Colder eastern equatorial Pacific and stronger Walker circulation in the past decades: an ocean thermostat vs natural variability in models and observations

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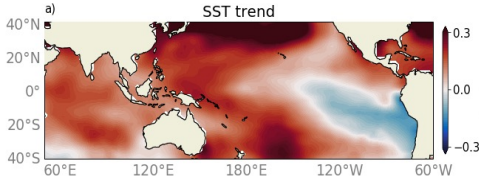
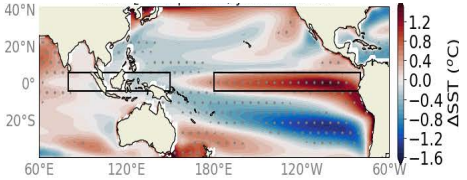


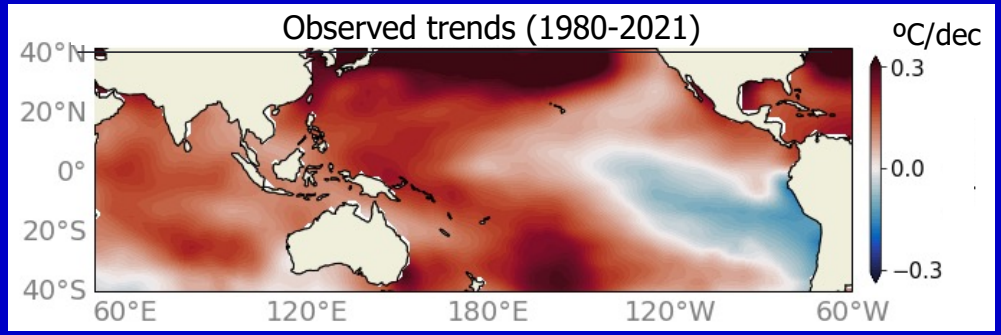


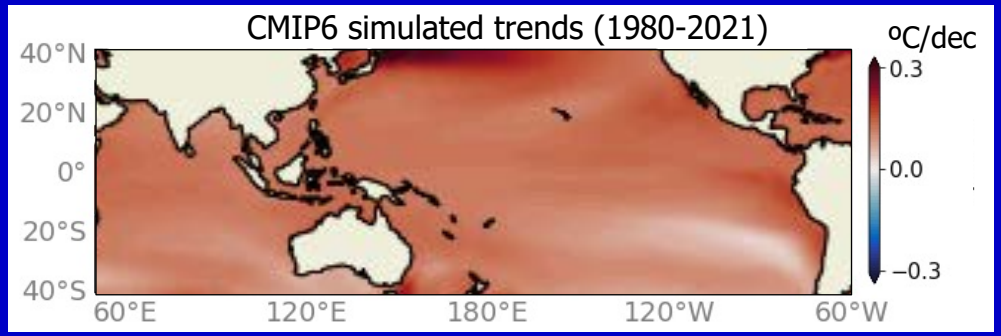
Boulder 2024

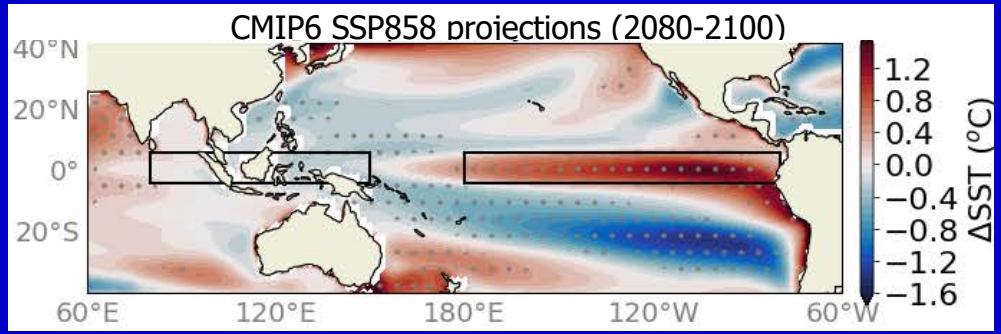
Observed trends of past 40 years

CMIP6 simulated historical trends

CMIP6 century-end projections



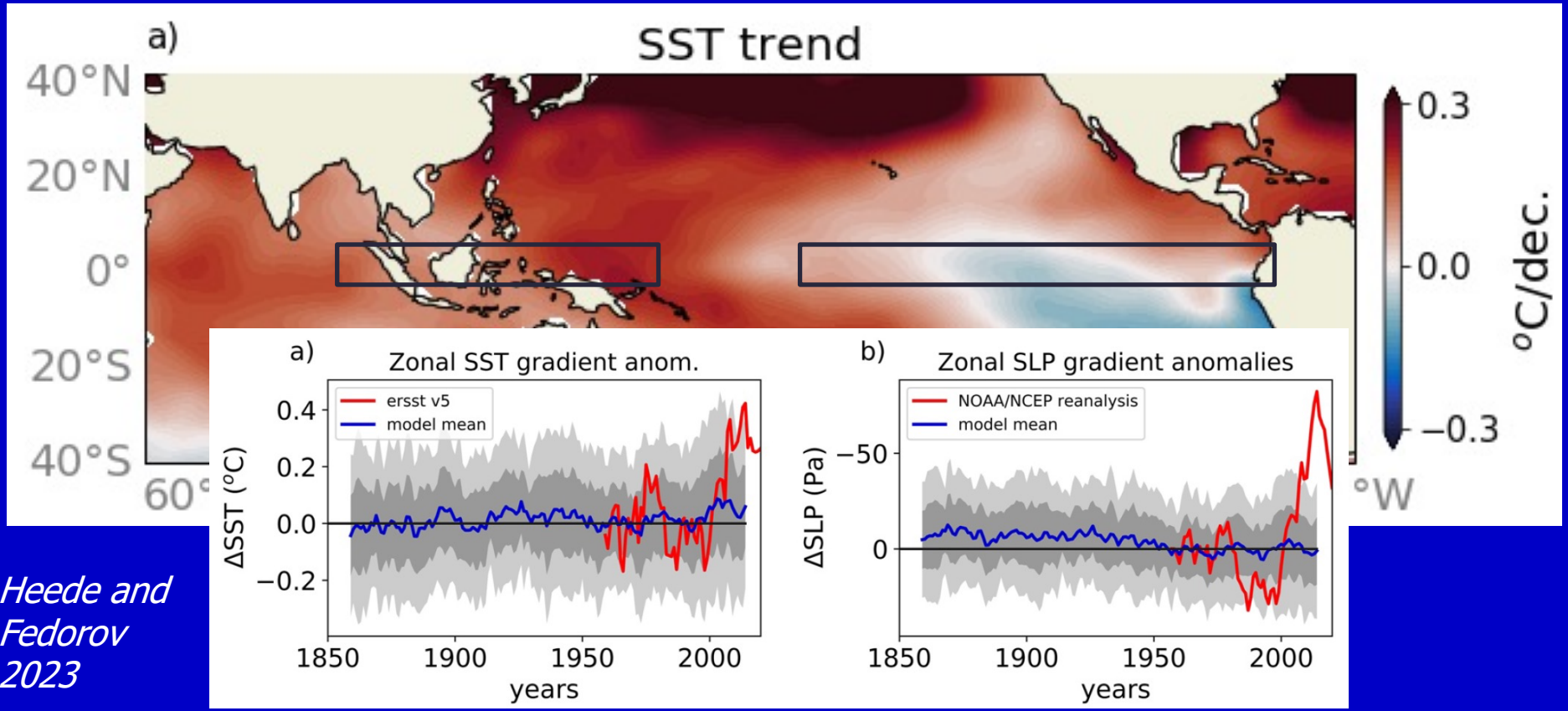




Heede and Fedorov 2021, 2023; Li et al. 2023

Also, Wills et al. 2022; Dong et al. 2022; Kang et al. 2023…

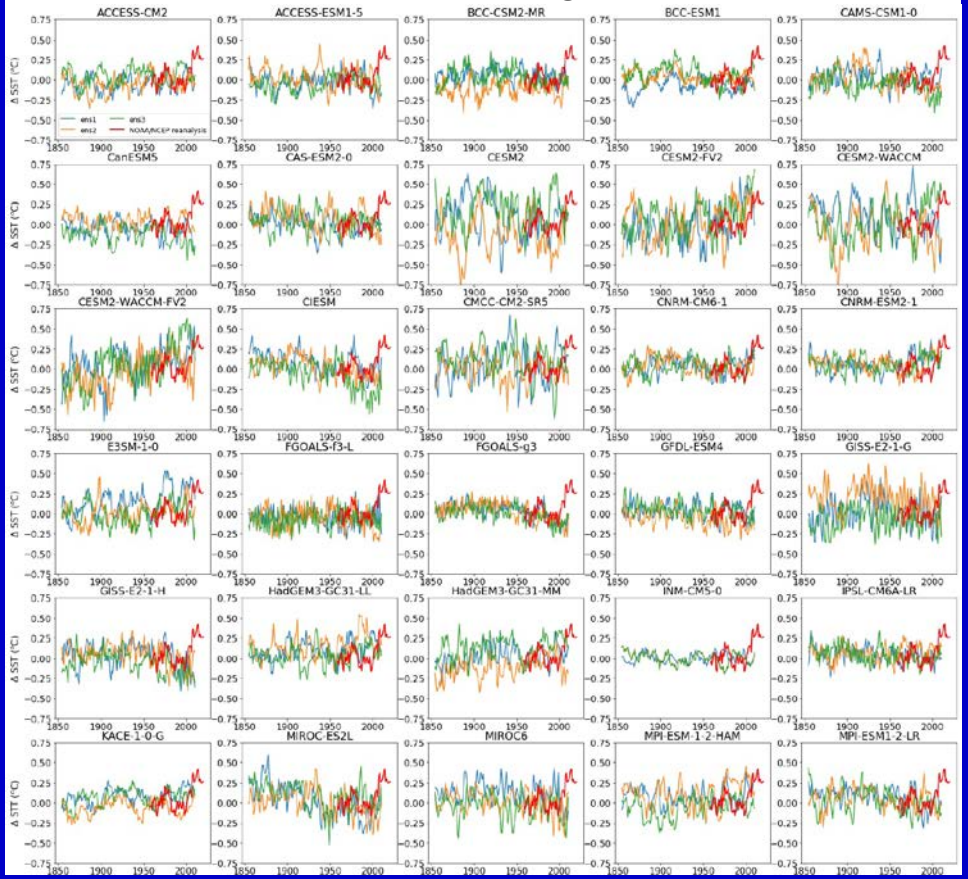
SST trends (1980-2020):
Stronger east-west SST gradient and stronger Walker circulation



