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CLIMATE, CLIMATIC CHANGE, AND SOCIETY (CLICCS)

GHG forcing a necessary, but not sufficient, causation for the northeast Pacific marine heatwaves

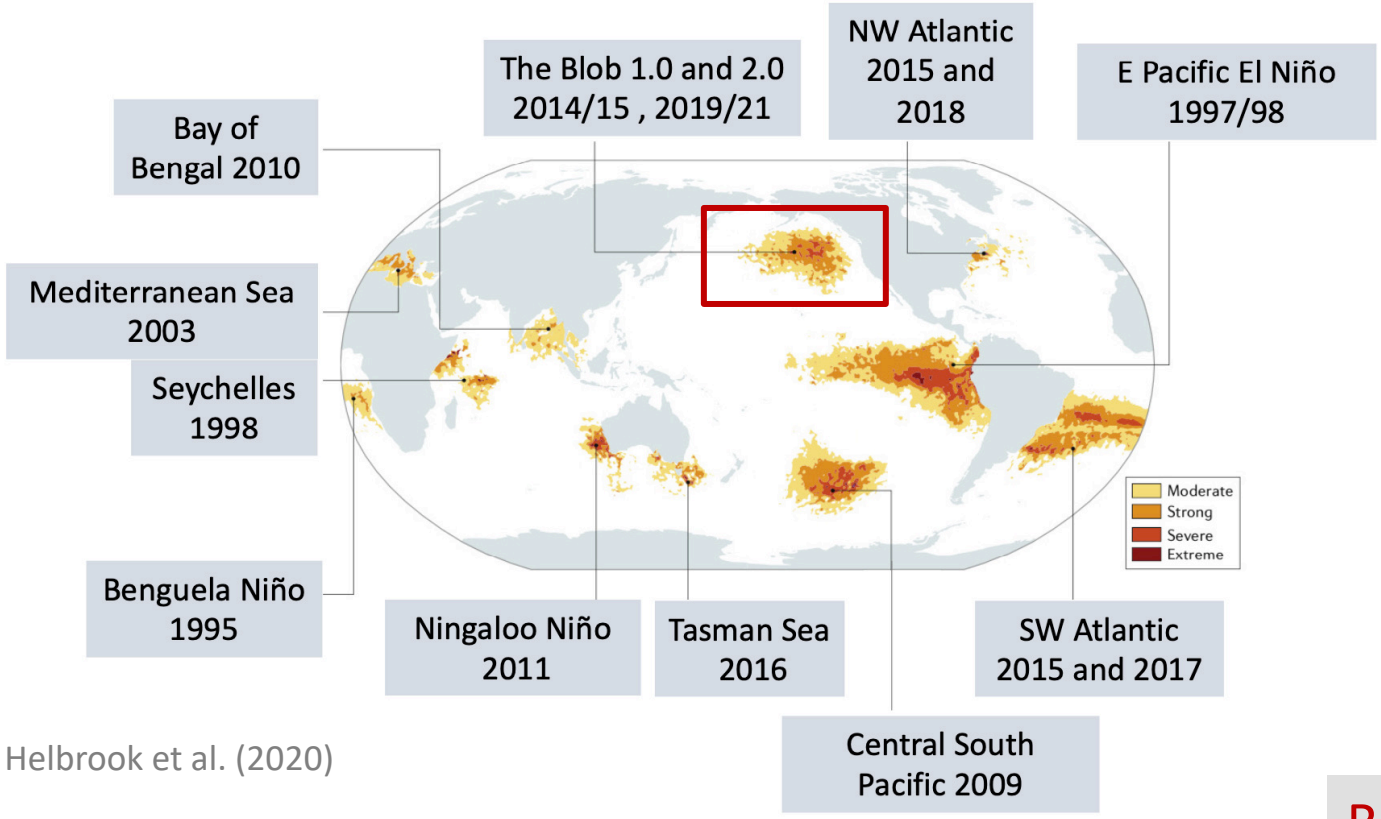
Armineh Barkhordarian[1]

David M. Nielsen[1,2] and Johanna Baehr[1]

1 Institute of Oceanography, CEN, Universität Hamburg, Hamburg, Germany
2 Max Planck Institute for Meteorology, Hamburg, Germany

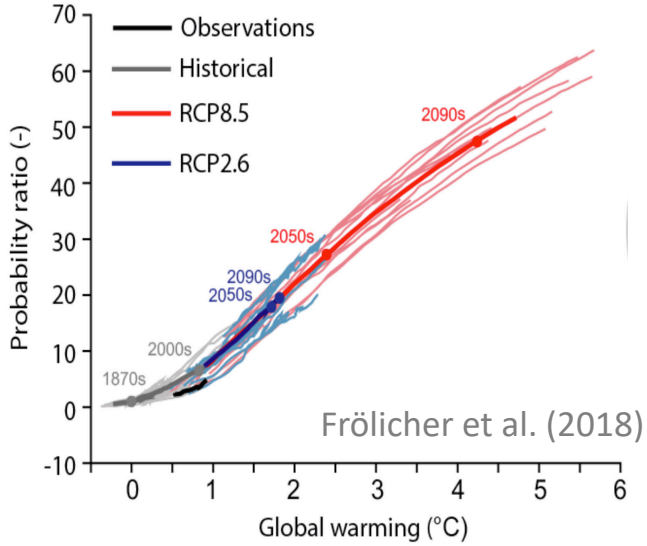
DFG Deutsche Forschungsgemeinschaft

More frequent marine heatwaves under future global warming



Helbrook et al. (2020)

