

Supplementary Material

Greenhouse gas forcing a necessary causation for marine heatwaves over the Northeast Pacific warming pool

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- Table S1: Name of the models used in the study from DAMIP-CMIP6 archive.
- Figure S1: **Detection of climate change signal.** Seasonal observed trends in SST based on NOAA OISST over 1996-2020 and regions where externally forced changes of SST are detectable with less than 5% risk of error.
- Figure S2: **Expansion of summer by more than one month and shrinking of winters over the warming pool.** Changes in daily mean SST and seasons based on NOAA OISST over the Northeast Pacific warming pool (indicated with a black box on Figure S3).
- Figure S3: **Reversal of cooling to significant warming trends of SST.** Area average 25-year trends of SST over the warming pool.
- Figure S4: **Response of SST to external climate drivers.** Response of SST to ALL forcing, anthropogenic aerosols (AER), and greenhouse gases (GHG) derived from CESM1-LE (ensemble mean of 20 members).

Table 1: Name of the models from DAMIP-CMIP6, number of model ensemble members and the Pre-industrial control years used in the study.

Model	Ensemble members GHG-forcing only	Ensemble members AER-forcing only	Pre-industrial runs years
CNRM-CM6-1	6	6	500 (20 of 25-year)
CanESM5	10	10	1000 (40 of 25-year)
GISS-E2-1-G	4	4	1000 (40 of 25-year)
HadGEM3-GC31	4	4	500 (20 of 25-year)
CNRM-CM6-LR	10	10	1000 (40 of 25-year)

