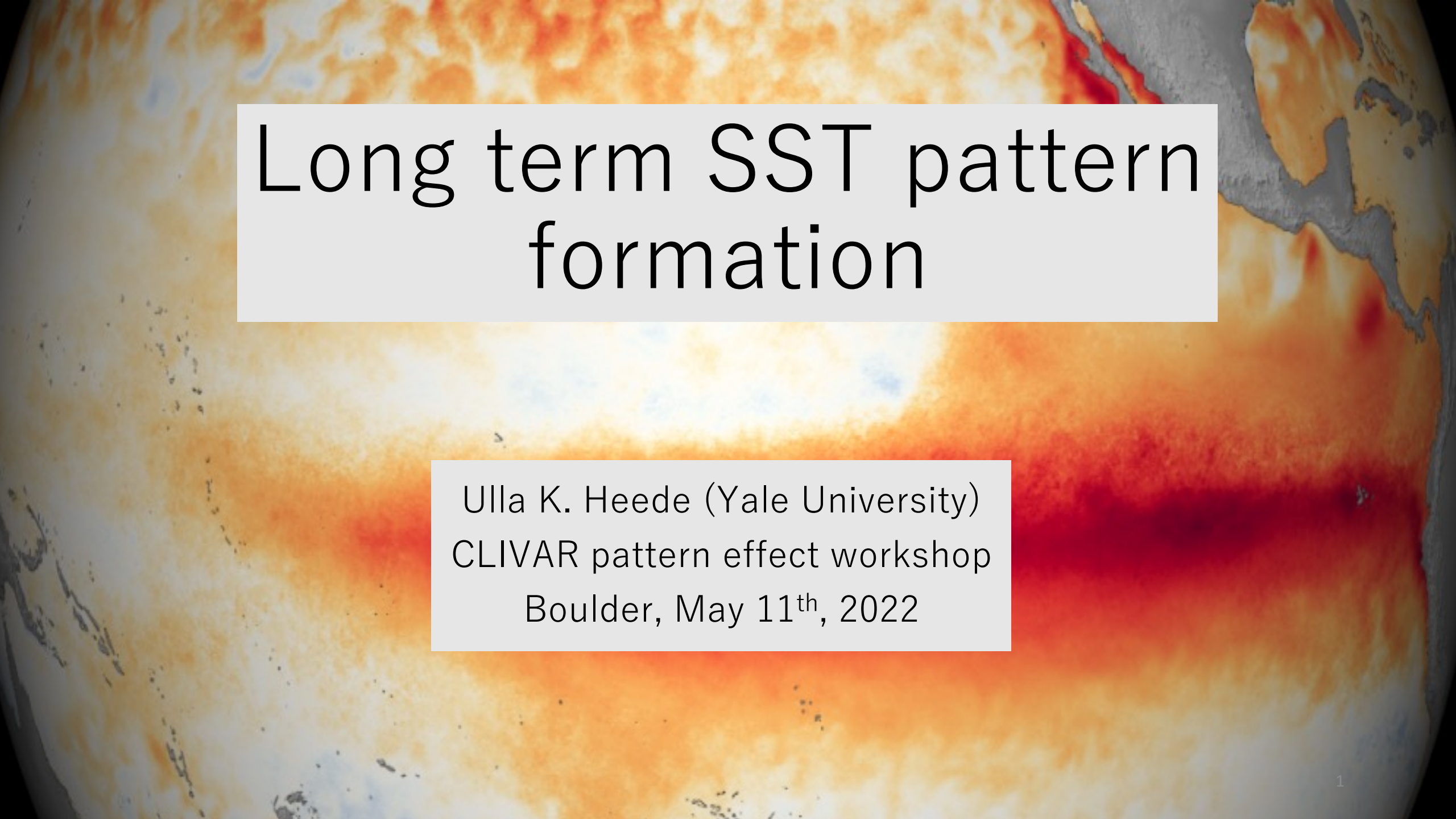


Long term SST pattern formation

Ulla K. Heede (Yale University)

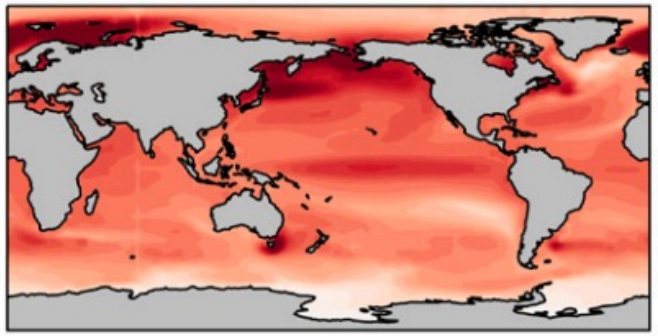
CLIVAR pattern effect workshop

Boulder, May 11th, 2022

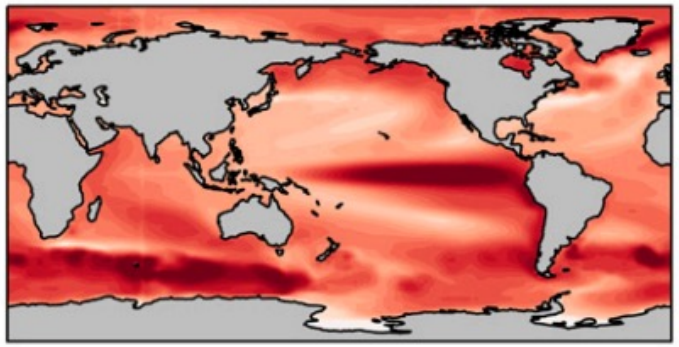
The main warming patterns in climate models

CMIP6

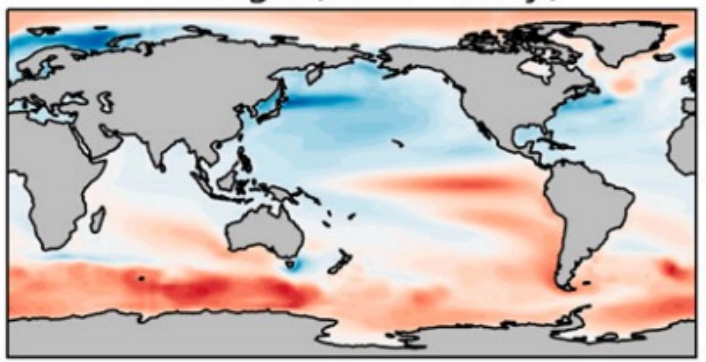
b. Yrs 1-20



e. Yrs 21-150



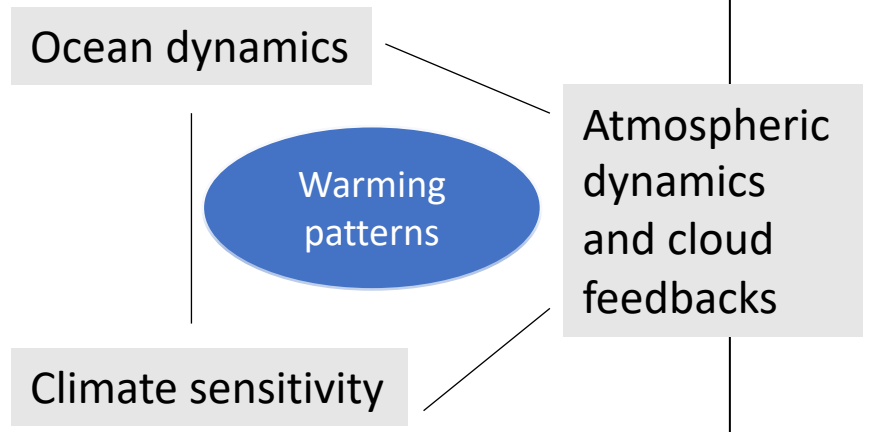
h. Change (late - early)



