Causes and consequences of the unique Pacific Ocean sea-surface temperature trend pattern

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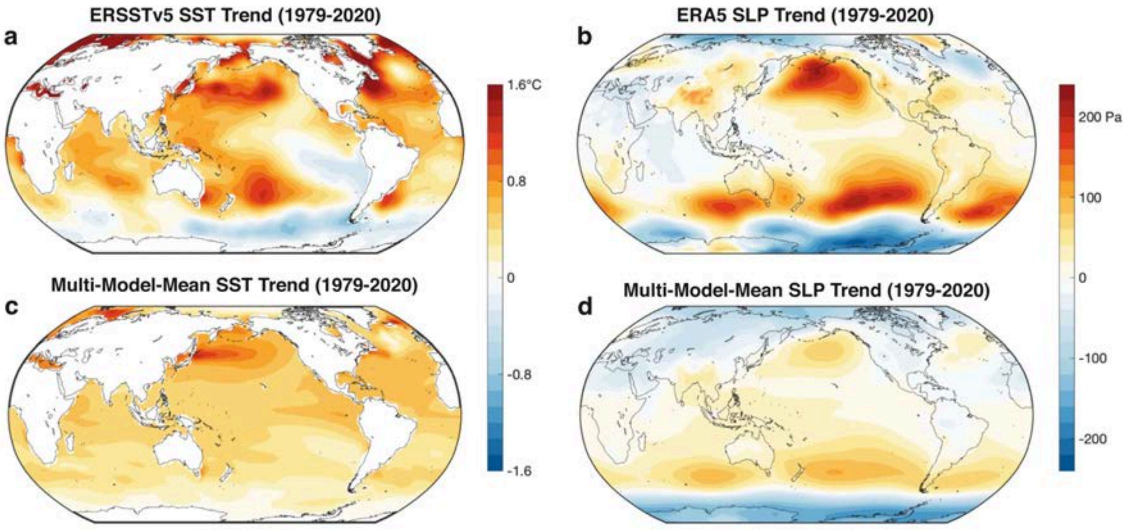
Courtesy of NASA's
Earth Observatory

The pattern of Pacific SST and SLP trends since ~1980 has been unique



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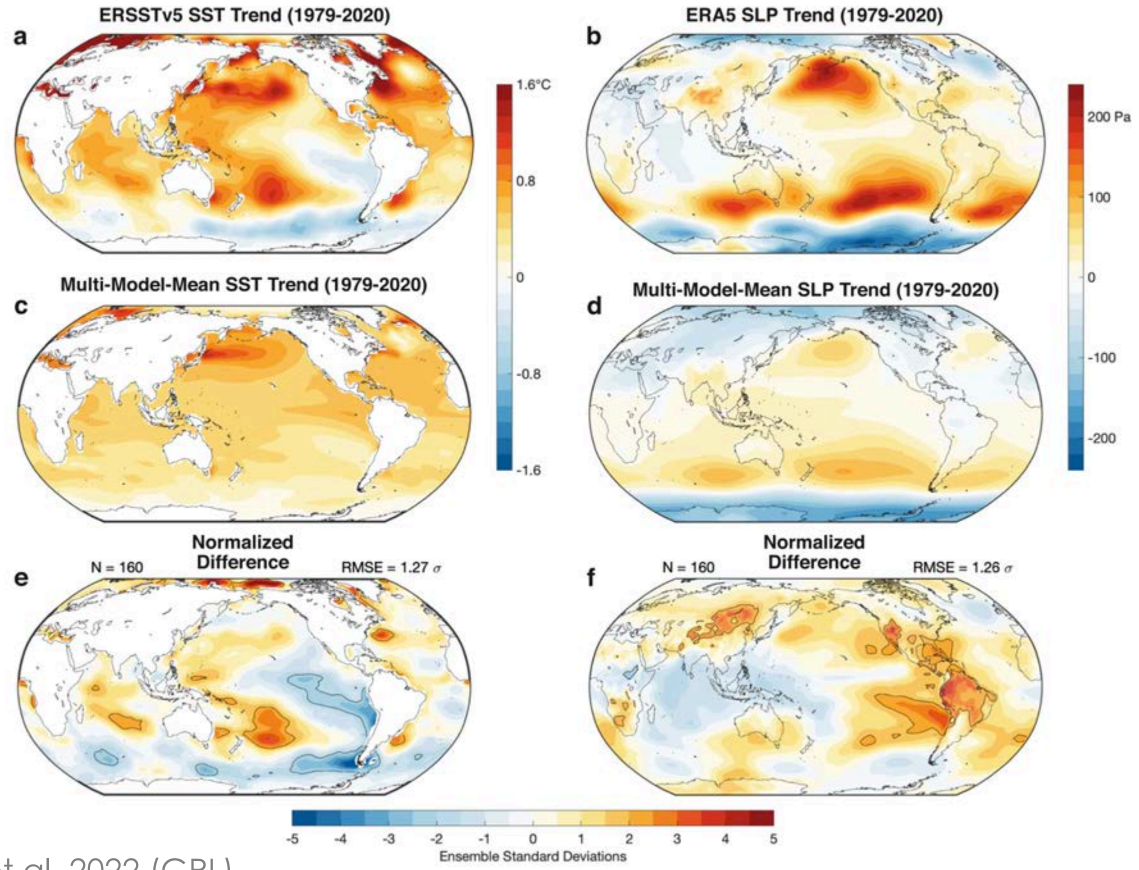