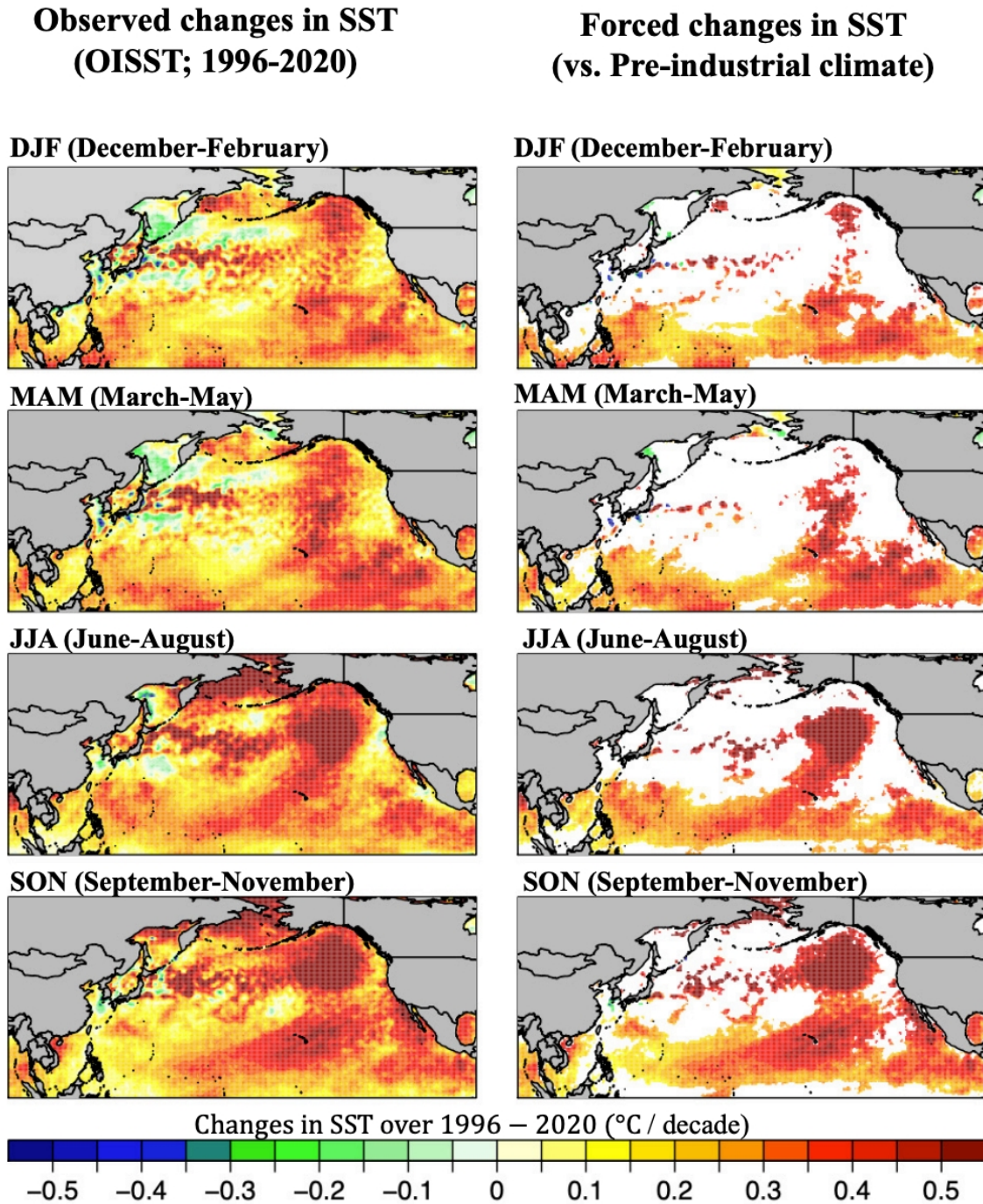


Figure 1: **Detection of climate change signal** *Left column:* Seasonal observed trends in SST based on NOAA OISST over 1996-2020 time period in winter (December-February), spring (March-May), summer (June-August) and autumn (September-November). *Right column:* Regions where externally forced changes of SST are detectable with less than 5% risk of error (in comparison with 280 pseudo-realizations of unforced trends derived from 7,000-year Pre-industrial CMIP6 control simulations).

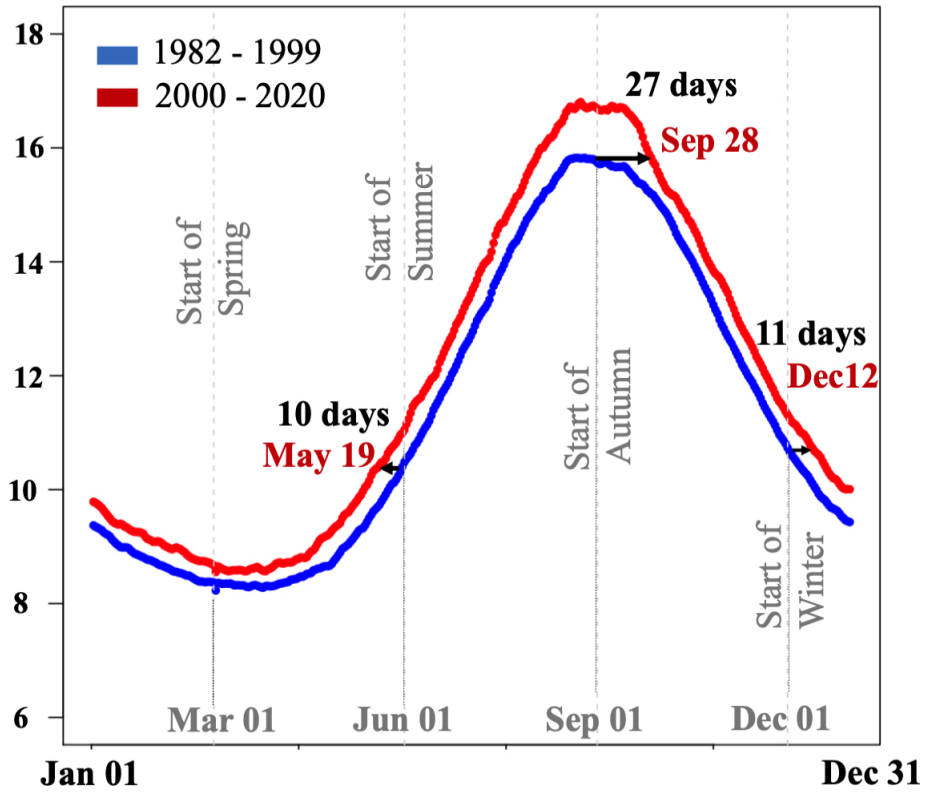


Figure 2: Changes in daily mean SST and seasons based on NOAA OISST over the here-detected Northeast Pacific warming pool (indicated with a black dashed box on Figure S3).

