Southern Ocean teleconnections underestimated due to the double ITCZ problem

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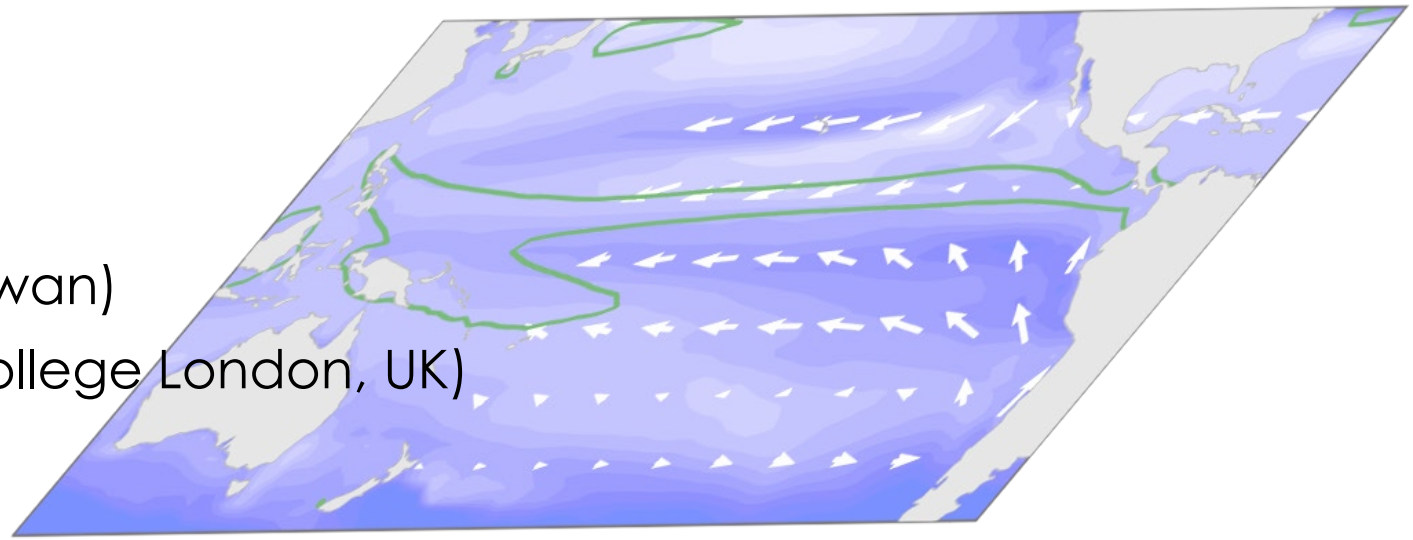
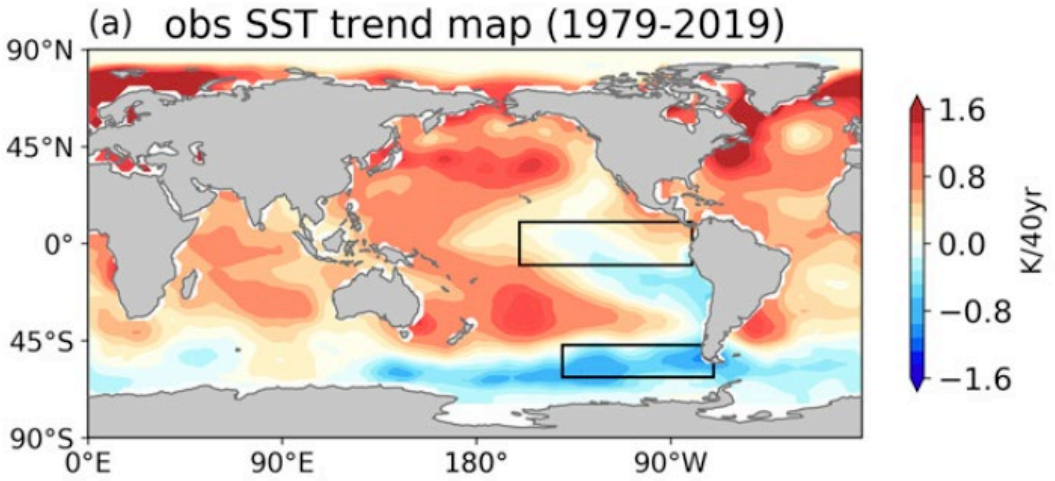
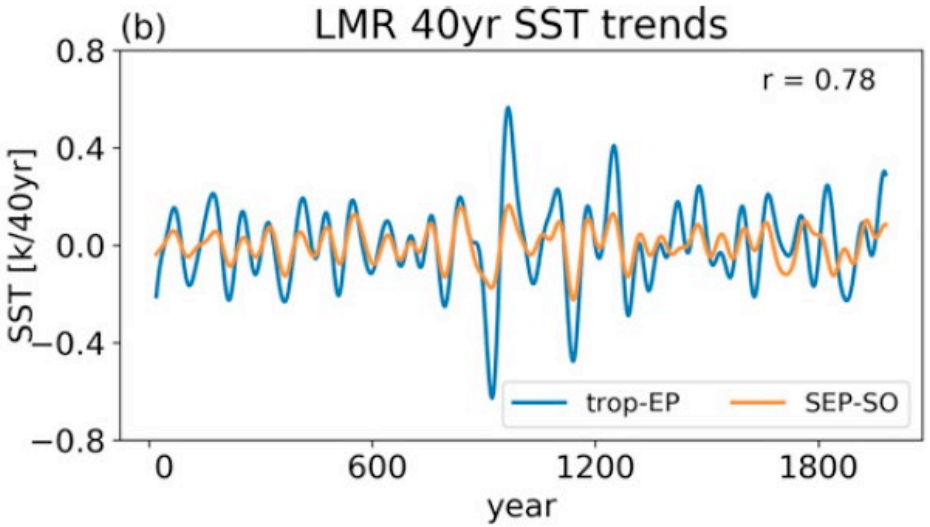
Yen-Ting Hwang, Ruei-Jia Hu (NTU, Taiwan)
Paulo Ceppi, Philipp Breul (Imperial College London, UK)
Lettie Roach (AWI, Germany)



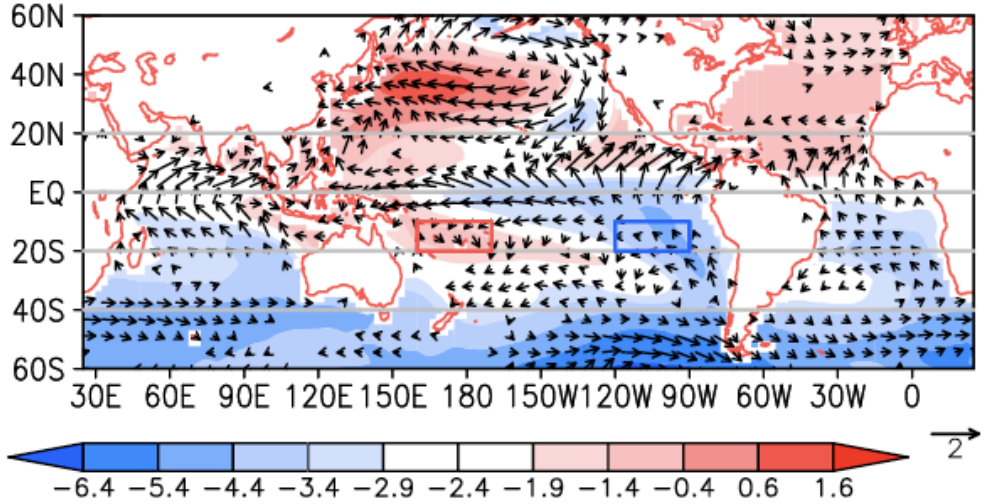
Southern Ocean – Tropical Pacific teleconnections





