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Tropical Pacific Climate Trends: Predictable But Wrong?

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Abstract

Trends in the tropical Pacific zonal sea surface temperature (SST) gradient have implications for patterns of extreme weather worldwide, and are projected to be strongly influenced by future climate change. The majority of coupled climate models simulate a weakening of the zonal SST gradient in the mid-to-late 21st century, which would indicate a reduction in the strength of the Pacific Walker circulation. However, models have known SST biases, and generally do not represent the recent (~1990s-present) strengthening of the zonal SST gradient. This raises the question of whether biases in the forced response over the historical period are predictive of biases in the projected late 21st century forced response. Here we analyze output from a comprehensive suite of Single Model Initial-Condition Large Ensembles (SMILEs), including several sets of 'single-forcing' ensembles isolating GHG, anthropogenic aerosols, and other forcing factors. The zonal SST gradient sensitivity to forcing is relatively constant within a given model, when scaled to the global-mean temperature increase. Models with a higher sensitivity (more "El Niño-like" equatorial warming) tend to show relatively suppressed Northern and Southern Hemisphere subtropical warming, suggesting a possible role for subtropical cloud-radiative feedbacks. Additionally, the ensemble-mean forced SST gradient change over the most recent 30-40 years is predictive of the simulated forced response in the late 21st century. This suggests the potential for application of observational estimates of the recent trend as an emergent constraint on future projections. However, the magnitude of internal variability in observations is extremely large, making it difficult to apply this constraint in practice. Improving estimates of the forced SST gradient response in the real world is critical to resolving inter-model disagreements - and improving future projections.

Research Questions

1. How consistent are equatorial Pacific SST gradient changes across model ensembles?
2. Do past SST gradient changes predict future behavior?
3. Can we use observations to constrain future projections?

Model Ensembles

Data used in the analysis: Single-Model Initial-Condition Large Ensemble (SMILE) database of Maher et al. (2022), updated with more full- and single-forcing runs

Model name	Historical	SSP5-8.5	SSP3-7.0	SSP2-4.5	SSP1-2.6	RCP8.5	RCP4.5
ACCESS-ESM1-5	40	40	40	40	40		
CanESM2	50					50	
CanESM5	40	25	25	25	25		
CESM1	40					40	15
CESM2	100		100				
CSIRO-Mk3-6-0	30					30	
EC-Earth3[a]	25	15					
GFDL-CM3	20					20	
GFDL-ESM2M	30					30	
GFDL-SPEAR	30	30					
IPSL-CM6A-LR	33	7	11				
MIROC6	50	50	3	50	50		
MIROC-ES2L	30	10	10				
MPI-ESM	100					100	100

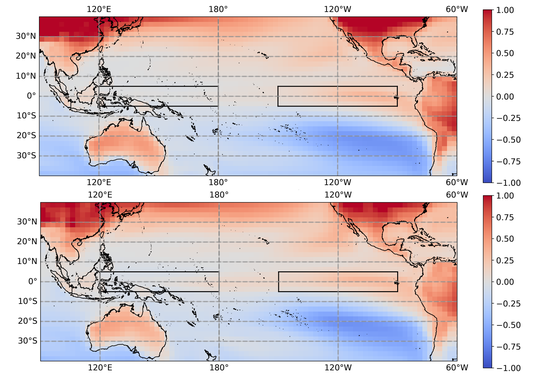
[a]EC-Earth: SSP5-8.5 data used only for members corresponding to a historical simulation

Model name	Full-forcing	GHG	Aerosol	Biomass Burning	Other
CanESM5	50	50	50	50	50
CESM1	20	20	20	20	
CESM2	50	15	20	15	15

Mean Pacific Trend Patterns

Relative SST (tropical Pacific mean removed): 2021-2060 vs. 1981-2020

SSP5-8.5



SSP1-2.6

El Niño-like warming: some consistencies across scenarios

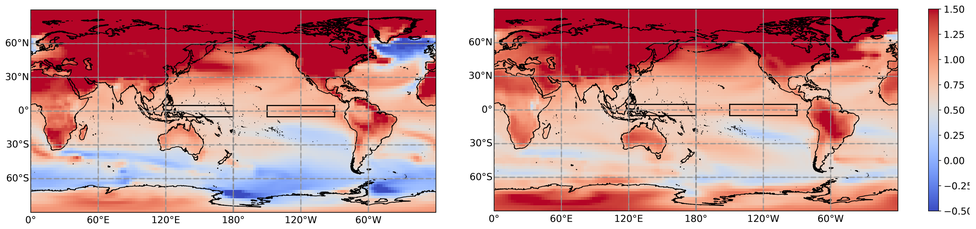
Mechanisms for Inter-Model Differences

There are coherent trend patterns which differ across model ensembles

High-sensitivity model: MIROC6 | Low-sensitivity model: CanESM5

Gridpoint SST trend normalized to global-mean T trend 2015-2100
Units: C/decade/C

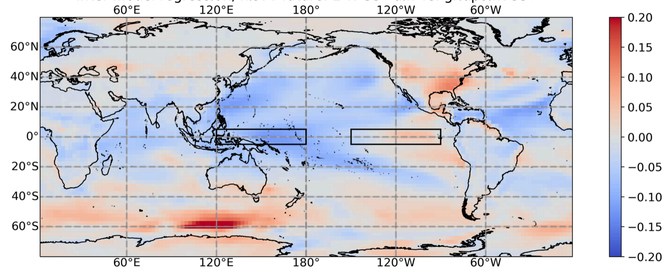
(Avg of four SSP ensembles)



