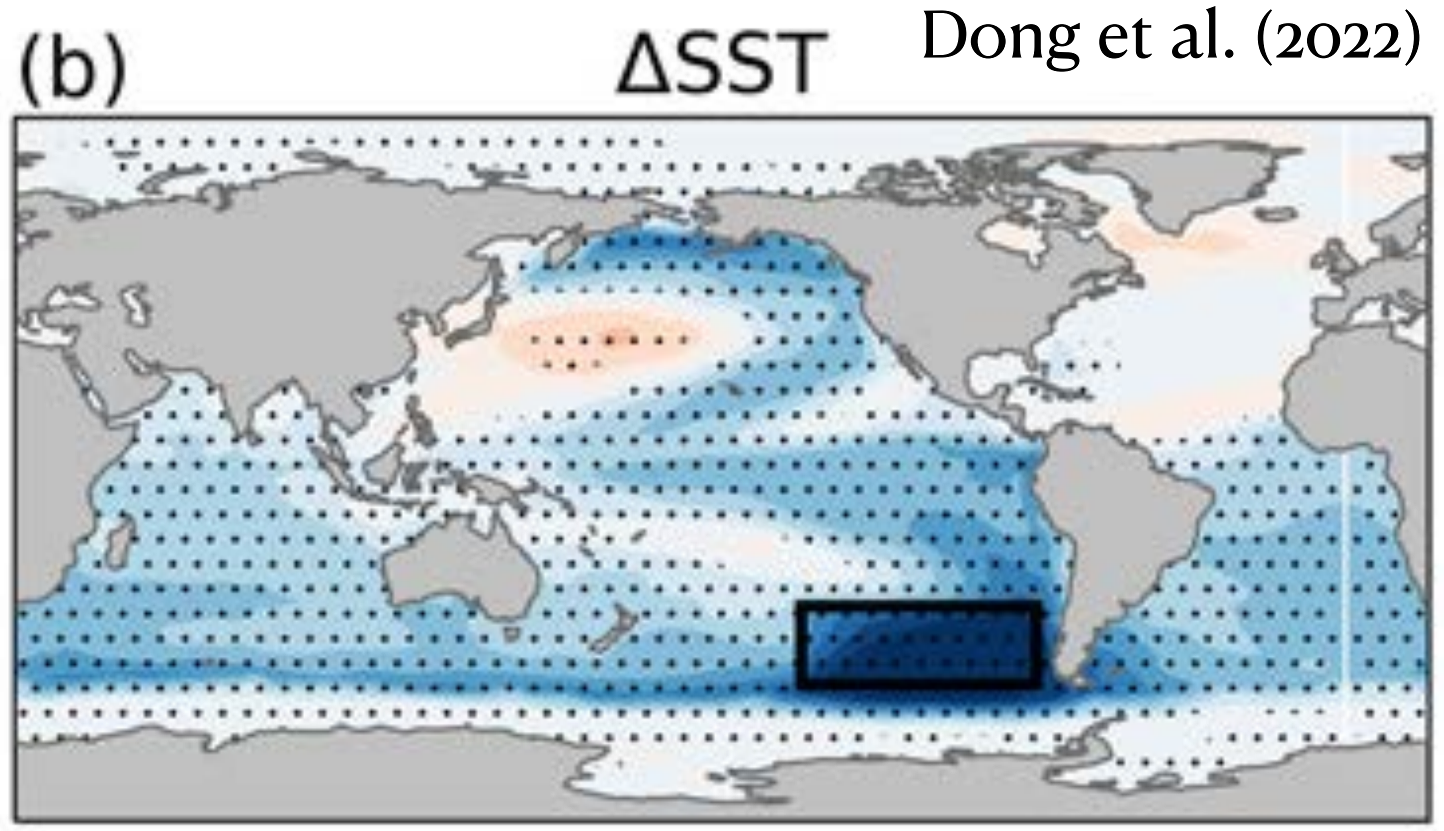
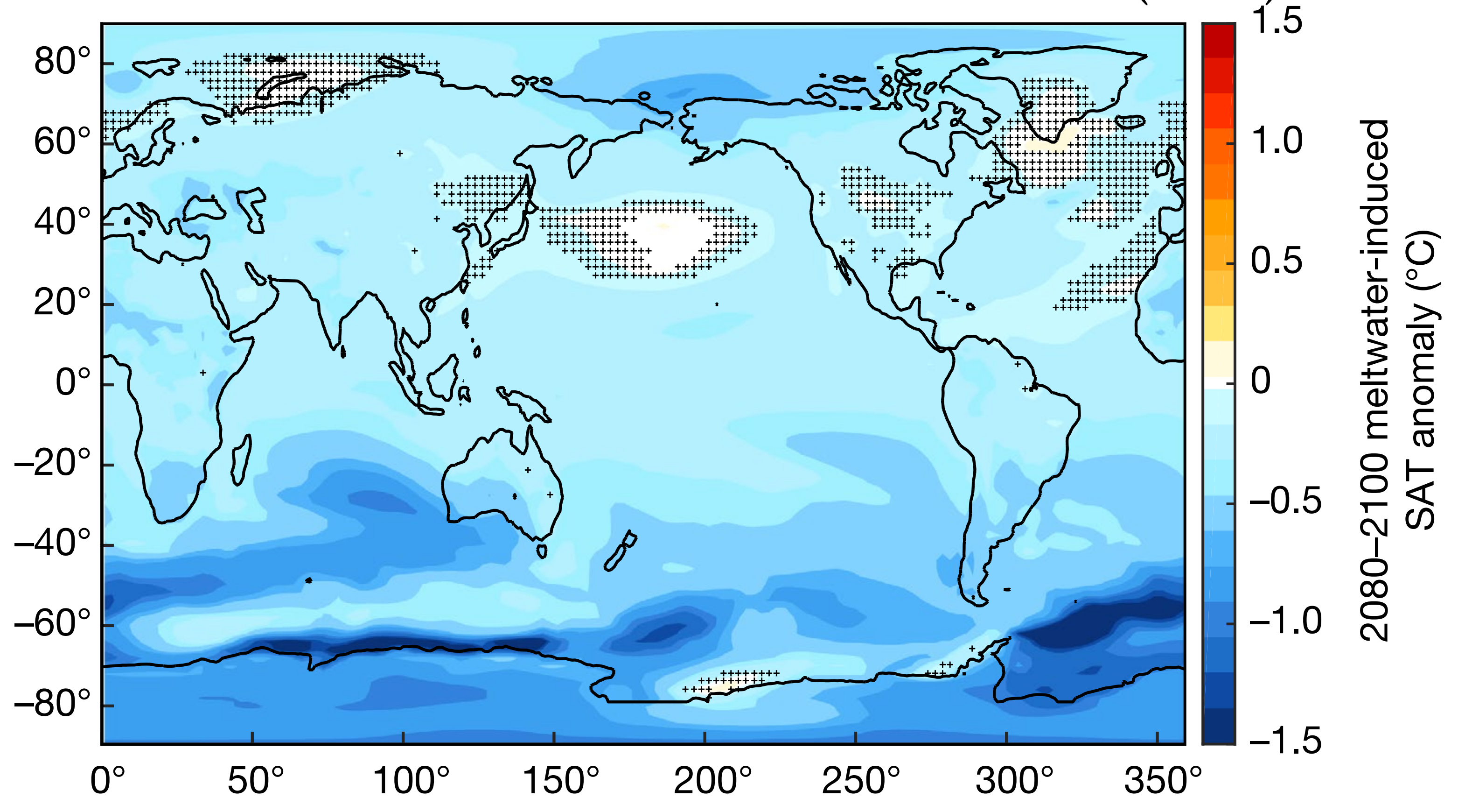
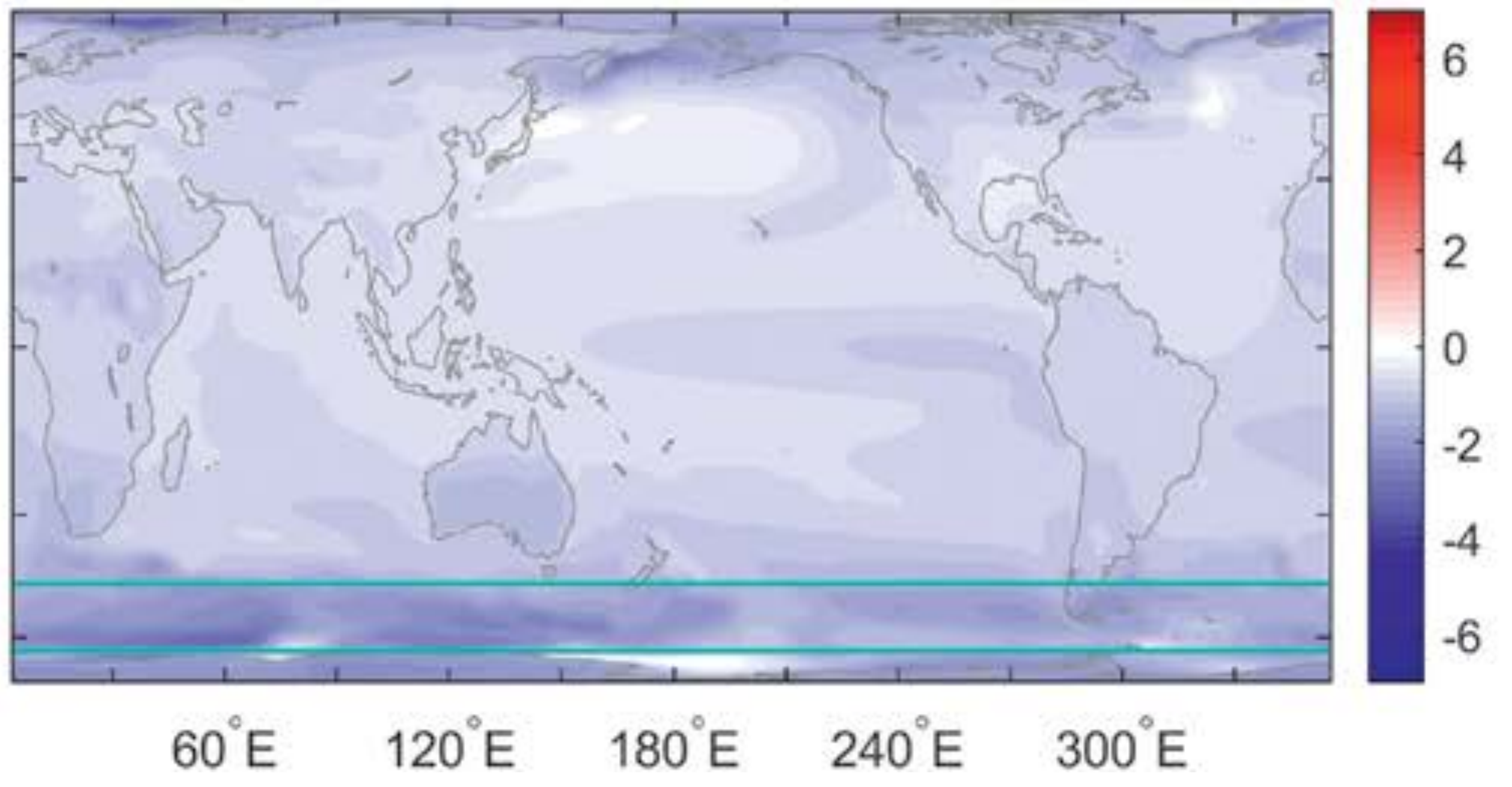


Dynamic ocean

Bronselaer et al. (2018)



Kang et al. (2019)



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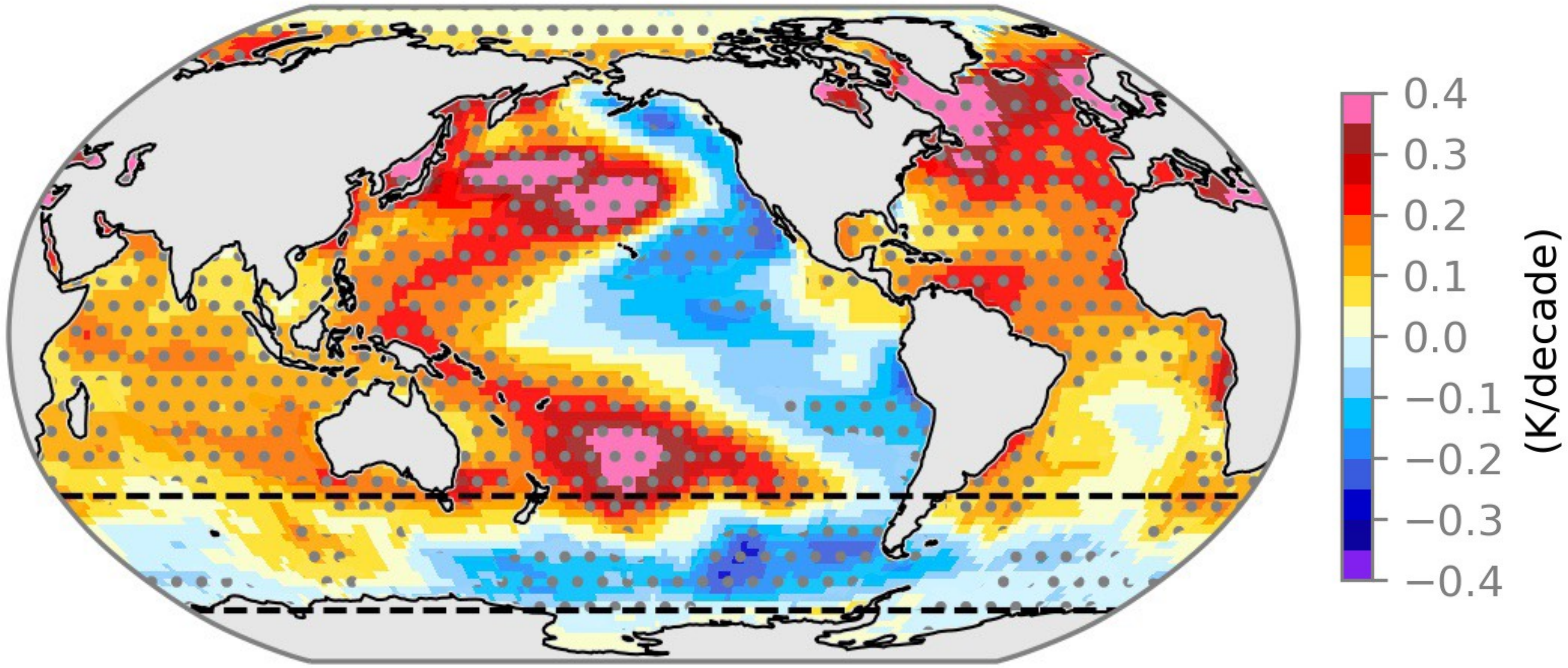
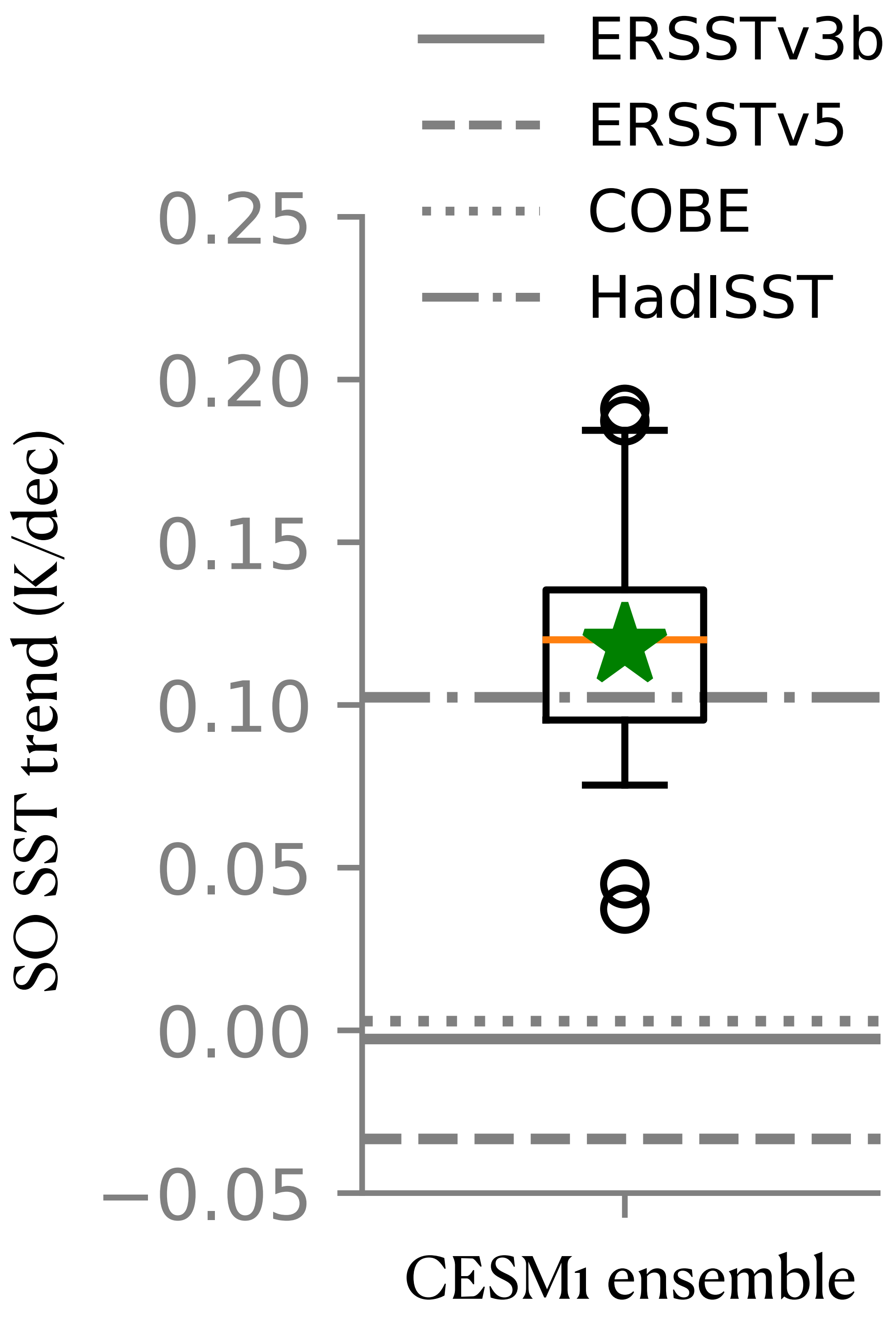
Climate models are unable to capture observed SO SST trends

Observed trends 1979-2013





Stippling shows significant trends at 95% level
Data: ERSSTv3b; Zhang et al. (2021)

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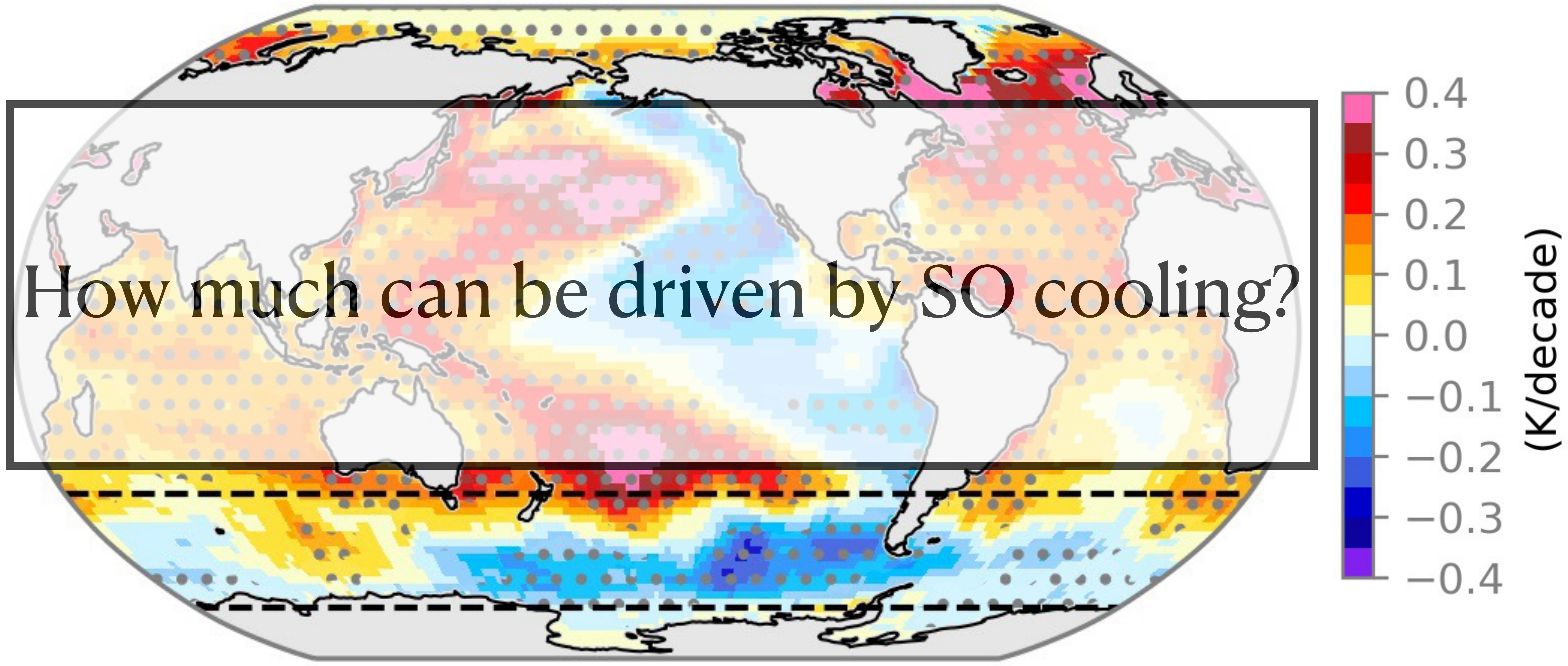