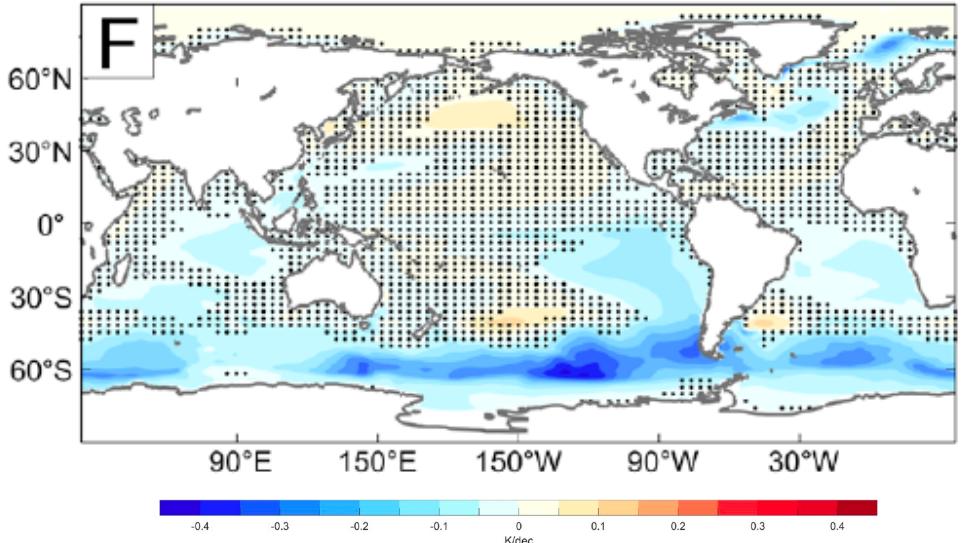
Dong et al. 2022

TS response to enhanced SO heat uptake



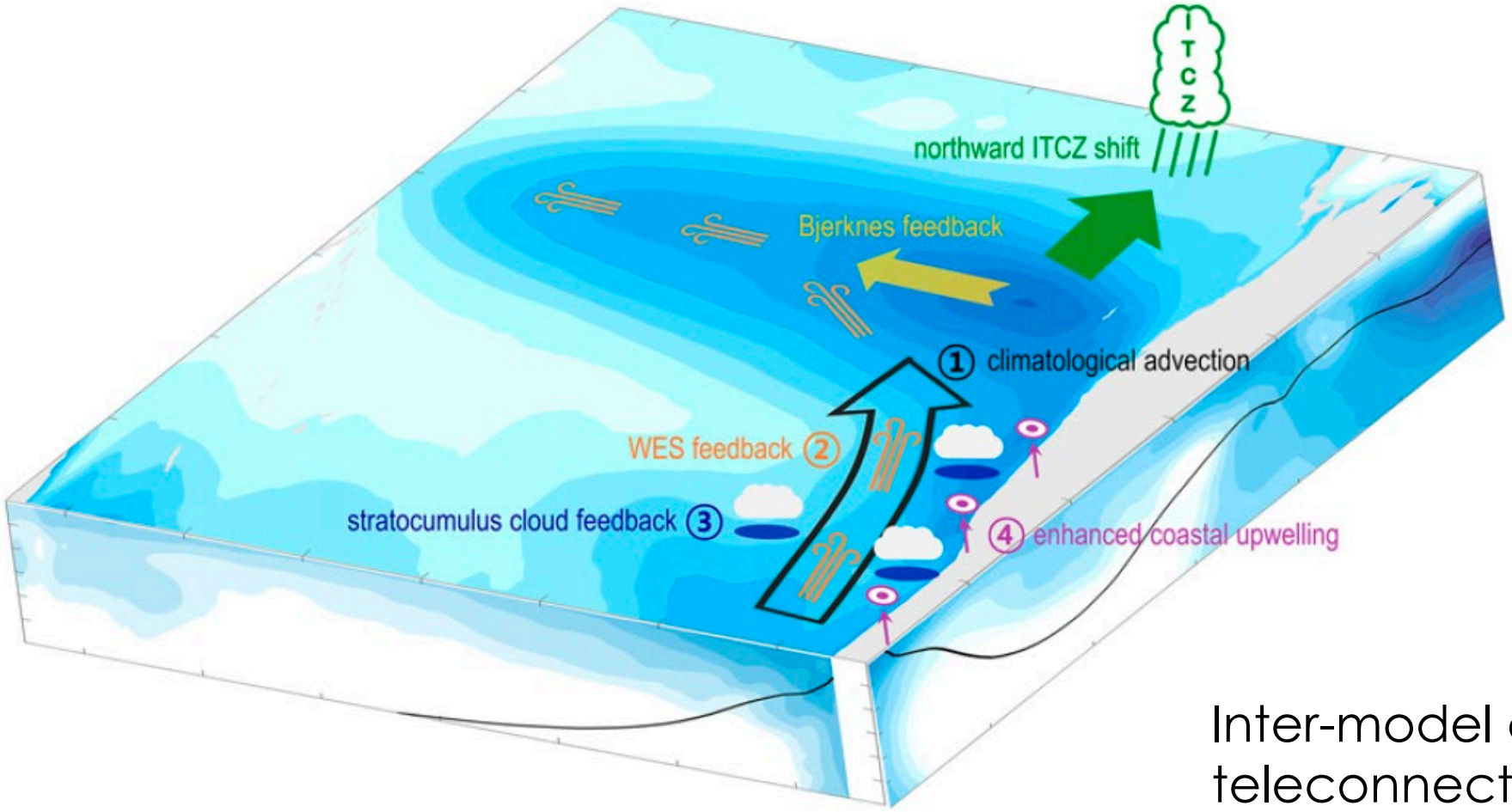
Hwang et al. (2017)

TS response to observed SO SST anomaly



Kang et al. (2023)

key processes in SO teleconnections



Kim et al. 2022 PNAS

Inter-model diversity in SO teleconnections is governed by subtropical cloud-SST feedback

Guiding Questions

What's the role of **the tropical mean state (ITCZ)** in SO-Tropical Pacific teleconnections?

- Does improving the double-ITCZ bias change the tropical response to SO SST forcing?
- Does the spread in ITCZ mean state contribute to the inter-model spread in SO teleconnections?
- If so, is it directly mediated by subtropical cloud feedback?

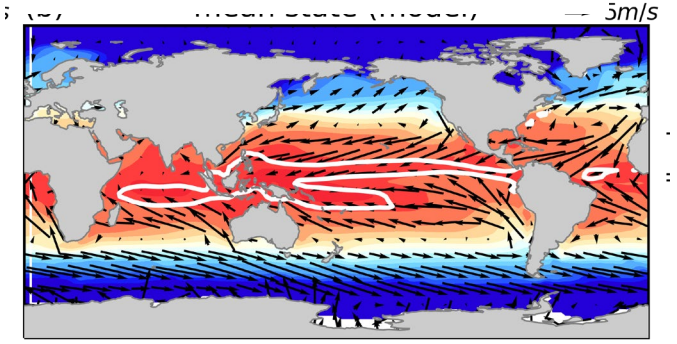
This work:

I. idealized CESM1 slab-ocean simulations
II. Two model inter-model comparison projects,
with SO heat flux forcing (ETIN-MIP) and freshwater forcing (SOFIA)

1. CESM1-CAM4 slab-ocean simulations

control

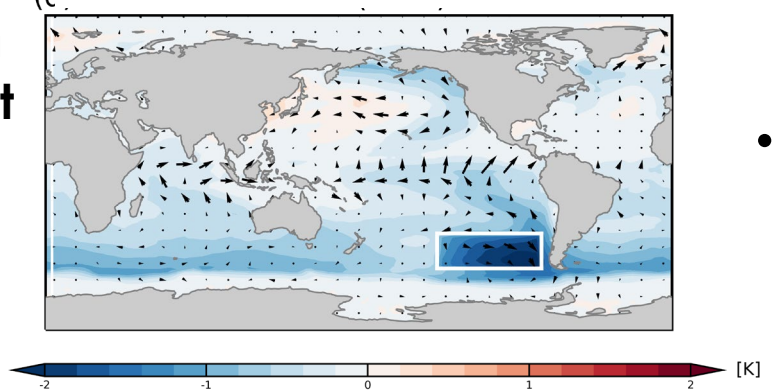
CESM1 mean state



- CESM1-CAM4 (2° atm)
- fixed radiative forcing at present-day levels
- qflux climatology from fully-coupled CESM1 piControl

SO cooling experiment

SST response



- constant qflux anomalies imposed in SEP

Dong et al. 2022 JC

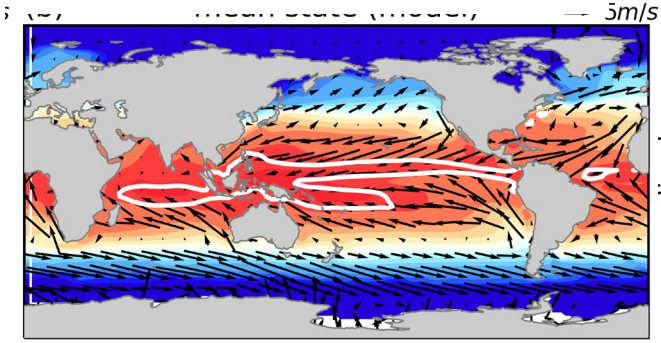
Intrinsic model mean-state biases

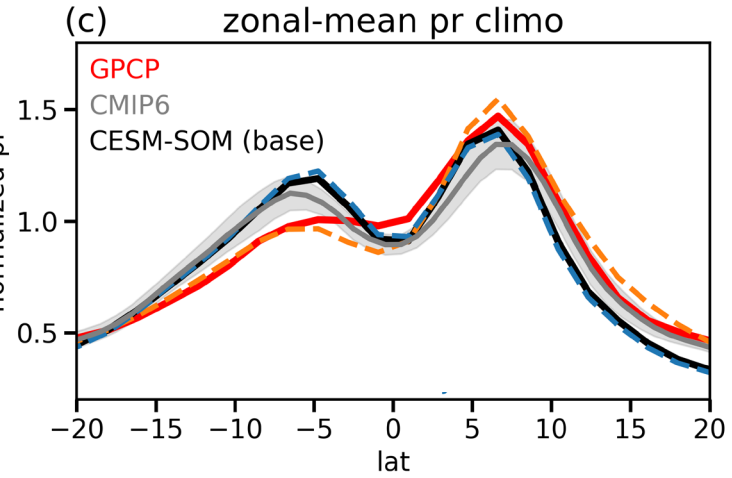
“base”