Dong et al., 2020

Overview

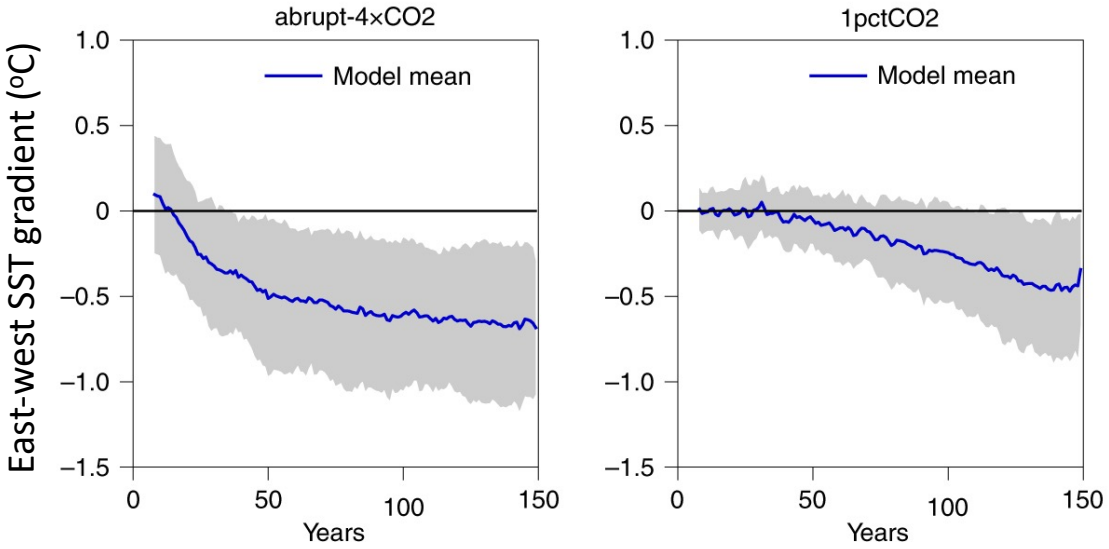
- What are the main long term patterns in CMIP6?
- The Pacific:
  - Enhanced tropical eastern Pacific warming
  - Shift in the North Pacific warming
- The Southern Ocean: delayed warming
- The North Atlantic: The warming hole



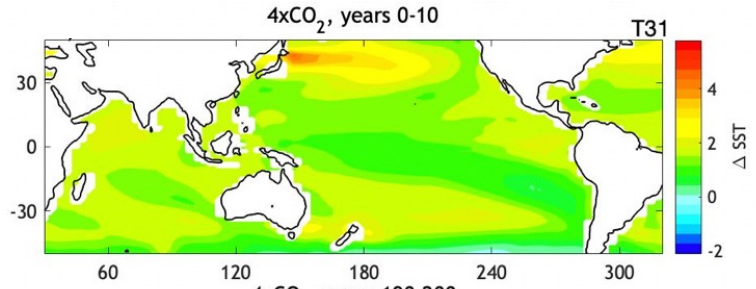
The tropical Pacific

- Mechanisms of formation: The ocean thermostat vs Weaker Walker

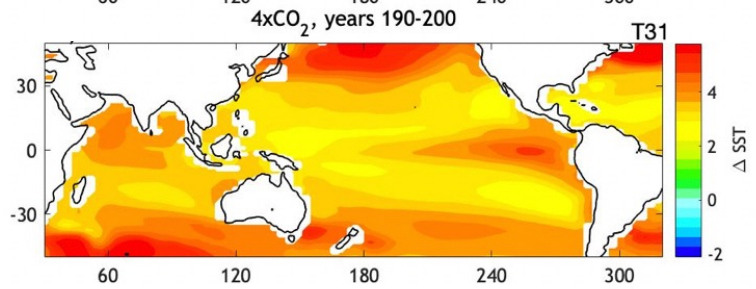
CMIP6 models



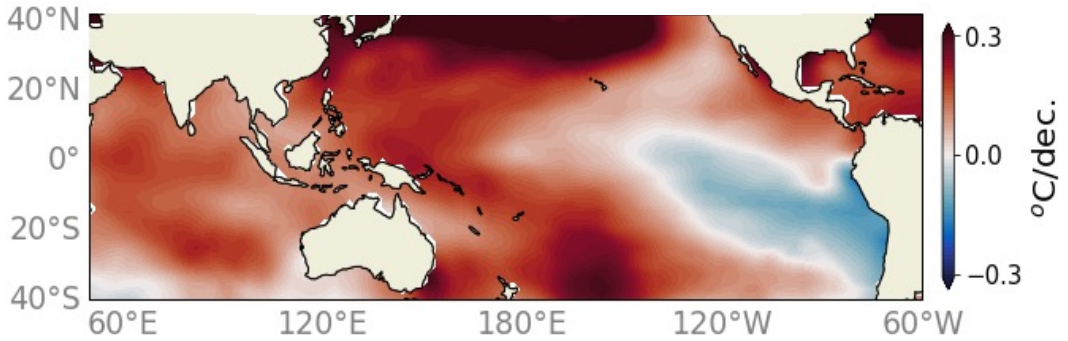
Transient cooling



Long term warming

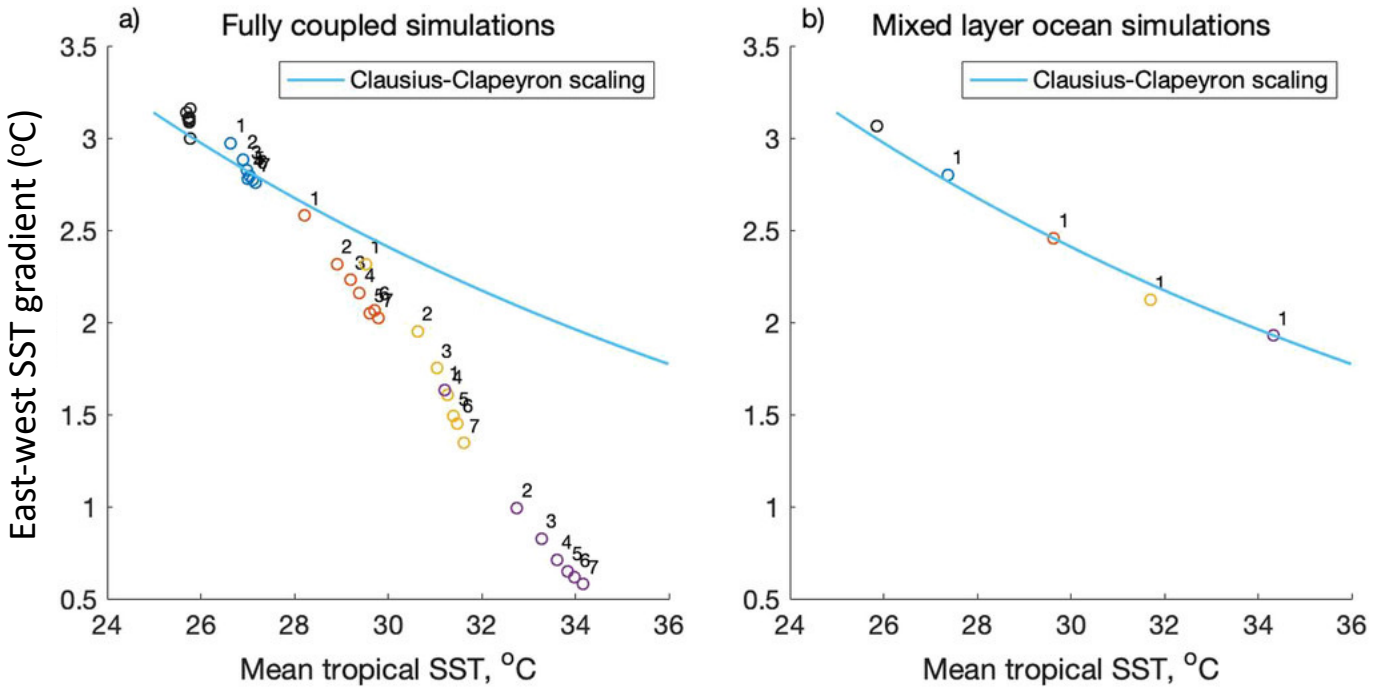


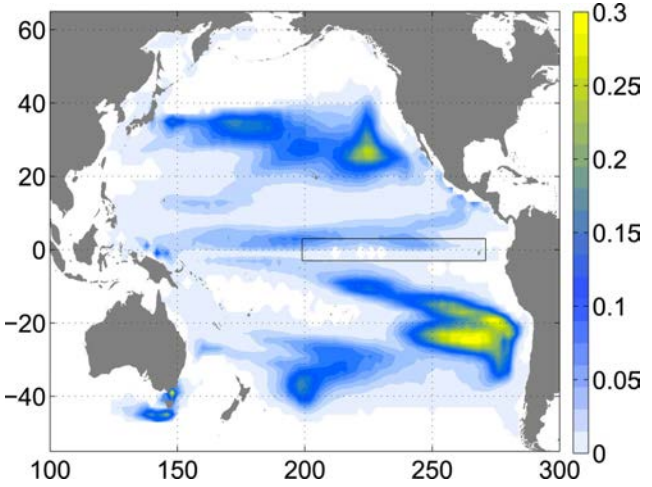
Observed SST trend since 1980



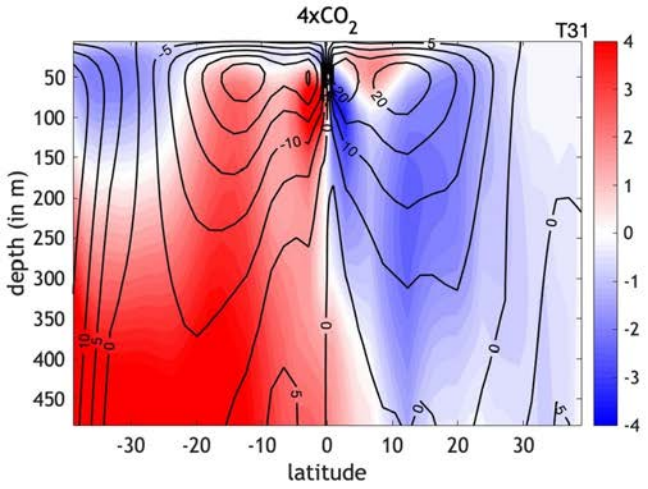
Heede et al., 2021, Heede and Fedorov, 2021, Heede and Fedorov, 2021 [in prep.]