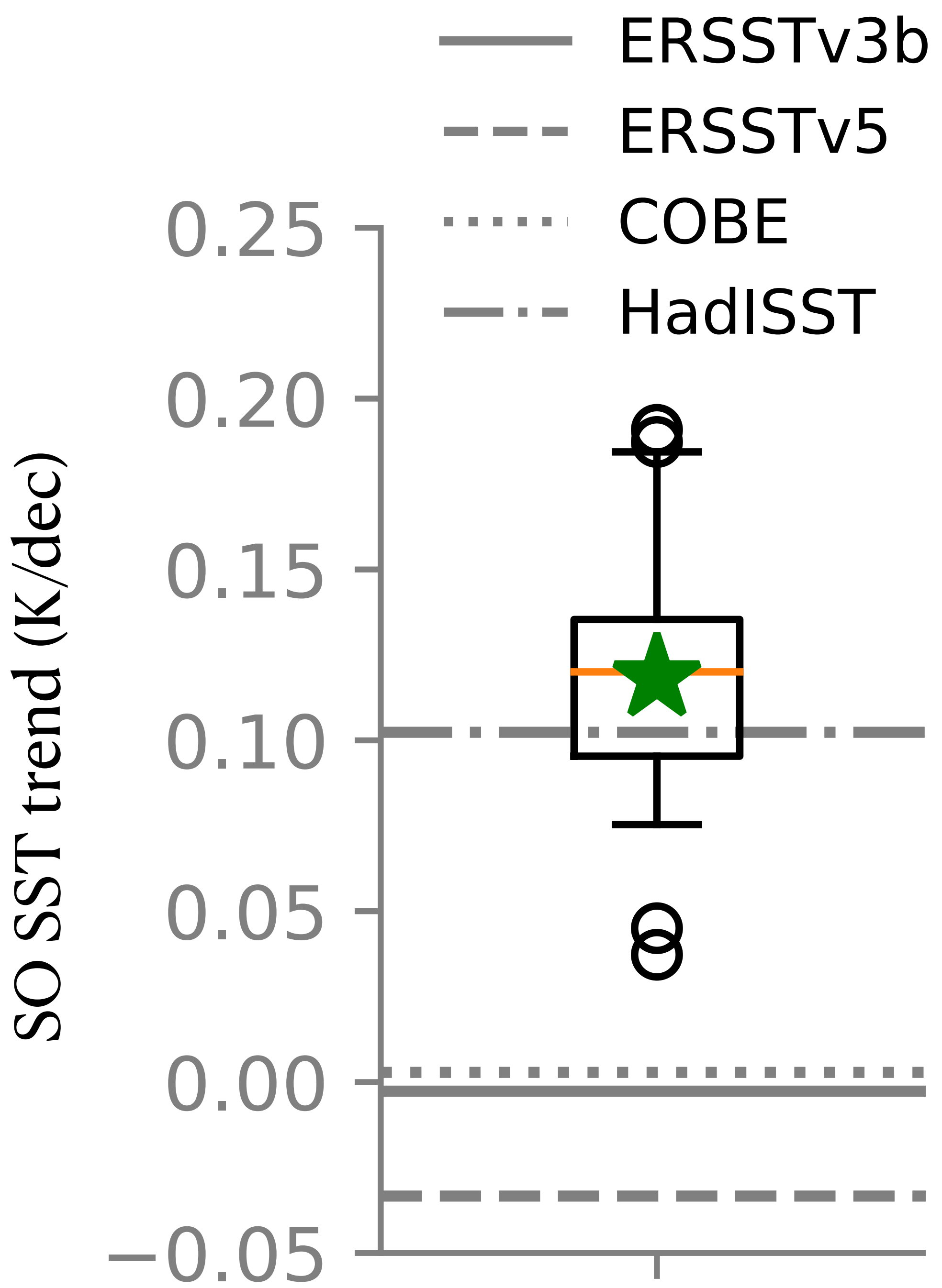

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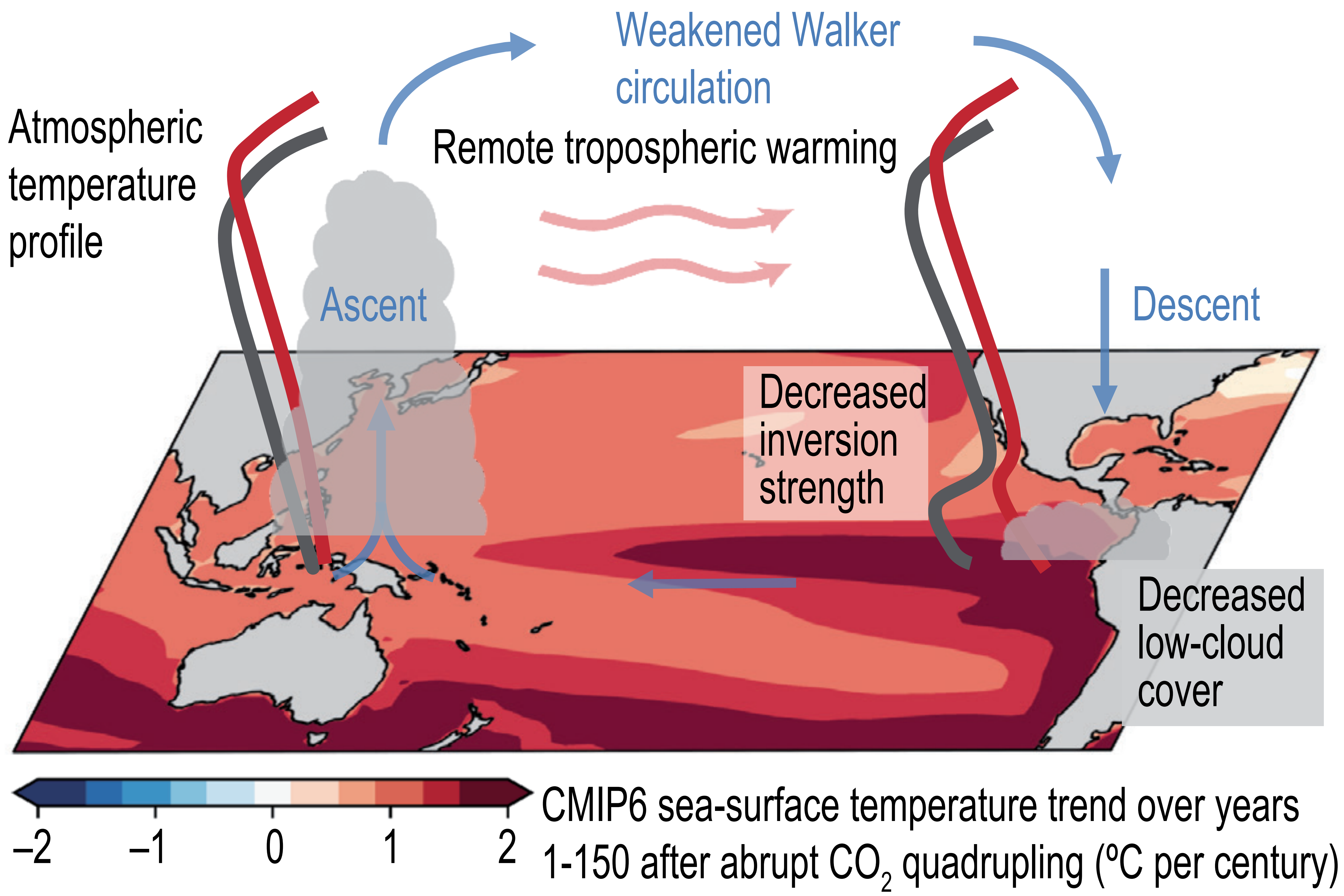
SO-induced teleconnection can affect the tropical warming patterns and climate sensitivity

Projected warming pattern



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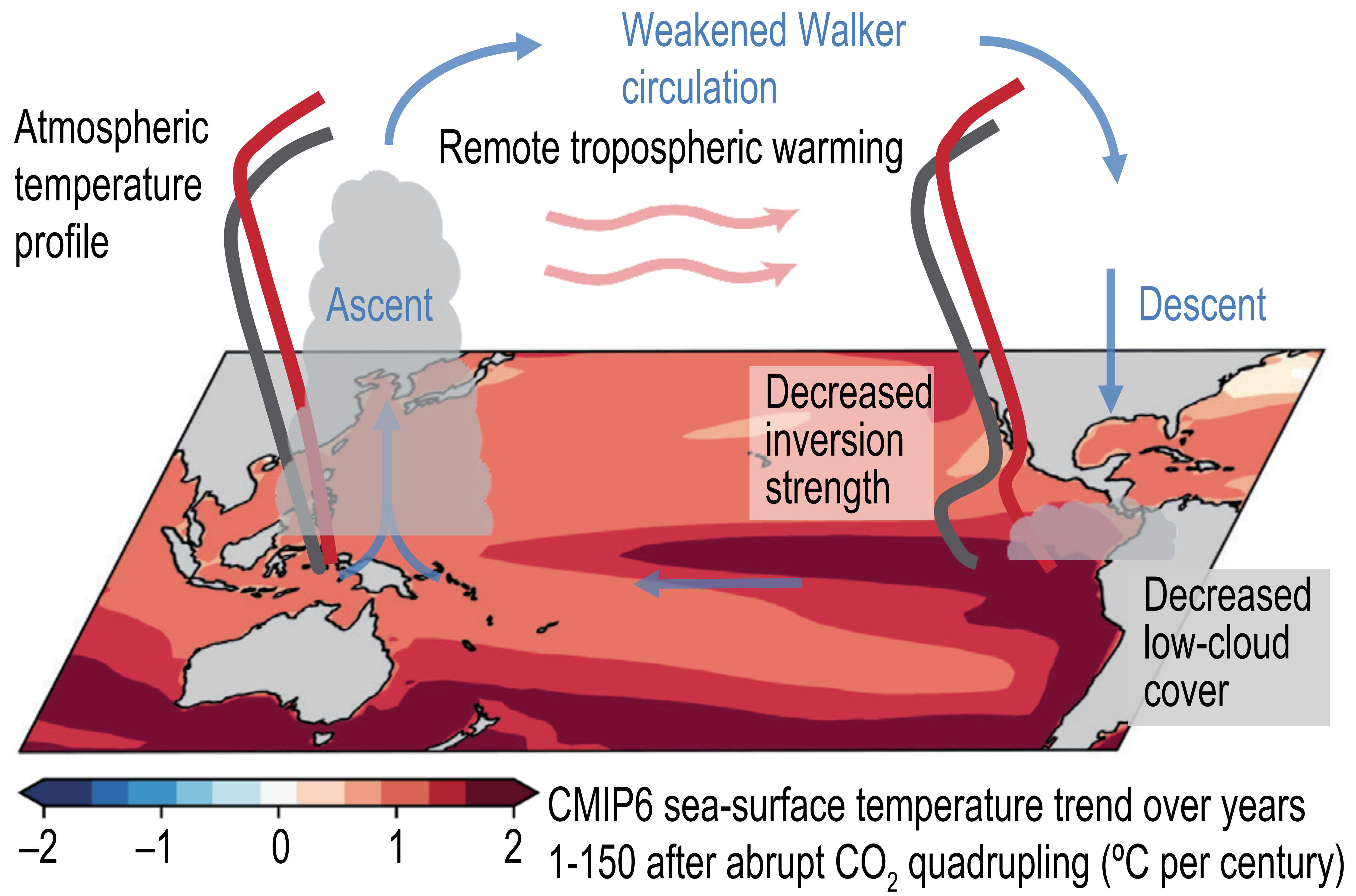

Positive Feedback

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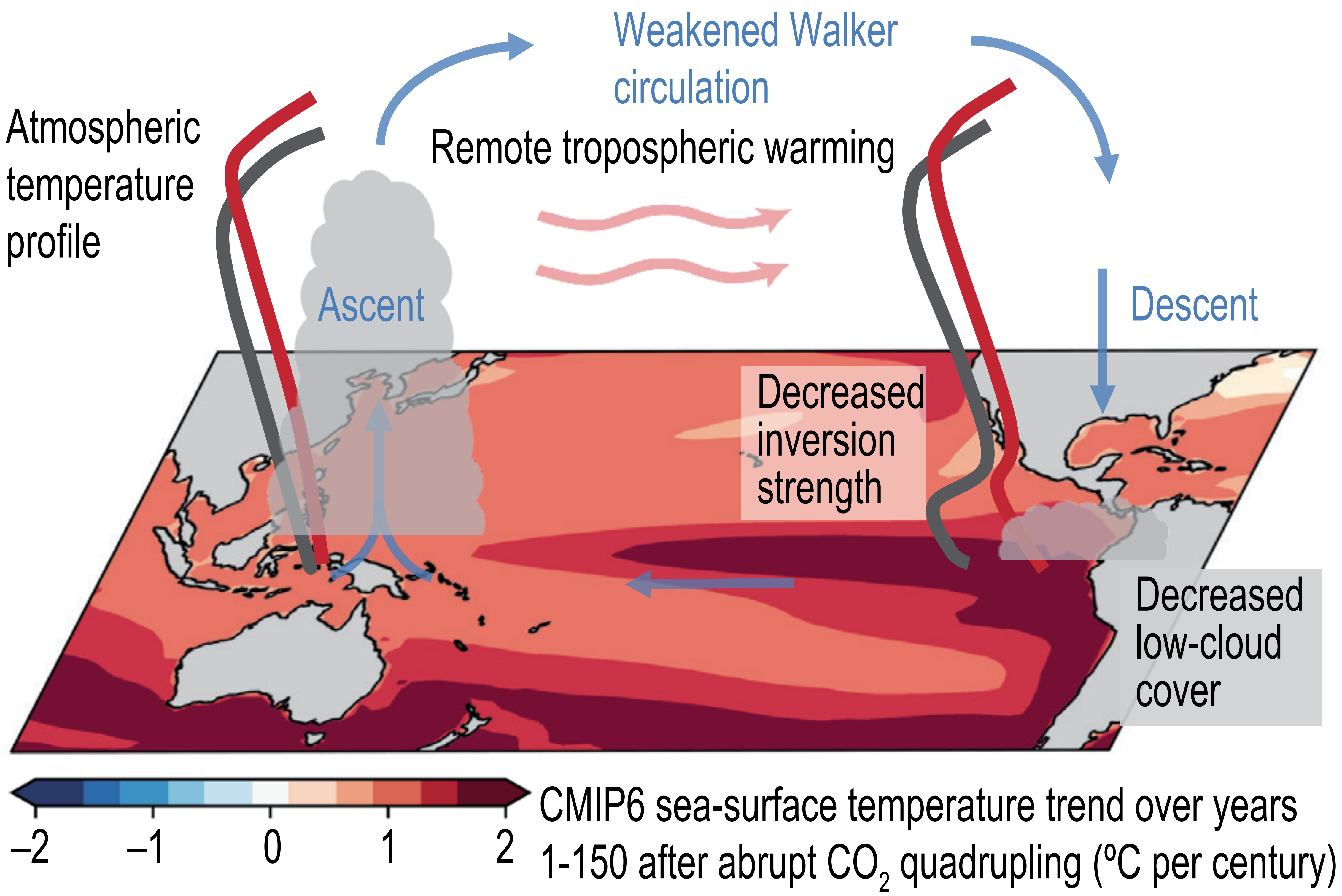

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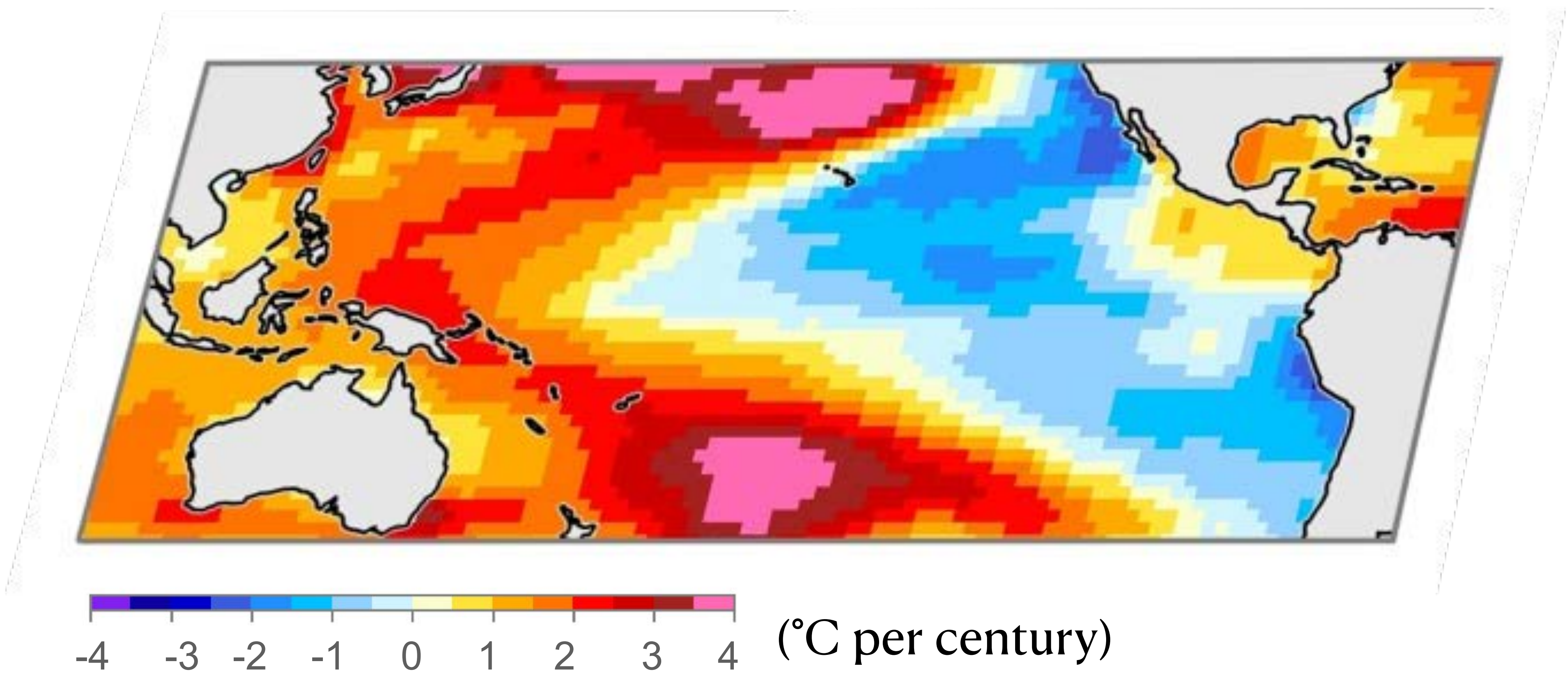

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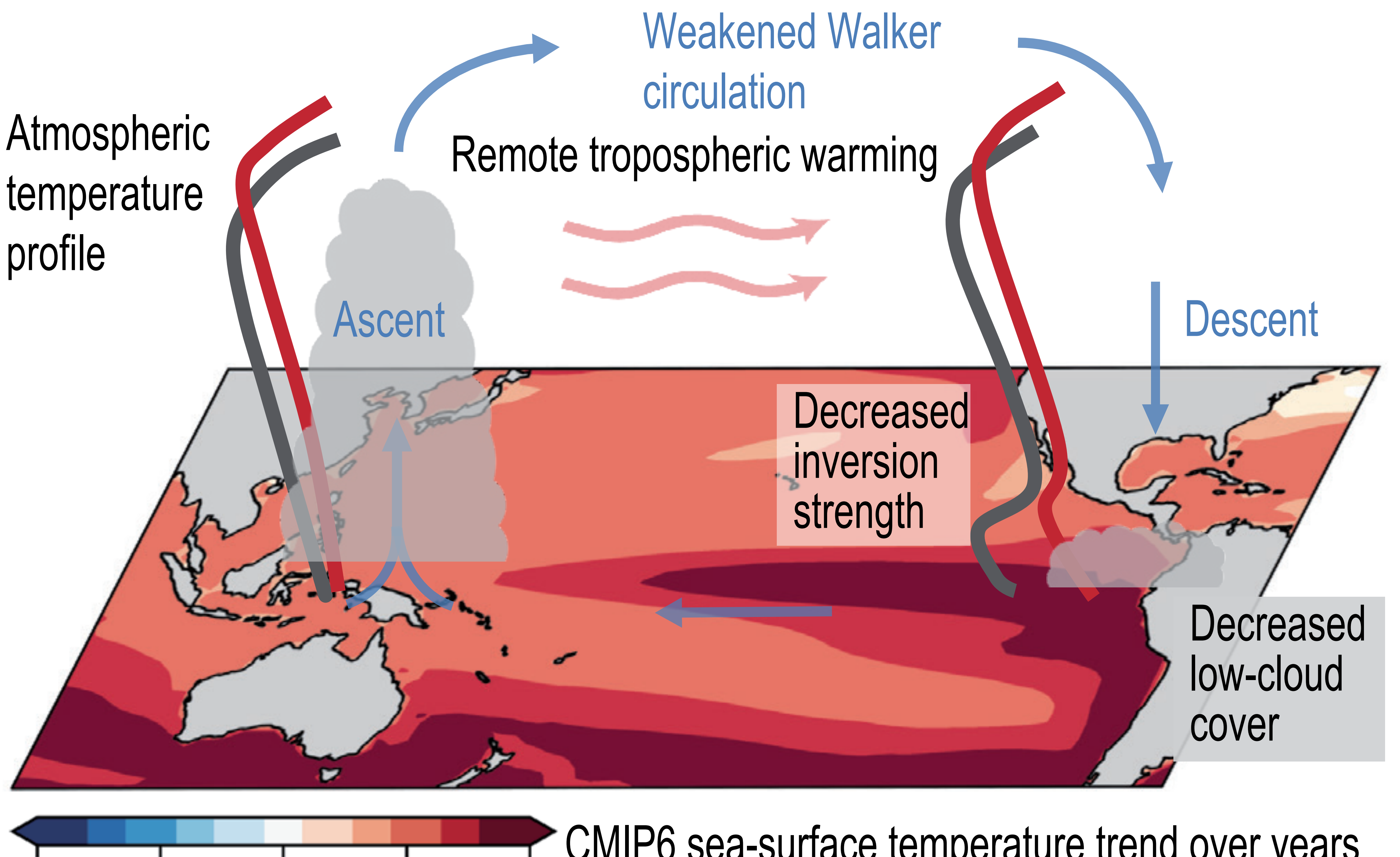
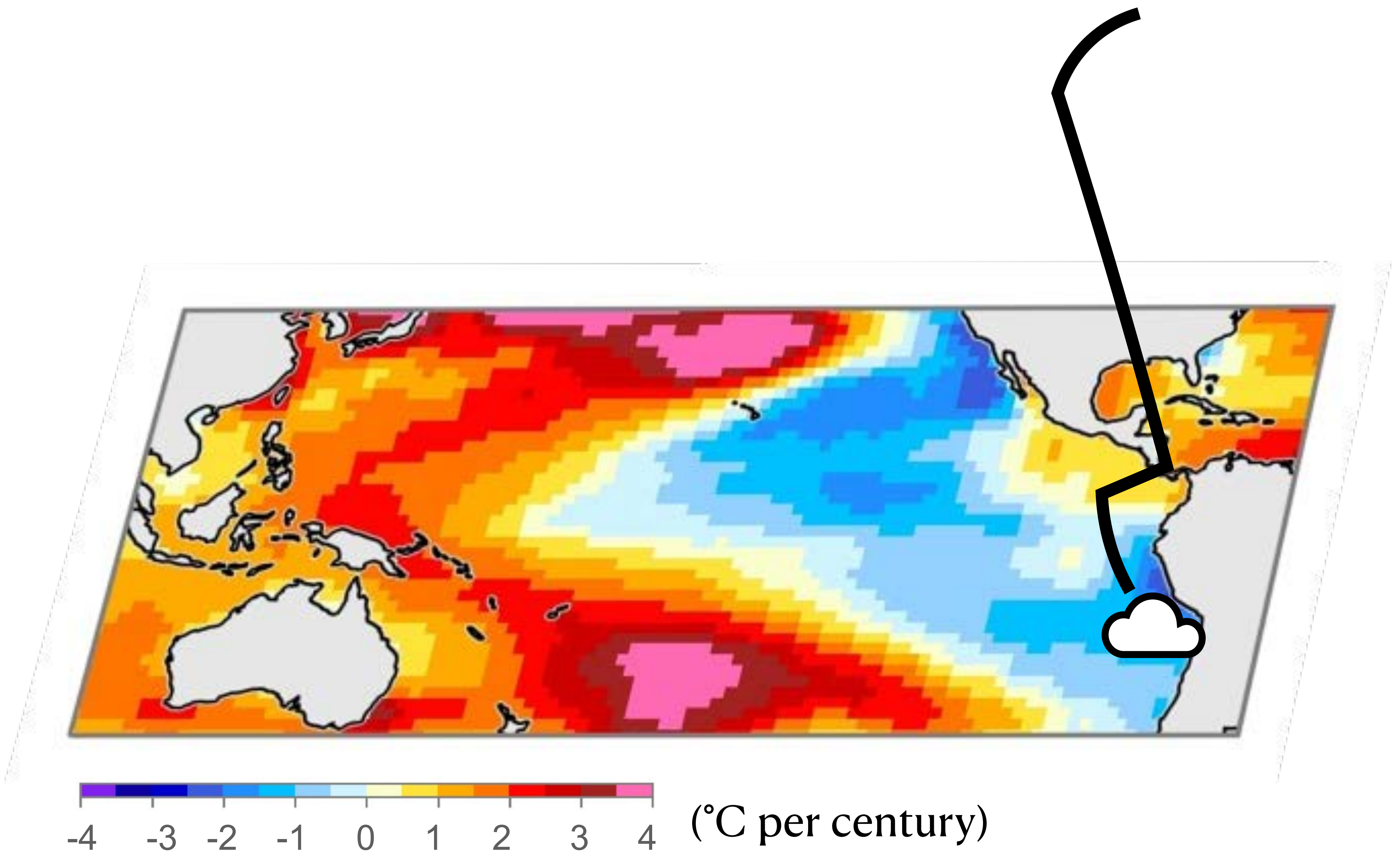