- double-ITCZ bias
- too-weak cloud-SST feedback

control

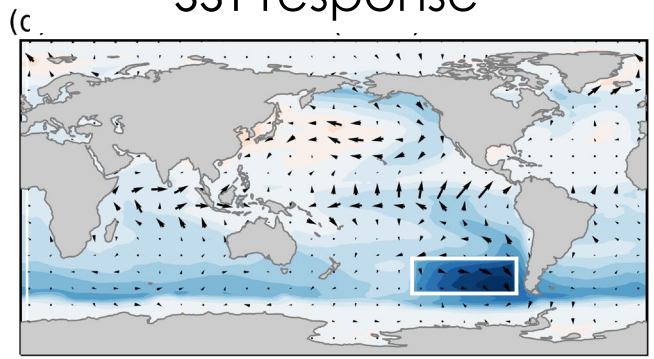
CESM1 mean state

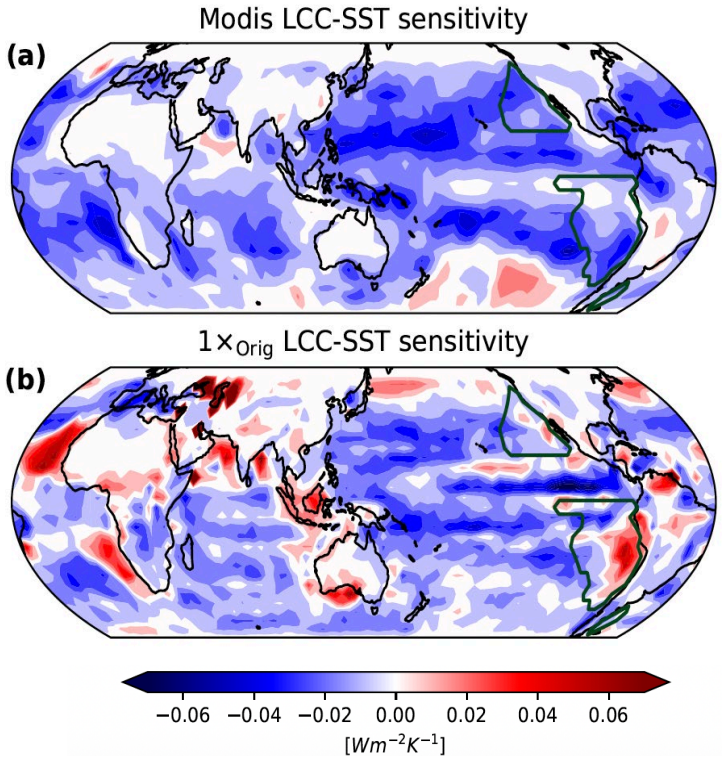




SO cooling experiment

SST response





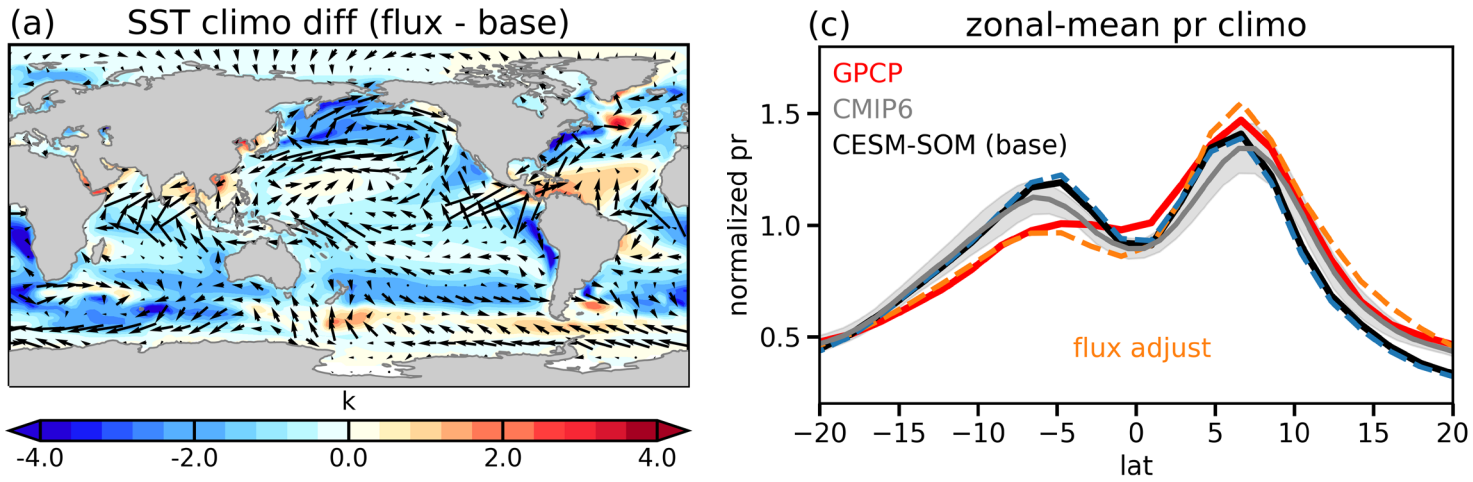
Breul et al. 2025 EGUsphere

“flux adjustment”: correct SST and pr distribution

“base”

“flux adjust”
better ITCZ,
unchanged cloud feedback

control

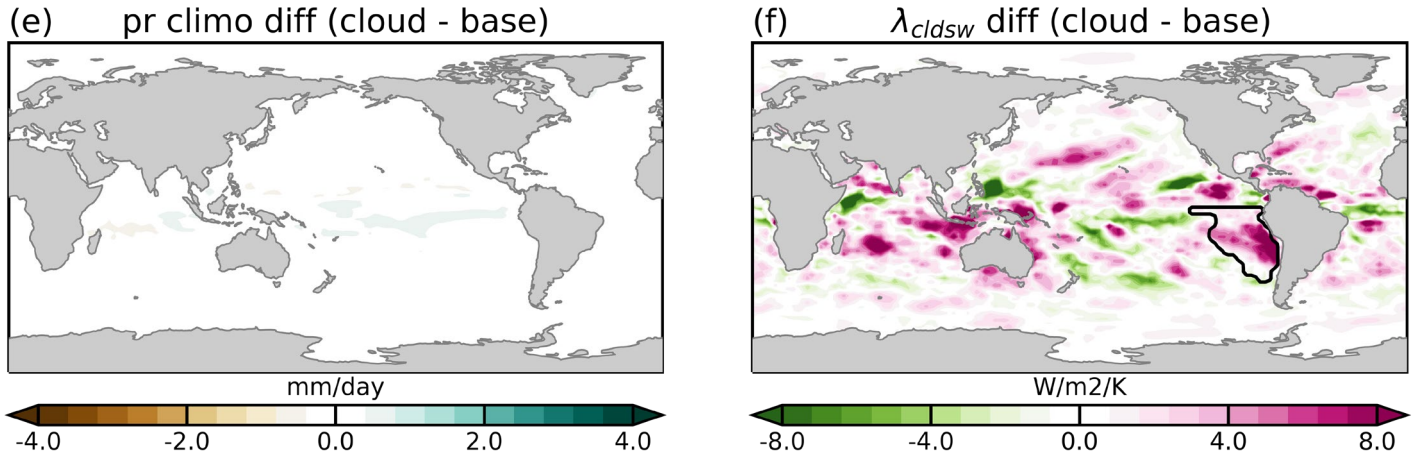


SO cooling experiment

- modified qflux climatology to match the observed SST mean state => reduced double-ITCZ bias
- cloud-SST feedback biases remain

“cloud adjustment”: strengthen low cloud feedback

	“base”	“flux adjust” better ITCZ, unchanged cloud feedback	“cloud adjust” stronger cloud feedback, unchanged ITCZ
control			
SO cooling experiment			



- Change CAM4 radiation code to increase low cloud cover sensitivity to local SST over the subtropical east Pacific
- SST and precipitation mean-state biases remain

Breul et al. 2025 EGUsphere

Stronger tropical SST response from adjustments

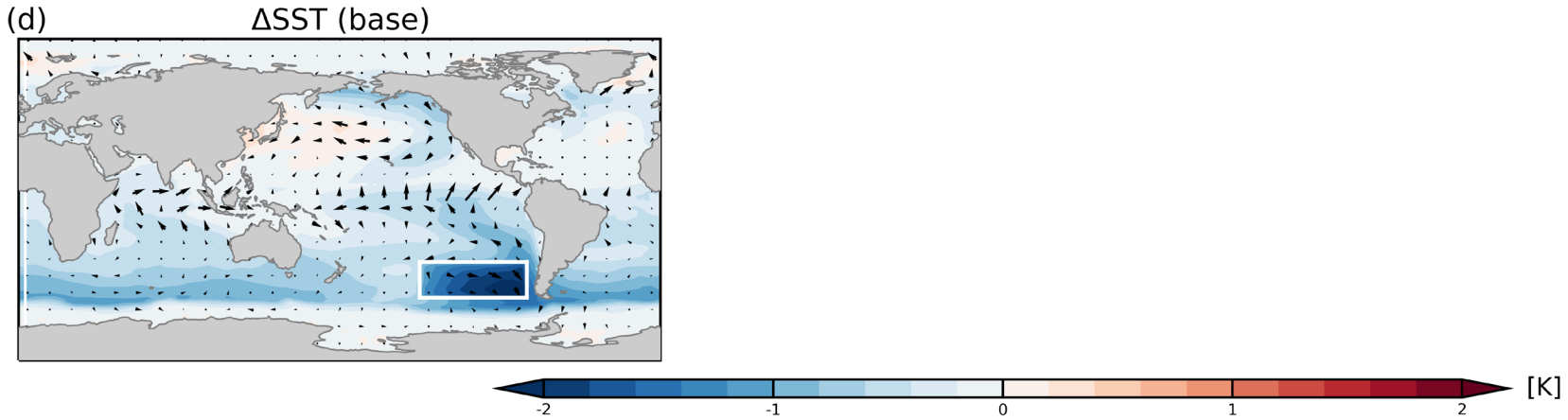
“base”

“flux adjust”
better ITCZ,
unchanged cloud feedback

“cloud adjust”
stronger cloud feedback,
unchanged ITCZ

control

SO cooling experiment



Stronger tropical SST response from adjustments

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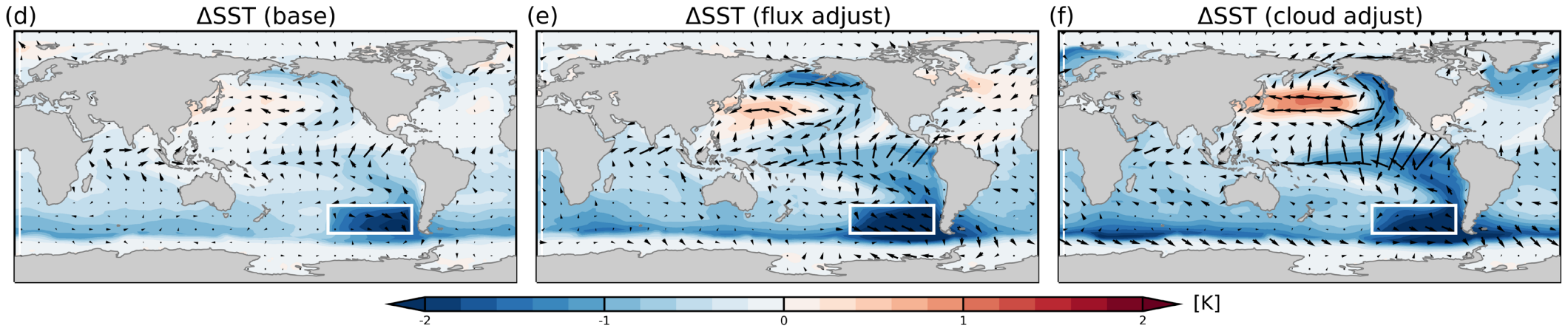
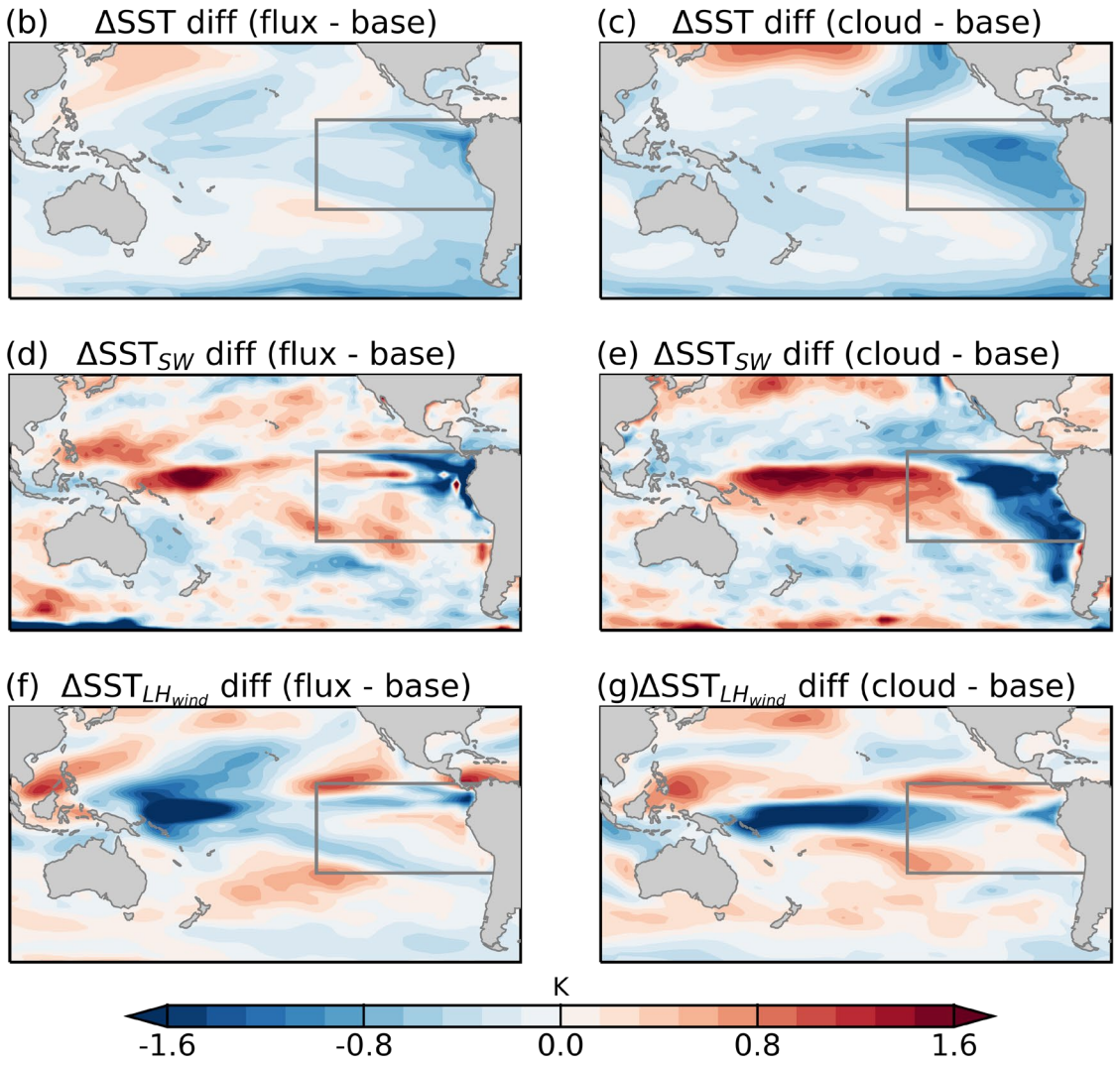
control