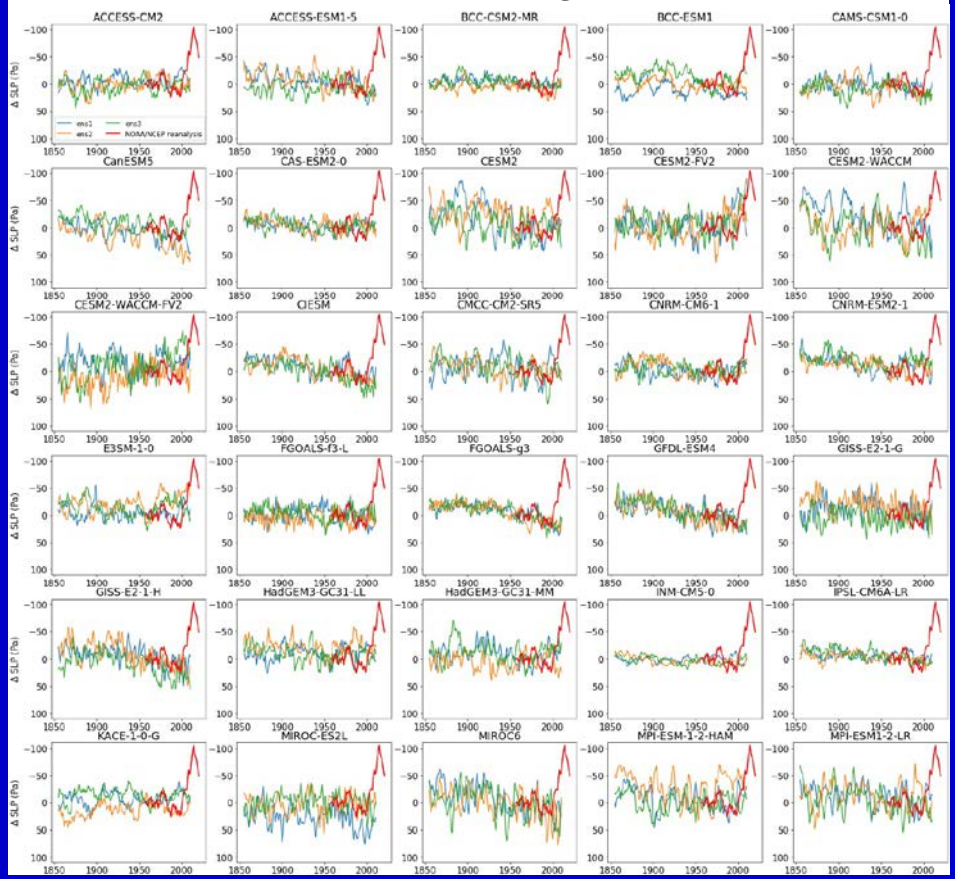
Heede and Fedorov 2023

Observations (red) versus CMIP6 historical simulations

East-west SST gradient

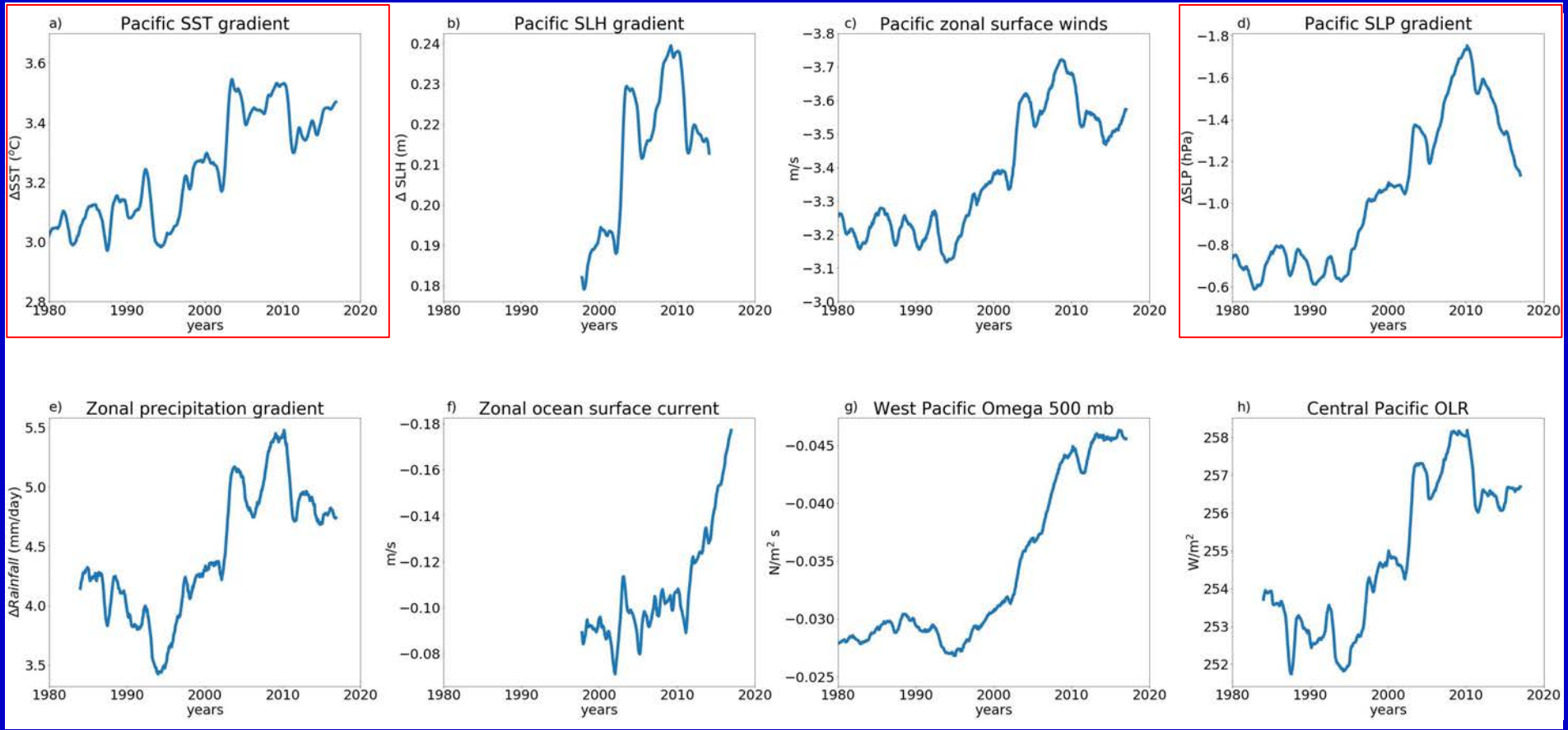


East-west SLP gradient



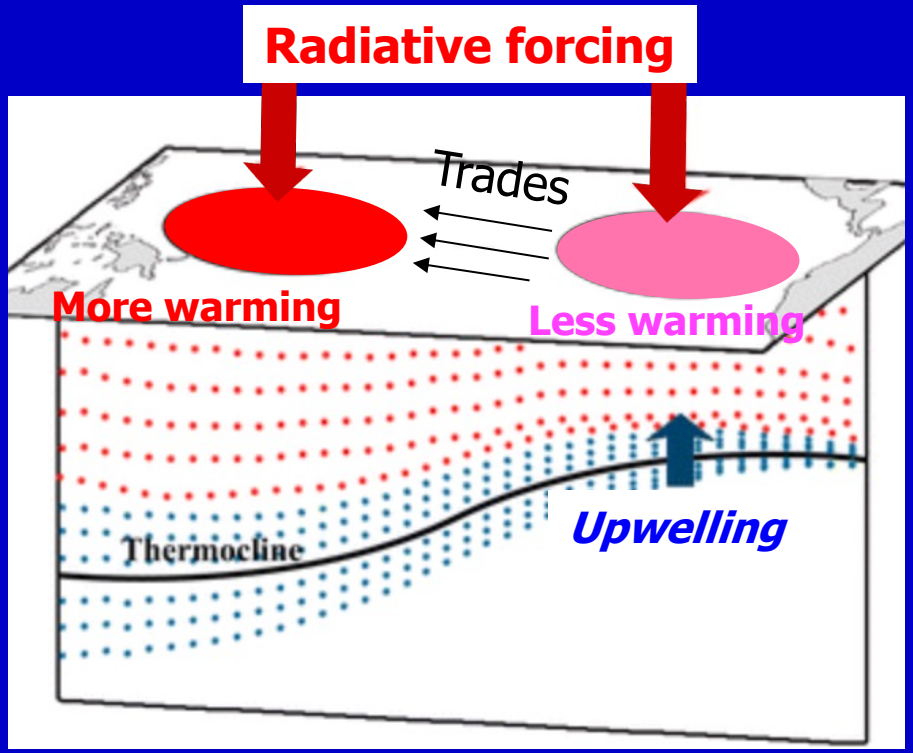
Heede and Fedorov 2023

Observed strengthening of the Walker circulation: different metrics



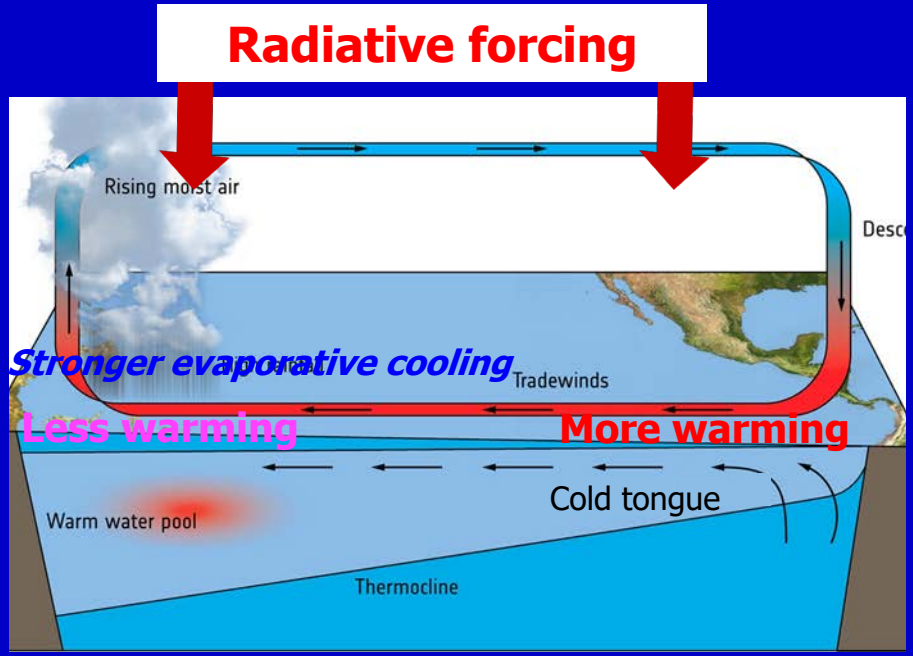
Heede and Fedorov 2022

Ocean Thermostat (OT)



Clement et al1996; Sun and Liu 1996; More recently Seager et al. 2019; Heede et al. 2020; 2021: Heede and Fedorov 2021, 2023; ***OT is transient!***

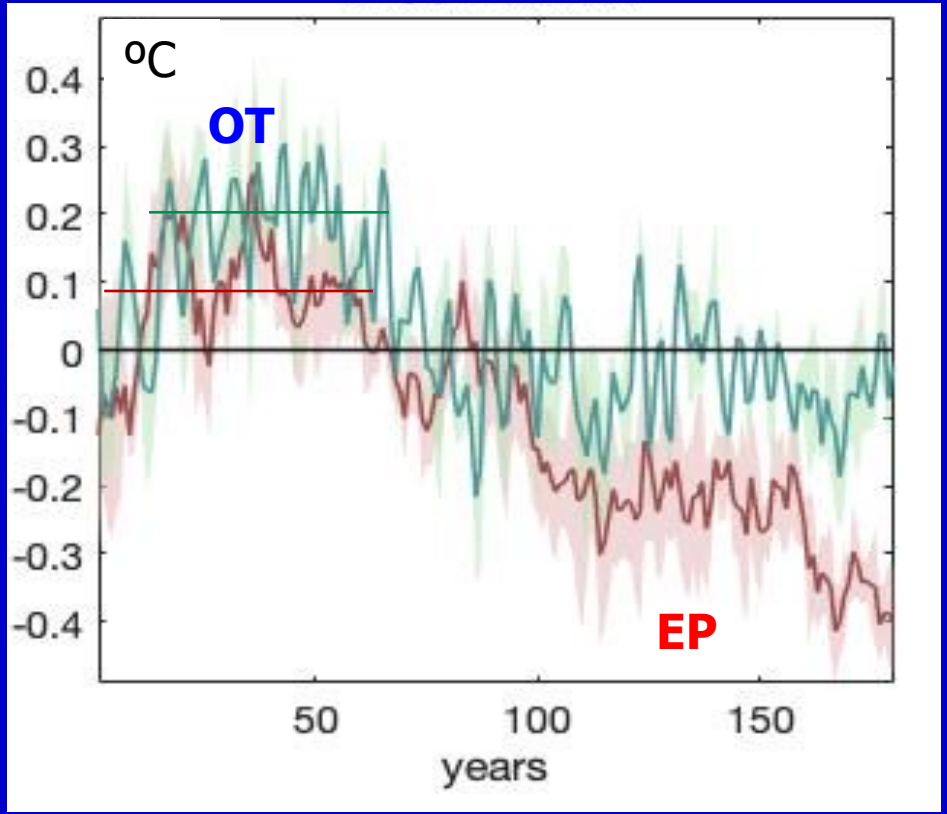
Weaker Walker cell (EP warming)



Knutson and Manabe 1995, Xie et al. 2010; Merlis and Schneider 2011; Held and Soden 2007, Vecchi et al. 2006; Burls and Efani 2019; Heede and Fedorov 2021, 2023;