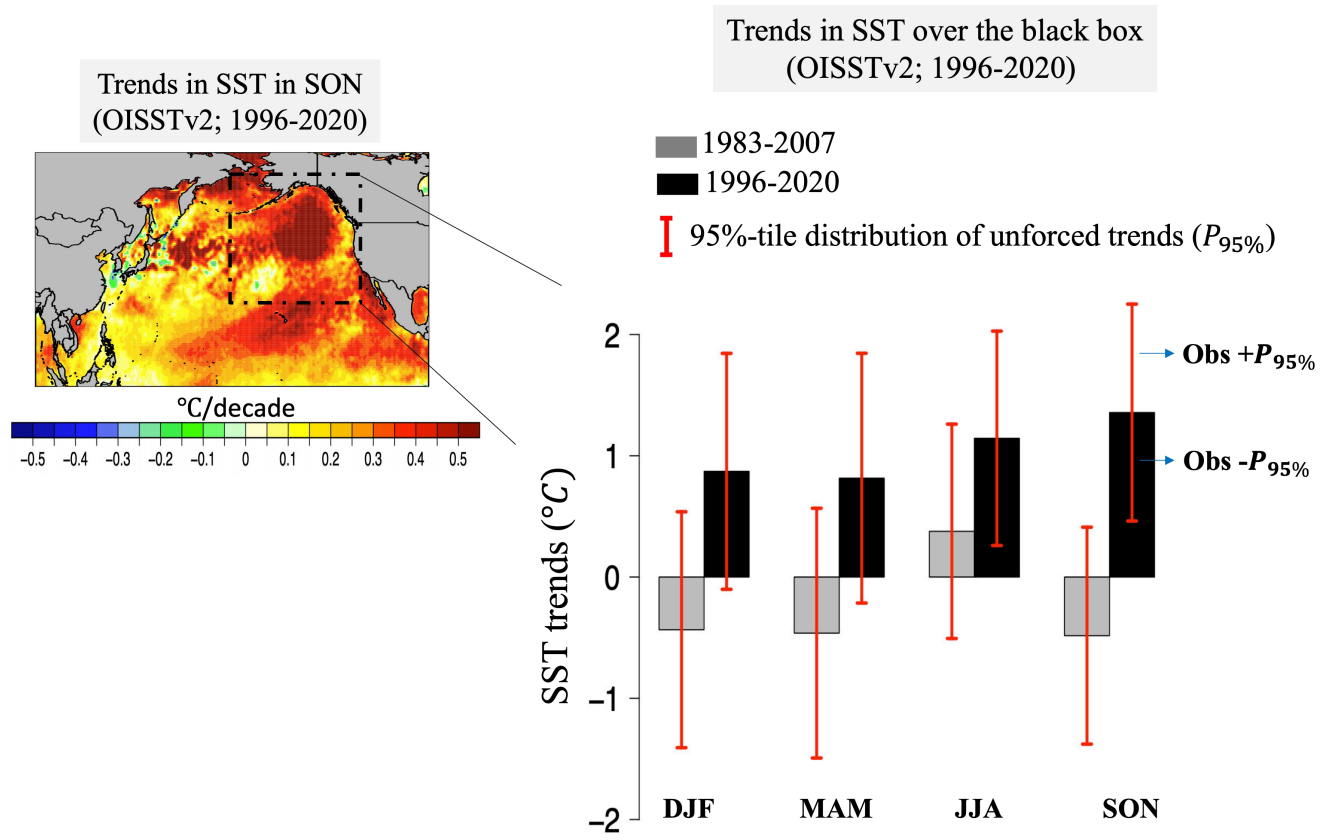


Figure 3: Observed trends pattern in SST over 1996-2020. Area average 25-year trends of SST (over the black box) over 1983-2007 (gray bars) and 1996-2020 (black bars). The red whiskers show the 95%-tile internal-variability generated uncertainty range (unforced trends derived from Pre-industrial control runs).