Ocean and atmospheric mechanisms driving eastern Pacific warming





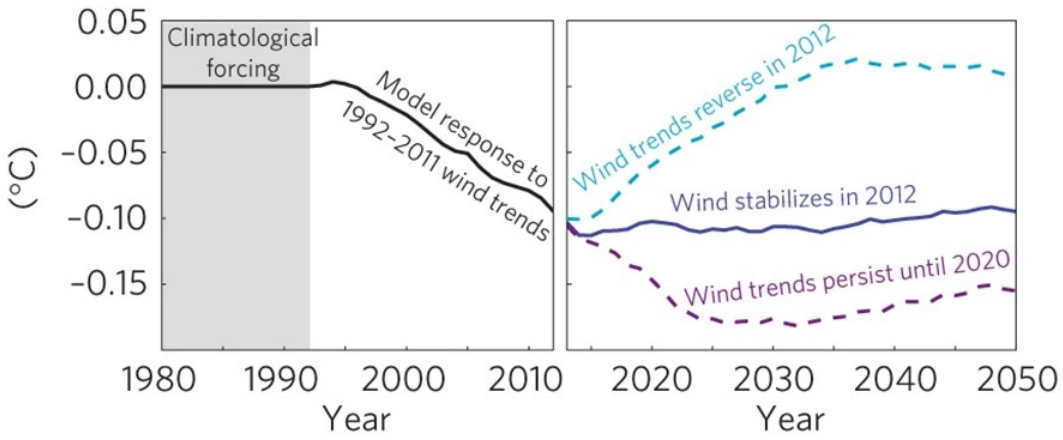
Source water for eq. upwelling

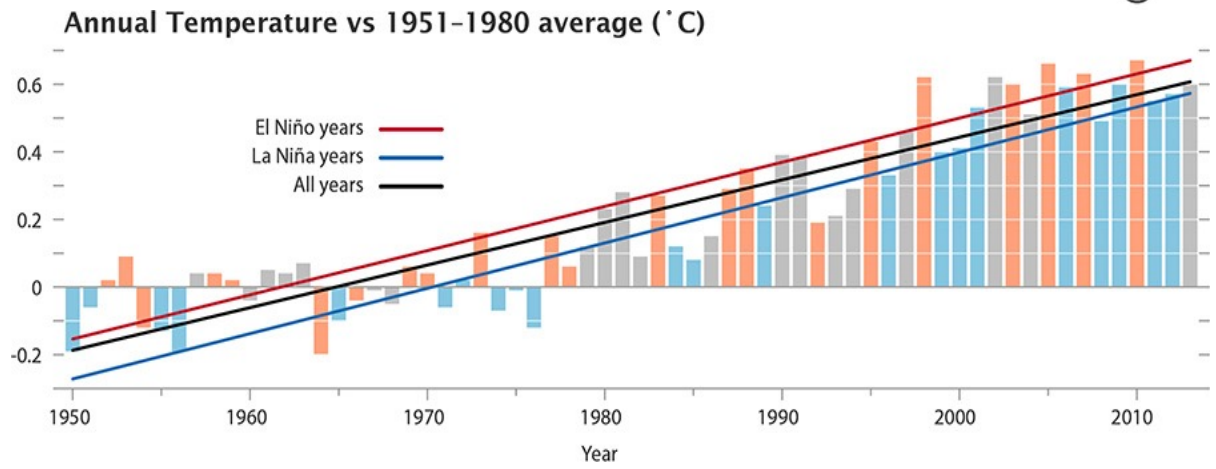


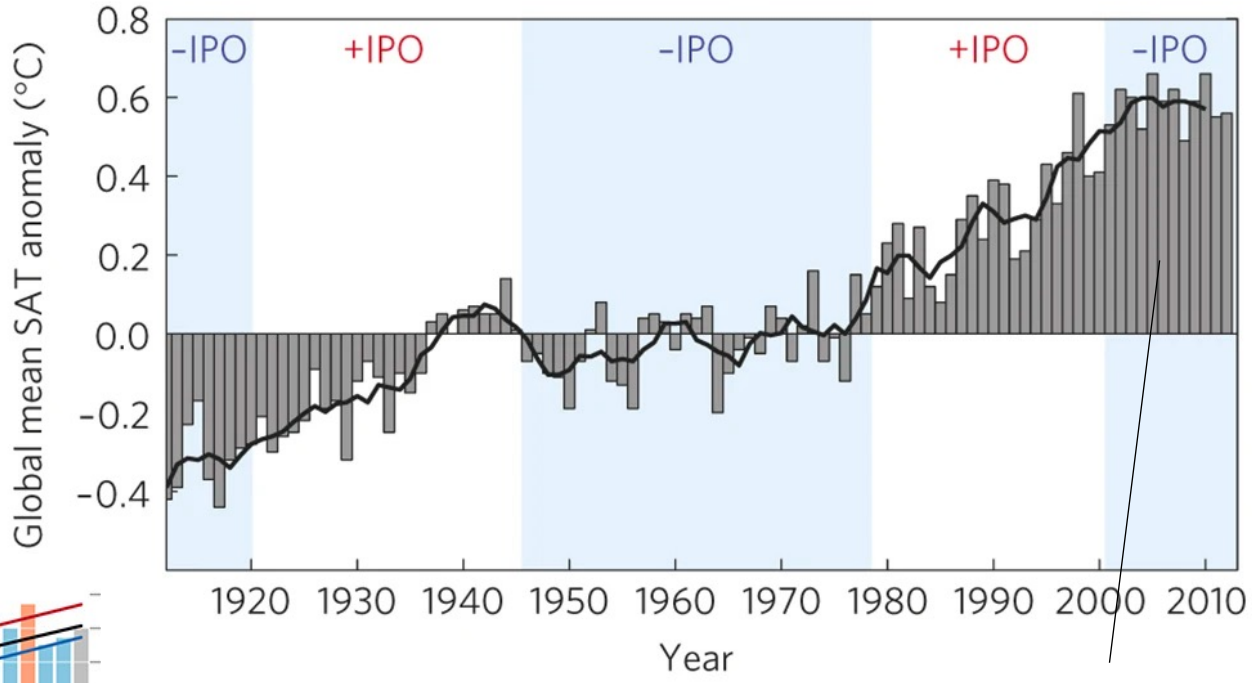
Ocean transport

Heede et al., 2020, Heede and Fedorov, 2021, Thomas and Fedorov, 2017

Lessons from the global warming hiatus and ENSO







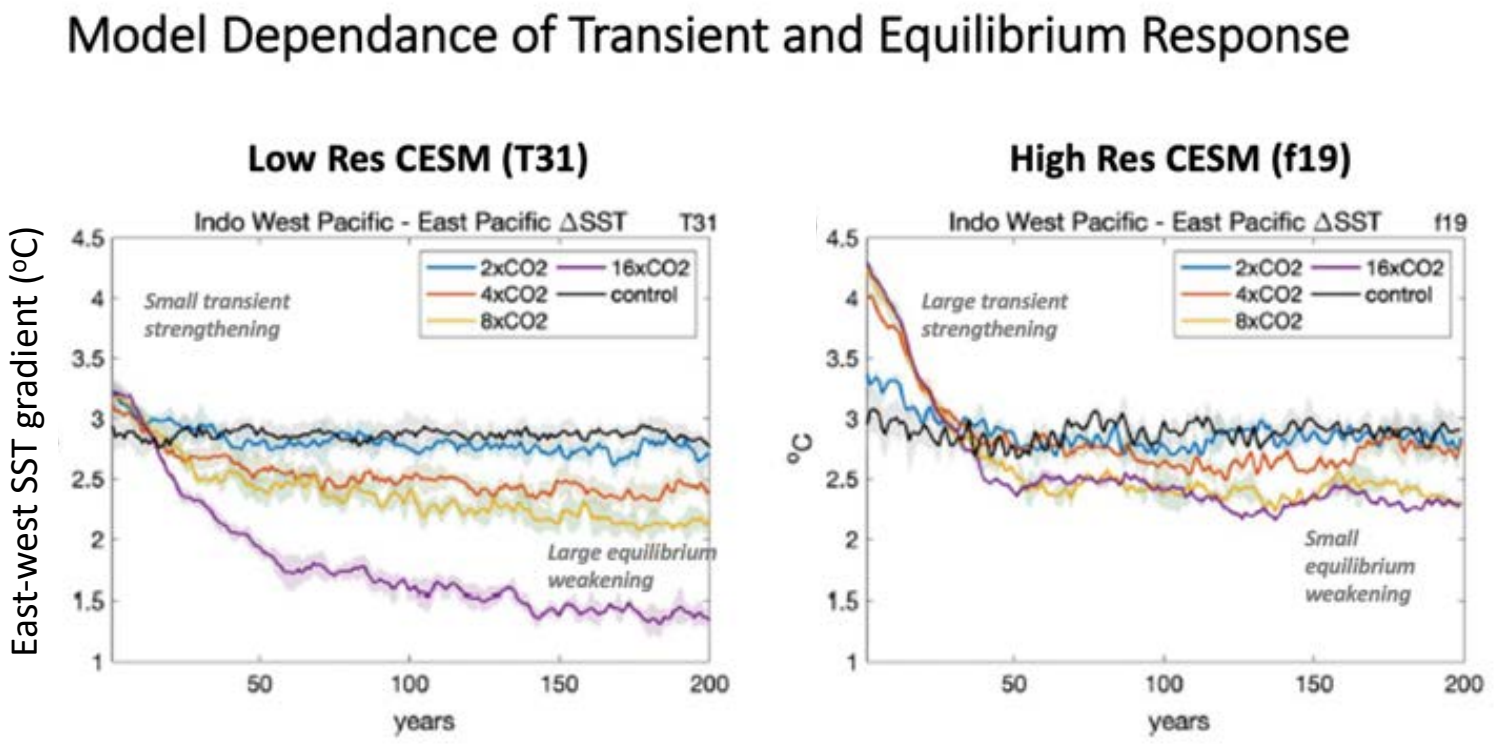
Stronger winds

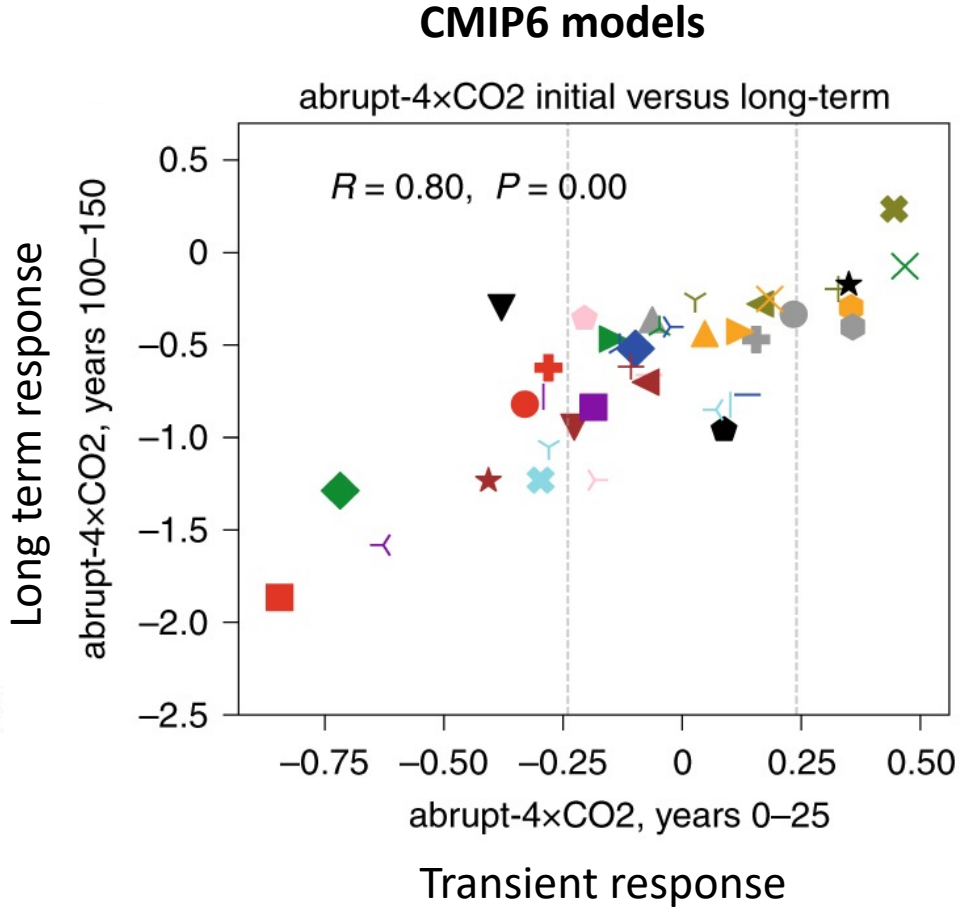