More "El Niño like" equatorial changes go with less subtropical warming

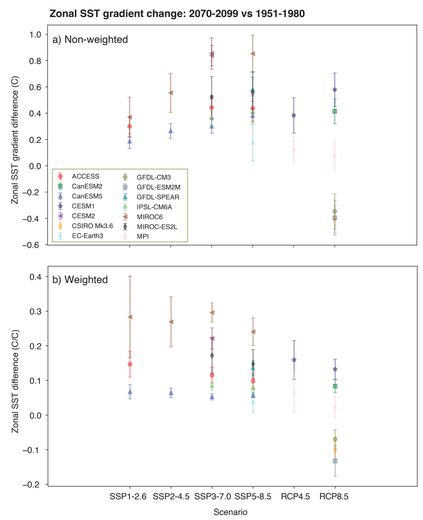
Which spatial patterns matter for the equatorial SST gradient?

Regress ensemble-mean E-W SST difference on ensemble-mean grid point SST change: 2070-2099 vs 1951-1980



Forcing Sensitivity

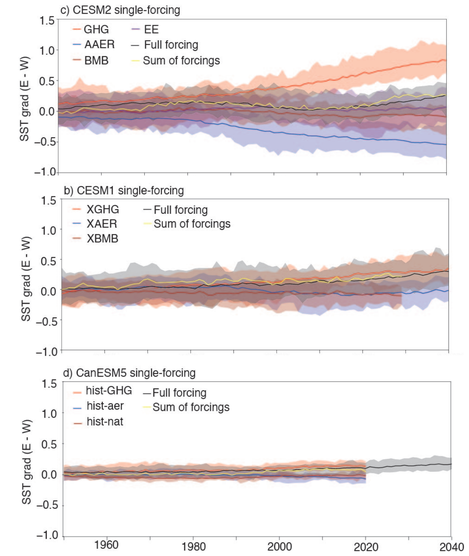
Gradient changes scale with magnitude of forcing



When normalized by global-mean warming, gradient changes are (more) constant - within a given model

Historical trends: compensation between GHG, aerosol emissions

Zonal SST gradient: (5S-5N, 210-270E) - (5S-5N, 120-180E)
Single-forcing ensembles: CESM1, CESM2, CanESM5



CESM2: high sensitivity

CESM1: moderate

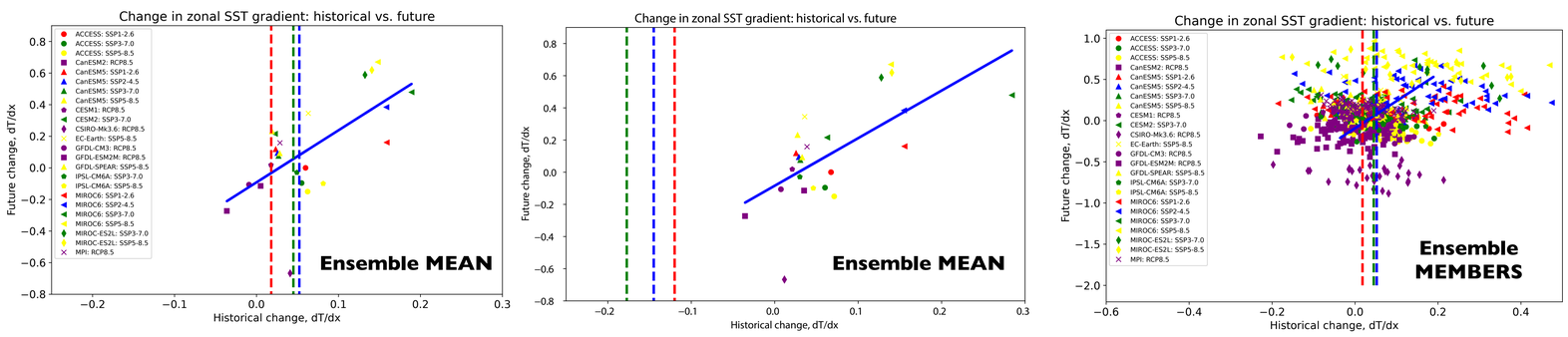
CanESM5: low sensitivity

Potential for Observational Constraints?

Historical changes in the zonal SST gradient predict future (late 21st c) changes! In theory....

Zonal SST gradient: (5S-5N, 210-270E) - (5S-5N, 180-220E)
Different definition from above; predictability mainly arising from central/eastern Pacific

"Historical" = (1991-2020) - (1961-1990) | "Historical" = (2001-2020) - (1981-2000) | "Historical" = (1991-2020) - (1961-1990)



In all cases: "Future" = (2070-2099) - (1961-1990)

Conclusions

El Niño-like warming: a consistent response to greenhouse gas emissions in CMIP6 models
(CMIP5 models appear less consistent)

El Niño-like response scales with warming; models have distinct 'sensitivities' of the zonal SST gradient response to forcing

Models with high 'gradient sensitivities' exhibit preferentially less subtropical warming, especially in the Northern Hemisphere

The eastern vs central Pacific gradient shows some predictability: historical changes can predict end-of-century responses

BUT this is only true for the ensemble mean; a true observational "emergent constraint" is limited by our ability to characterize the observed forced response