CMIP6 sea-surface temperature trend over years 1-150 after abrupt CO_2 quadrupling (ºC per century)

Positive Feedback

Observed pattern 1979-2013



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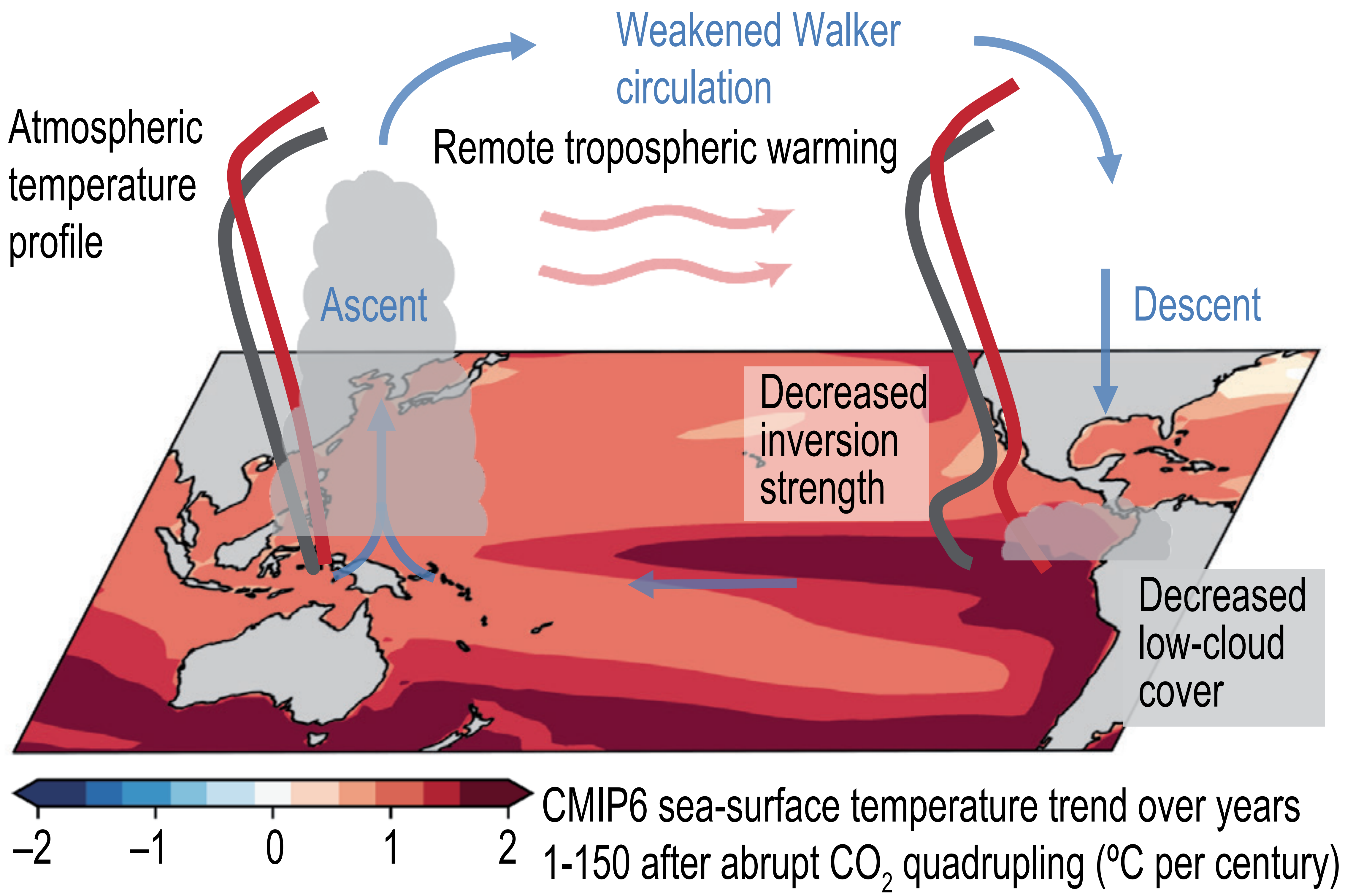

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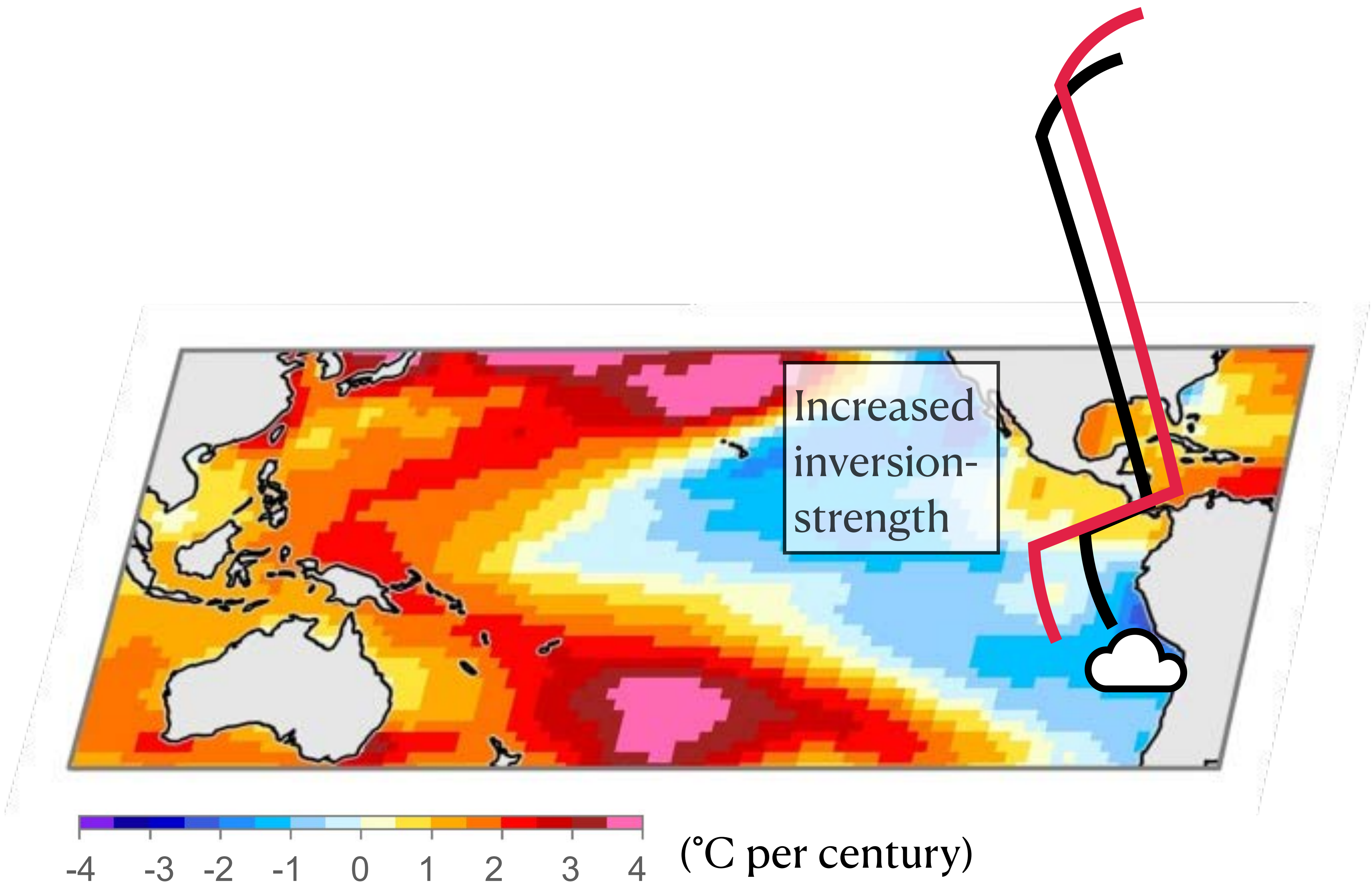

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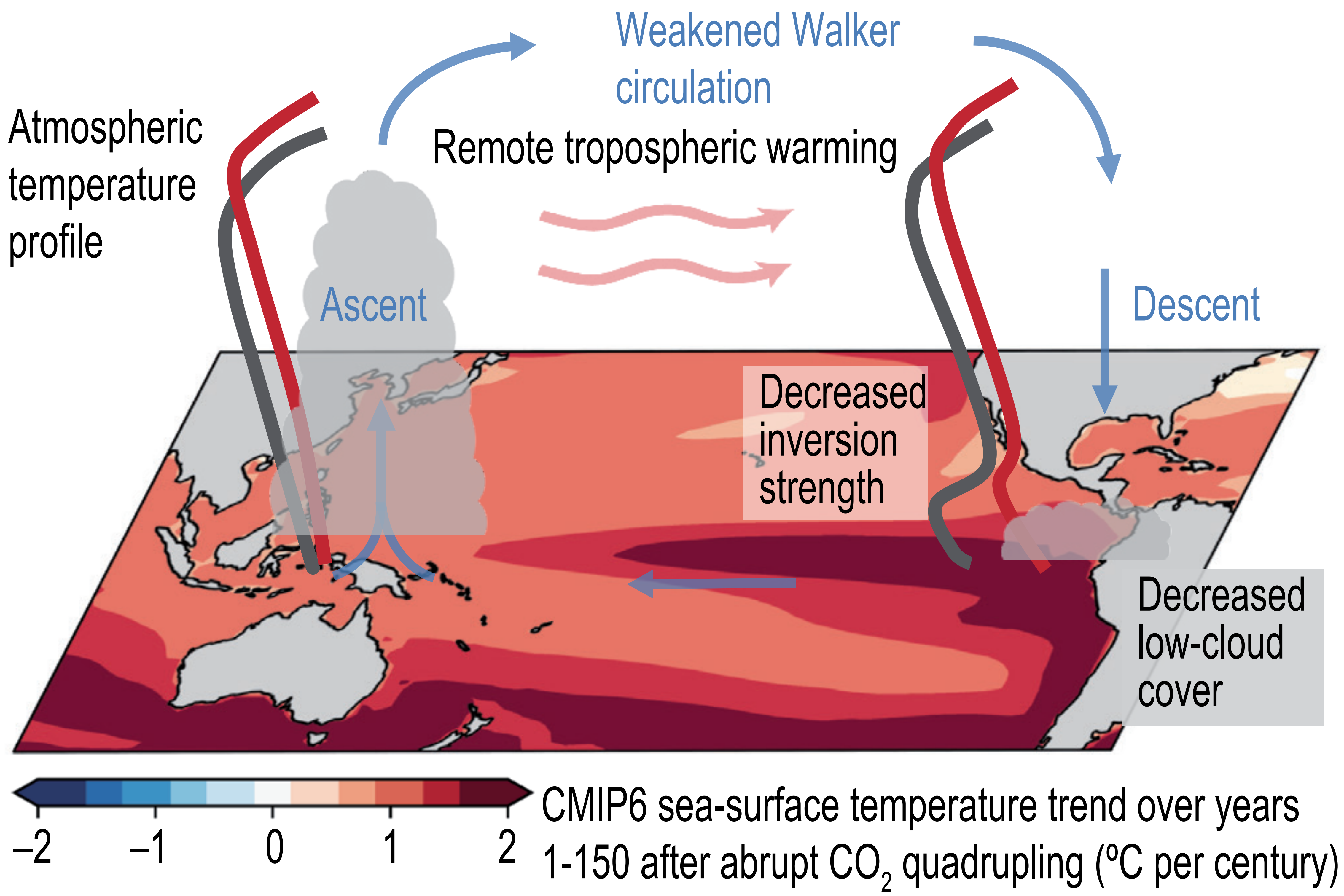

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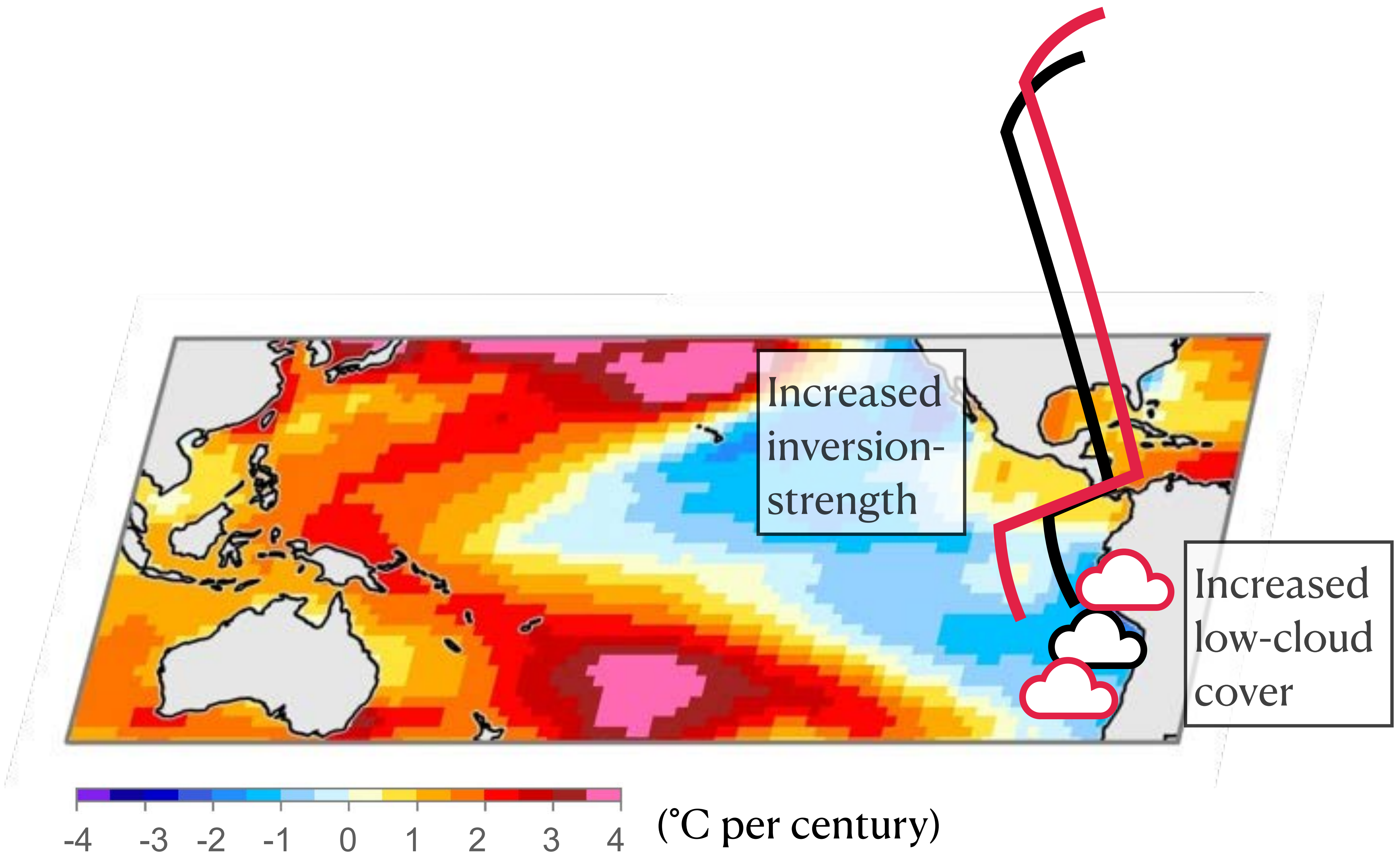

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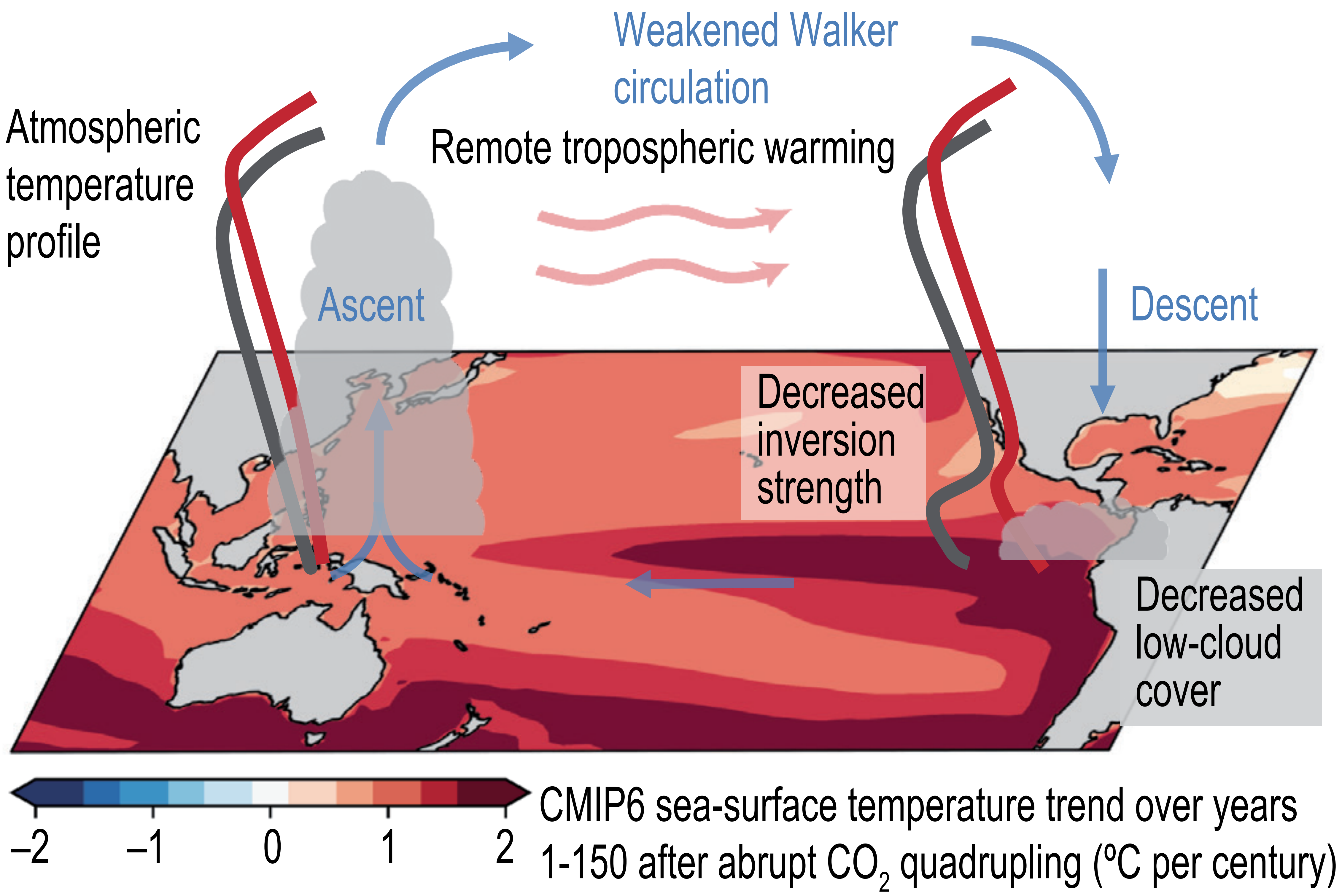