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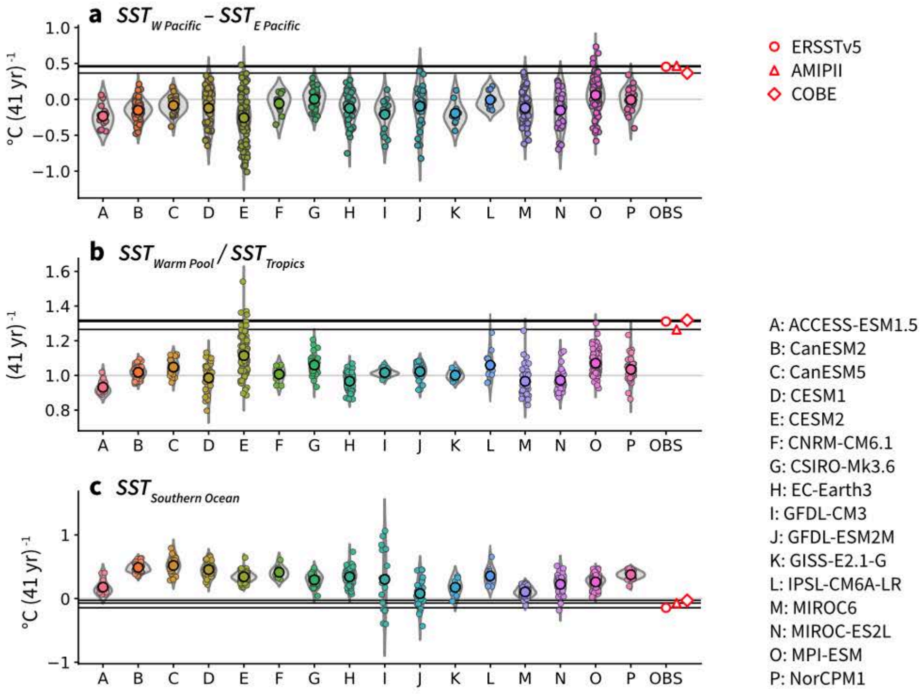

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What's driven the pattern and why do models fail to replicate it?

- As summarized in Andrews et al. 2022 (JGR) and Ulla's talk, candidate mechanisms are:
    - internal variability (originating in tropical Pacific or Southern Ocean)
    - non-CO_2 forcing (ozone depletion, Southern Ocean freshwater forcing, tropospheric or stratospheric aerosols)
    - role of teleconnections (from Southern Ocean or from Atlantic Ocean)
    - response to CO_2 forcing (delayed E Pacific warming or nonlinear ENSO mechanisms)
    - or some combination of these

- Fundamental issue: multiple potential mechanisms project onto same pattern of SST response (ENSO/PDO dynamics), yet all imply different future evolutions

- Perhaps the most important unsolved problem in climate dynamics

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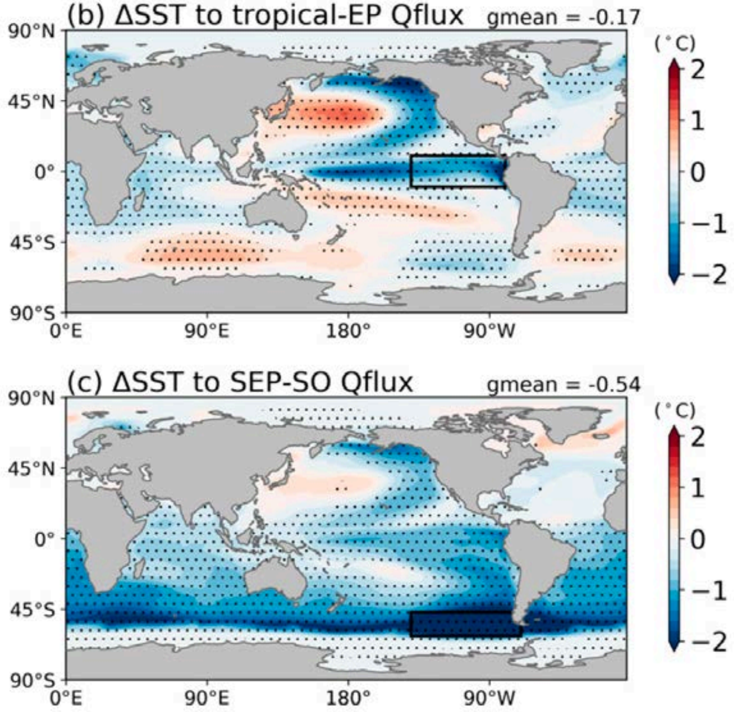
Two-way teleconnections between the Southern Ocean and the tropics