Changes in east-west SST gradient in 1pct/year CO_2 experiments

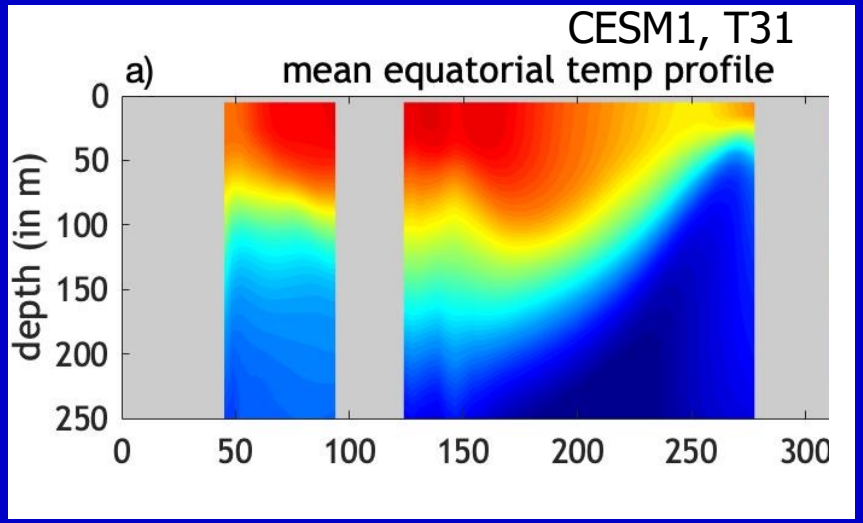
Transient ocean thermostat (OT) vs longer-term Eastern Pacific warming (EP)



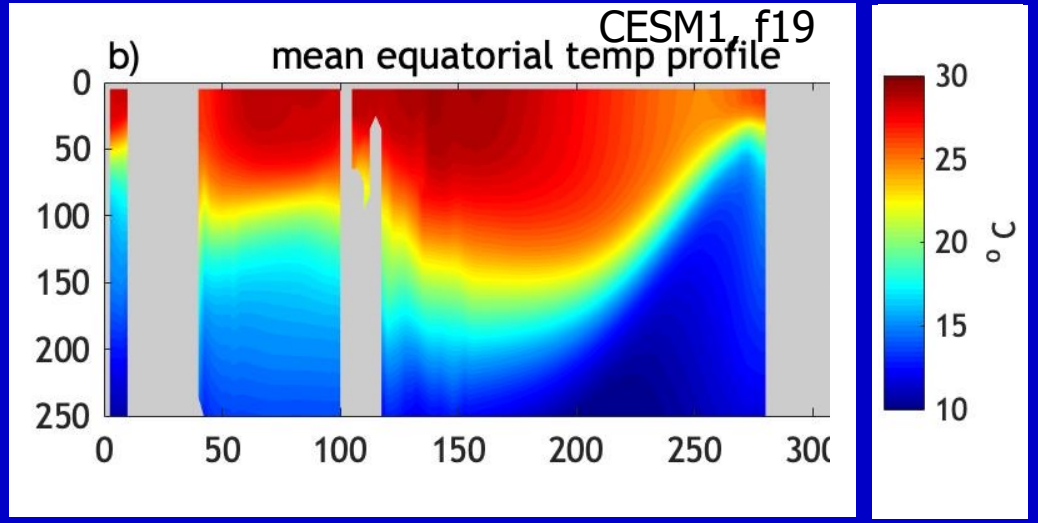
Heede, Fedorov, Burls 2021

The strength of OT vs EP response depends on the structure of the equatorial thermocline

Weak OT



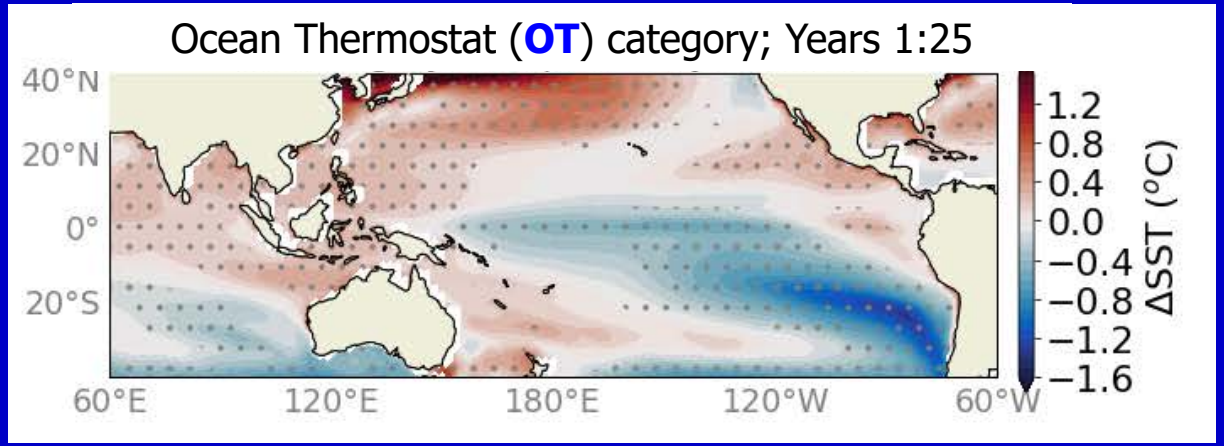
Strong OT



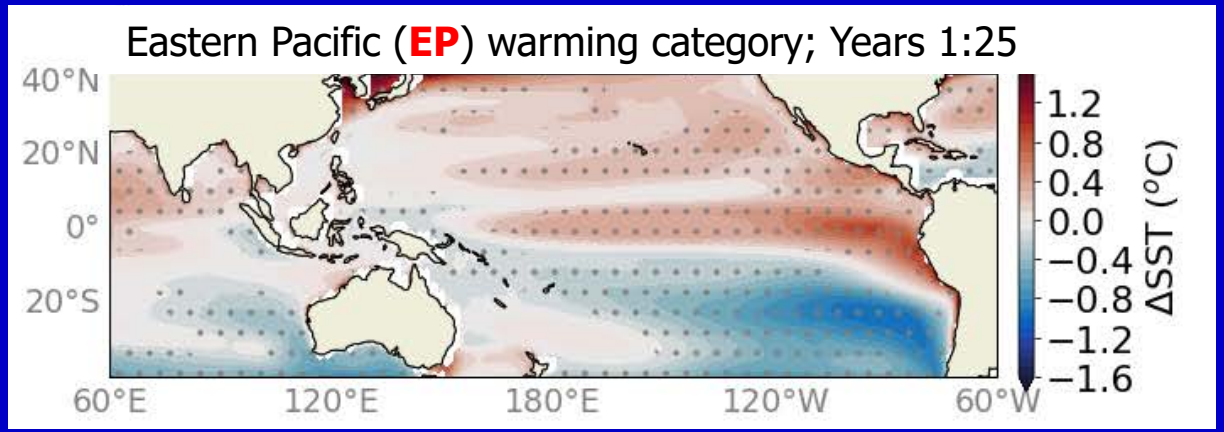
Heede, Fedorov, Burls 2021

Transient SST response to 4xCO_2 in CMIP6

OT category (7 models)



EP category (10 models)