More upwelling

Less surface warming

England et al., 2014, NOAA

Model Intercomparison: a weak versus strong transient response

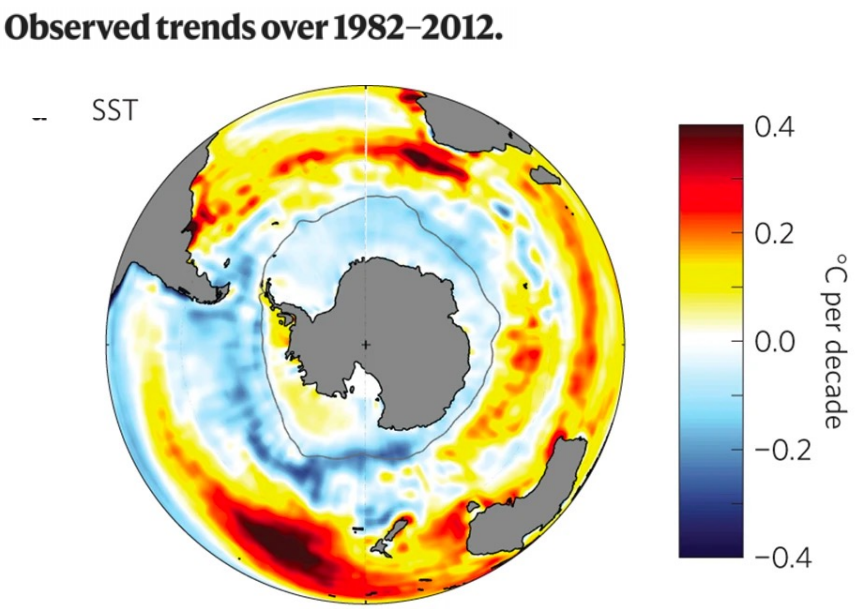


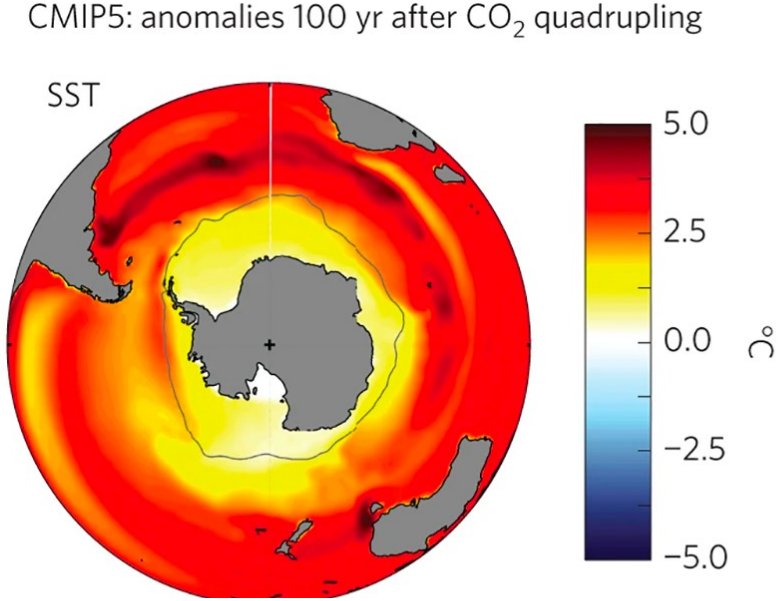


Heede et al., 2021, Heede and Fedorov 2021

The southern ocean

- Mechanism of formation: Ocean heat uptake from Antarctic Circumpolar current
- Consequence for global warming: the southern ocean cloud feedbacks