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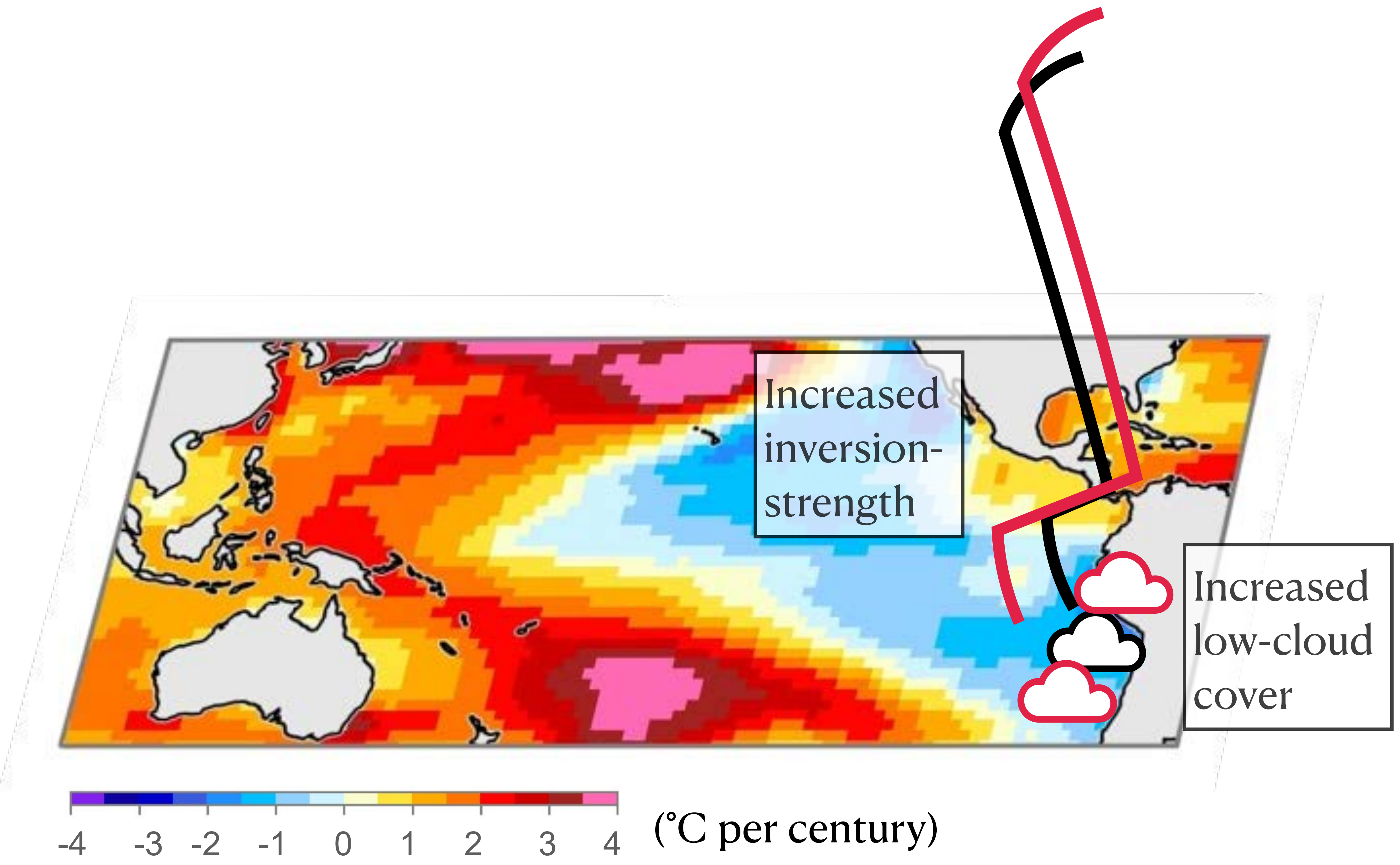
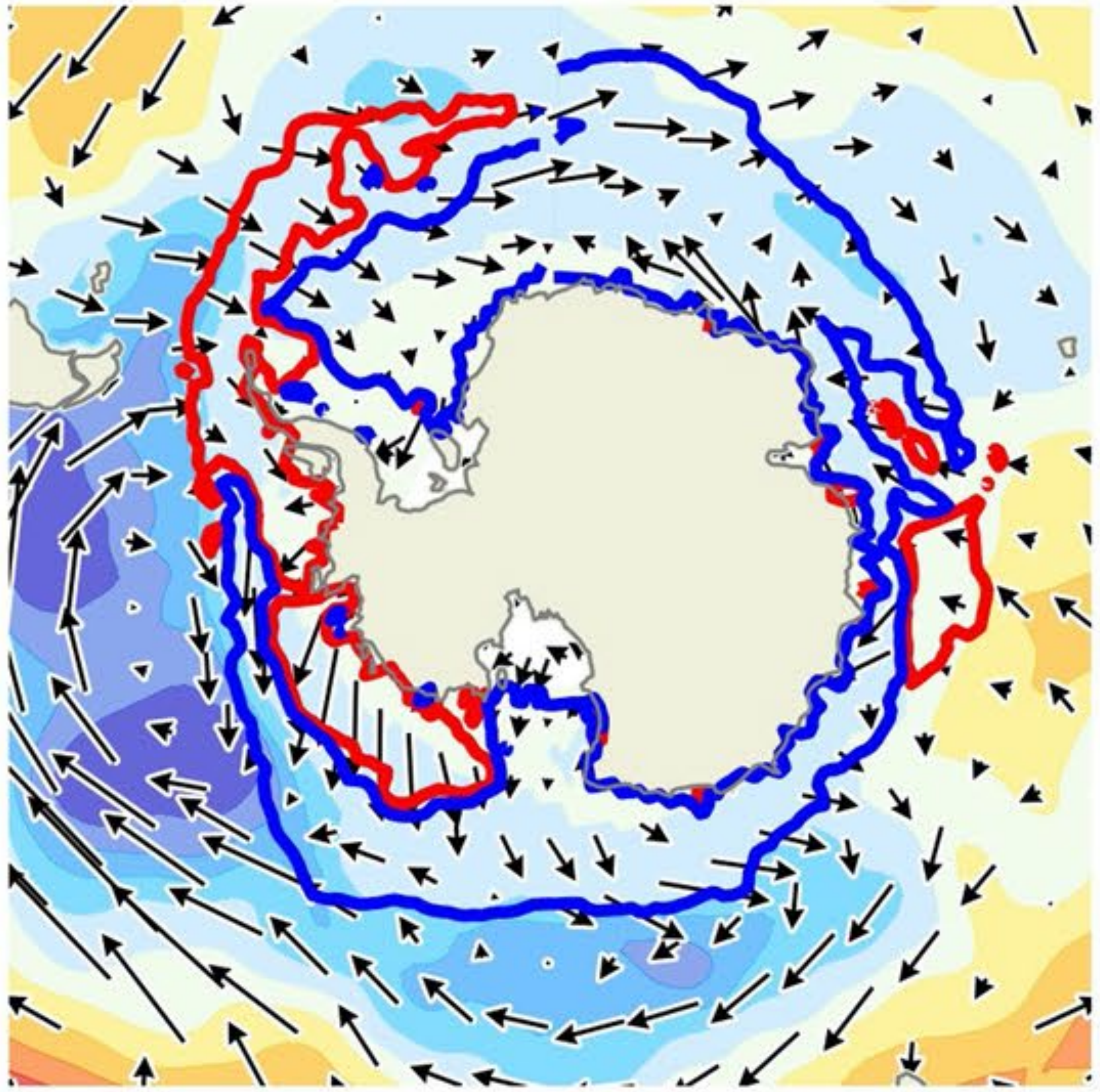


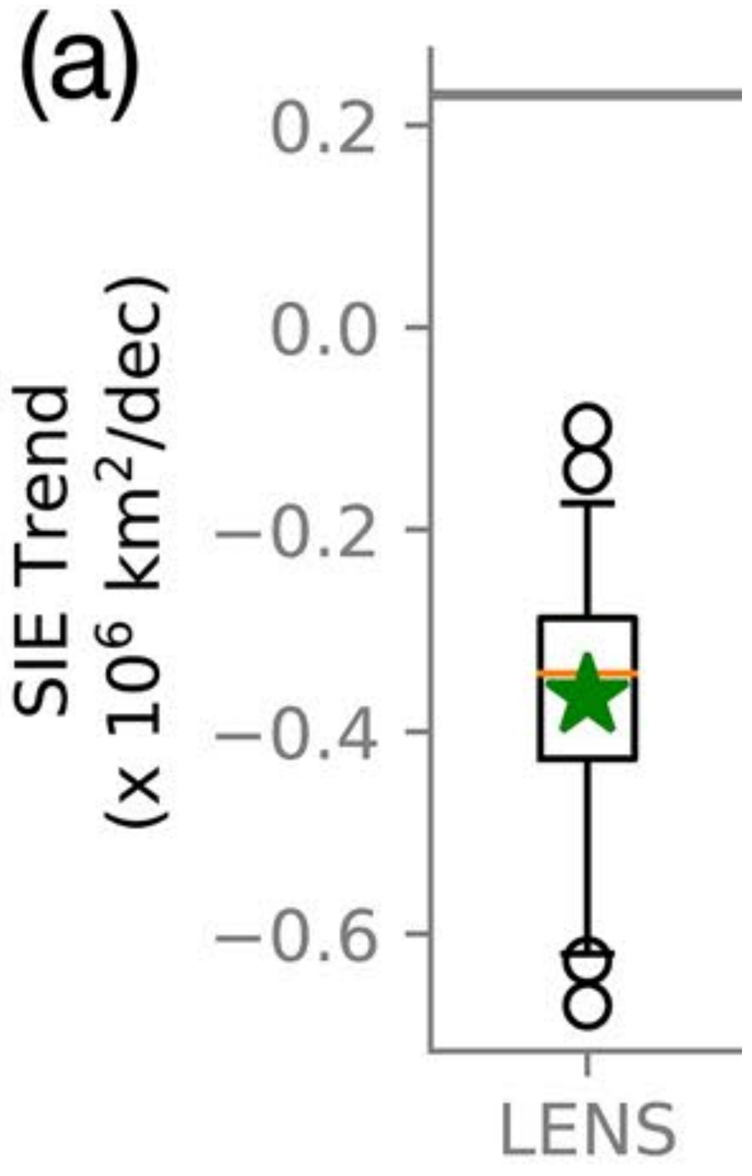
Negative Feedback

IPCC AR6 WG I; Zhou et al. (2016); Zhang et al. (2021)

SO surface cooling may explain model's inability to simulate observed Antarctic sea ice expansion

Observed SST (colors), wind (vectors), and sea ice (contours) trends





Observed sea ice extent trend is positive

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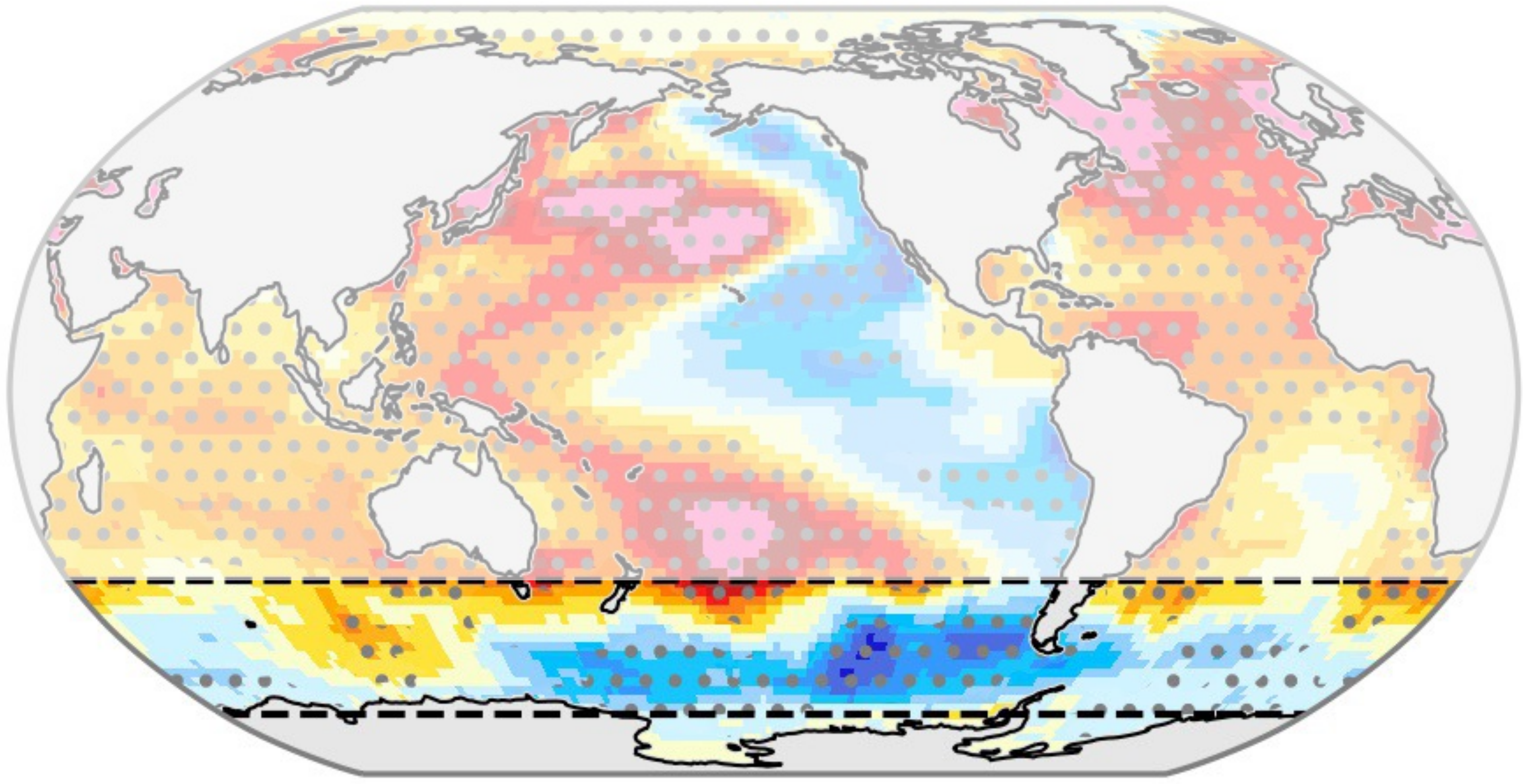
Zhang et al. (2021)

Using Southern Ocean pacemaker experiment (SOPACE) to study SO teleconnection

By including observed SO SST evolution in historical simulations

ERSSTv3b 1979-2013 trends



We nudge SST at each grid point in SO to **observed monthly anomaly** + **CESM1 mean state**.

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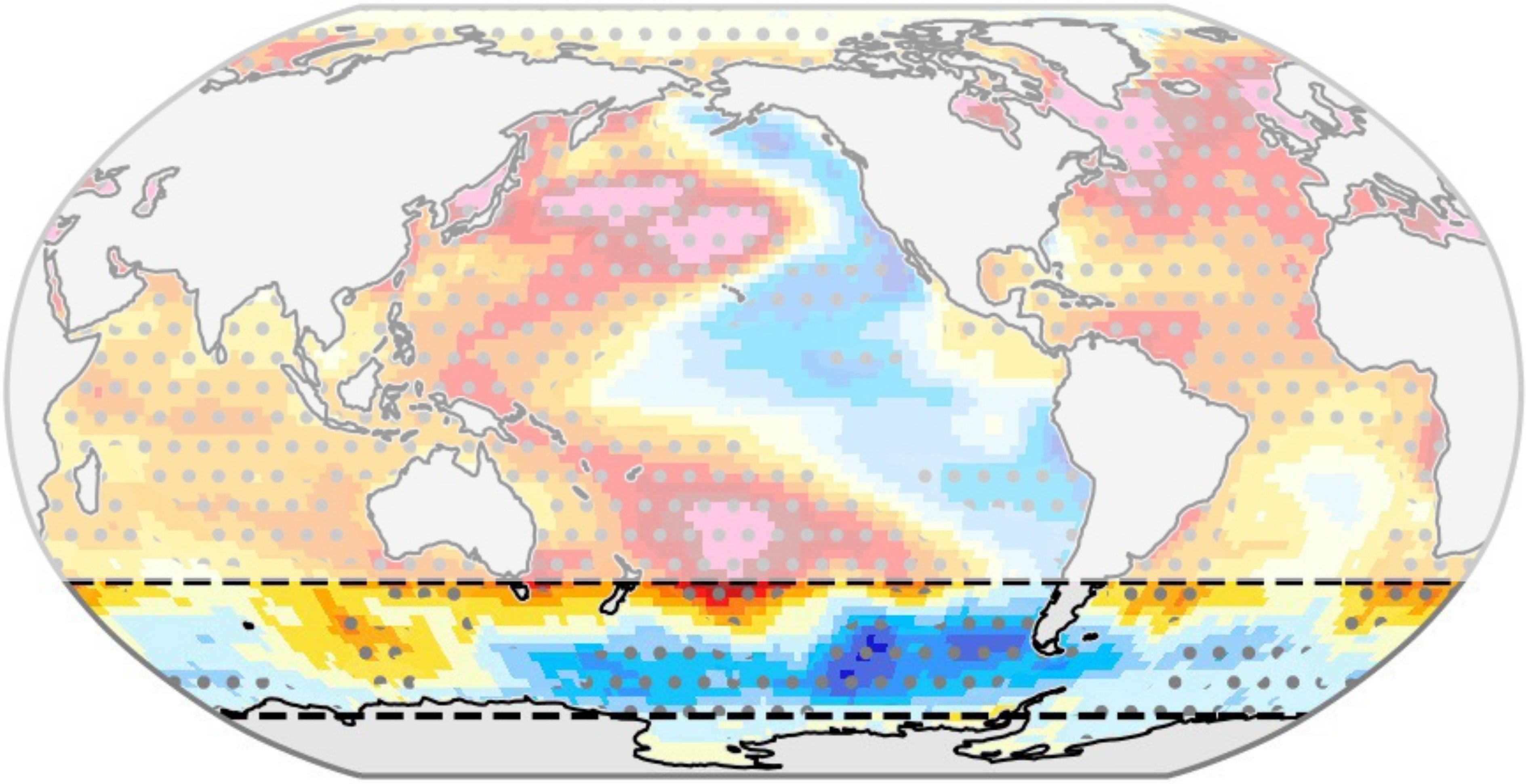
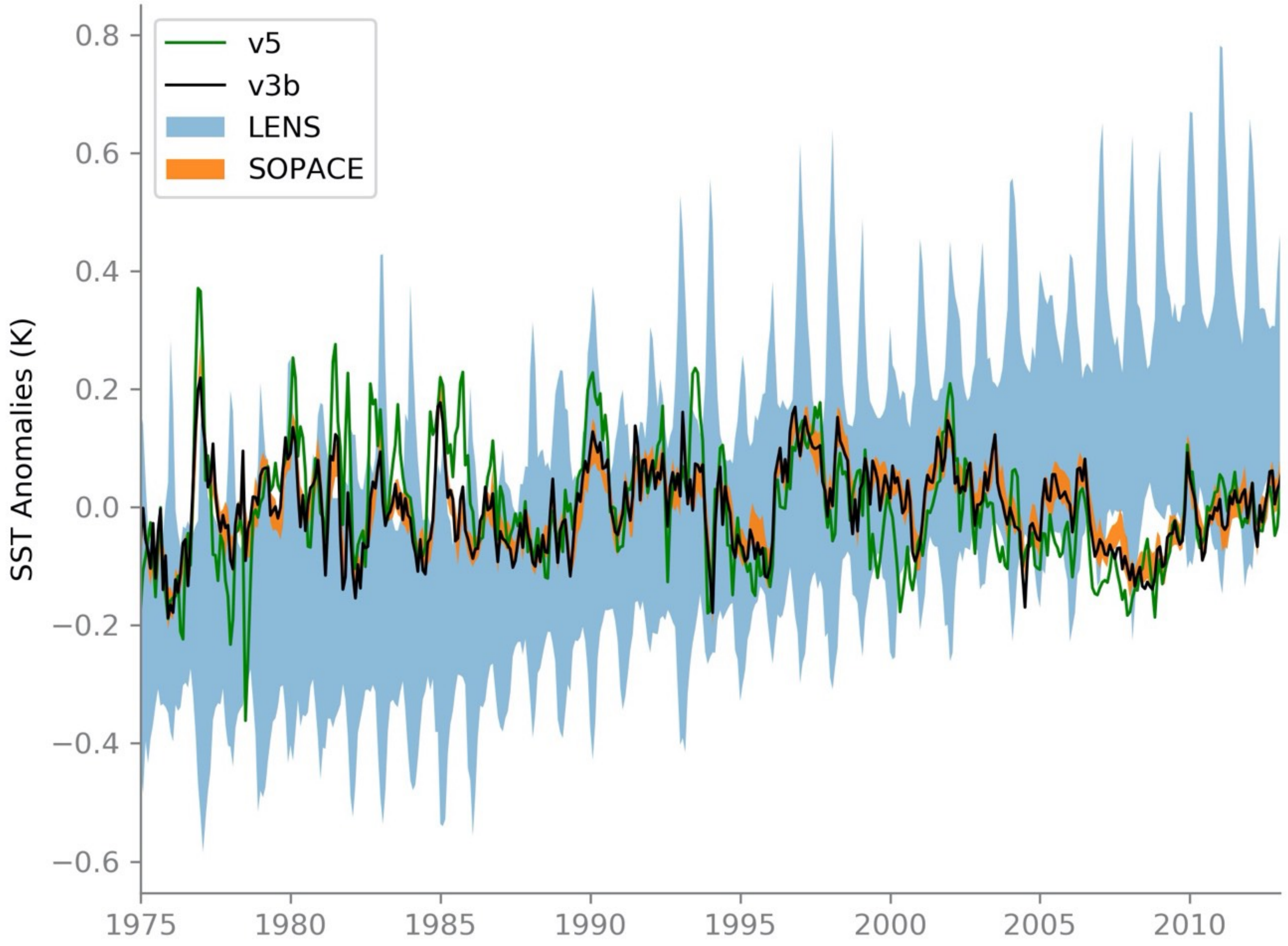