Response to localized patches of heat uptake in a slab ocean model (CAM4)



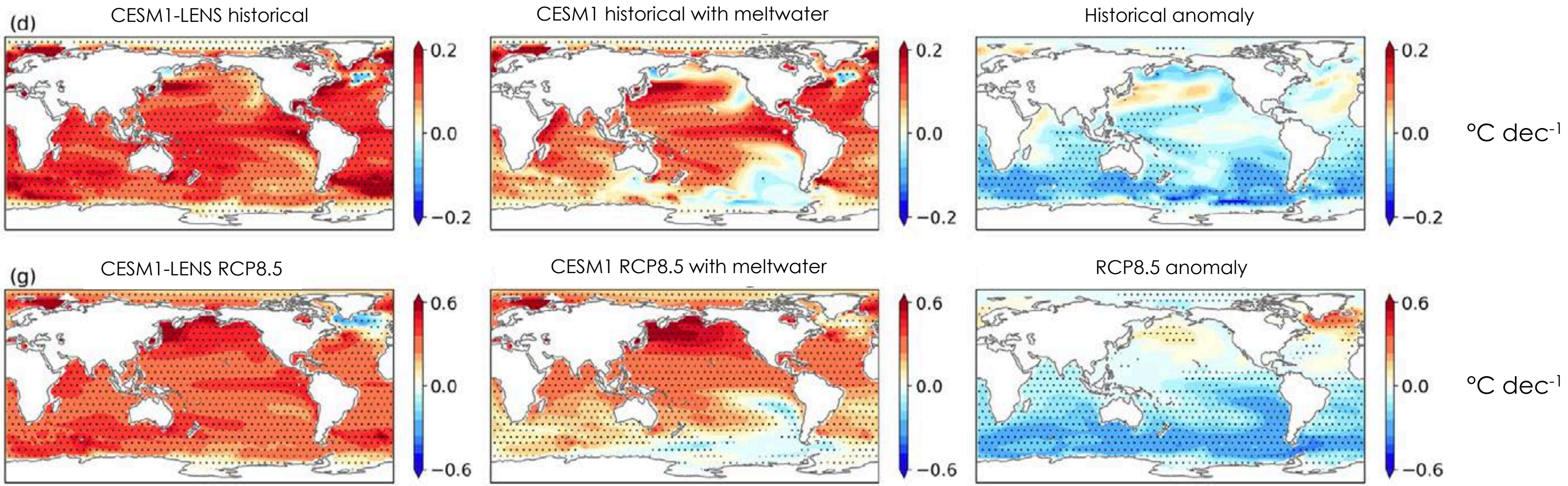
The tropical Pacific and Southern Ocean influence each other through atmospheric teleconnections, making it difficult to determine which is driving which

But that the Southern Ocean has cooled more than the tropical Pacific in observations is at least consistent with the Southern Ocean driving the tropics

Dong et al. 2022 (J Climate); see also Kang et al. 2023 (PNAS) and Sally Zhang's talk from yesterday

One potential mechanism: Southern Ocean freshening

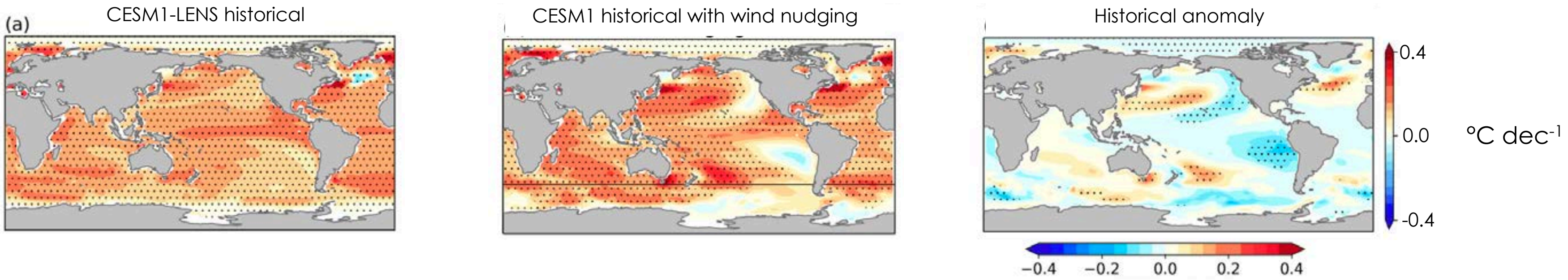
Response to adding Antarctic meltwater to the Southern Ocean in a coupled model (CESM1-CAM5)