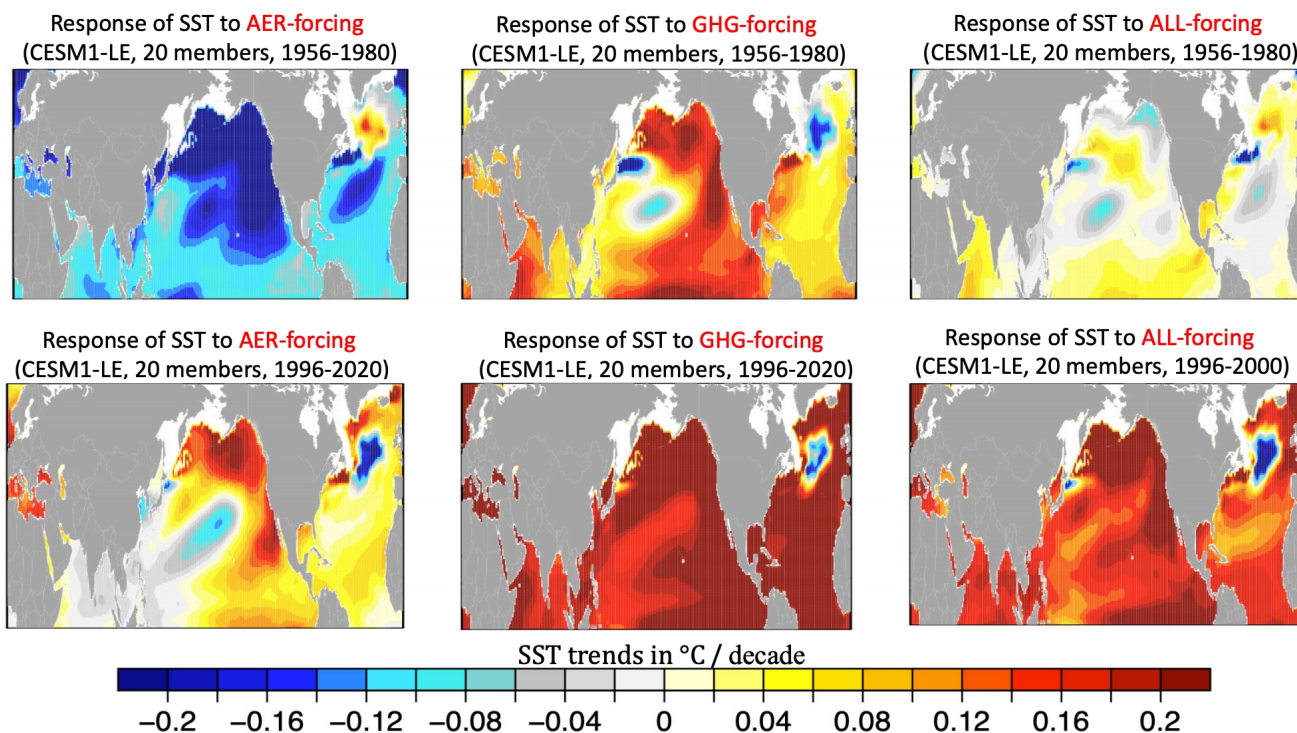


Figure 4: **Response of SST to external climate drivers.** Simulated response of SST from CESM1-LE (ensemble mean of 20 realizations) in SON (September-November) to AER-only (anthropogenic aerosols) forcing, GHG-only forcing and ALL forcing (anthropogenic+natural) (**top row**) over 1956-1980, (**bottom row**) over 1996-2020 time period.