SO averaged SST anomalies



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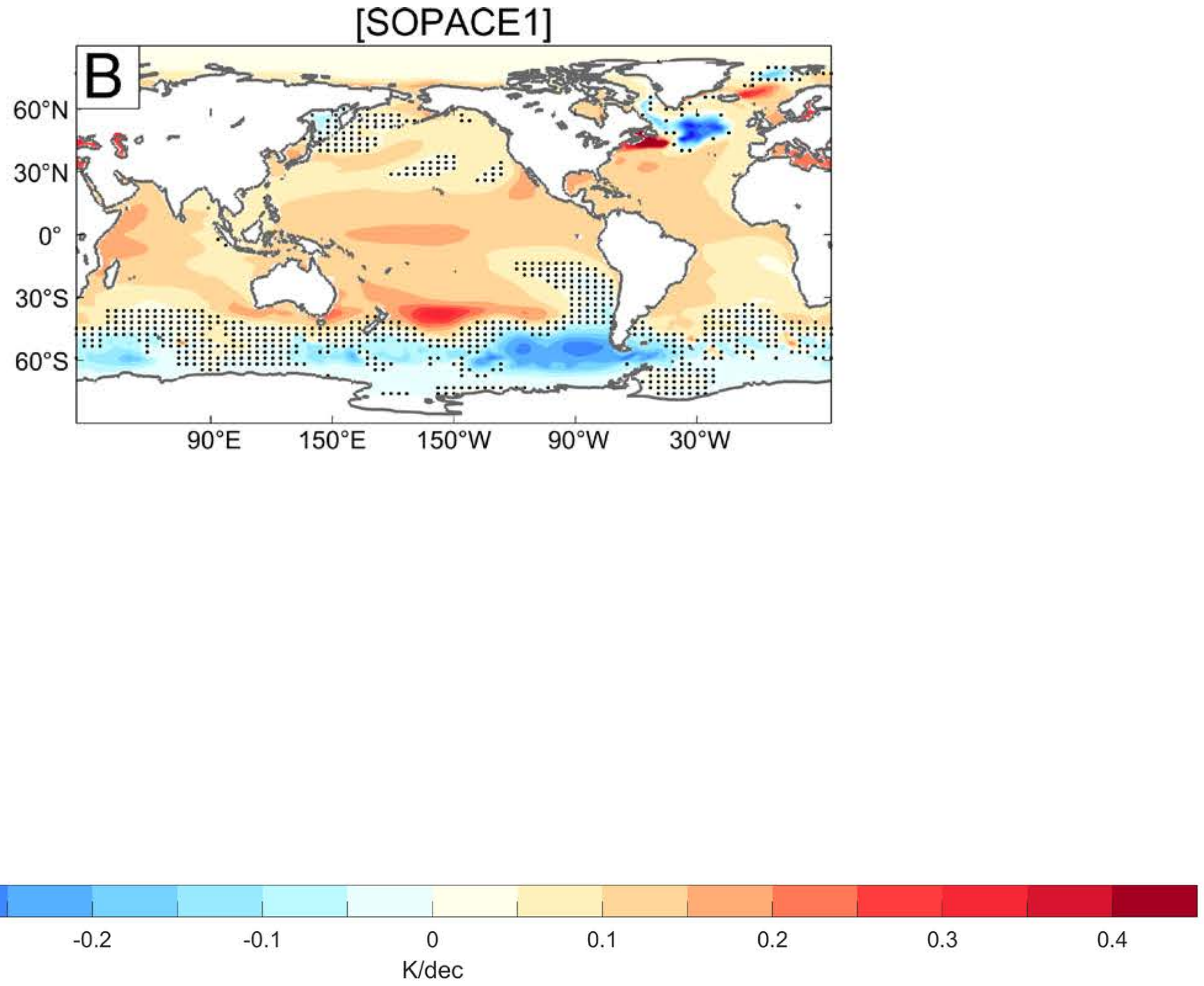
Global SST response to observed SO cooling

Results from CESM1



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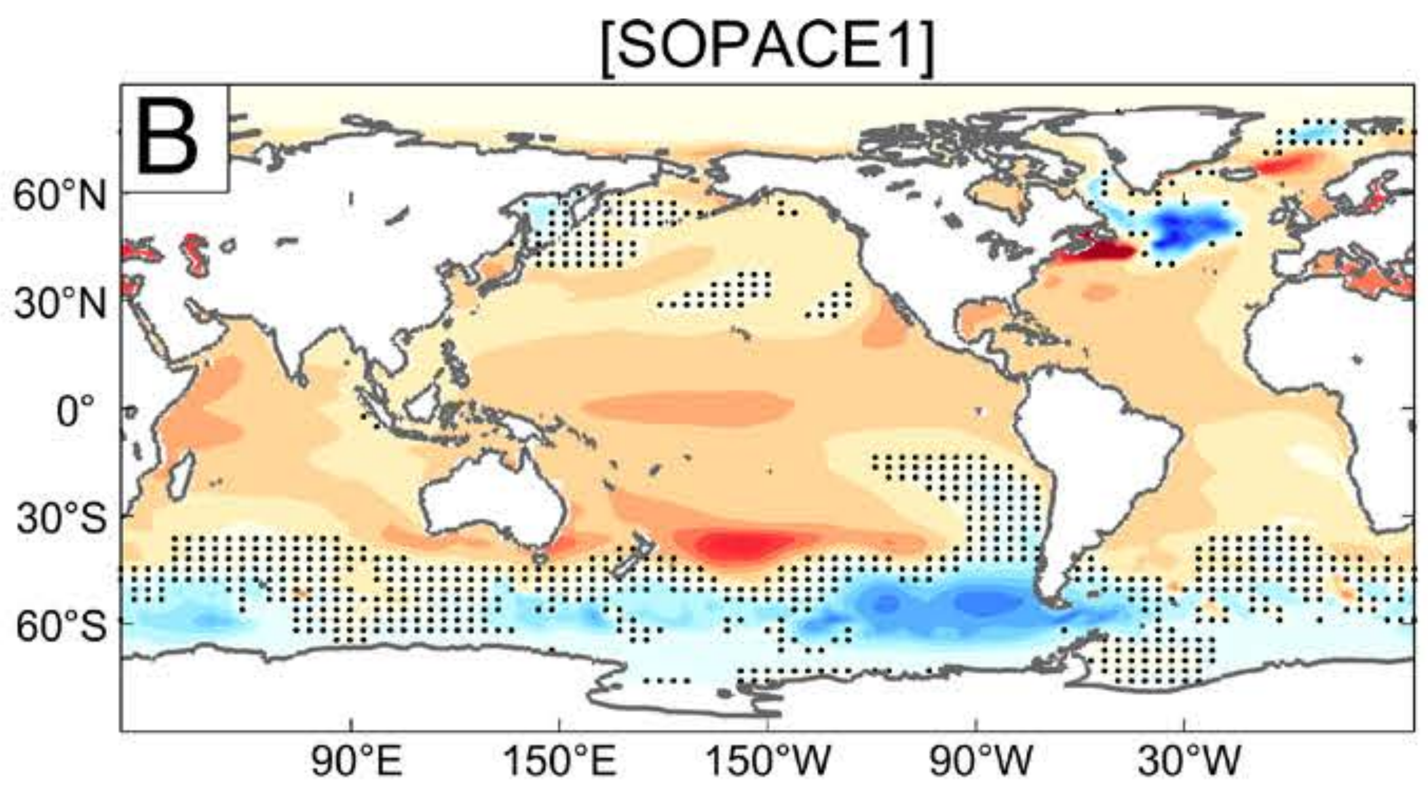
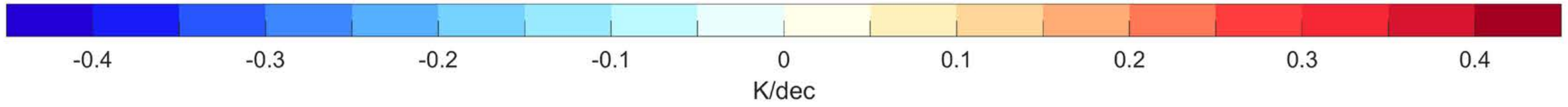


Radiatively-forced response + SO-driven response



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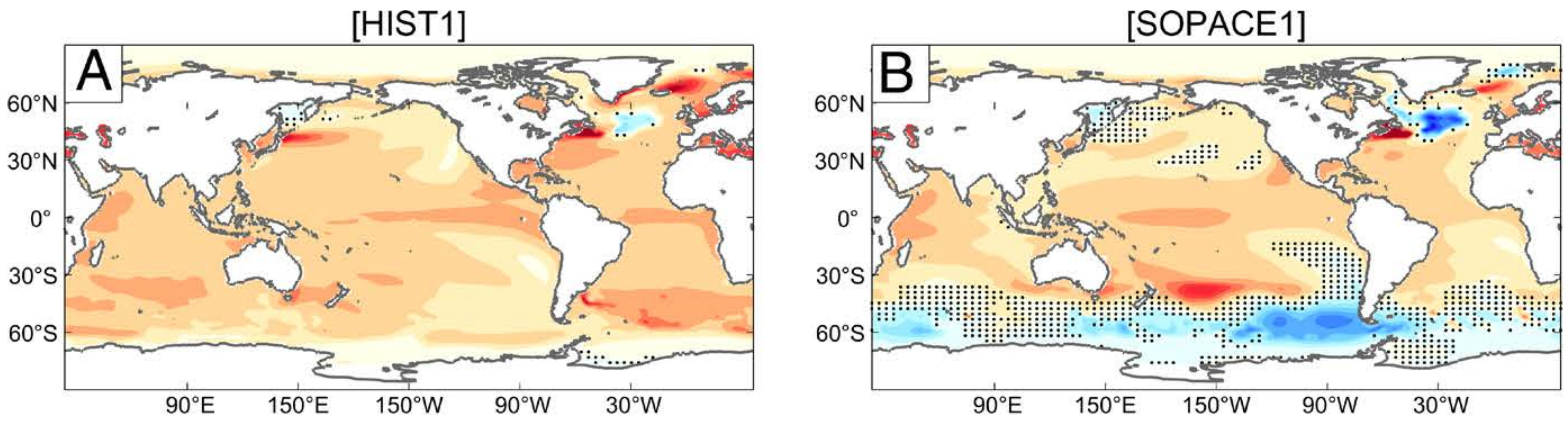

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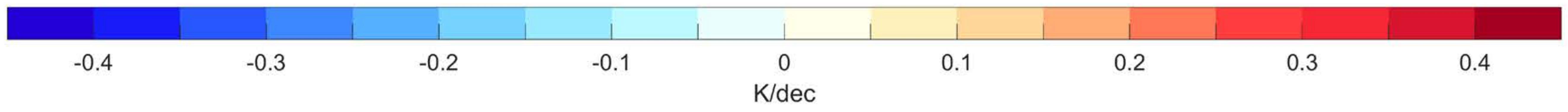

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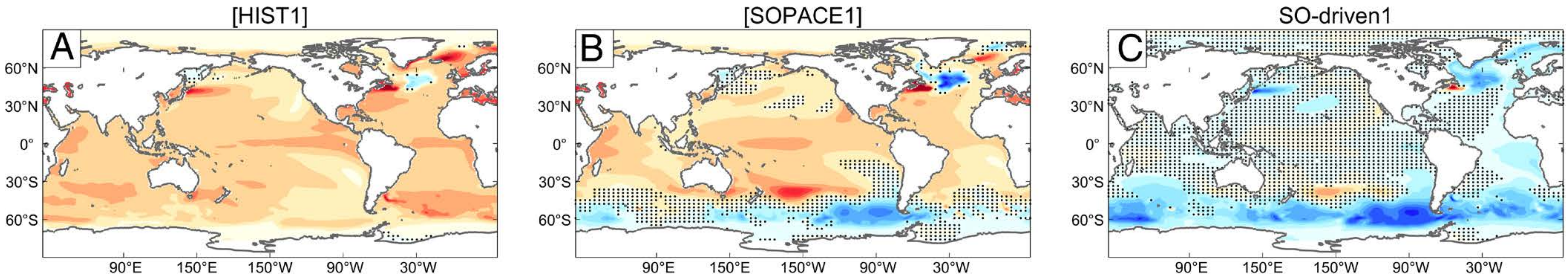

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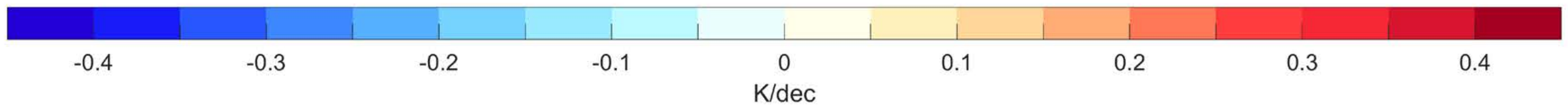
SO-driven response



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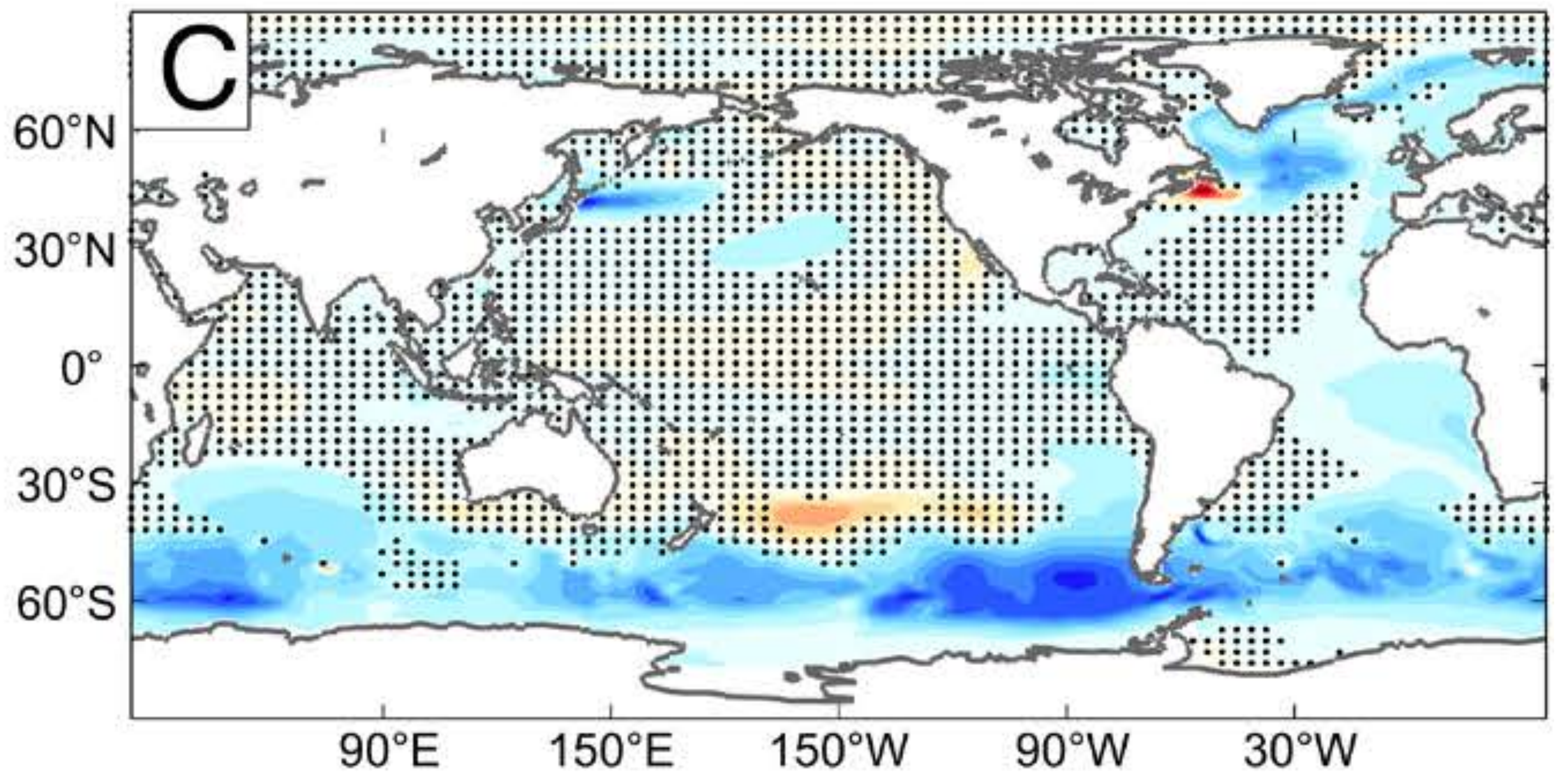
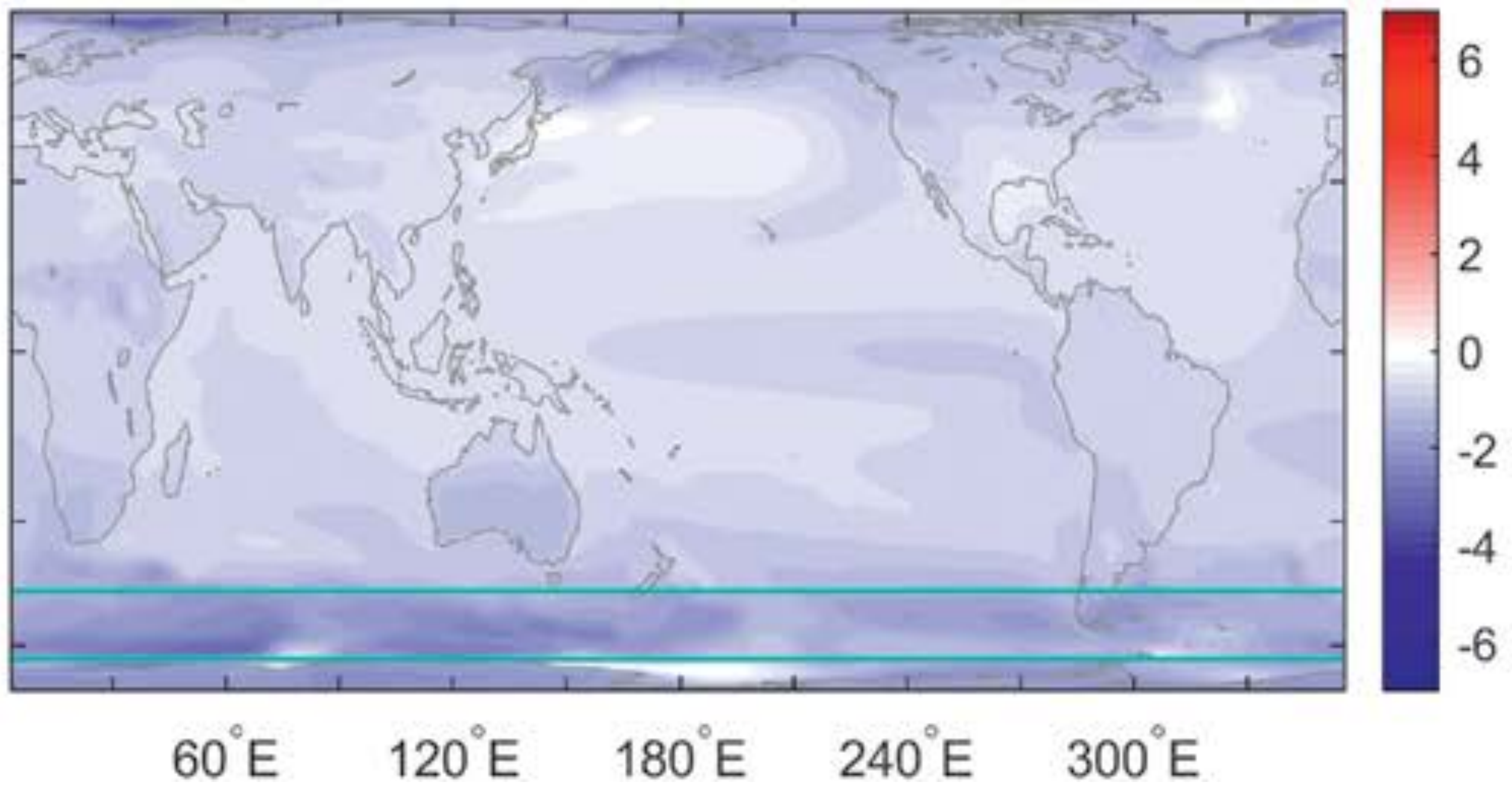
Why is the response so weak in the tropical Pacific?

Pacemaker experiment



VS

Idealized experiment



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CESM1 has a subtropical low cloud bias in the Pacific

Subtropical stratocumulus cloud feedback west of South America

CMIP version	Model name	Institution	CF_{wSA}
CMIP6	CESM2-WACCM	NCAR, USA	11.95
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CMIP6	CESM2-FV2	NCAR, USA	9.31
CMIP6	NorESM2-MM	NCC, Norway	8.49
CMIP6	CESM2-WACCM-FV2	NCAR, USA	8.15
ISCCP-FH & OISST 2 (observational data)			7.51
CERES-EBAF 4.1 & OISST 2 (observational data)			7.30
CMIP5	IPSL-CM5B-LR	IPSL, France	7.11
CMIP6	NorESM2-LM	NCC, Norway	6.84
CMIP6	KIOST-ESM	KIOST, South Korea	6.82
CMIP5	ACCESS1-0	CSIRO and BOM, Australia	6.32
CMIP5	MIROC-ESM	AORI, NIES, and JAMSTEC, Japan	6.10
CMIP5	CSIRO-Mk3-6-0	CSIRO and BOM, Australia	6.09
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CMIP6	GFDL-CM4	GFDL, USA	5.92
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CMIP5	CESM1-FASTCHEM	NCAR, USA	3.57
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CMIP6	EC-Earth3-Veg	EC-Earth consortium	3.19
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- CESM1's stratocumulus cloud feedback is too weak
- CESM2 has much stronger stratocumulus cloud feedback
- Will SOPACE with CESM2 show a stronger tropical Pacific response?