Dong et al. 2022 (J Climate) and 2022 (GRL)

Another potential mechanism: Southern hemisphere atmospheric circulation

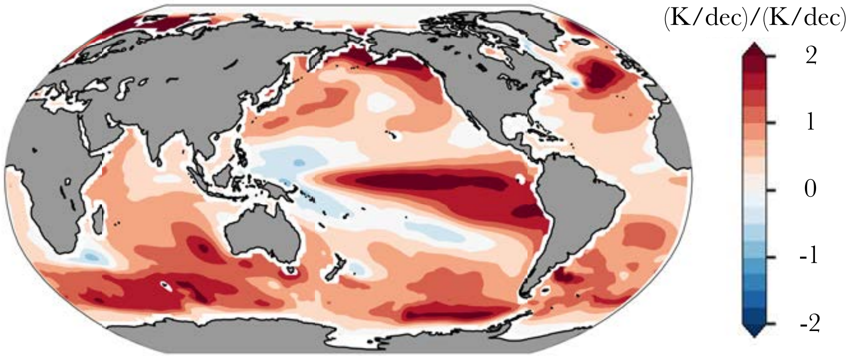
Response to nudging tropospheric winds to reanalysis over the Southern Ocean in a coupled model (CESM1-CAM5)



Dong et al. 2022 (J Climate); see also Hartmann 2022 (PNAS)

Impact of the SST trend pattern on global warming

CESM1-LENS regression of local SST trend on the global-mean warming rate over 1981-2014



Ensemble members that warm more show enhanced warming in the eastern tropical Pacific (El Niño-like) and Southern Ocean

Armour et al. (submitted)

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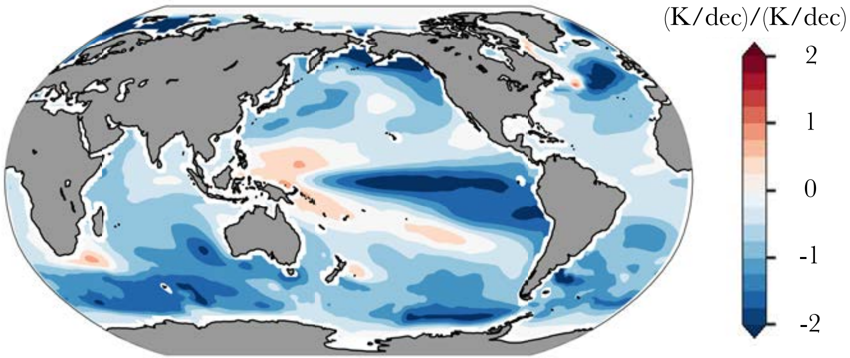

Ensemble members that warm less show reduced warming in the eastern tropical Pacific (La Niña-like) and Southern Ocean

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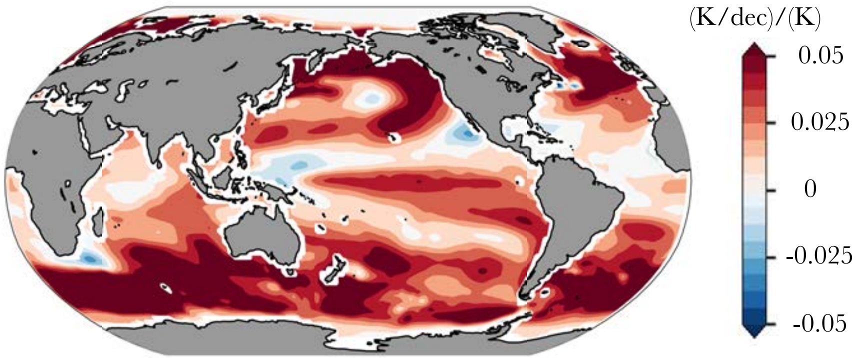
Impact of the SST trend pattern on global warming

CESM1-LENS regression of local SST trend on effective climate sensitivity (EffCS) over 1981-2014



Ensemble members that have a higher effective climate sensitivity (EffCS) over this period show enhanced warming in the eastern tropical Pacific (El Niño-like) and Southern Ocean