SO cooling experiment



What causes the additional tropical cooling?



"flux adjustment": intensified surface winds drive stronger **WES feedback**

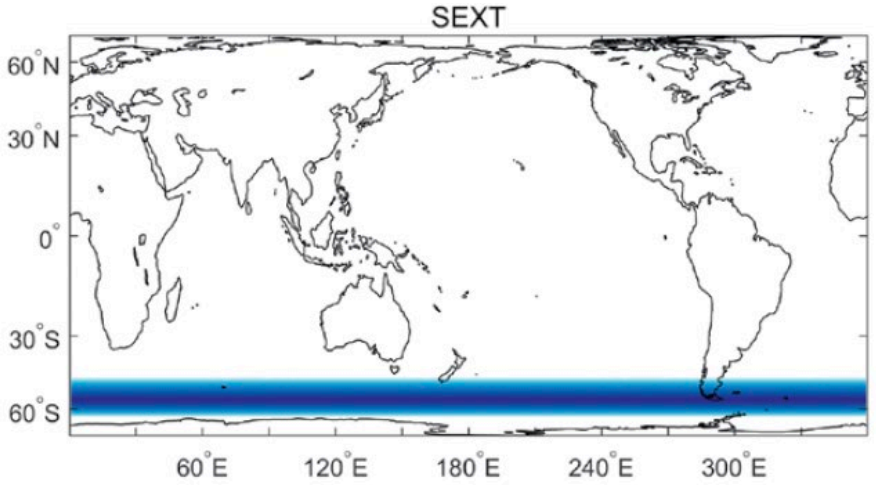
"cloud adjustment": enhanced SW **cloud feedback** (off South America's coast)

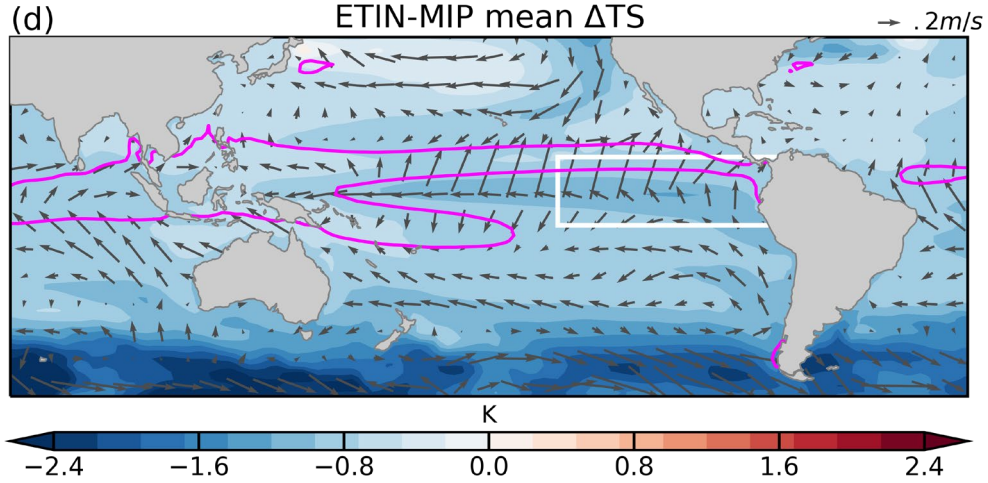
2. ETIN-MIP coupled simulations with SO heat flux

EXTRATROPICAL–TROPICAL INTERACTION MODEL INTERCOMPARISON PROJECT (ETIN-MIP)

Protocol and Initial Results

Sarah M. Kang, Matt Hawcroft, Baoqiang Xiang, Yen-Ting Hwang, Gabriel Cazes, Francis Codron, Traute Crueger, Clara Deser, Øivind Hodnebrog, Hanjun Kim, Jiyeong Kim, Yu Kosaka, Teresa Losada, Carlos R. Mechoso, Gunnar Myhre, Øyvind Seland, Bjorn Stevens, Masahiro Watanabe, and Sungduk Yu

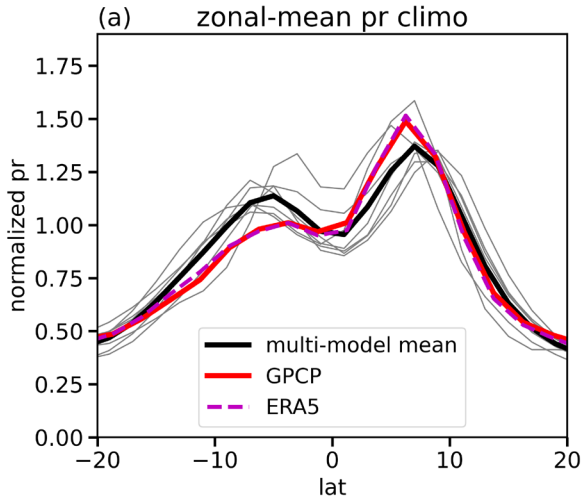


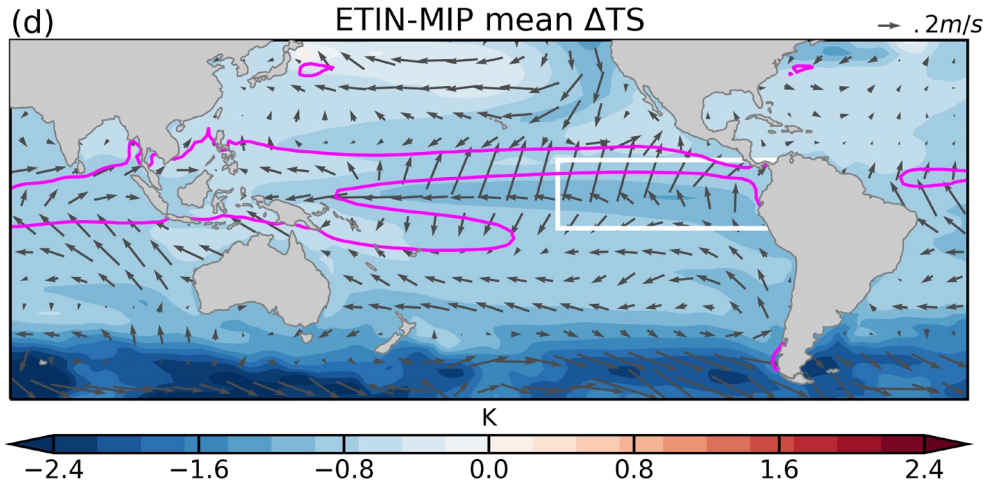


Tropical SST response to SO forcing related to ITCZ

pr asymmetry metric (pr*)

$$pr^* = \frac{\overline{pr}_{max,NH} - \overline{pr}_{max,SH}}{\overline{pr}_{tropics}}$$





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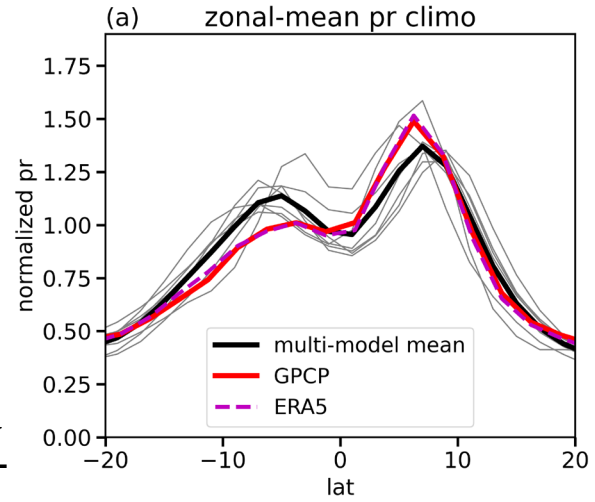