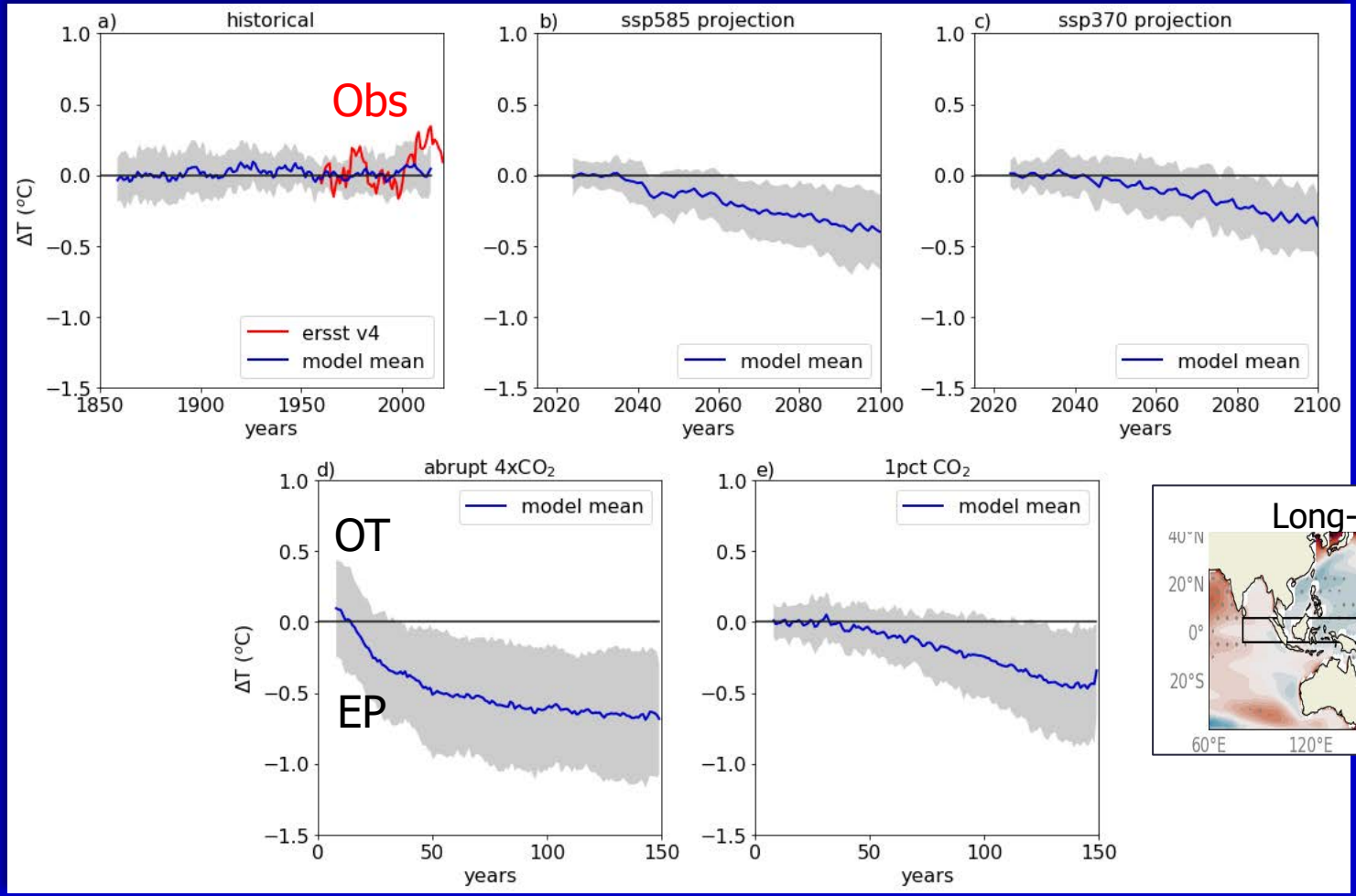


Out of 40

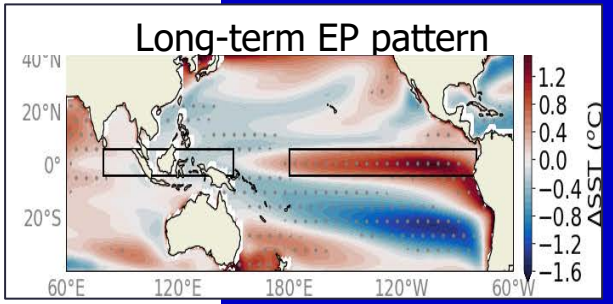
Models are divided into two categories in line with initial SST response in abrupt 4xCO_2: OT and EP

Heede and Fedorov 2021, Nature Climate Change

Transient ocean-thermostat (OT) vs east-west SST gradient weakening (EP)