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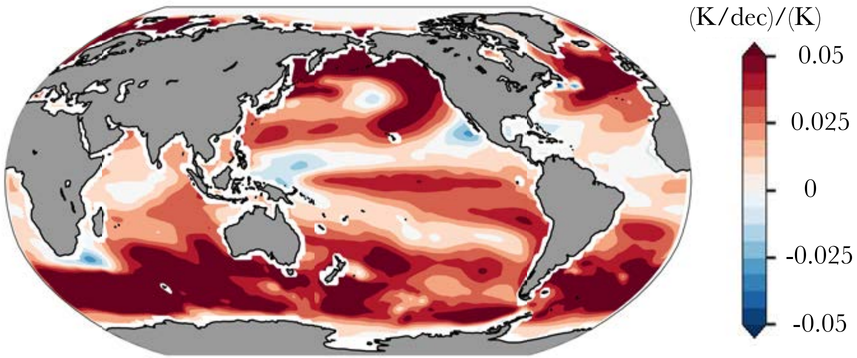
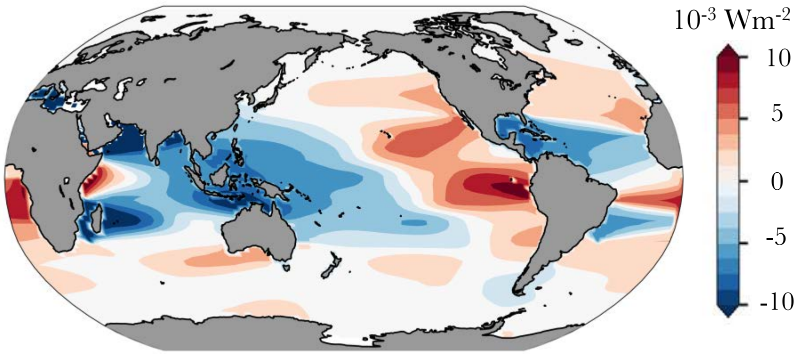


CAM5 Green's function showing global TOA radiative response to local surface warming (Zhou et al. 2017)



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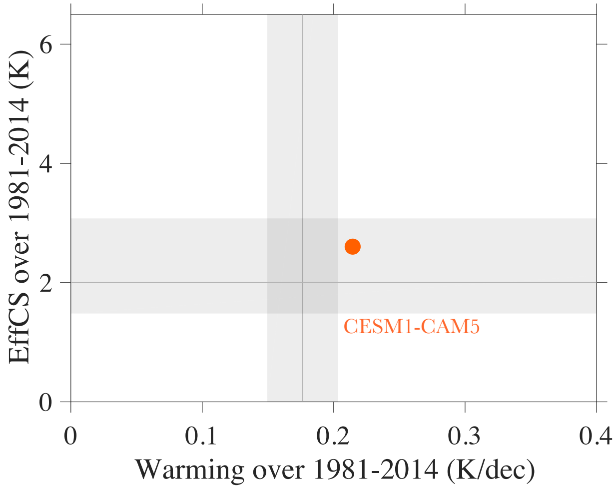
The unique SST trend pattern has slowed global warming



Observational constraint on EffCS over recent decades (Andrews et al. 2022)

Observed global warming over recent decades (HadCRUT5)

Like most CMIP5/6 models, CESM1-CAM5 warms too rapidly over recent decades and has an EffCS that appears too high compared to energy budget constraints

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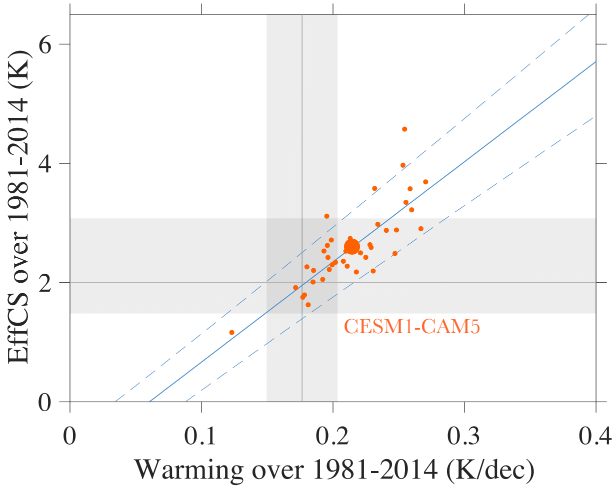

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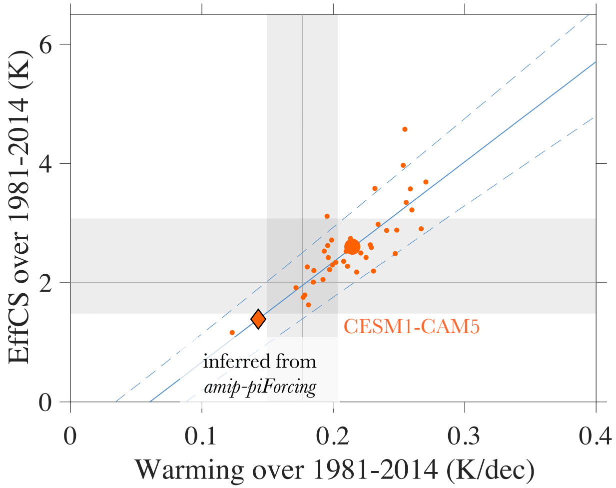