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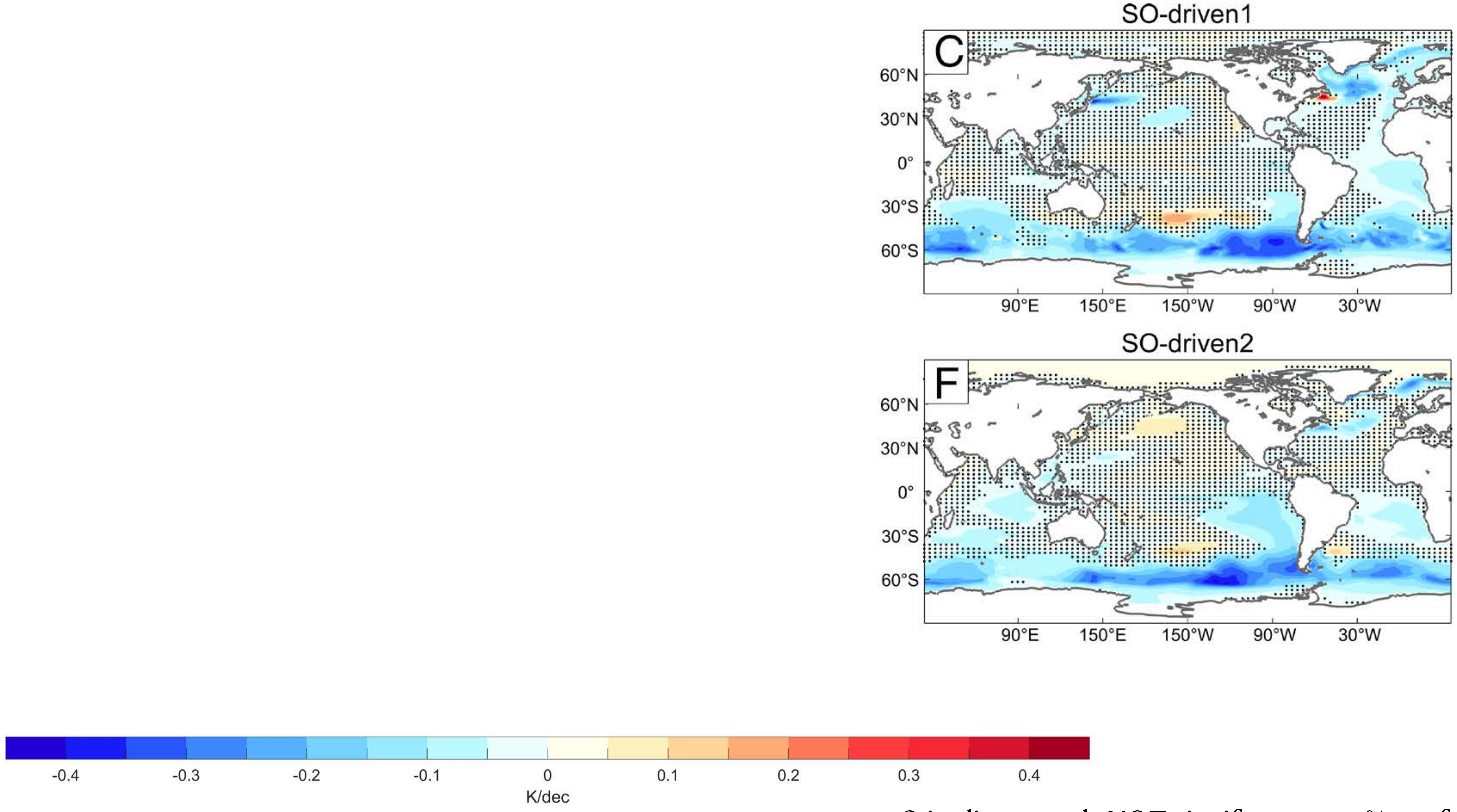
Kim et al. (2022)

Global SST response to observed SO cooling

CESM1 vs CESM2



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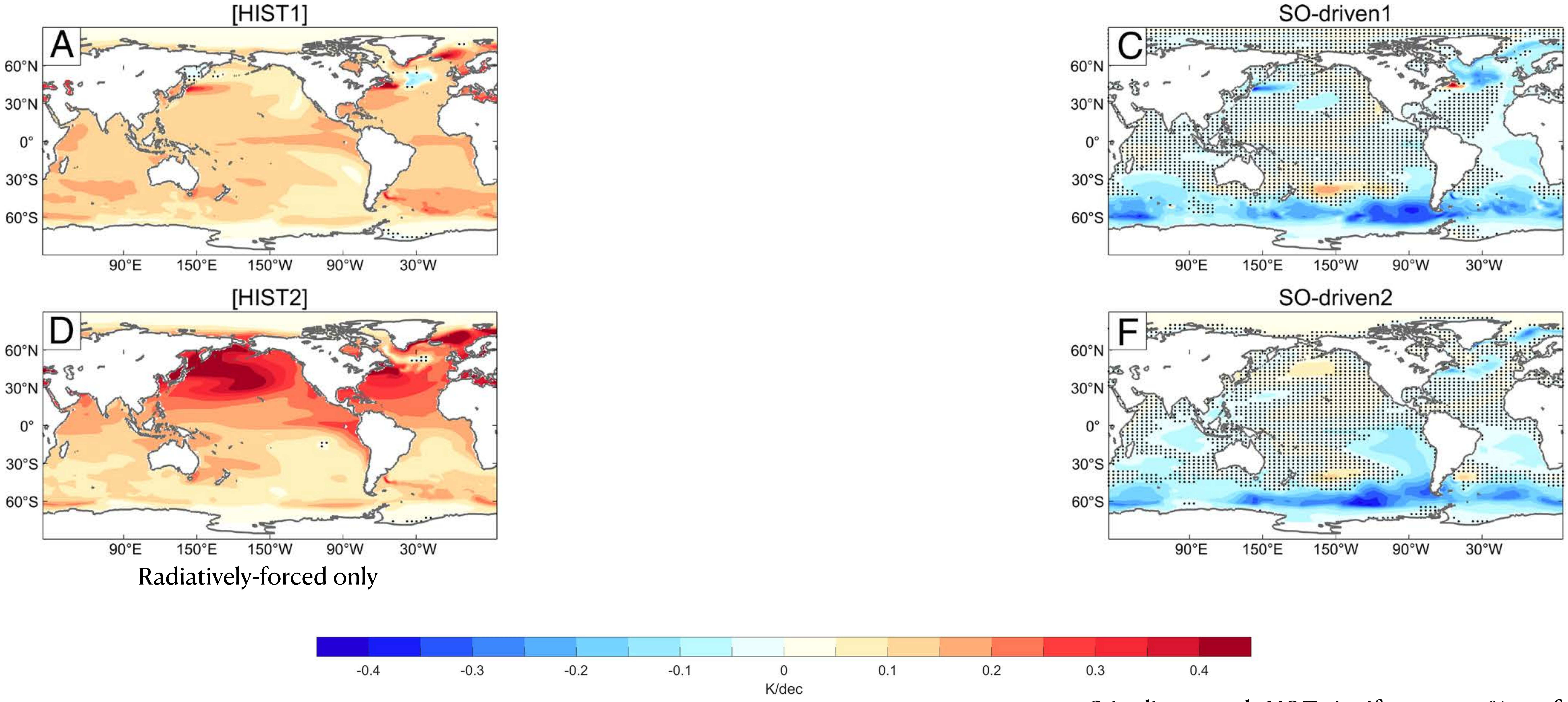

Radiatively-forced only

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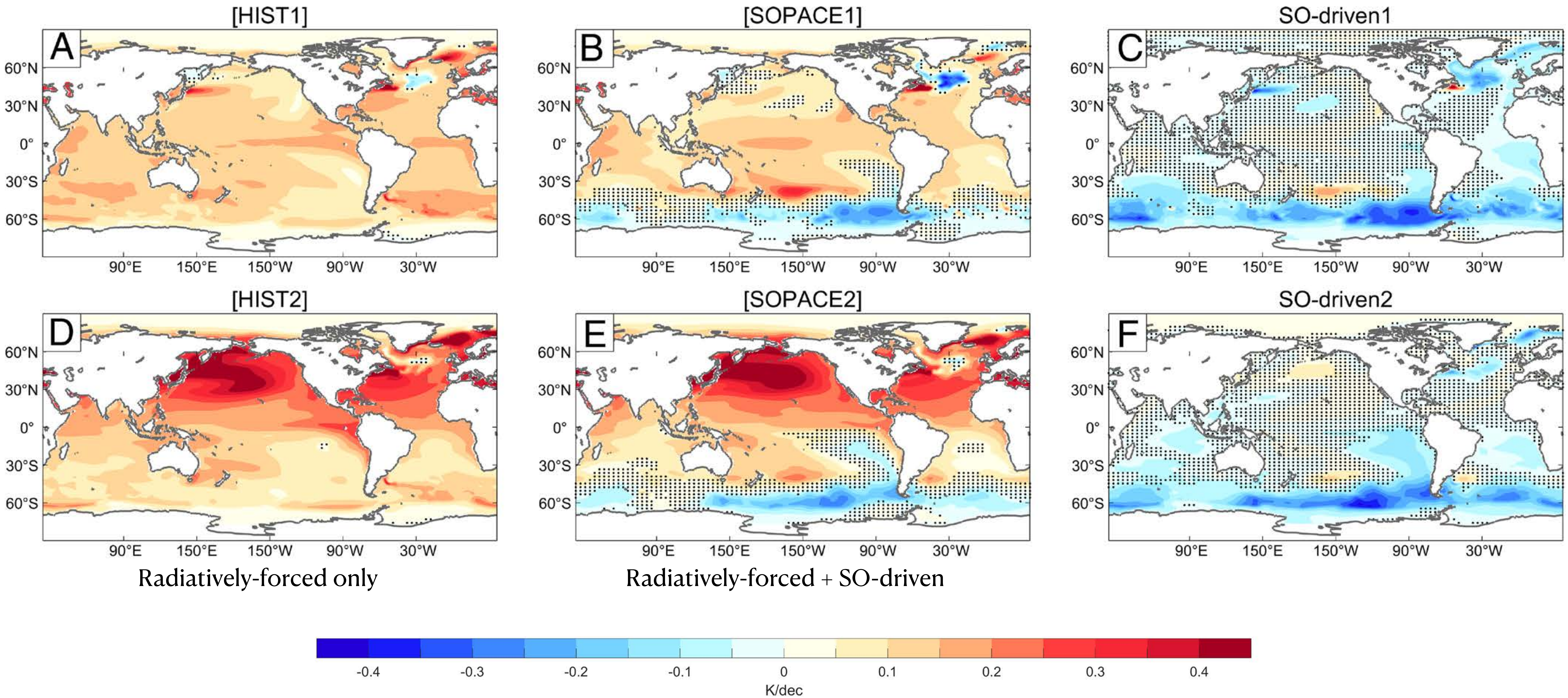

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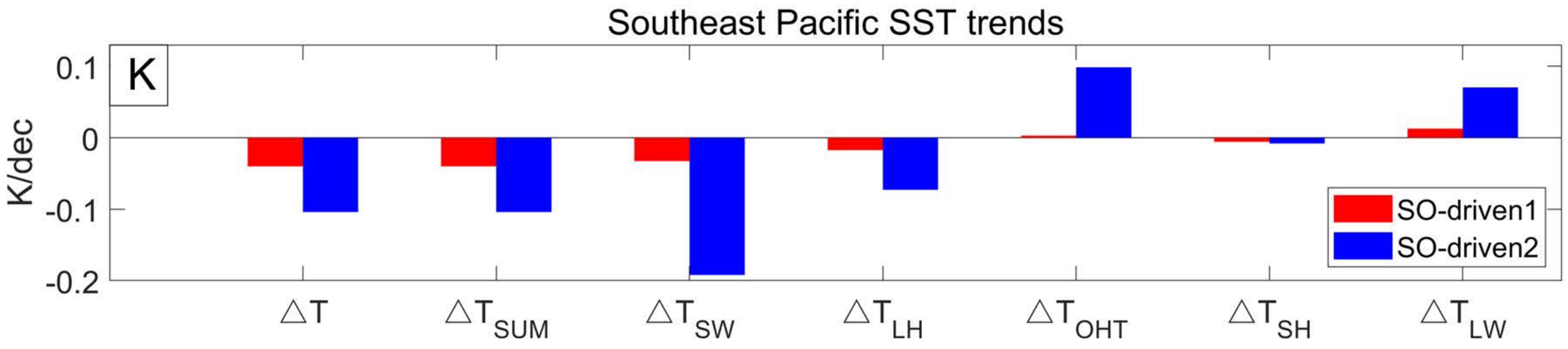
Decomposition of SST trends via surface energy budget

$$\rho c_p H \frac{\partial T}{\partial t} = \mathrm{SW} + \mathrm{LW} - \mathrm{LH} - \mathrm{SH} + \mathrm{OHT}$$



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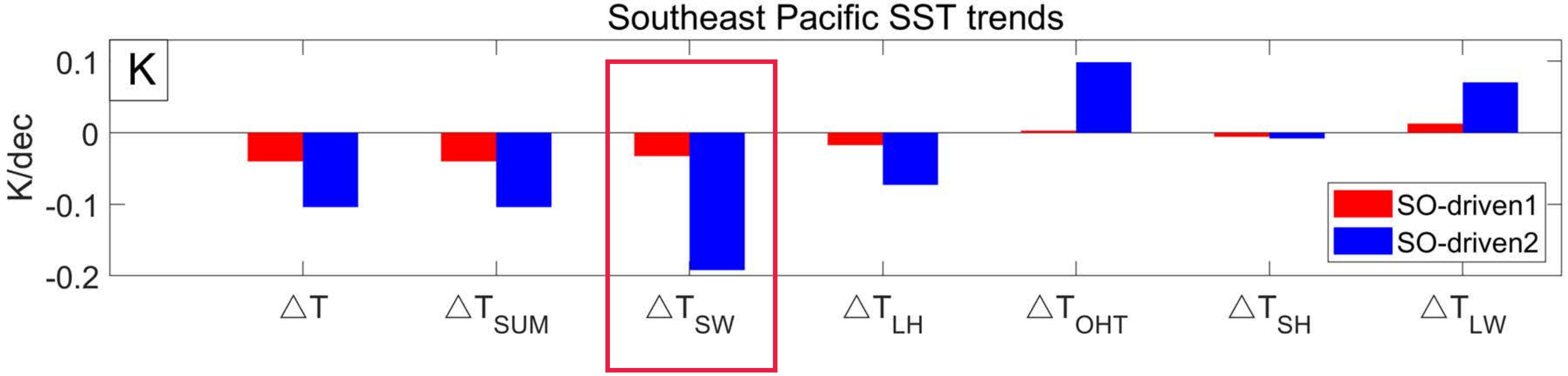

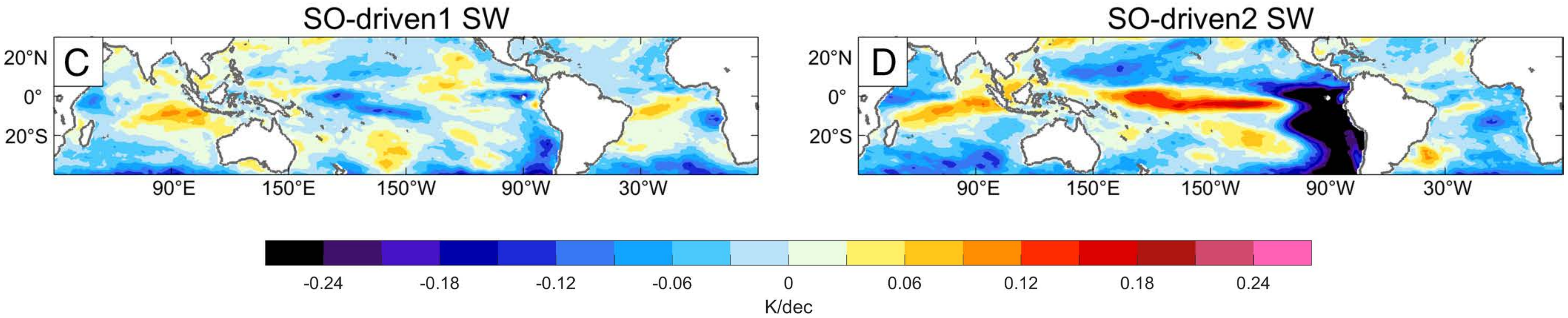

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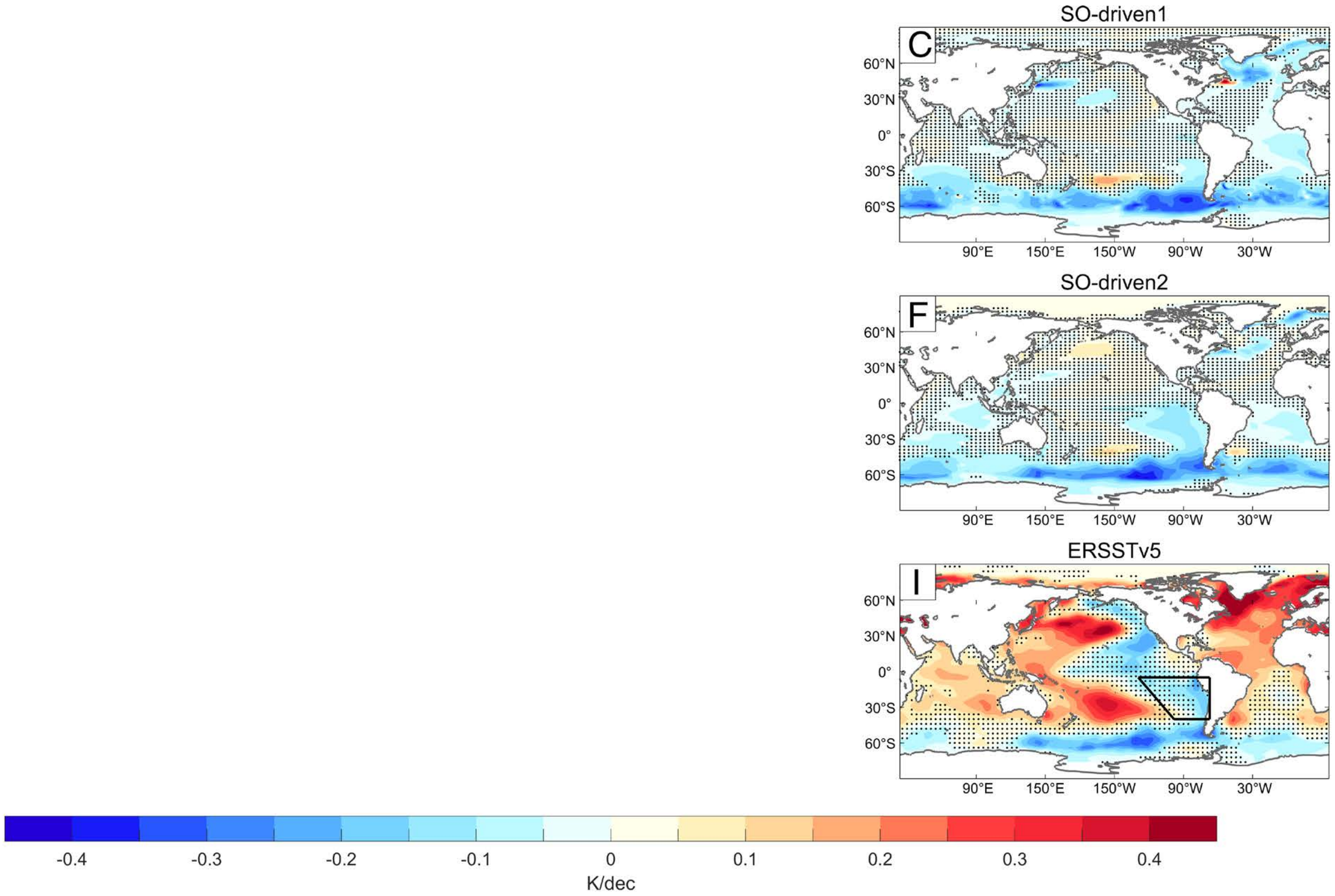
Kang et al. (2023)

Comparison with observations: Differences in radiatively-forced response



Stippling: trends NOT significant at 95% confidence level
Zhang et al. (2021); Kang et al. (2023)

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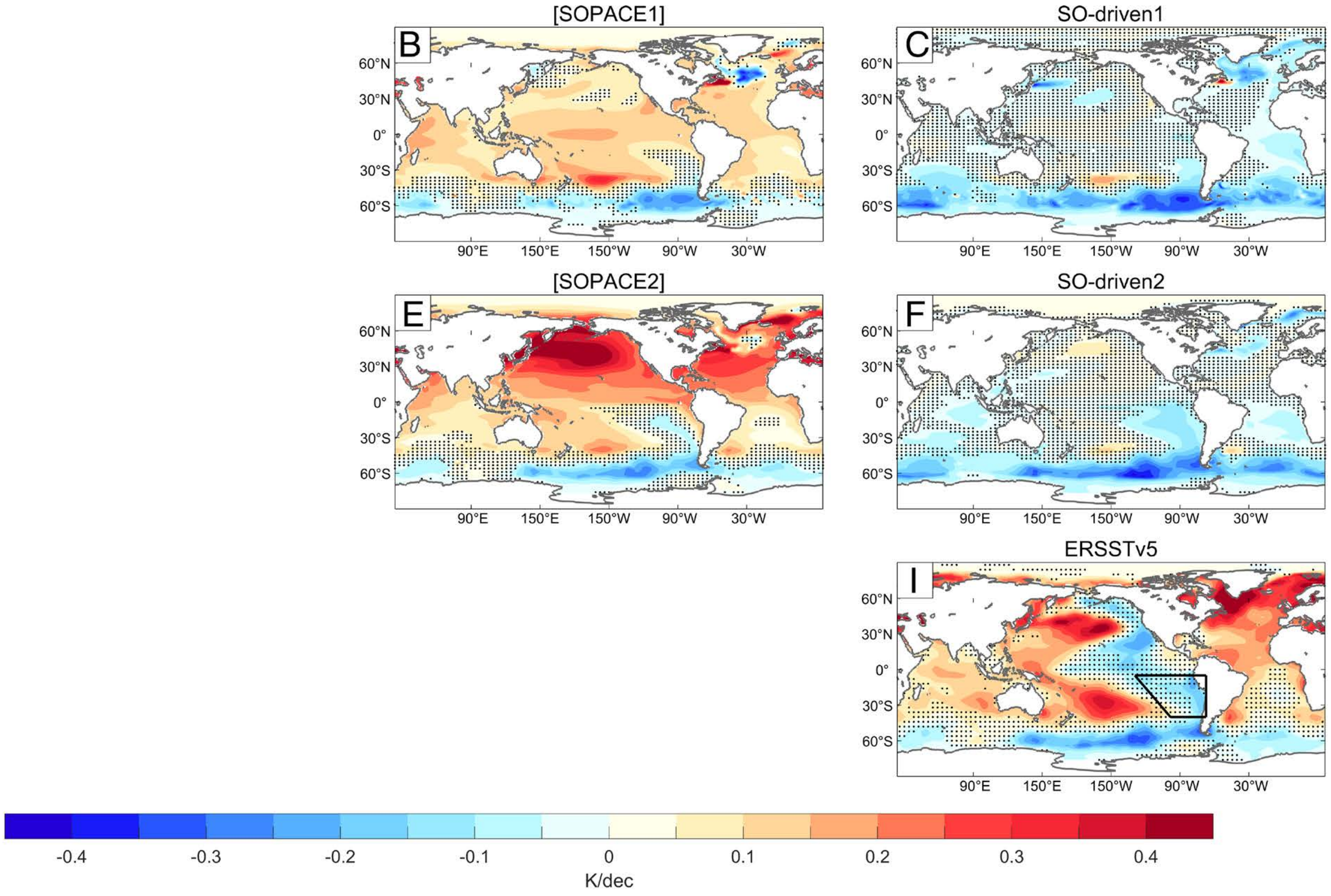