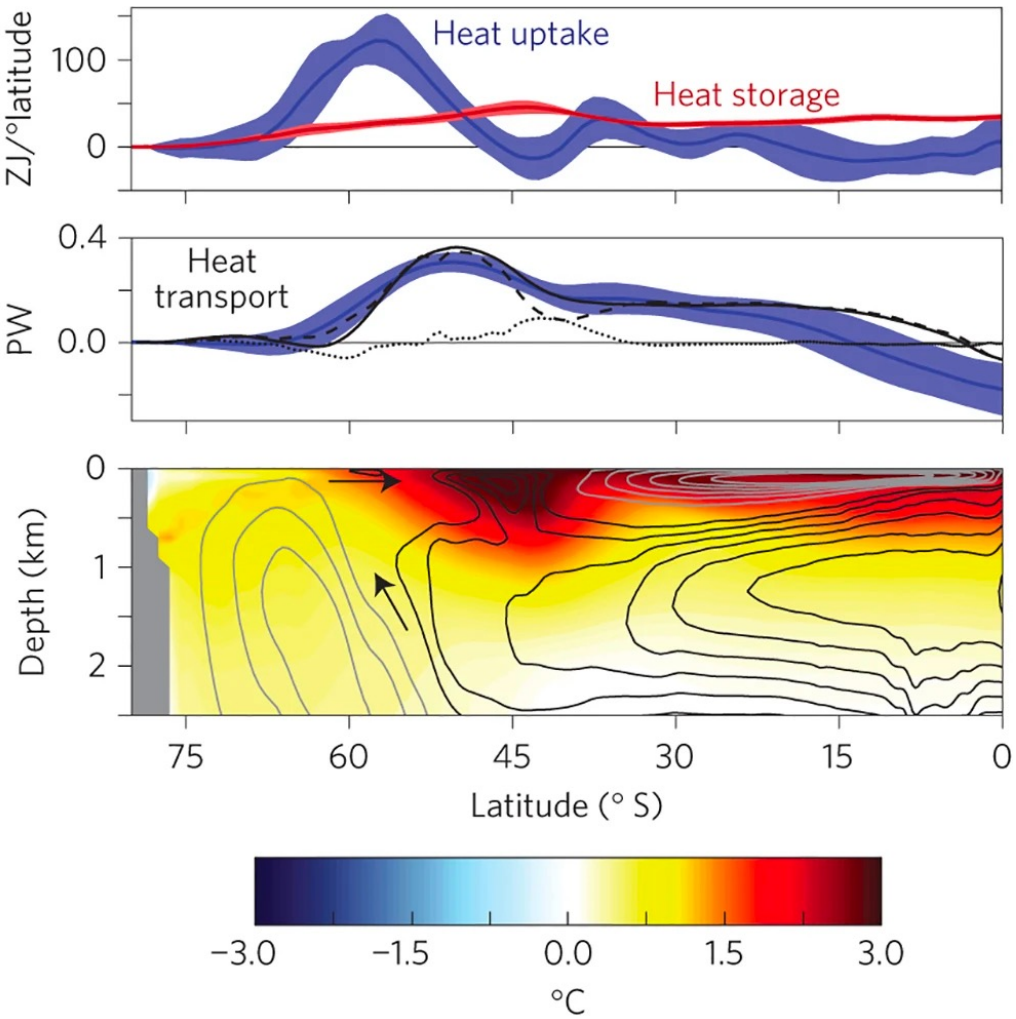




Armour et al., 2016

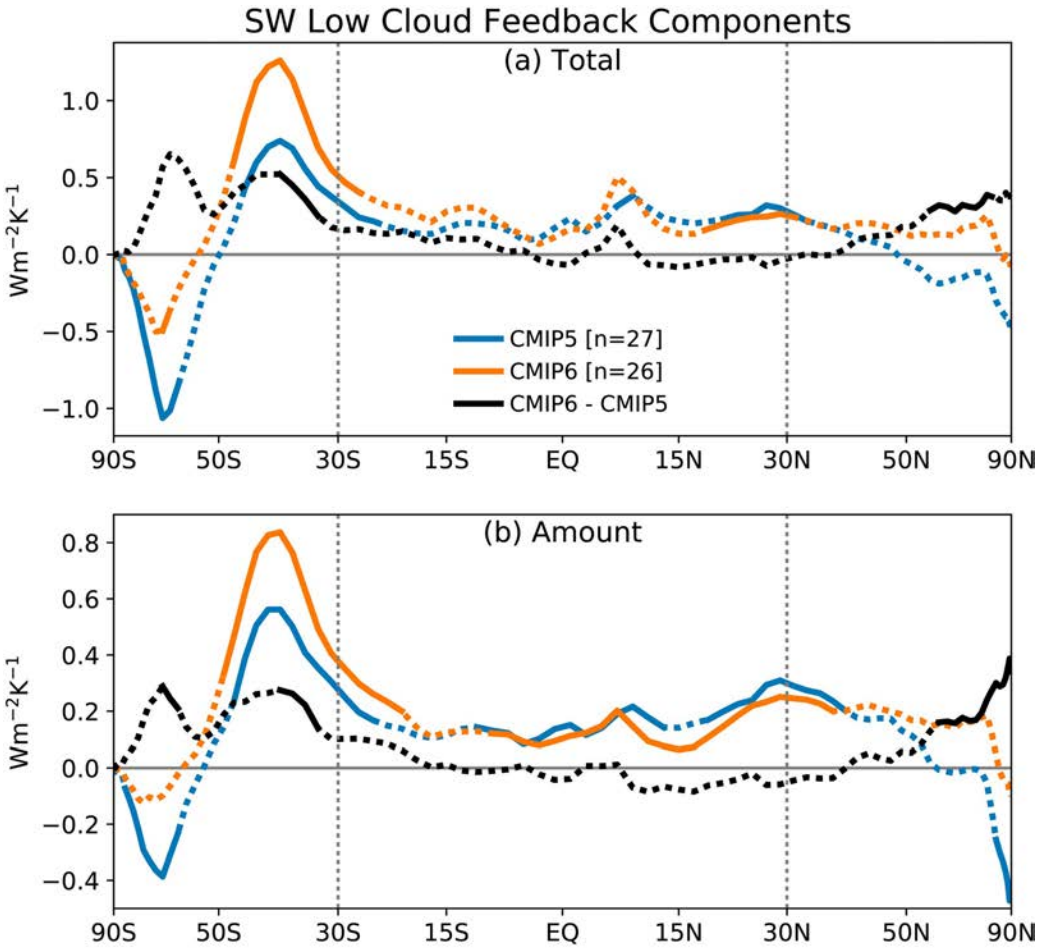
Why is Southern Ocean warming delayed?