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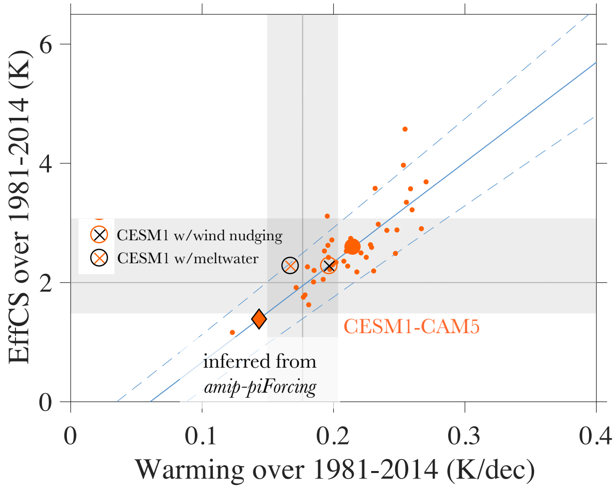

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CESM1 nudged toward observed SST trend pattern with Antarctic meltwater or southern hemisphere wind nudging produces a lower global warming rate

Armour et al. (submitted)

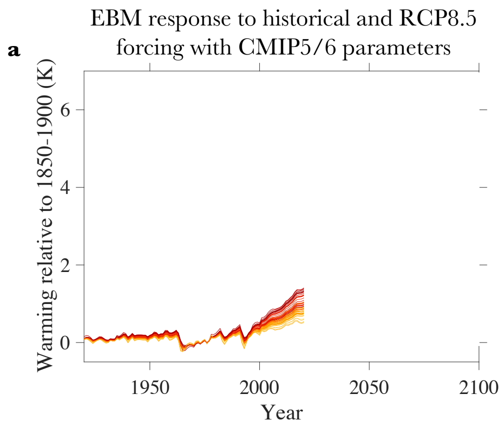
Key takeaways so far

- The observed warming pattern since ~1980 has been unique, and CMIP5/6 models are not able to replicate its key features

- The pattern implies low effective climate sensitivity (EffCS) over this period, even in models with high ECS. This lower EffCS implies slower global warming (relative to what it could have been had the pattern been more uniform)
    - CMIP5/6 models likely overestimate global warming over recent decades because they fail to replicate its spatial pattern (not because they have too-high values of ECS)

- Fundamental issue: multiple potential mechanisms project onto the same pattern of historical SST pattern trends, yet all have different future evolutions
    - e.g., low-frequency internal variability, Antarctic meltwater and teleconnections to the tropics, southern hemisphere atmospheric circulation trends, response to aerosol or CO_2 forcing…

How does the pattern effect impact future warming?



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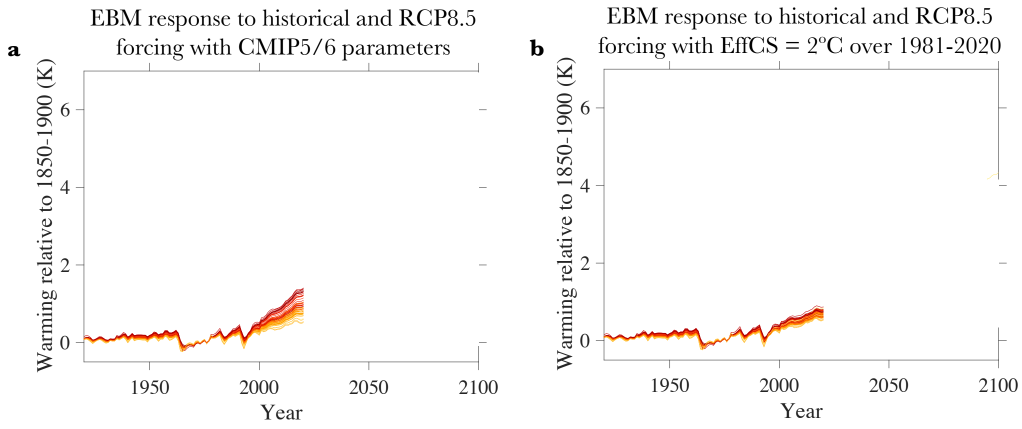

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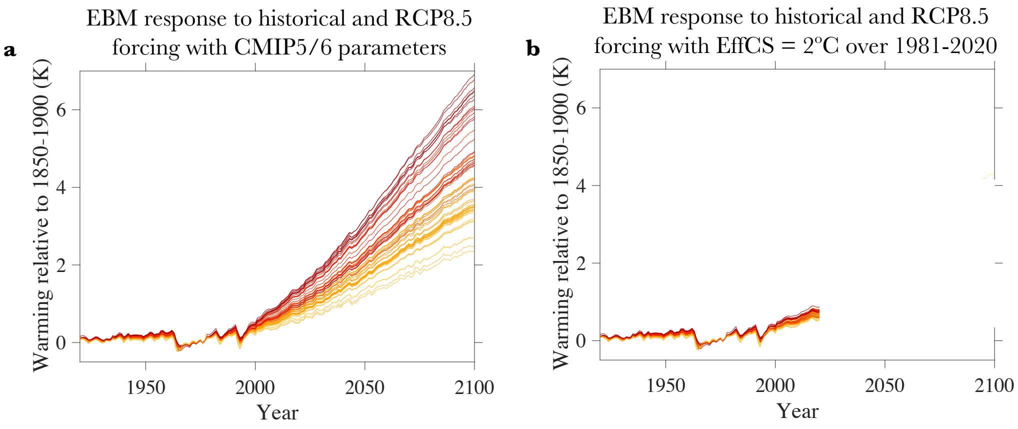