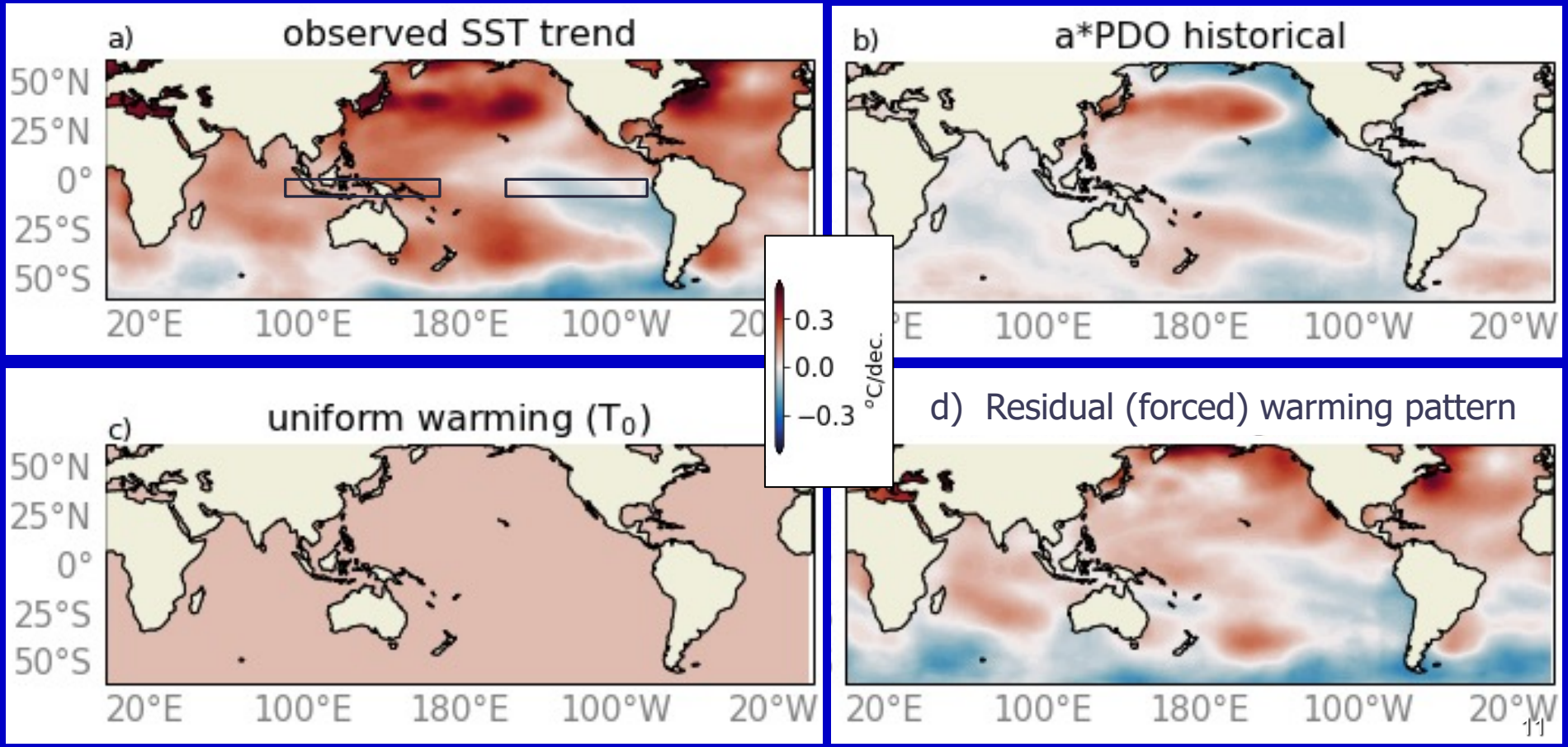


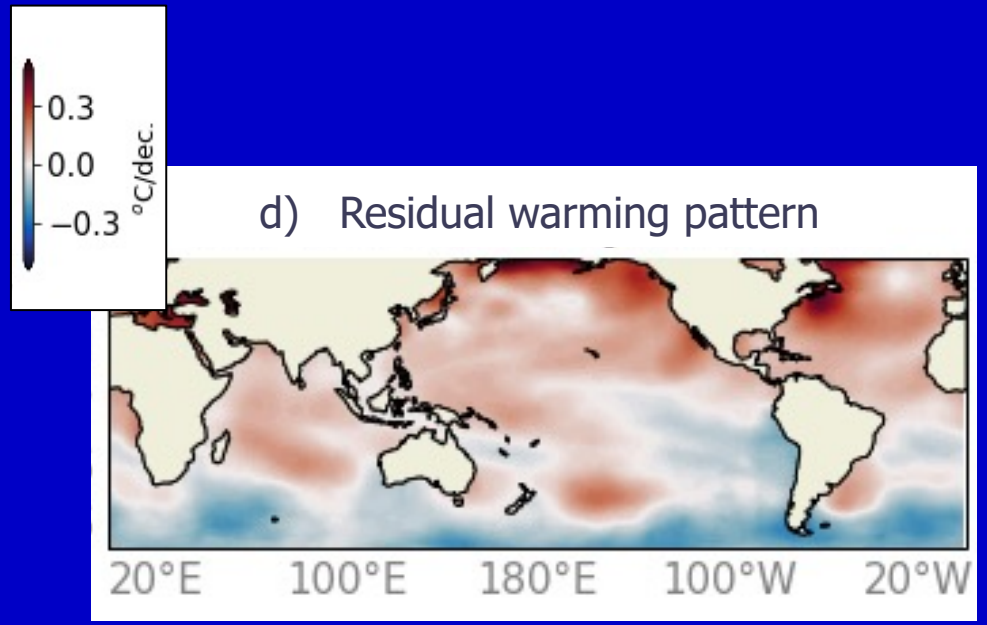
CMIP6:
40 models



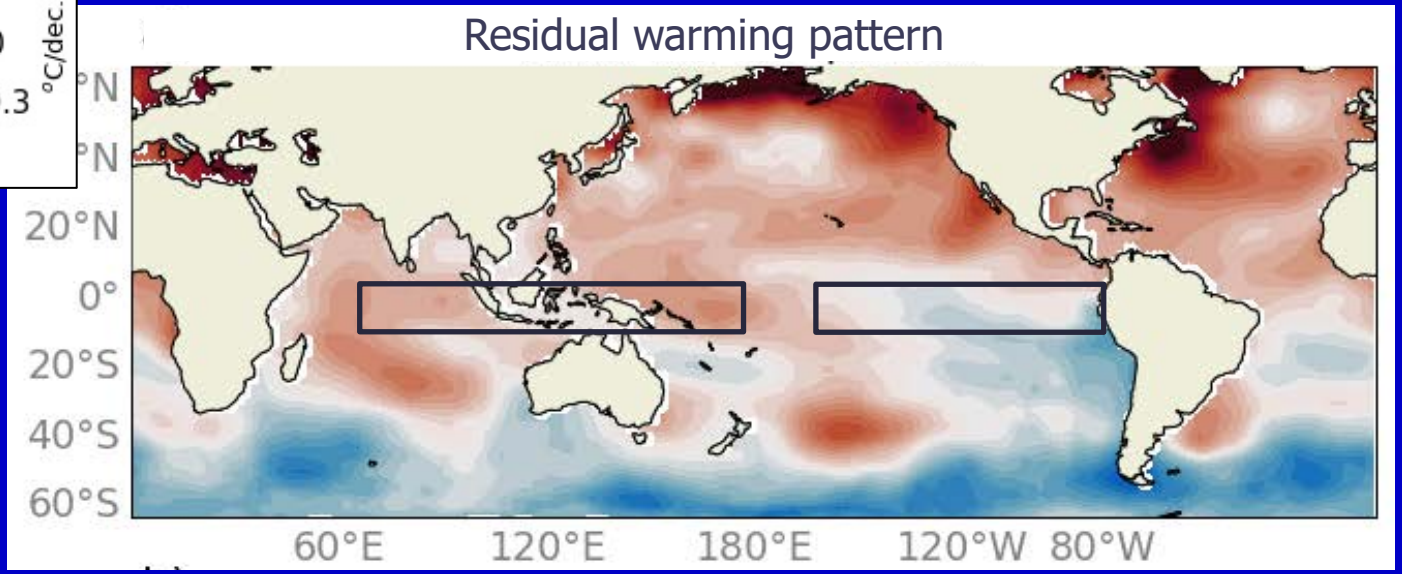
Heede and Fedorov (2021)