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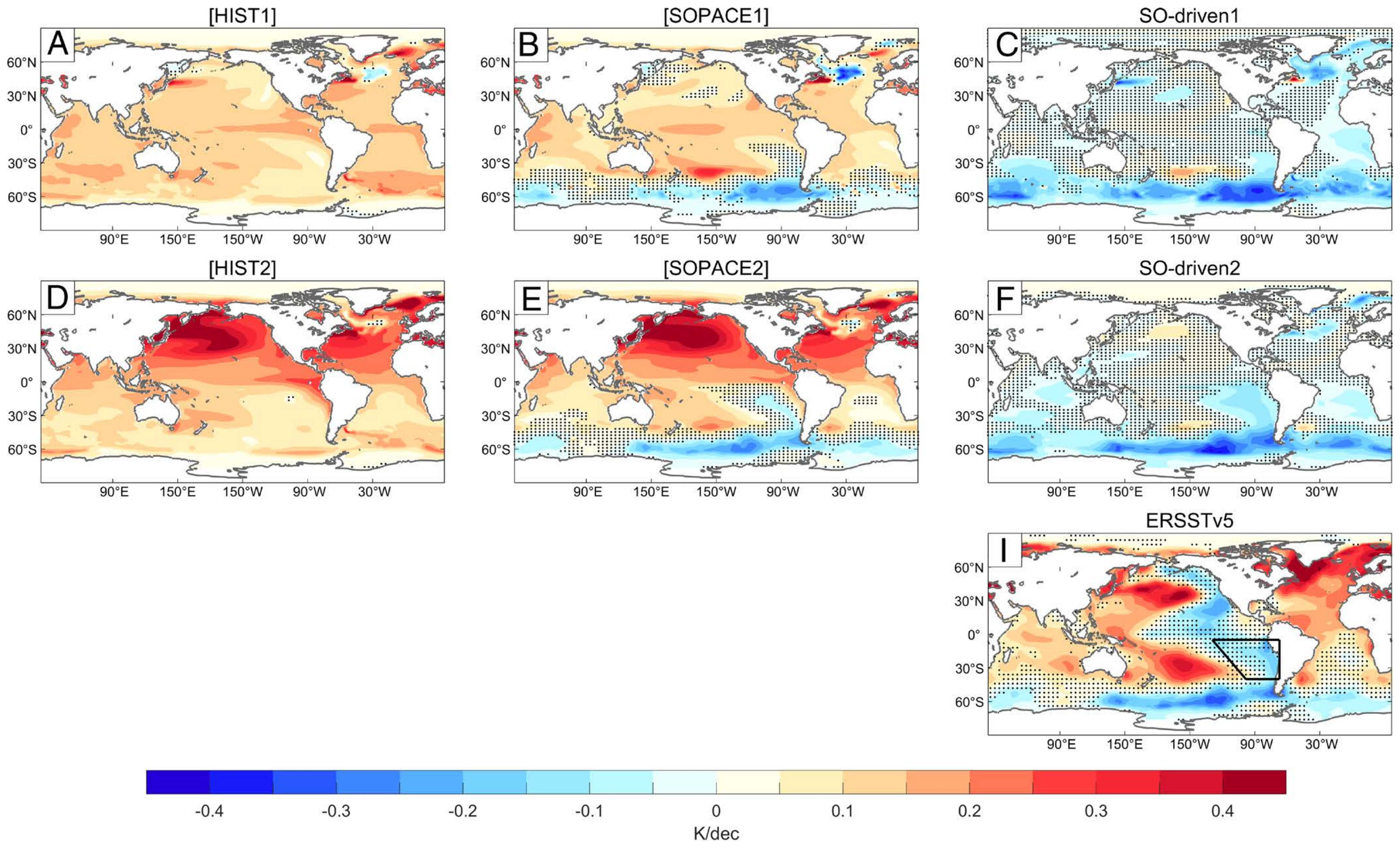

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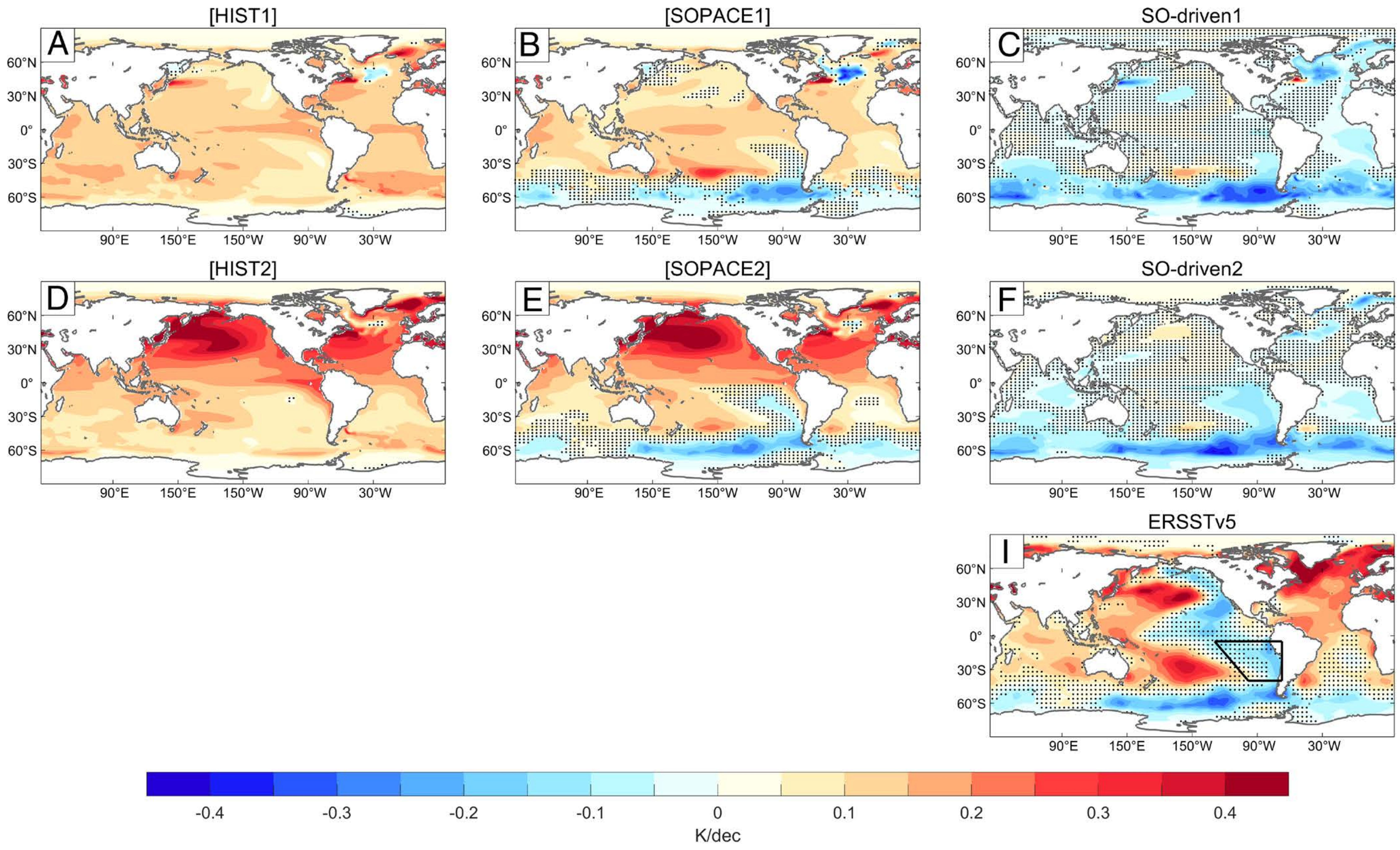
Comparison with observations: Differences in radiatively-forced response

CESM1 + CMIP5 forcing

CESM2 + CMIP6 forcing

CESM2 + CMIP5 forcing



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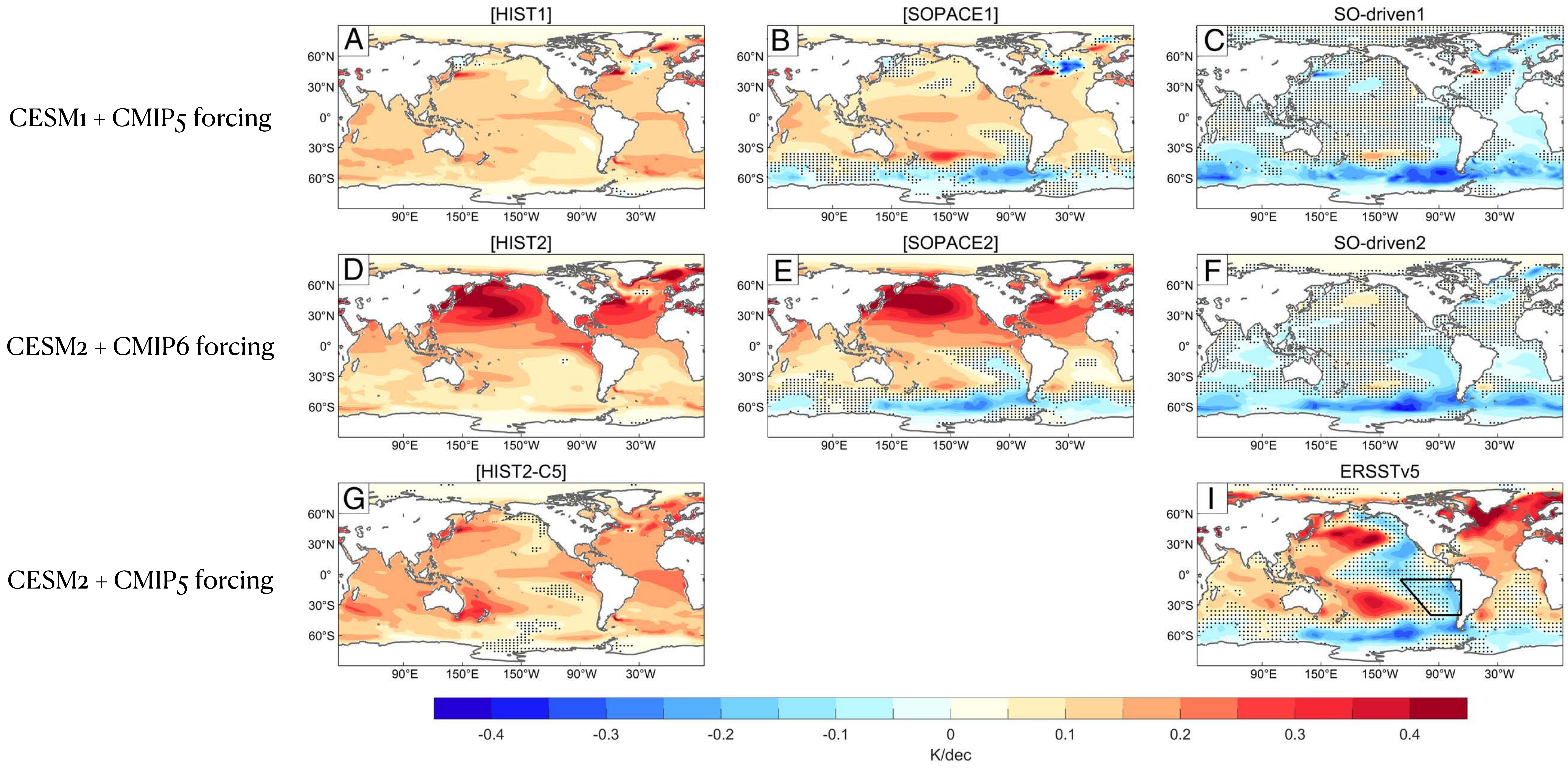

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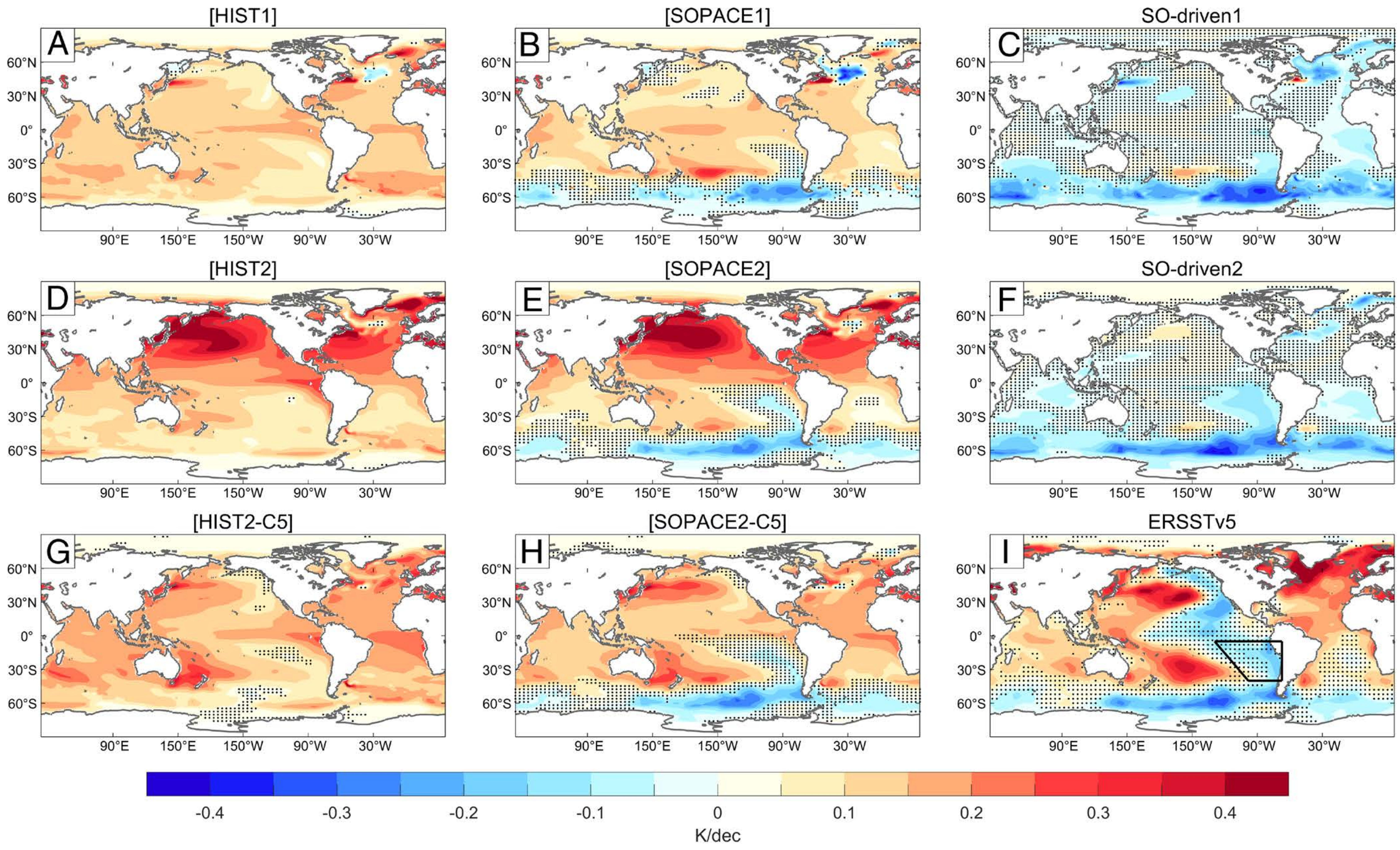

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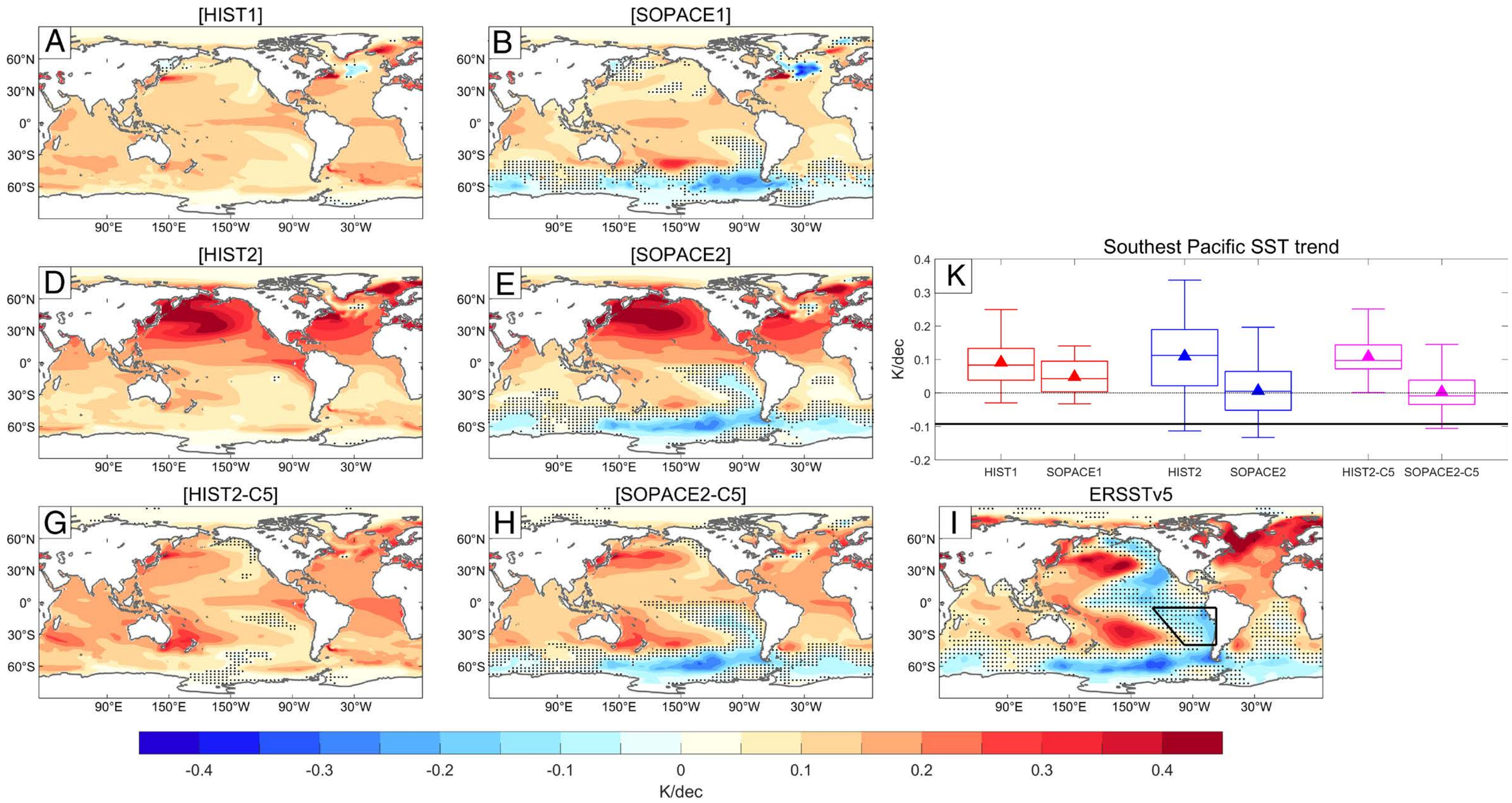

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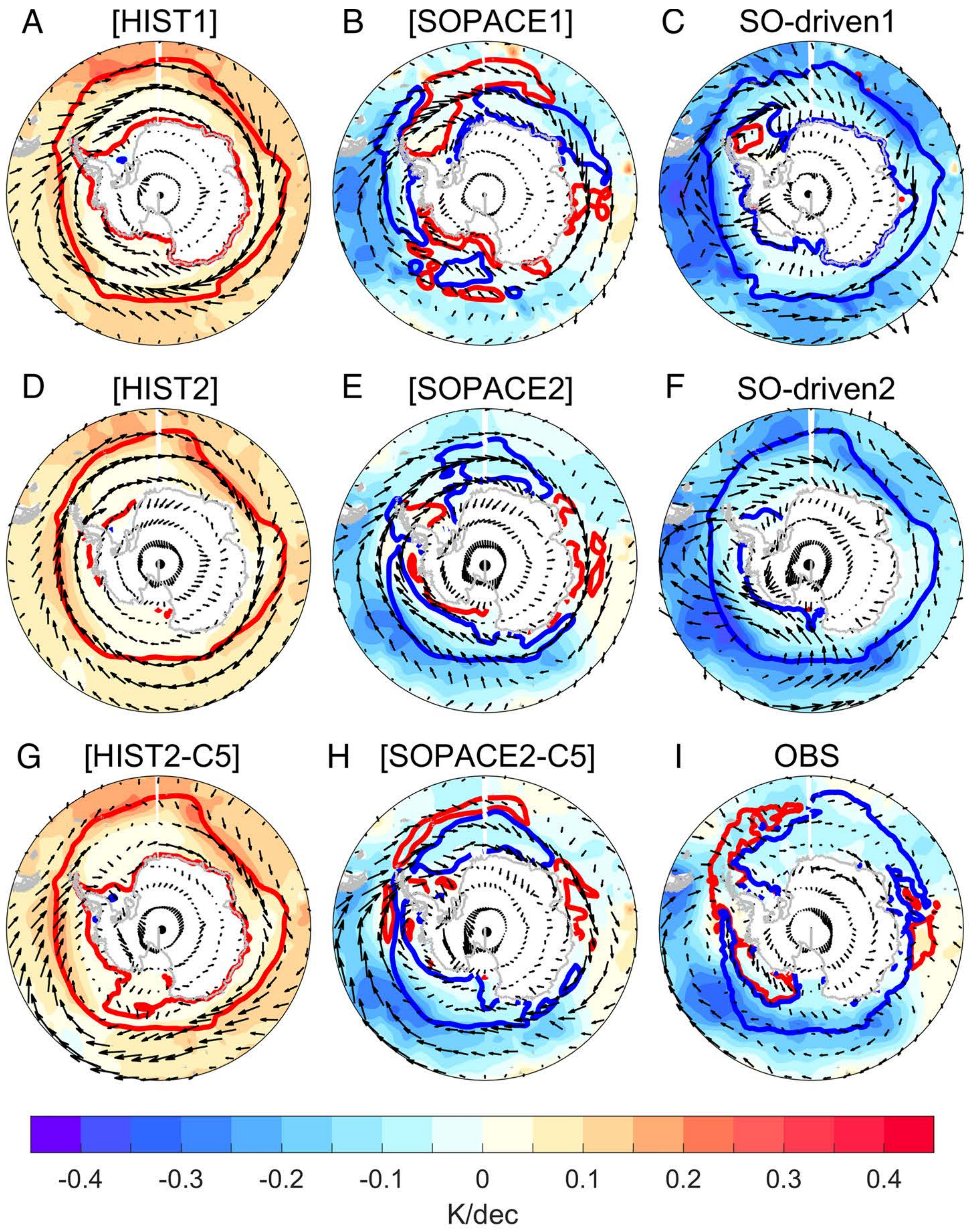
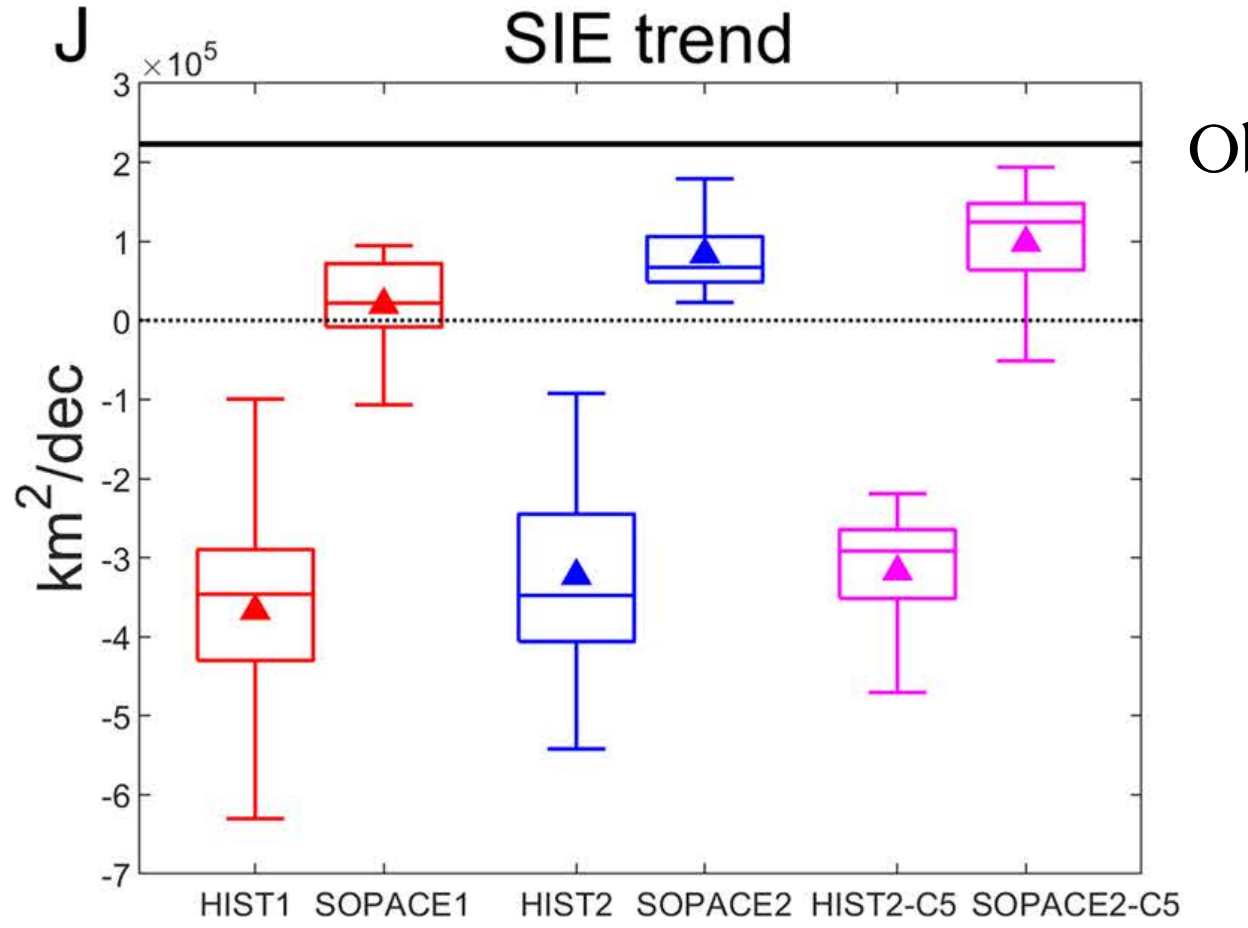
Observed Antarctic sea ice trends are also better represented in SOPACE2