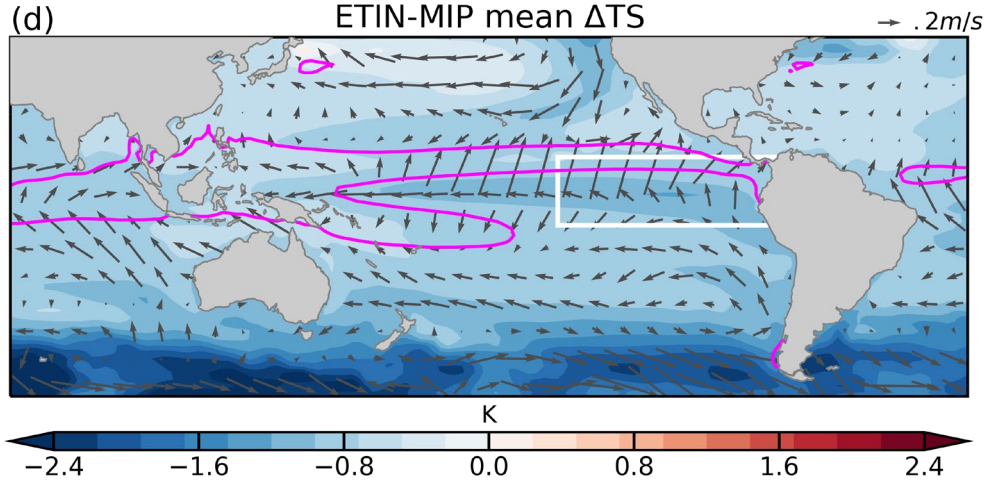

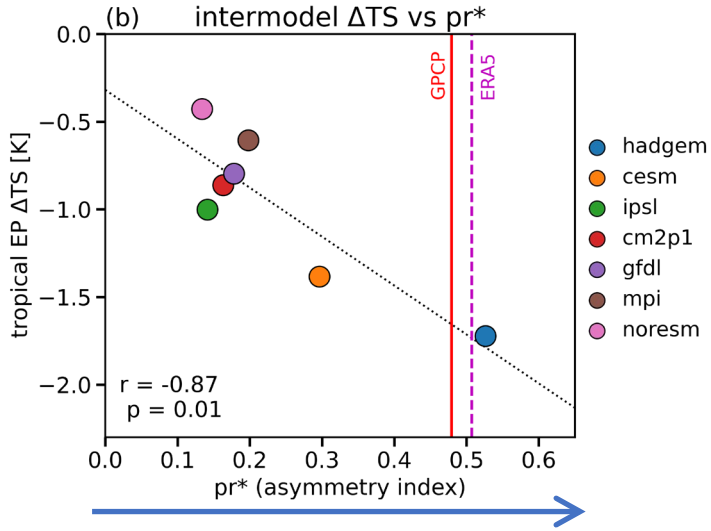

more tropical EP cooling

more asymmetric pr (smaller double ITCZ bias)

Tropical SST response to SO forcing related to ITCZ

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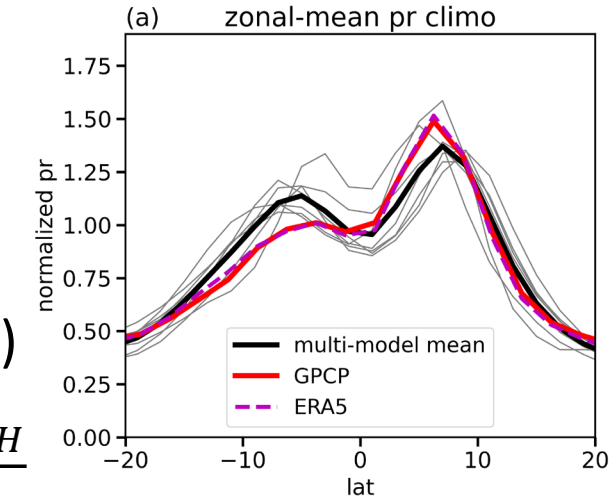

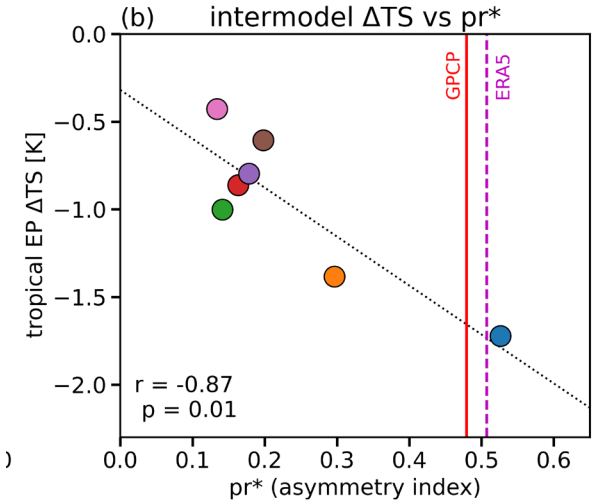

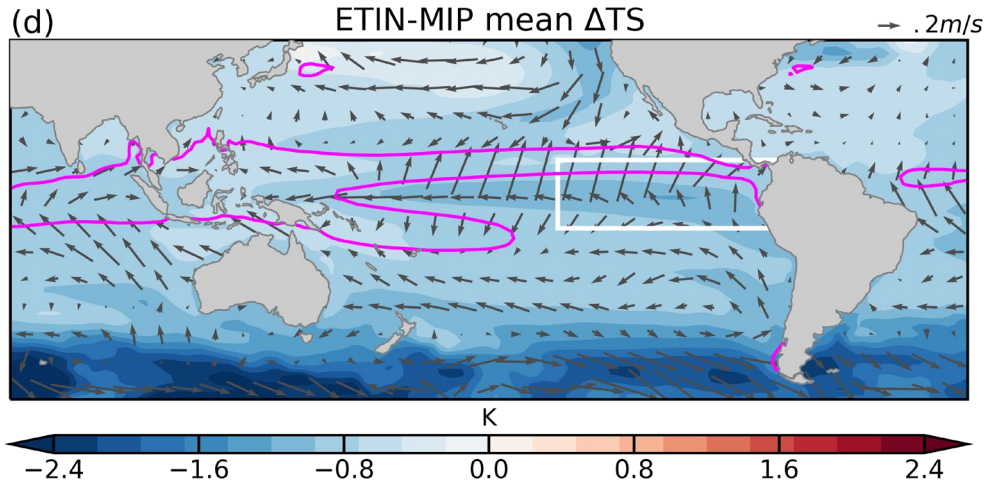

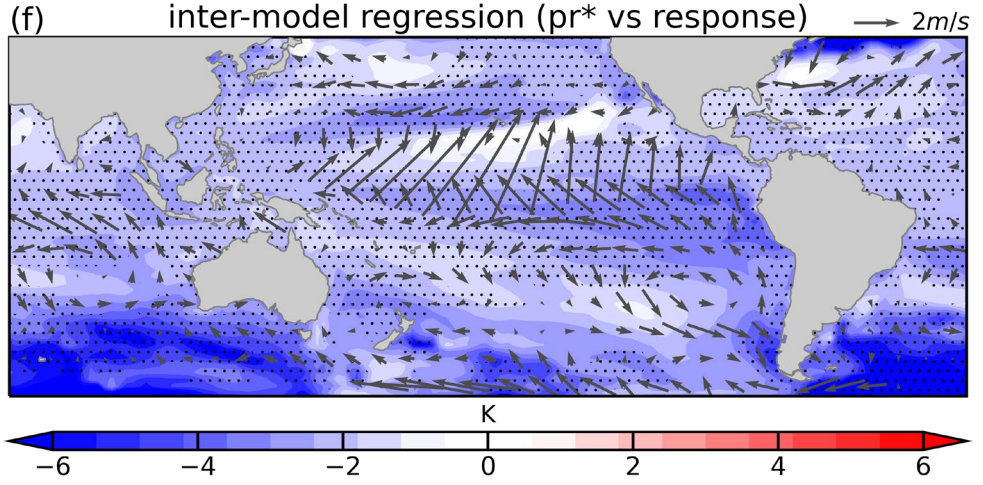

better ITCZ mean state => greater tropical SST response to SO forcing

Tropical SST response to SO forcing related to ITCZ

pr asymmetry metric (pr*)

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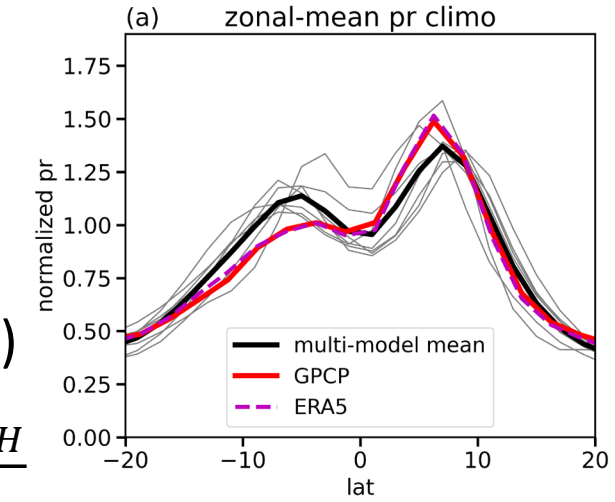
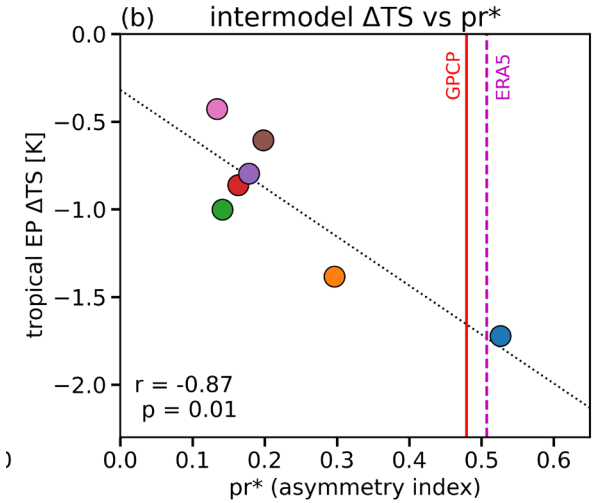
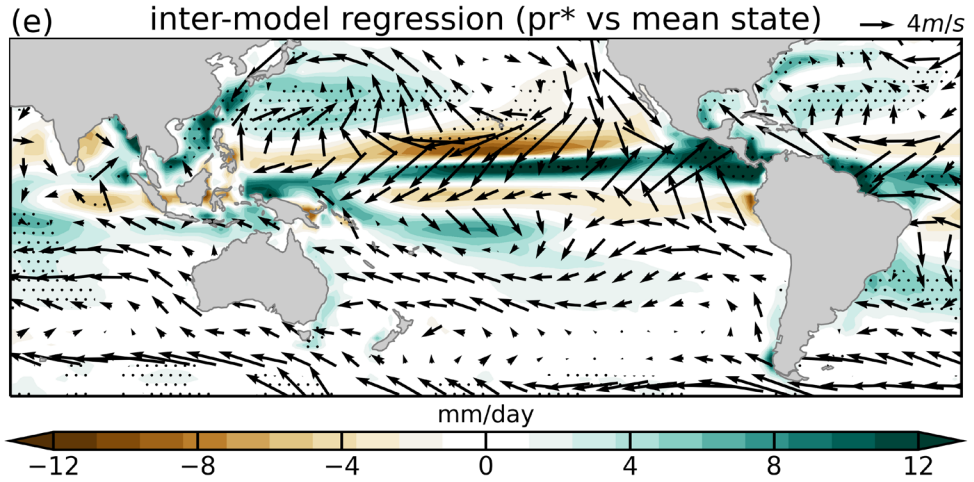
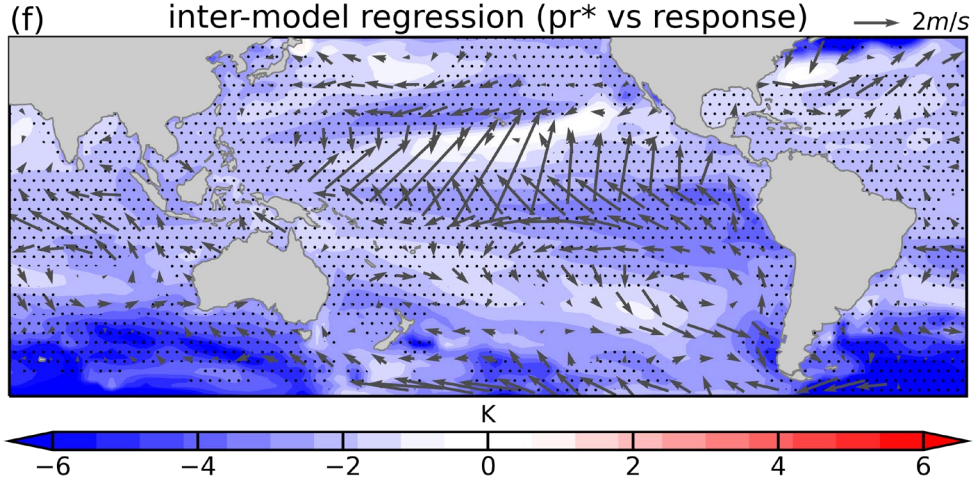