Armour et al., 2016

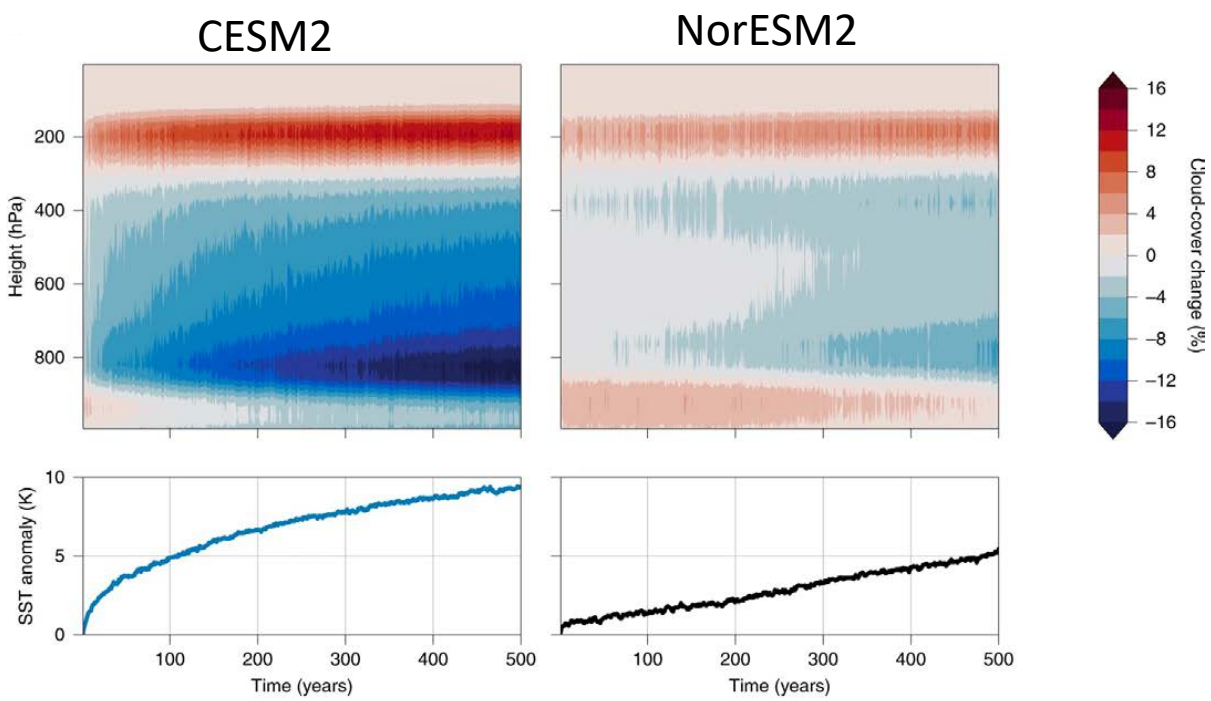


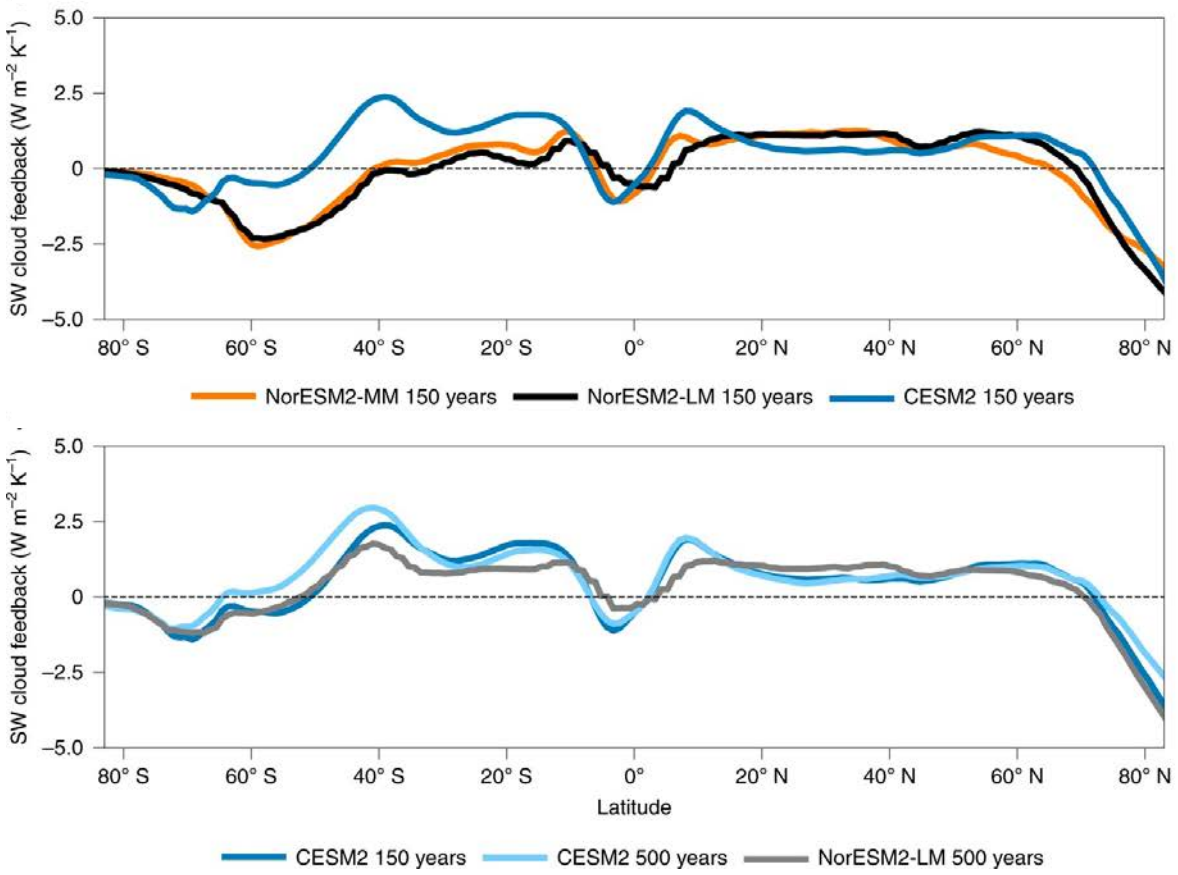
Why is it significant for climate sensitivity?

Zelinka et al., 2020



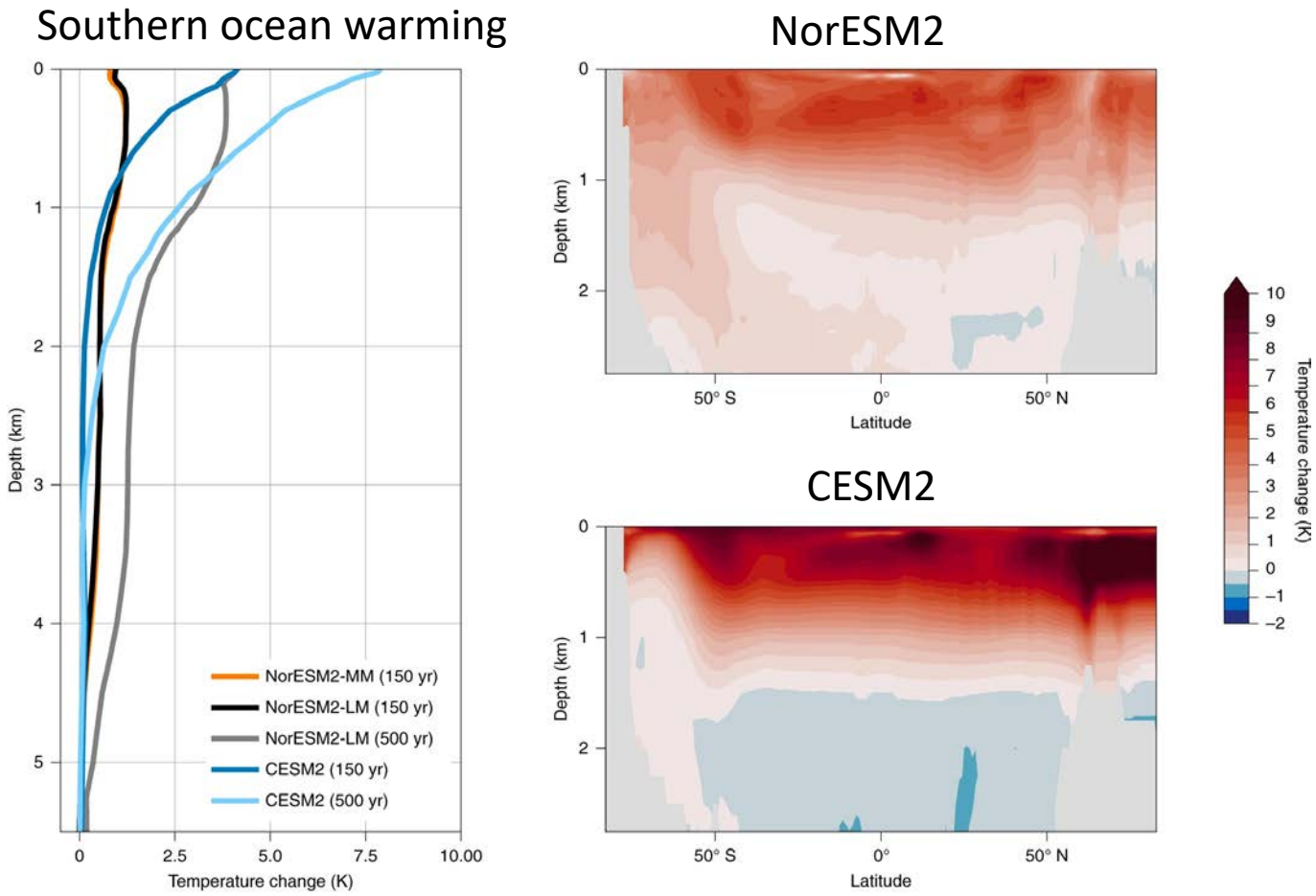
Model Intercomparison: Southern ocean heat uptake linked to cloud feedback strength





Gjermundsen et al., 2021

Model Intercomparison: Southern ocean heat uptake linked to cloud feedback strength