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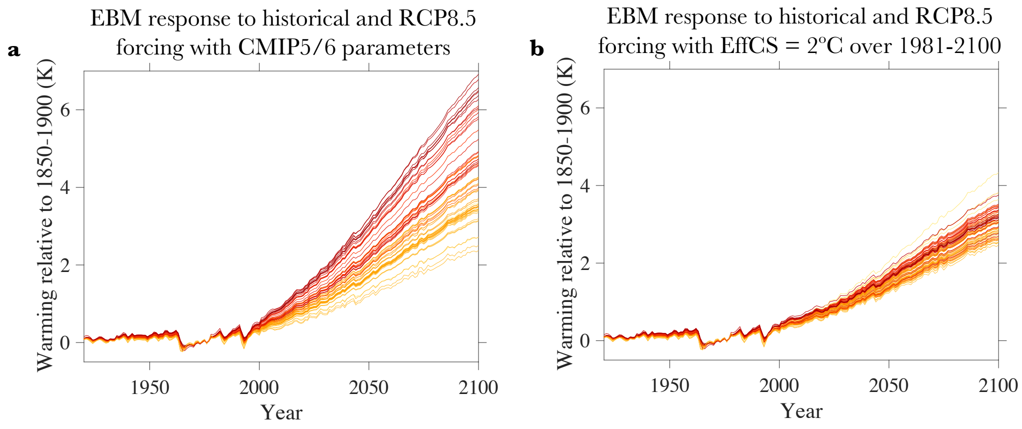

SST trend pattern since ~1980 continues indefinitely

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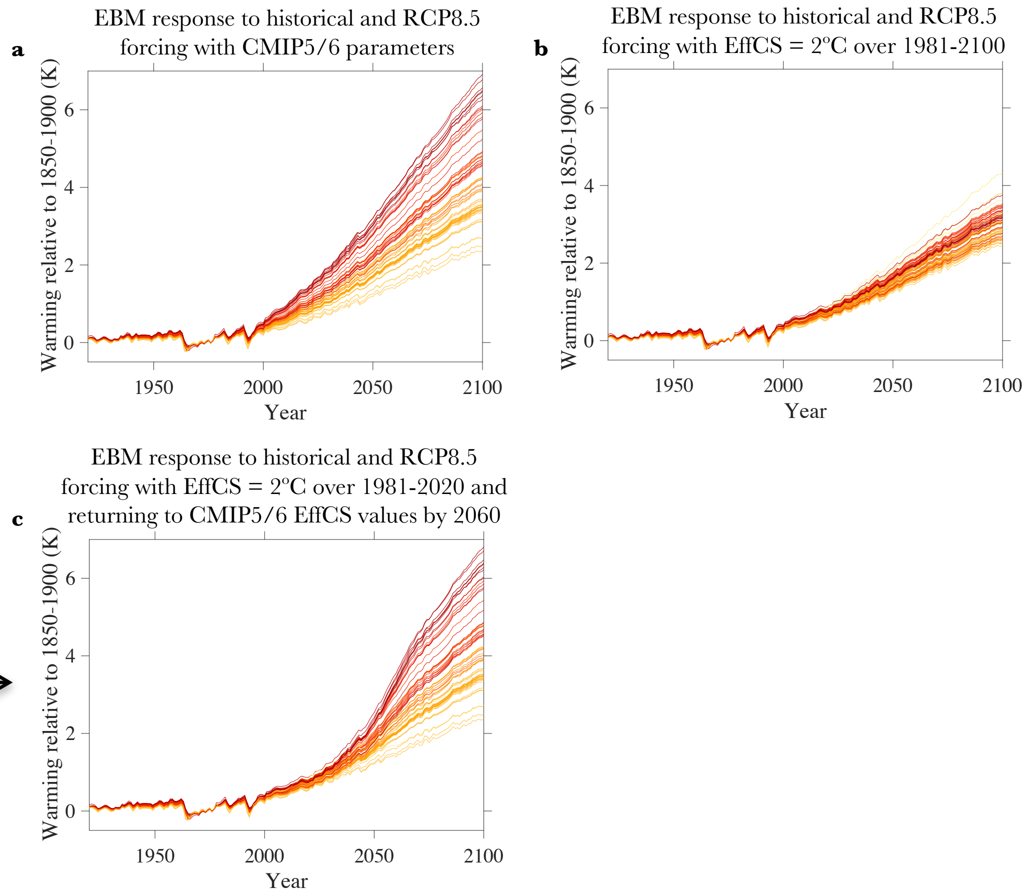