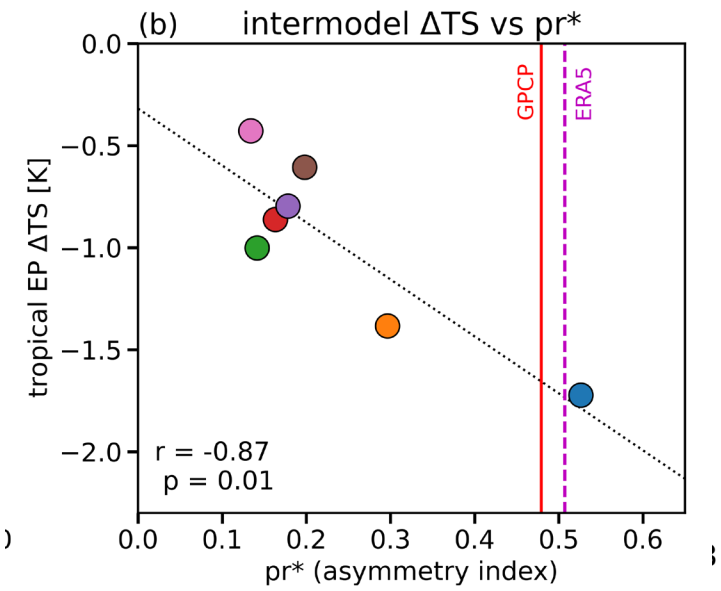




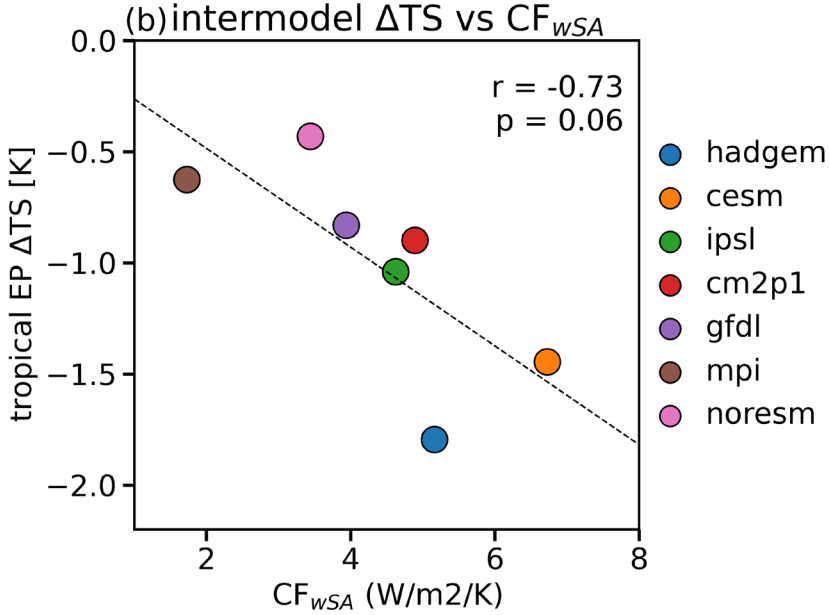


better ITCZ mean state => greater tropical SST response to SO forcing => due to stronger southeasterlies and southerlies leading to stronger WES feedback and advection

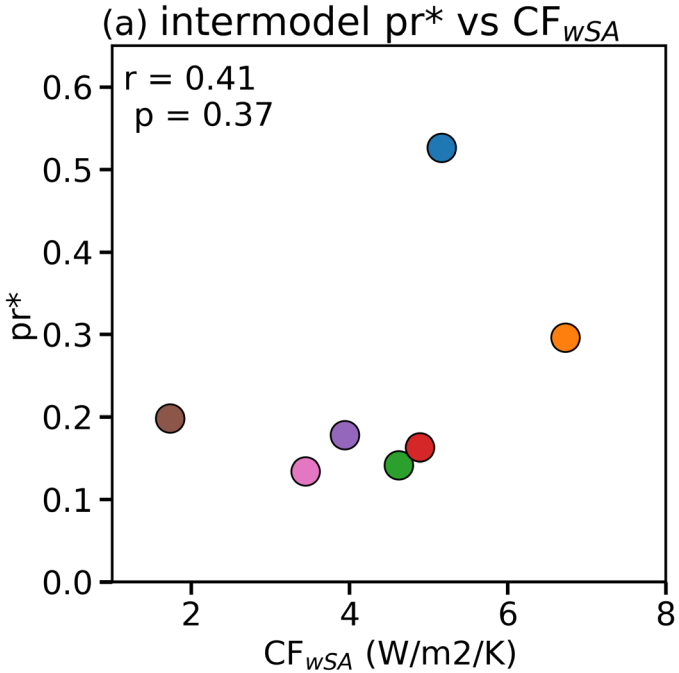
Is the ITCZ modulation via cloud feedback?



this study`



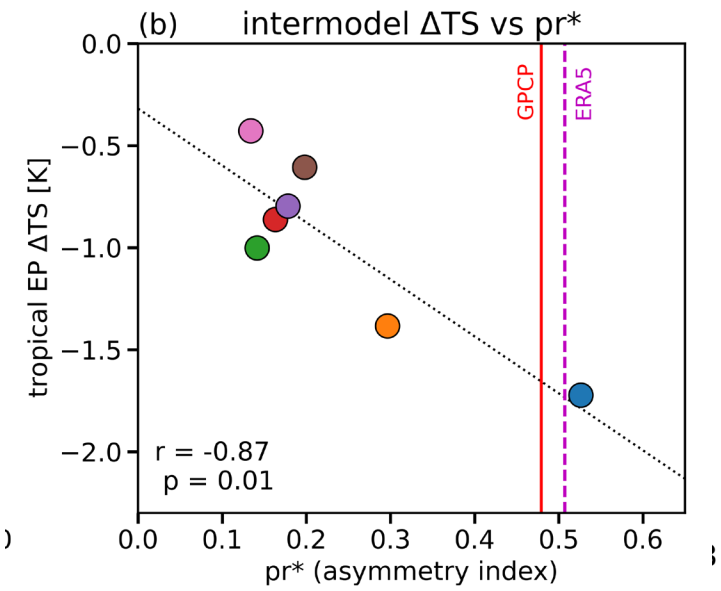
Kim et al. (2022)