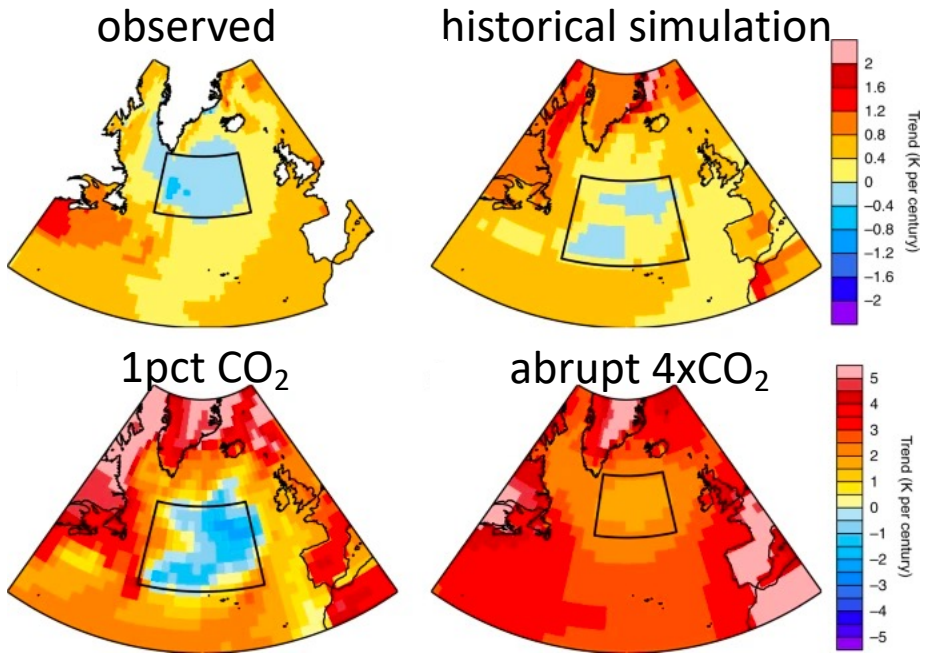


Gjermundsen et al., 2021

The Atlantic ocean

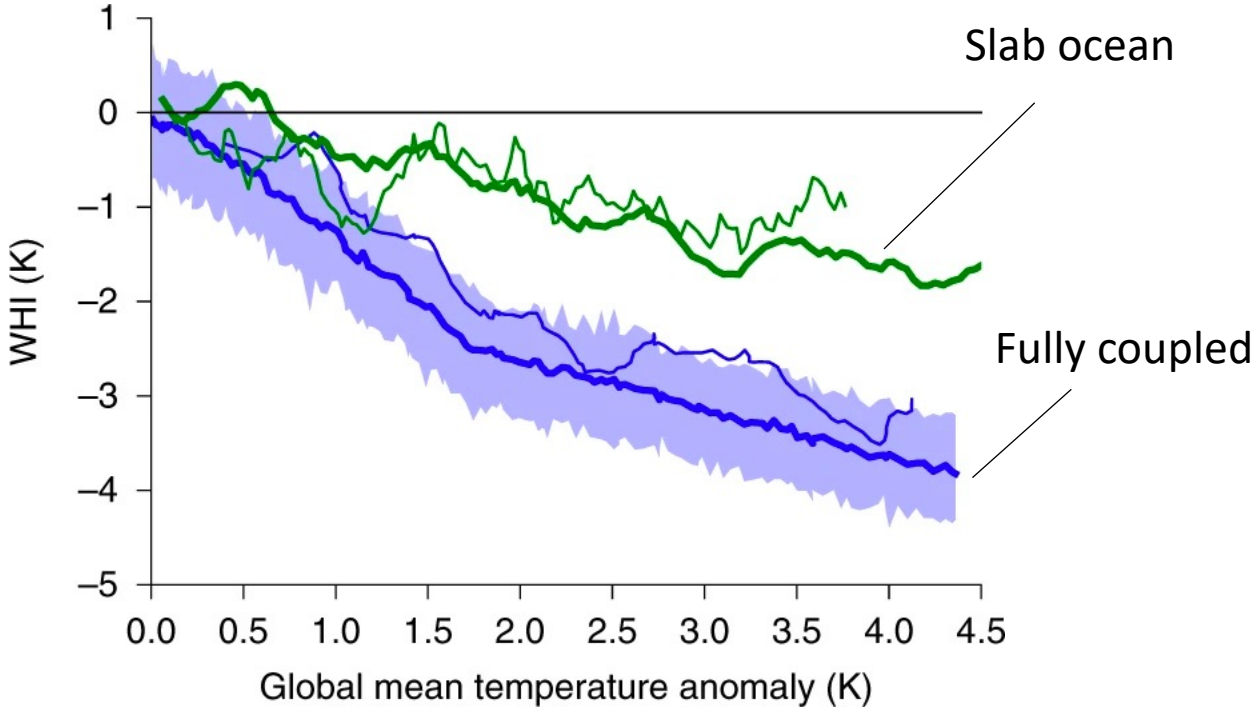
Mechanisms of formation:

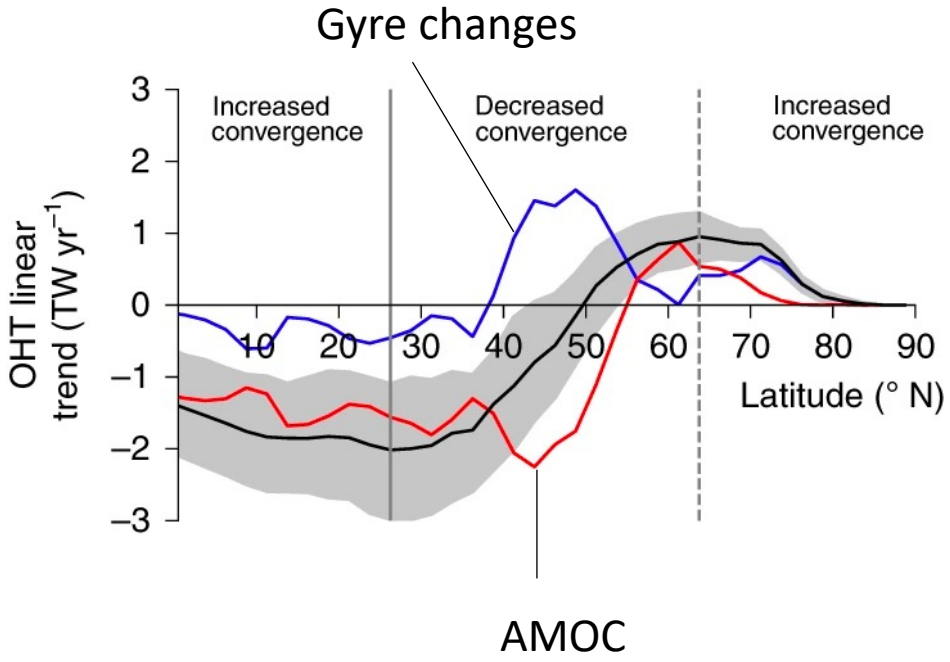
- Atmosphere: cloud feedbacks and Indian Ocean warming
- Ocean: AMOC slowdown and heat convergence



Keil et al., 2020

Drivers of the warming hole: changes in heat conversion and atmospheric feedbacks