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SST trend pattern relaxes to CMIP5/6 patterns by 2060

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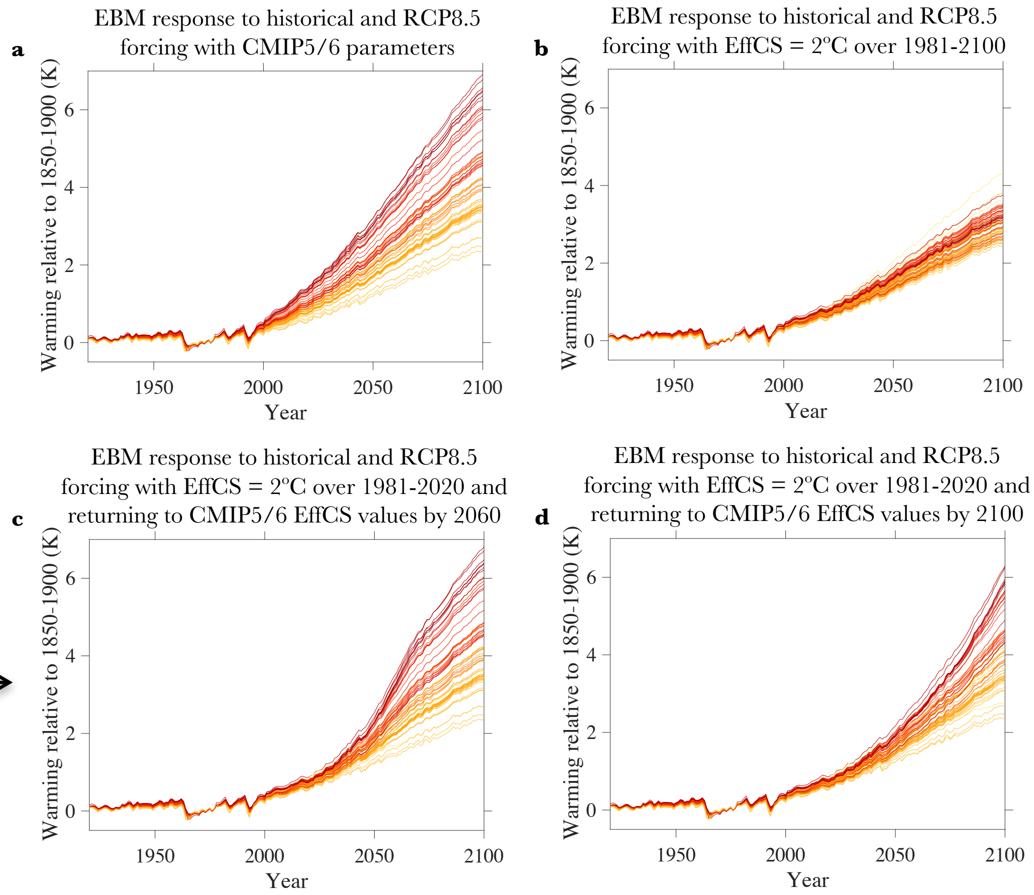

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SST trend pattern relaxes to CMIP5/6 patterns by 2100

Parting thoughts

- The unique Pacific Ocean sea-surface temperature trend pattern has likely slowed global-mean warming since ~1980
- Future warming will depend on how the pattern of warming evolves, and on what timescale… which in turn depends on what has driven the historical pattern
  - This is a major source of uncertainty in climate prediction
  - Caution is needed when devising model weighing schemes or "emergent constraints" based on historical warming

Our recent papers

- Armour, Proistosescu, Dong, Hahn, et al.: Sea-surface temperature pattern effects have slowed recent global warming and biased emergent constraints on climate sensitivity, submitted
- Dong, Pauling, Sadai, Armour (2022) Antarctic ice-sheet meltwater reduces transient warming and climate sensitivity through the sea-surface temperature pattern effect. *Geophysical Research Letters*, 49, e2022GL101249, doi: 10.1029/2022GL101249
- Wills, Dong, Proistosecu, Armour, Battisti (2022) Systematic climate model biases in the large-scale patterns of recent sea-surface temperature and sea-level pressure change. *Geophysical Research Letters*, 49, e2022GL100011, doi: 10.1029/2022GL100011
- Andrews, Bodas-Salcedo, Gregory, Dong, Armour, Paynter, et al. (2022). On the effect of historical SST patterns on radiative feedback. *Journal of Geophysical Research: Atmospheres*, 127, e2022JD036675. doi: 10.1029/2022JD036675
- Dong, Armour, Battisti, Blanchard-Wrigglesworth (2022) Two-way teleconnections between the Southern Ocean and the tropical Pacific via a dynamic feedback, *Journal of Climate*, 35, 2667–2682, doi: 10.1175/JCLI-D-22-0080.1