Decomposing the observed SST trend into three components



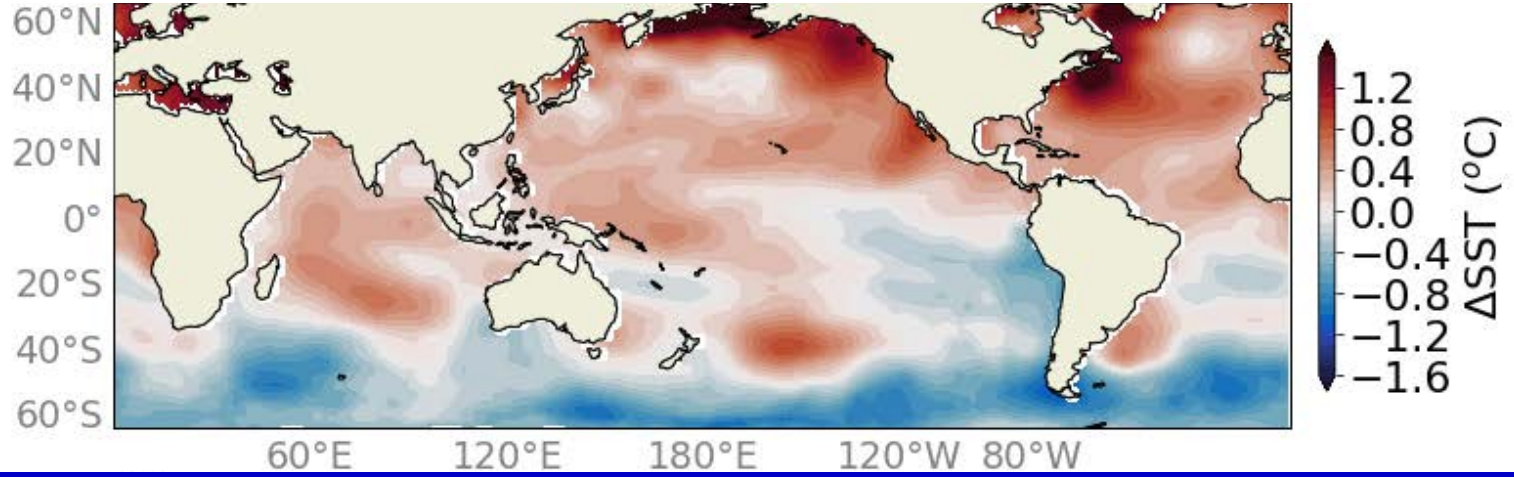


Heede and Fedorov 2021



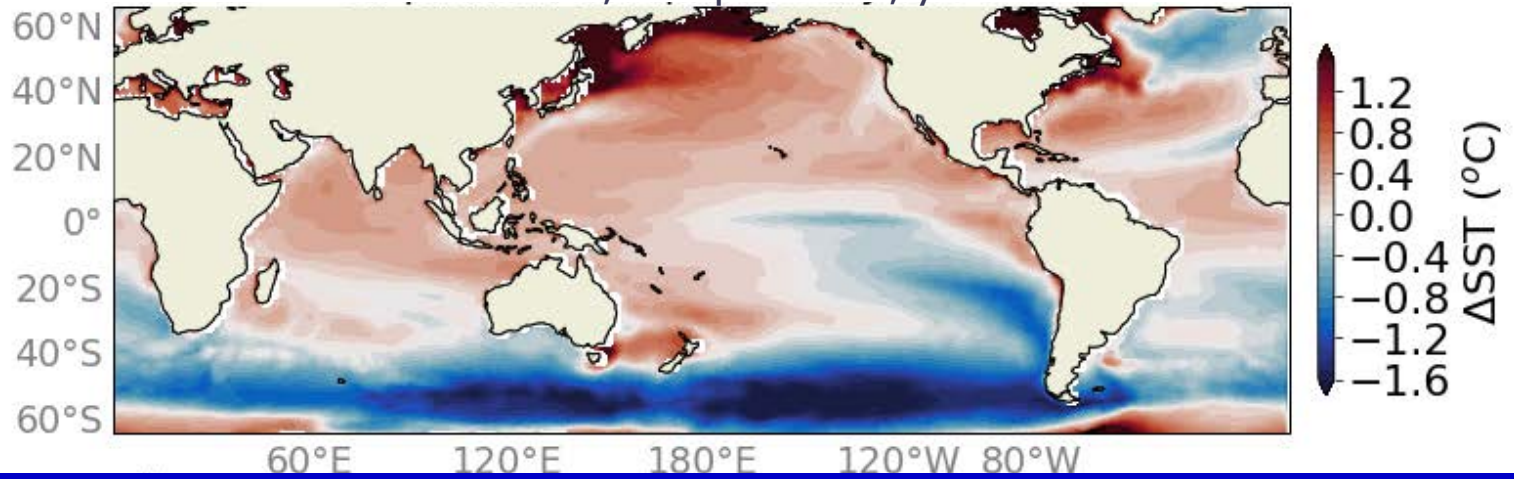
Heede and Fedorov 2021

Residual (forced) warming pattern



Observed

OT models, abrupt 4xCO2, years 1-25



Modeled, OT subset

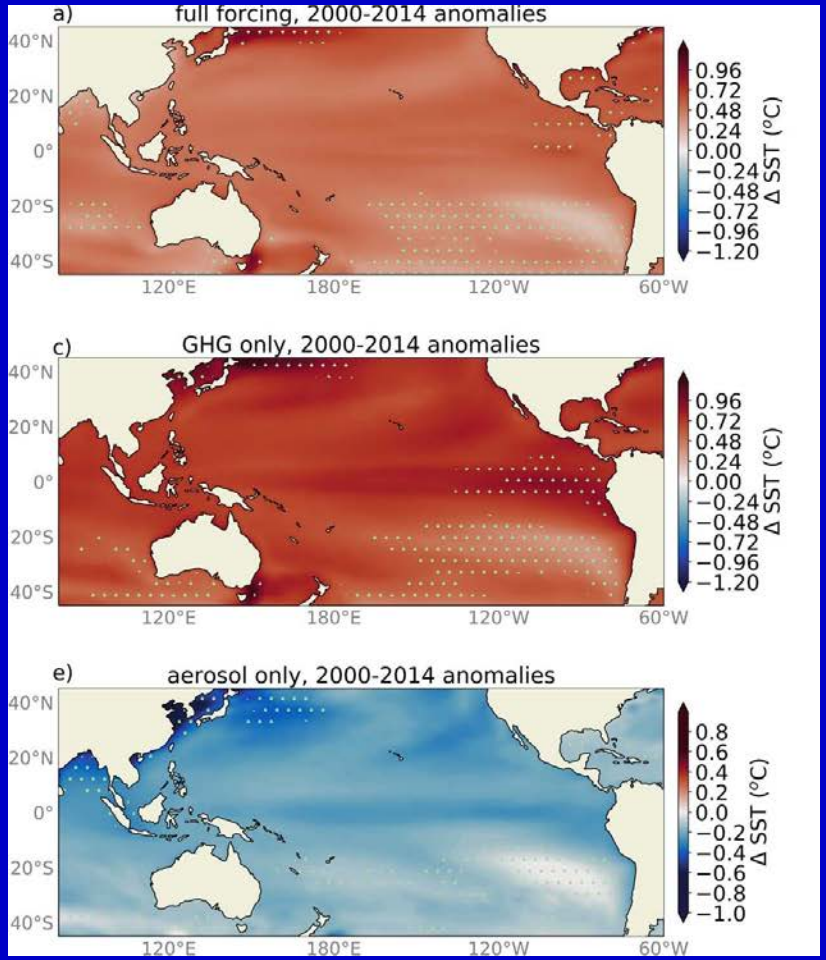
Heede and Fedorov 2021

Anthropogenic aerosols delay eastern eq. Pacific warming

GHGs + aerosols

No aerosols (GHGs only)

Only aerosols (no GHGs)



12 CMIP6 models

Anthropogenic aerosols may also delay eastern equatorial Pacific warming

Heede and Fedorov 2021

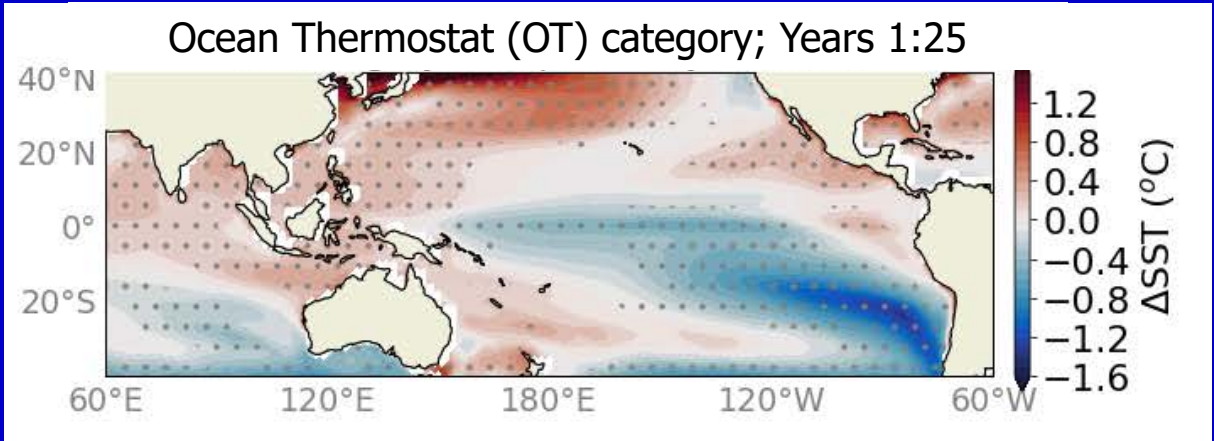
Yale

Summary

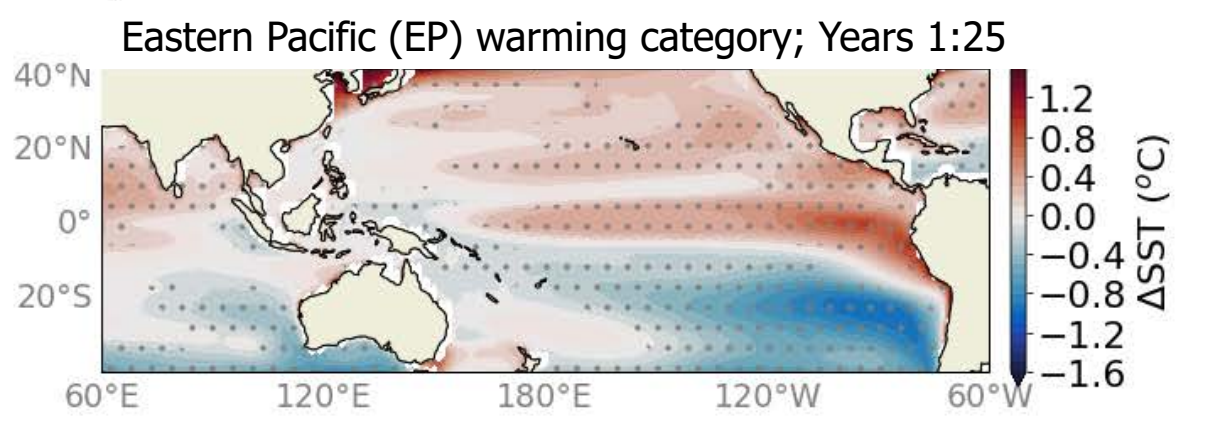