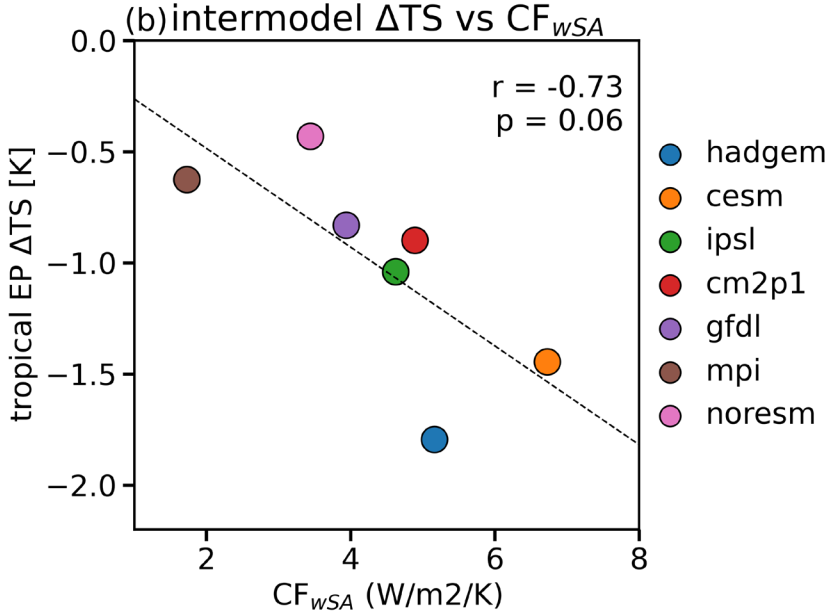


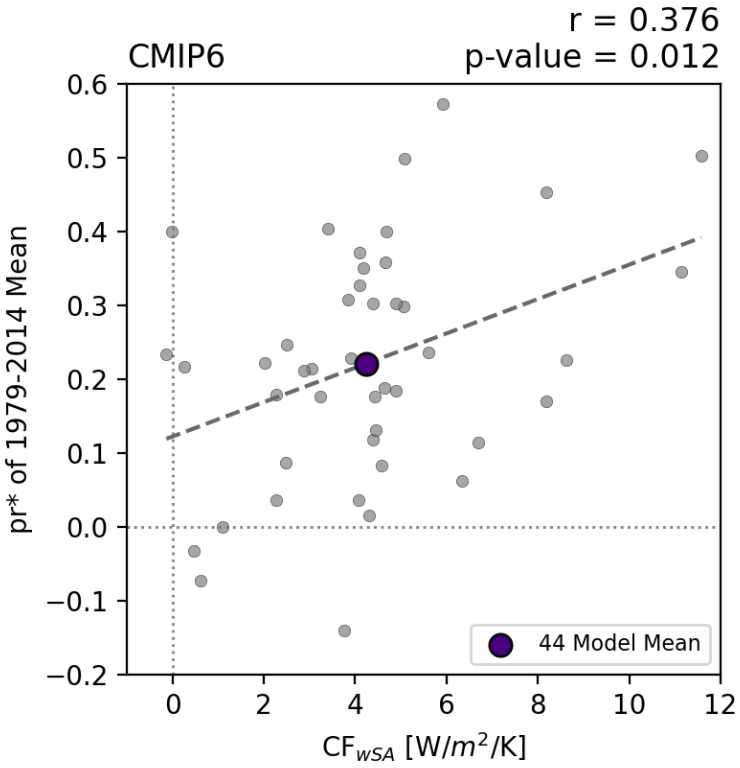
weak correlations between pr* and subtropical cloud-SST feedback

Data courtesy to Hanjun Kim

Is the ITCZ modulation via cloud feedback?







Kim et al. (2022)

weak correlations between pr* and subtropical cloud-SST feedback

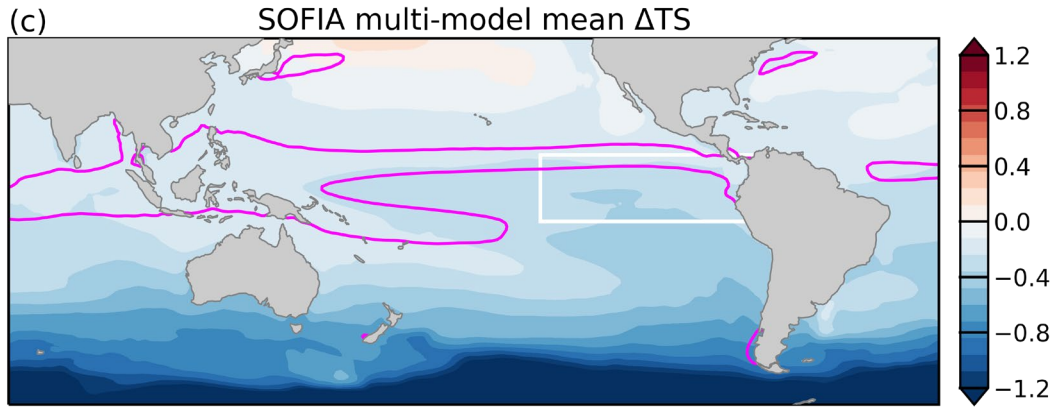
3. SOFIA Antarctic meltwater simulations

https://doi.org/10.5194/egusphere-2023-198
Preprint. Discussion started: 24 March 2023

EGUsphere Preprint repository

The Southern Ocean Freshwater release model experiments Initiative (SOFIA): Scientific objectives and experimental design

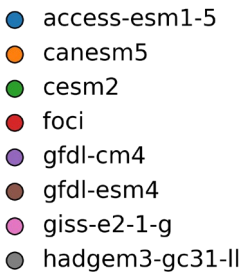
Neil C. Swart[1], Torge Martin[2], Rebecca Beadling[3], Jia-Jia Chen[4], Matthew H. England[5], Riccardo Farneti[6], Stephen M. Griffies[7,8], Tore Hattermann[9], F. Alexander Haumann[10,8], Qian Li[11], John Marshall[11,14], Morven Muilwijk[9], Andrew G. Pauling[12], Ariaan Purich[13], Inga J. Smith[12], and Max Thomas[12]

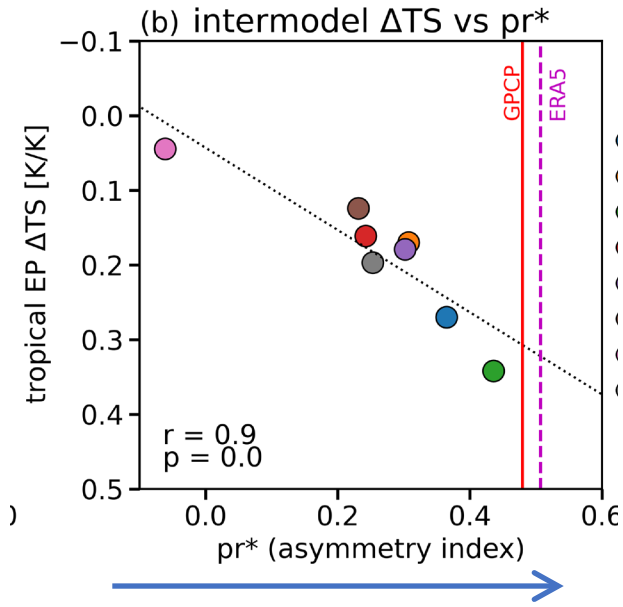


constant freshwater anomaly (0.1 Sv) imposed in the Antarctic adjacent distribution (for 100 years)

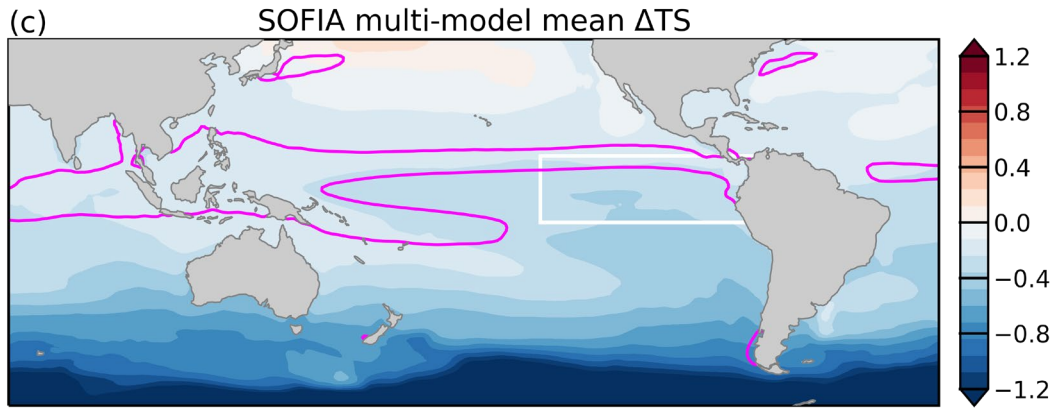
3. SOFIA Antarctic meltwater simulations

more tropical ΔTS per degree of SO ΔTS





more asymmetric pr (smaller double-ITCZ bias)



3. SOFIA Antarctic meltwater simulations

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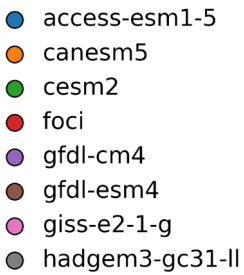