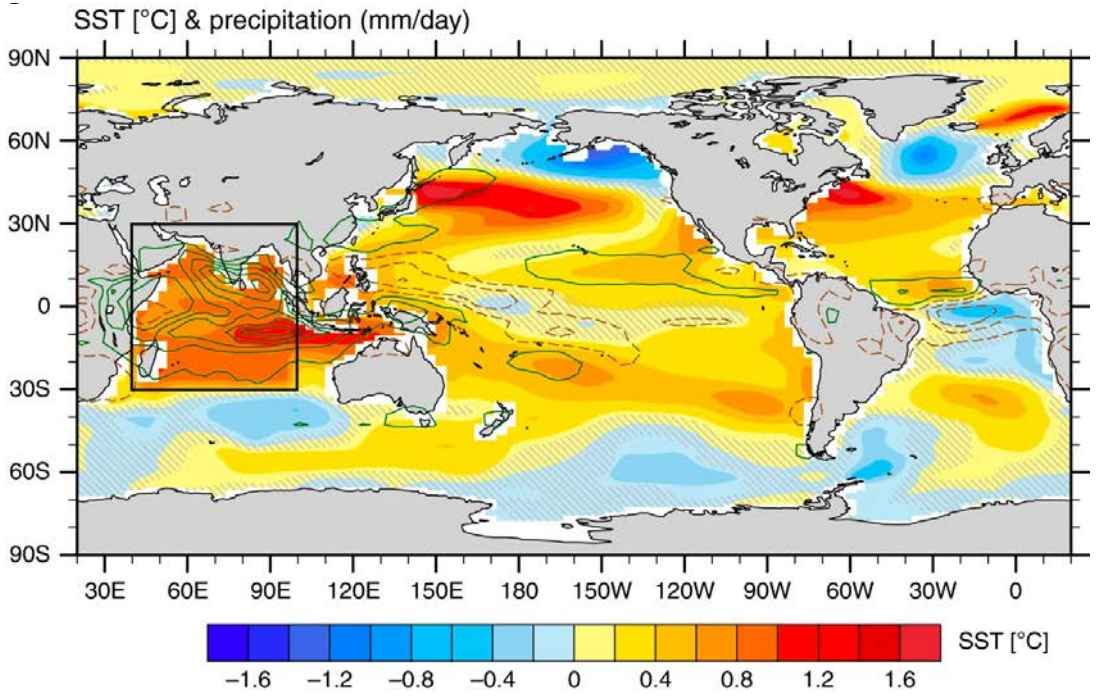


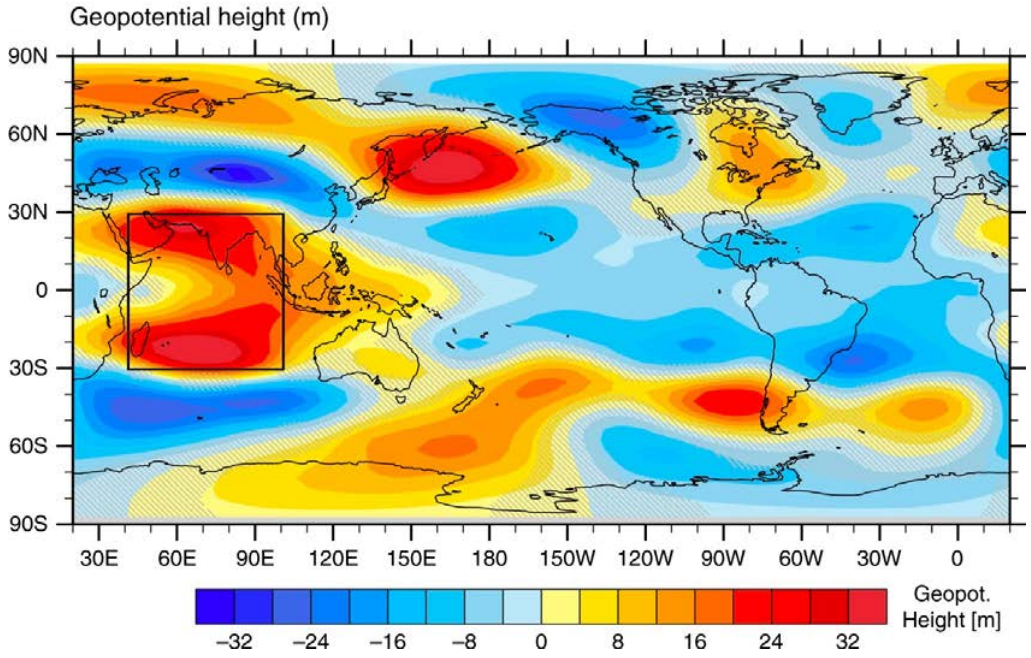


Keil et al., 2020

Drivers of the warming hole: Indian ocean warming

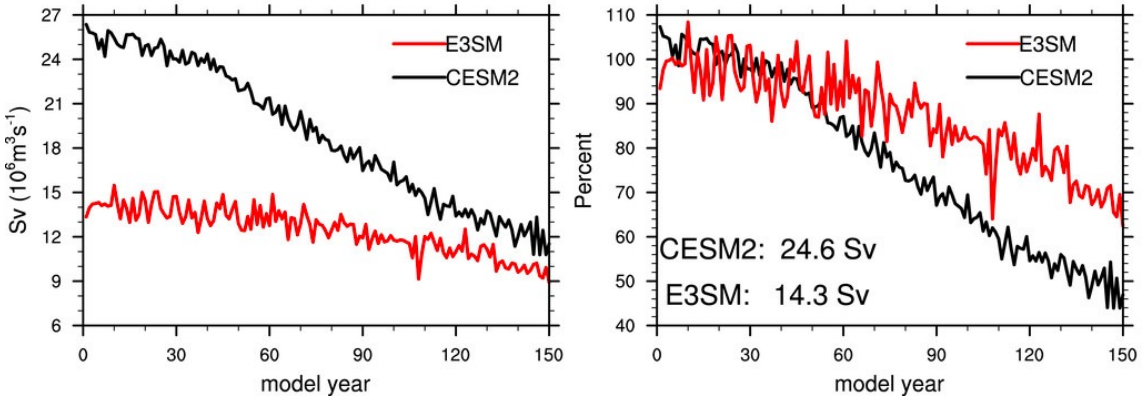
Results of a Indian Ocean warming experiment:

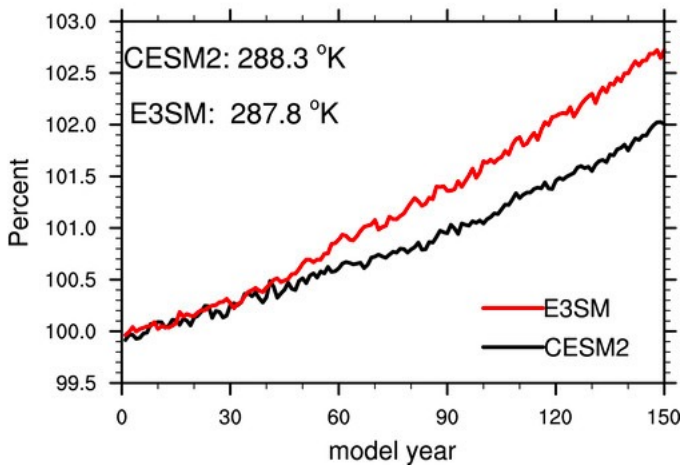


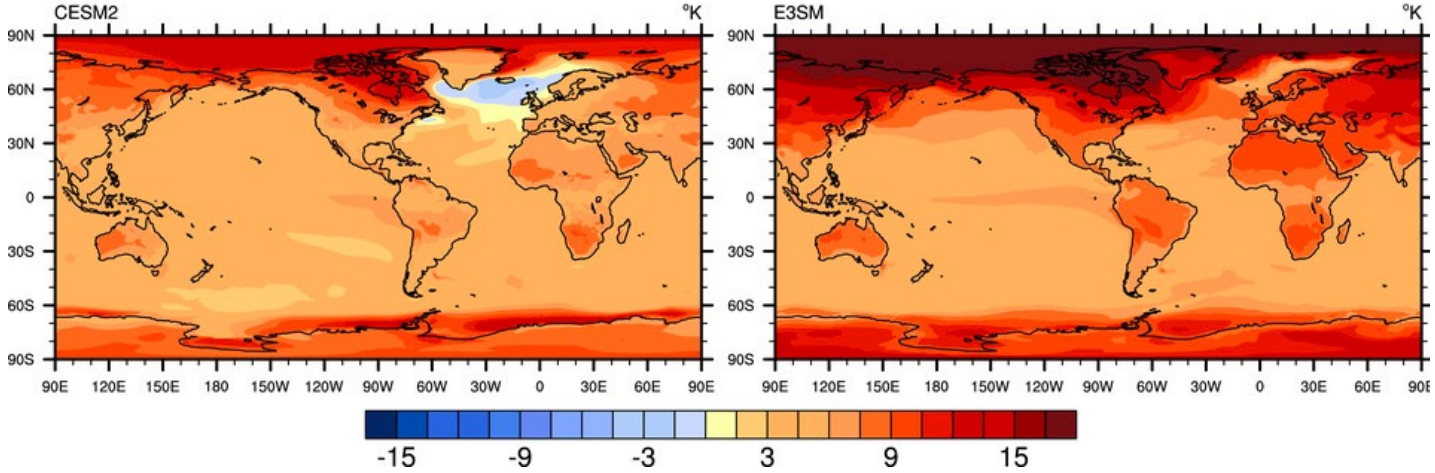


Hu and Fedorov, 2020

Climate model comparison: Consequences of warming hole for climate sensitivity







Hu et al., 2020

Summary

- The eastern Pacific warming is caused by atmospheric water vapor effects amplified by ocean dynamics
- It affects transient climate sensitivity via ocean upwelling

- The southern ocean delayed warming is caused by OHU and subsequent transport.
- The southern ocean warming rate is intertwined with SW cloud feedbacks

- The Atlantic Warming hole is caused by atmospheric circulation changes, cloud feedbacks, remote warming + gyre changes and eventual AMOC slowdown
- A largescale AMOC slowdown can reduce climate sensitivity due to the warming hole.

Open questions 1/2

- A delayed warming causing transient cooling (observed in Southern Ocean and Tropical Pacific) -> a common mechanism suggestion:

  Delayed warming –> surrounding areas warm faster -> increased surface temperature gradient -> **stronger winds** -> WES feedback + increased upwelling.

- Might delayed Southern Ocean warming and delayed Eastern Pacific warming be related?

  Stronger hemispheric temperature gradient -> stronger tropical winds?

Open questions 2/2

- **Model differences matter for warming patterns!** In each location, models disagree on magnitude of warming patterns and in turn climate sensitivity. How can we address this meaningfully to obtain more robust projections for the future?