- Climate models at large cannot reproduce the observed decadal cooling SST trends in the tropical Pacific and the corresponding strengthening of the Walker circulation
- This observed SST trends combine a transient (forced) ocean-thermostat (OT) component with a negative PDO phase
- This OT component closely resembles transient response to abrupt 4xCO_2 forcing in a subset of CMIP6 models. However, in historical simulations the modeled OT response is too weak
- Anthropogenic aerosols tend to reduce the warming in the eastern equatorial Pacific but their effect is insufficient to overcome the warming trends

Short-term (transient) SST response to 4xCO_2

OT category



EP category



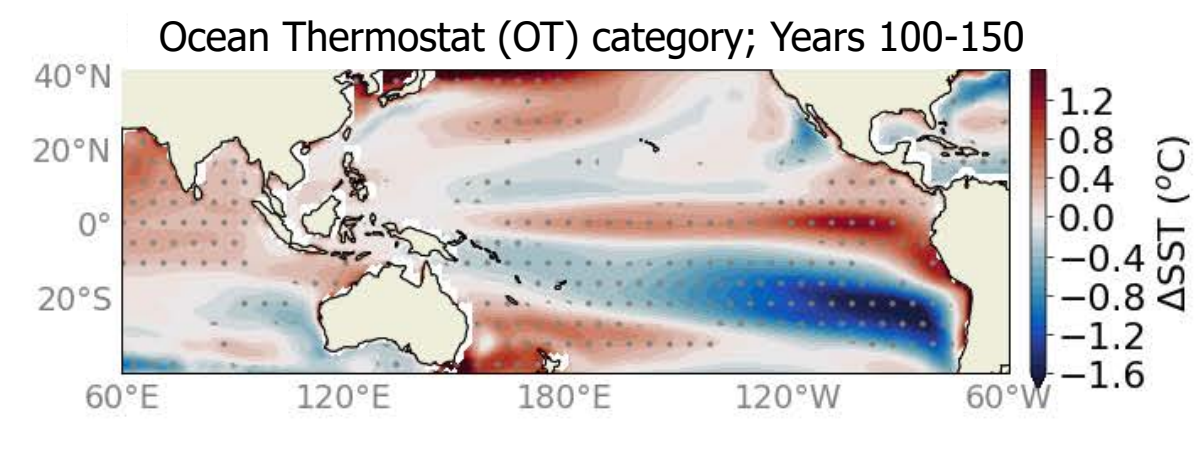
Two model categories based on initial SST response to abrupt 4xCO_2:

Ocean Thermostat (OT) vs Eastern Pacific warming (EP)

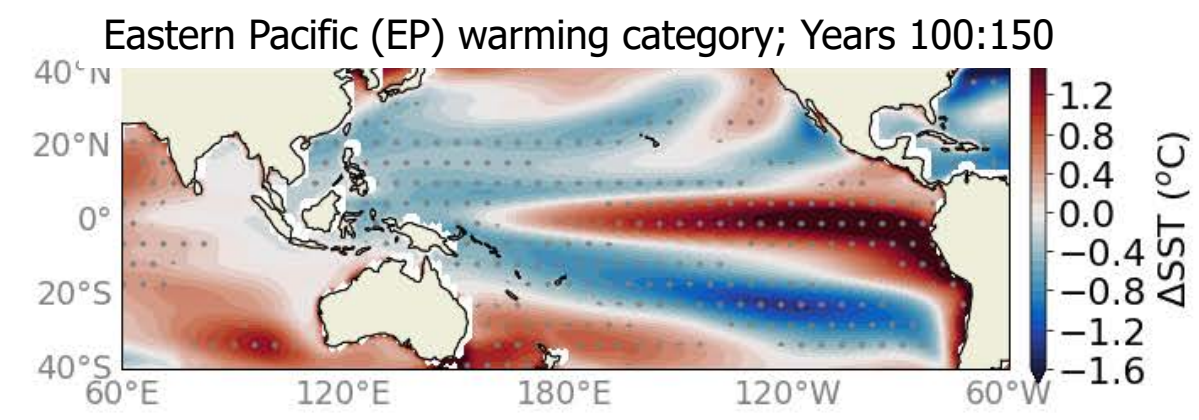
Heede and Fedorov 2021, 2023

Long-term SST response to 4xCO_2

OT category



EP category



Let's divide the models into two categories based on initial SST patterns in abrupt 4xCO_2: OT and EP

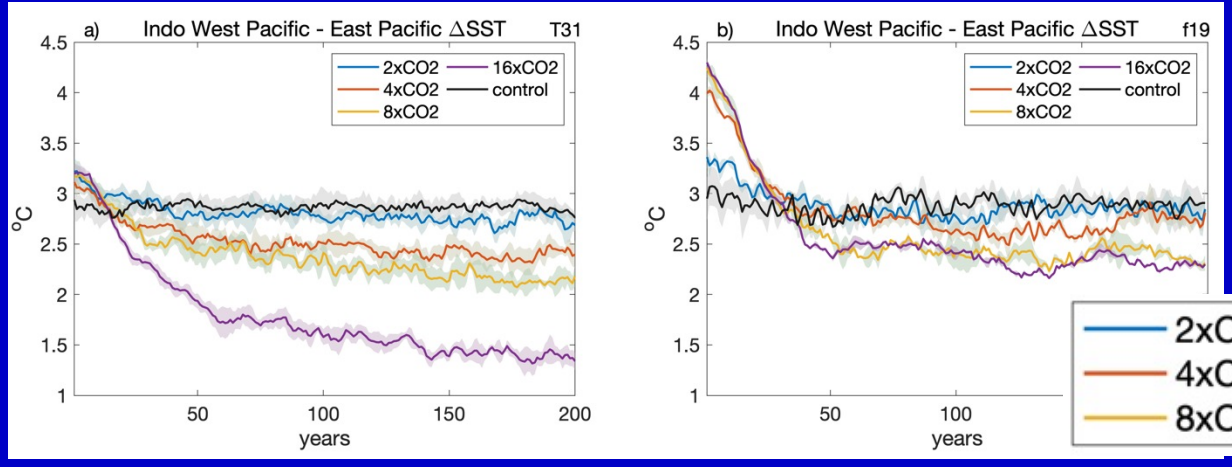
Heede and Fedorov 2021, revised for Nature Climate Change

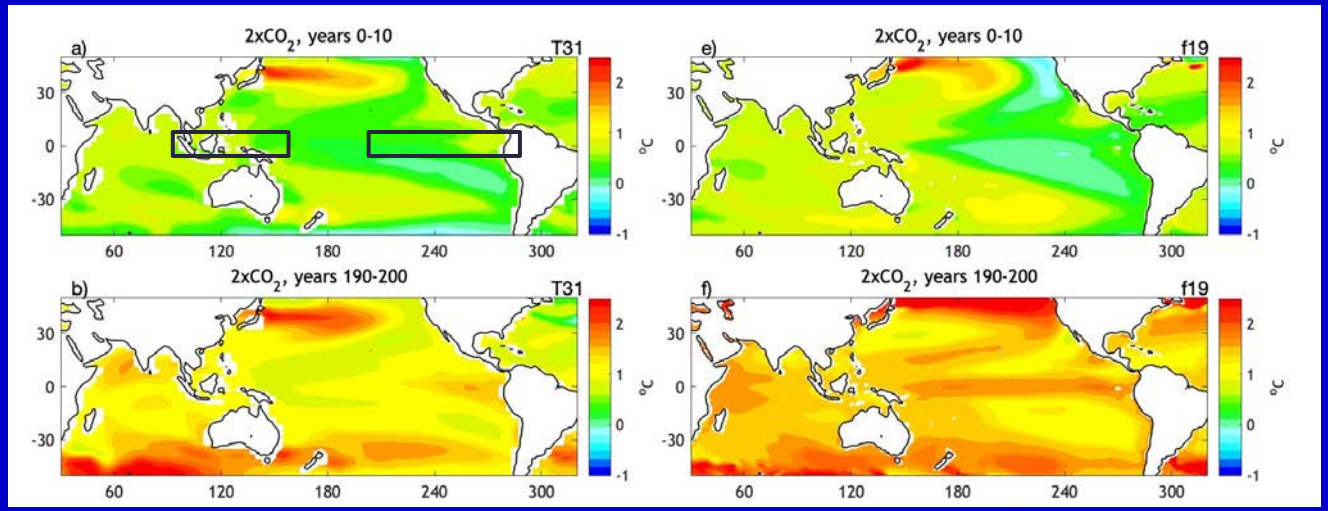
Transient Ocean Thermostat (OT) vs long-term Eastern equatorial Pacific (EP) warming

CESM1, T31

CESM1, f19

Changes in east-west SST gradient

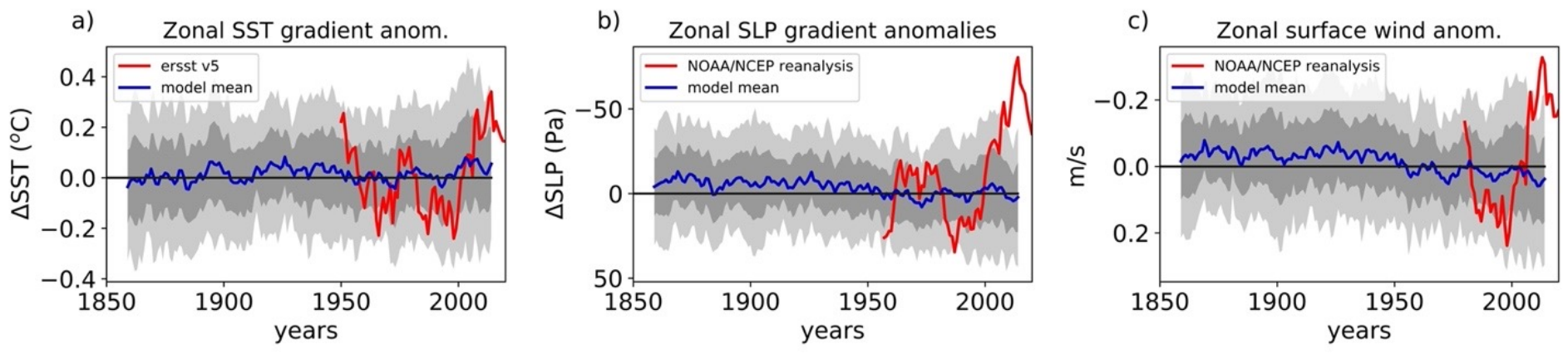




Heede, Fedorov, Burls 2021

Problem 1:

CMIP6 historical simulations of the gradients vs observations



Heede and Fedorov 2022, submitted