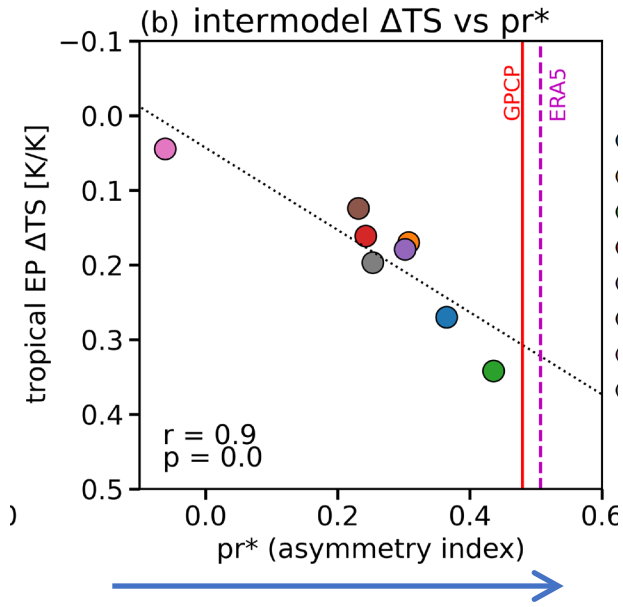

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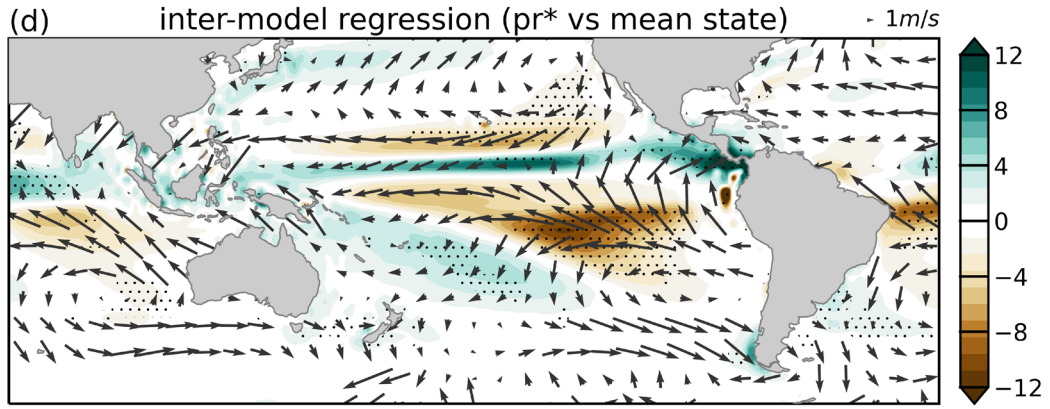
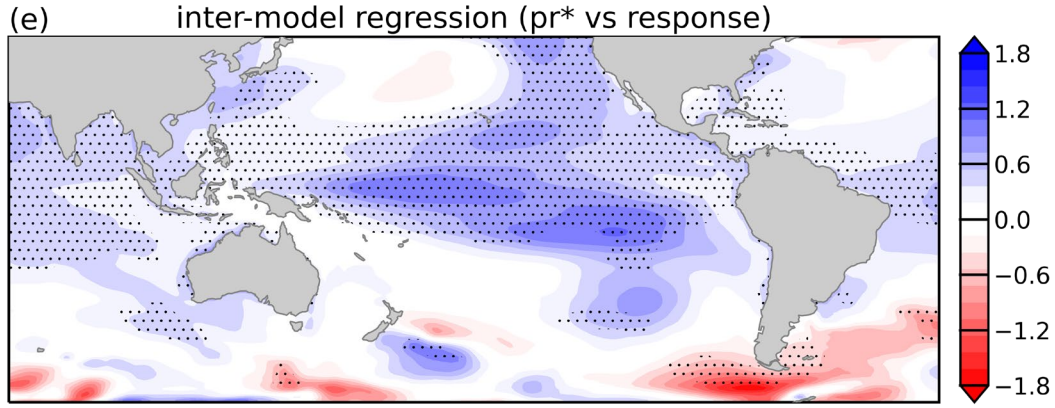
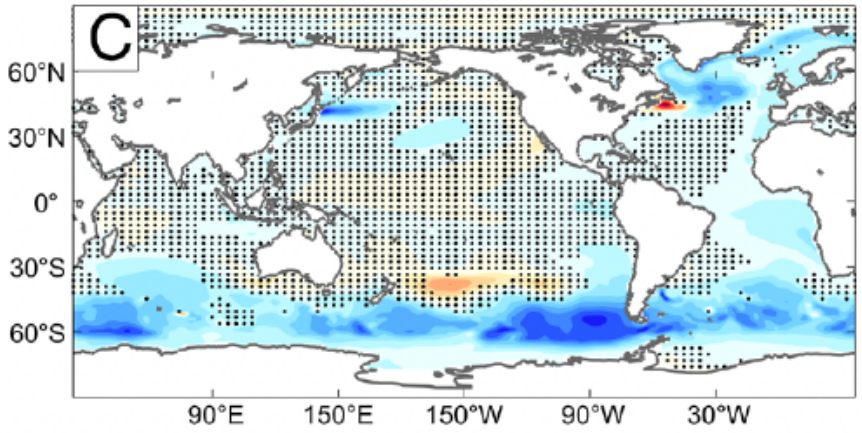




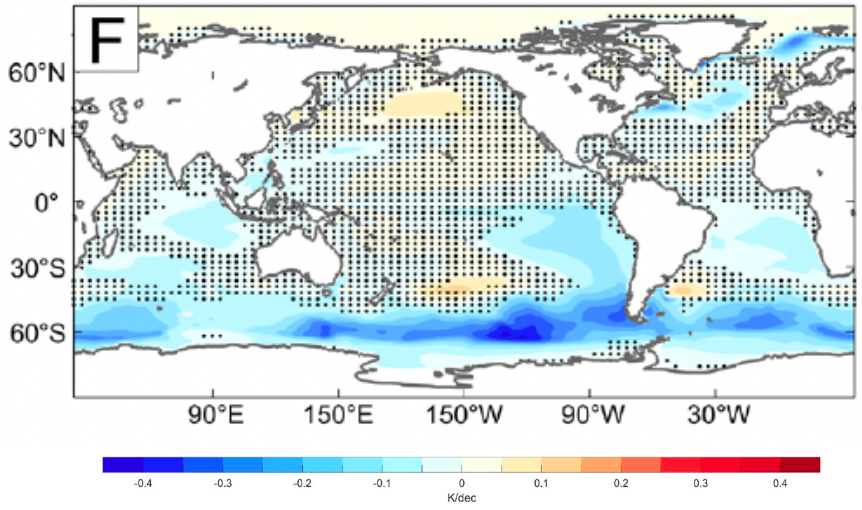
Tropical impacts of SO cooling (by Antarctic freshwater forcing or heat flux forcing) may be underestimated due to the double-ITCZ problem

Implications for CESM development?

CESM1 SO pacemaker



CESM2 SO pacemaker

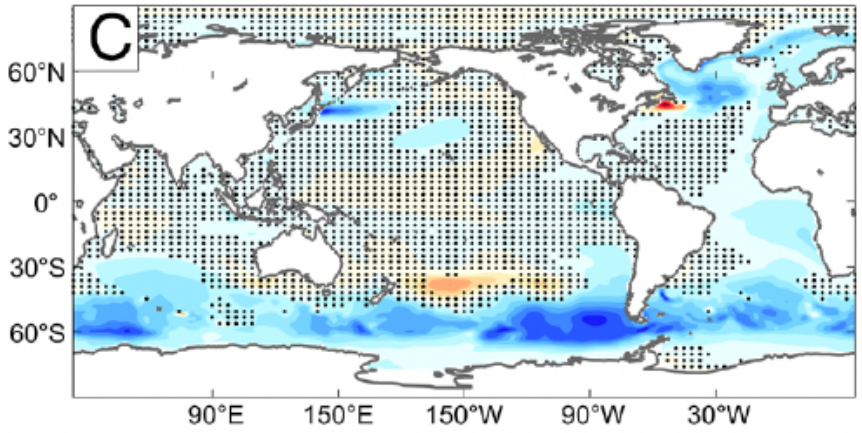


CESM2 has a stronger (more realistic) subtropical cloud feedback

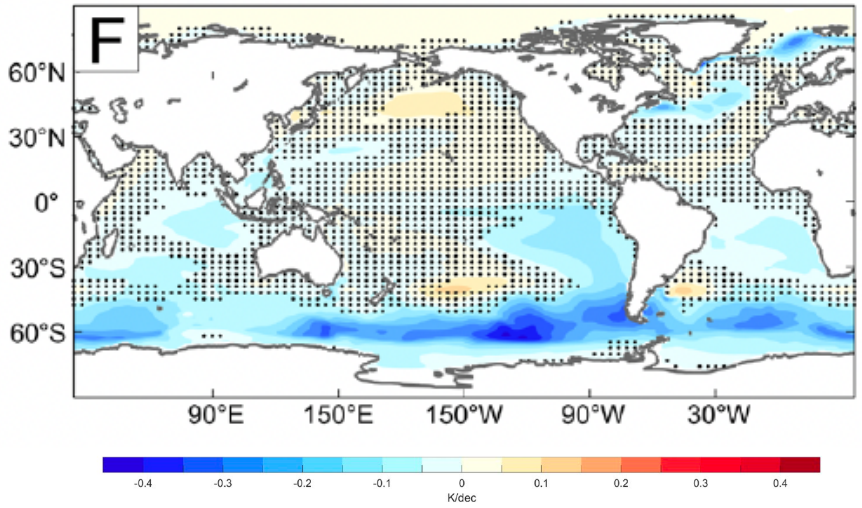
Kang et al. (2023)

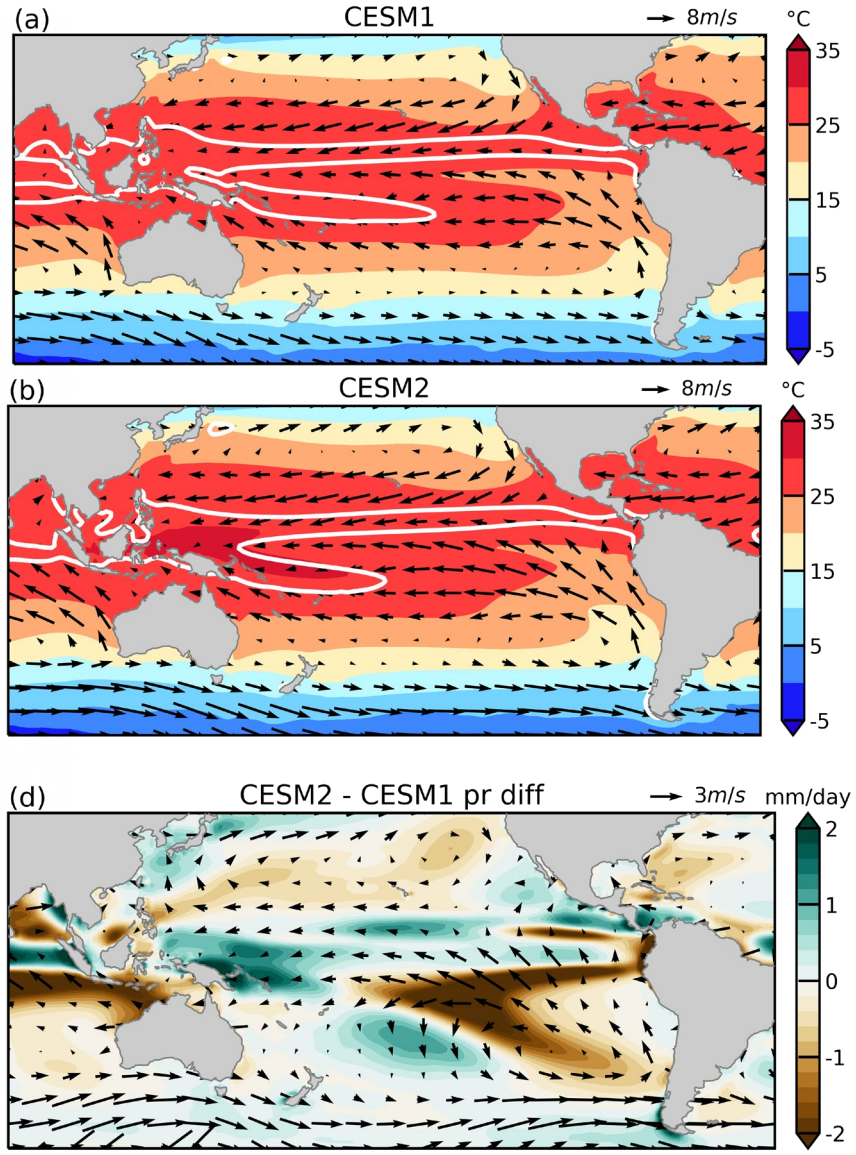
Implications for CESM development?

CESM1 SO pacemaker



CESM2 SO pacemaker





piControl mean state

CESM2 also has an improved ITCZ & stronger mean-state wind

Summary

- Does improving the tropical mean state change the simulated strength of SO-Tropical Pacific teleconnections?

Yes. improving ITCZ leads to a stronger tropical SST response to SO cooling

- If so, does it explain inter-model spread in SO teleconnections?

Yes. Better ITCZ leads to stronger and broader SST response to SO forcing

- If so, is it directly mediated by subtropical cloud feedback?

No. The ITCZ modulation highlights WES feedback (in the trade wind region) and mean-wind advection (along the equator)

Improving model mean-state biases is critical for accurately simulating tropical SST trends and remote impacts of Antarctic climate change