Observation

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Kang et al. (2023)

Summary

- The global response of observed SO surface cooling includes cooling of the southeastern tropical Pacific and Atlantic, as well as Antarctic sea ice expansion
- Observed SO surface cooling from 1979 to 2013 is partly responsible for driving cooling of the southeastern tropical Pacific SST
- The SO-tropical teleconnection is highly sensitive to the strength of the subtropical low cloud feedback
- There are implications for future warming patterns as the SO transitions from cooling to warming under increasing greenhouse gases

Geophysical Research Letters

RESEARCH LETTER
10.1029/2020GL091235

Is There a Tropical Response to Recent Observed Southern Ocean Cooling?

Xiyue Zhang[1,2], Clara Deser[1], and Lantao Sun[3]

Key Points:

- The global impact of recent

PNAS RESEARCH ARTICLE | EARTH, ATMOSPHERIC, AND PLANETARY SCIENCES OPEN ACCESS

Global impacts of recent Southern Ocean cooling

Sarah M. Kang[a,b,1], Yue Yu[c], Clara Deser[d,1], Xiyue Zhang[e], In-Sik Kang[c], Sun-Seon Lee[f,g], Keith B. Rodgers[f,g], and Paulo Ceppi[h]

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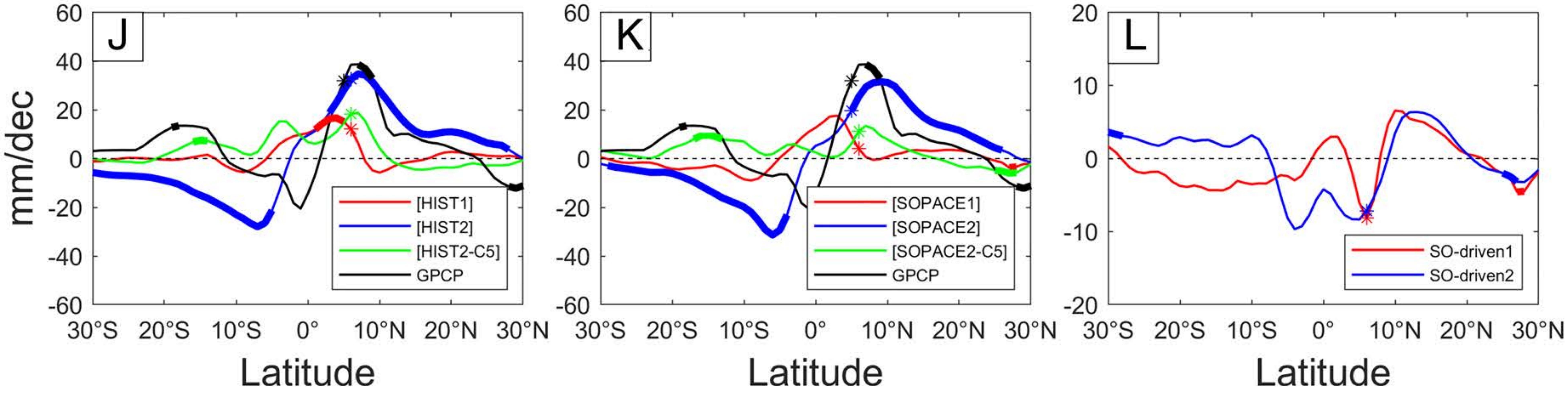
Challenges and open questions

- Uncertainties in historical radiative forcing hinder our understanding of the SO-tropical teleconnection (especially in the northern extratropics)
- Can we quantify the causes of SO SST multi-decadal variability (e.g., internal variability, CO_2 or ozone, ice melt…)?
- What other model/resolution-dependent feedbacks can influence the SO-driven teleconnection?

Questions and feedbacks? 📧 sallyz@jhu.edu

Extra Slides

SO cooling's impact on tropical precipitation



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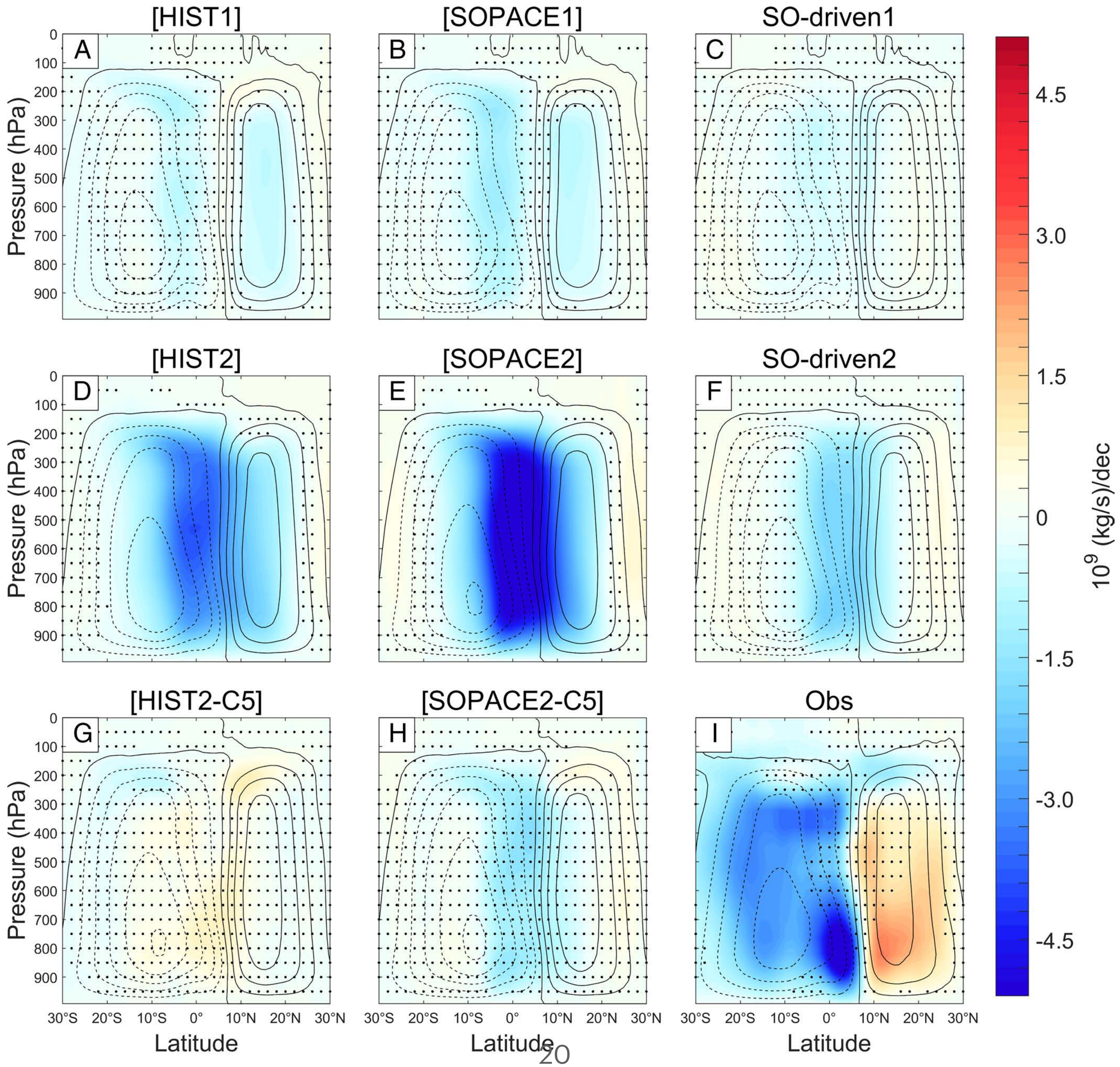
SO cooling's impact on tropical circulation



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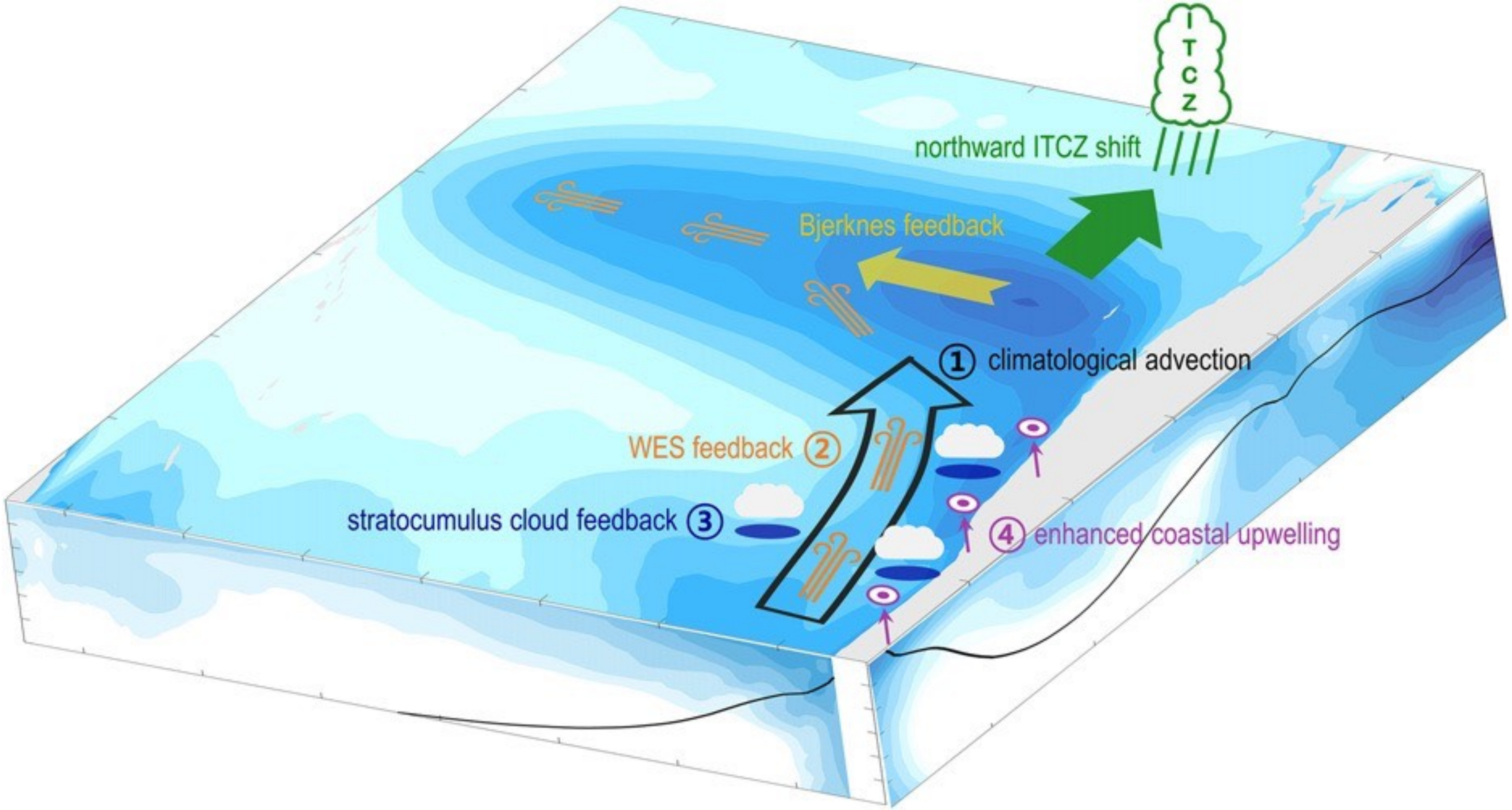
Schematic of SO teleconnection



Kim et al. (2022)

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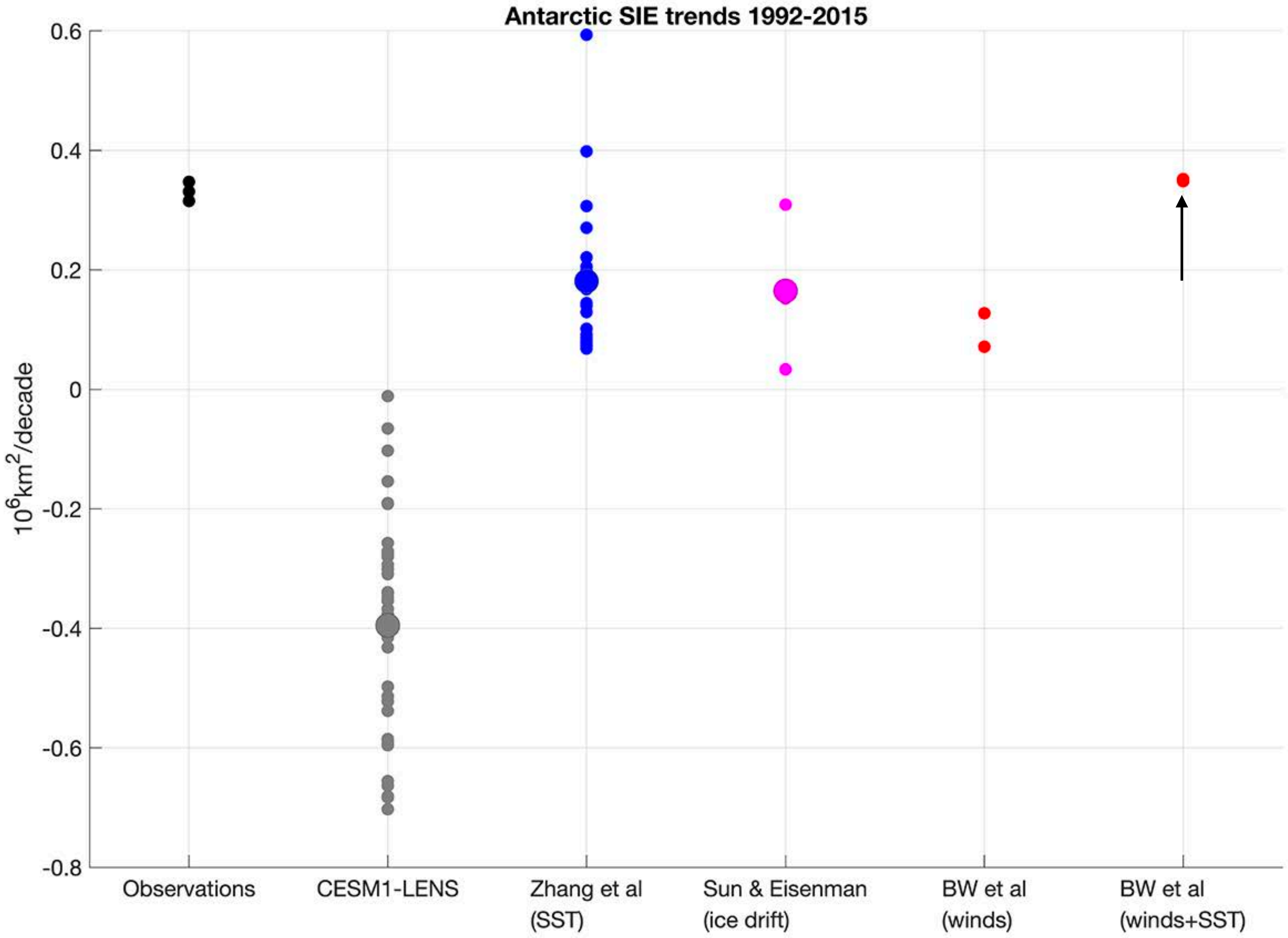
Antarctic sea ice trends are better captured

when observed SO SST trends are included



Blanchard-Wrigglesworth et al. (2022)

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Origin of SO SST variability is under debate

Forced response

- Ocean heat uptake (Marshall et al., 2015; Armour et al., 2016)
- Ozone (e.g., Ferreira et al., 2015; Hartmann 2022)
- Antarctic meltwater (e.g., Bronselaer et al., 2018)

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Internal variability

- Linked to tropical variability (e.g., Schneider and Deser 2018; Chung et al., 2022)
- Ocean deep convection (Latif et al., 2013; Zhang et al., 2017; Cabré et al., 2017)

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Observations: limited coverage; some evidence from paleo records (Latif et al., 2013)

Models: sensitive to parameterization; captured in high-resolution models (Chang et al., 2020)

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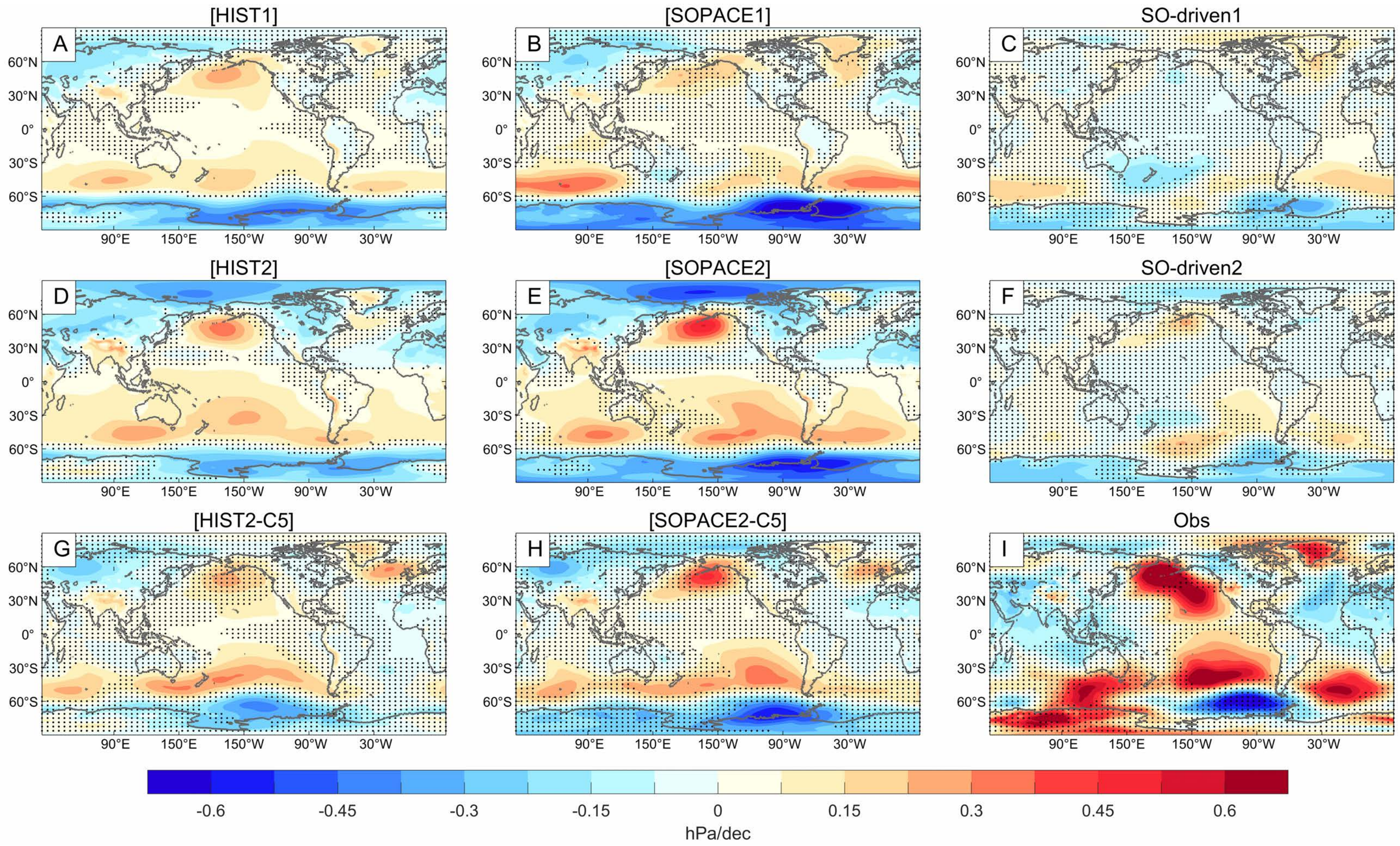
Sea level pressure



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