Probability of marine heatwaves exceeding the preindustrial 99th %-tile



- ✓ Marine heatwaves will increase in frequency and intensity under future global warming [1,2,3,4]

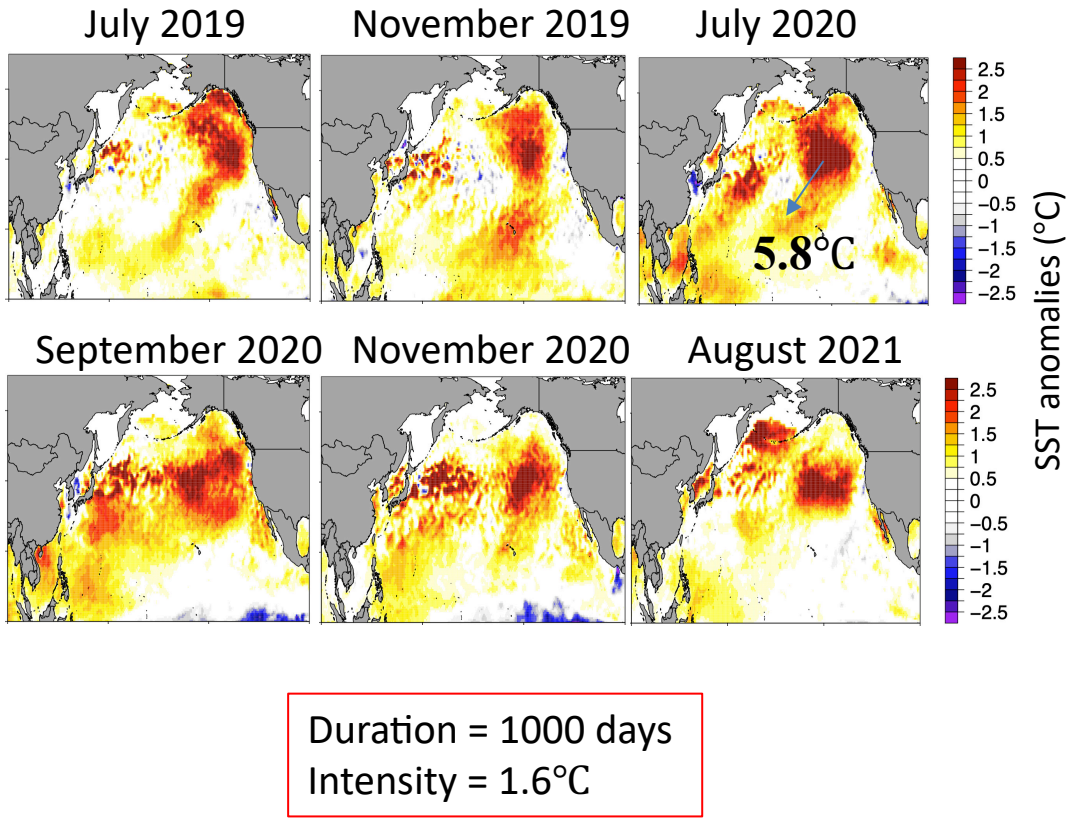
Research gap

The fraction of the likelihood of an event that is attributable to GHG forcing is still elusive.

[1] Frölicher et al., 2018. [2] Frölicher and Laufkötter, 2018. [3] Oliver et al., 2018. [4] Laufkötter et al., 2020.

Causal attribution of high-impact marine heatwaves

Evolution of the 2019-2021 MHW with ~3 years duration and 1.6 ℃ intensity



Duration = 1000 days
Intensity = 1.6℃

- The 2019/2021 MHW over the northeast Pacific is the most severe event that has ever been detected since the year 1982.

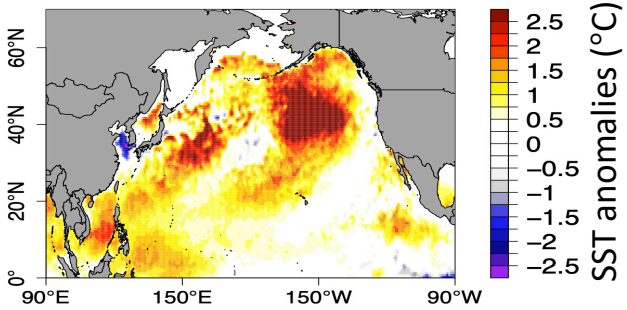
Research question

Is GHG forcing a necessary cause for high-impact MHWs to occur, and is sufficient for such events to continue to repeatedly occur in the future?

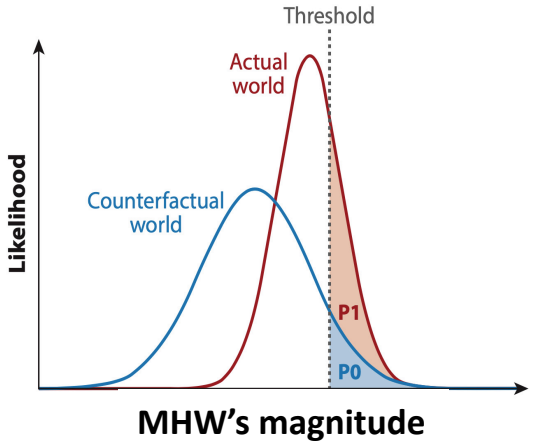
Extreme event attribution

GHG forcing caused multi-year marine heatwaves

2019-2021 MHW



Extreme Event attribution [1,2]



$P_1 = P_{ALL}^{duration}$ = P(MHW =1 | X_{GHG} = 1)

$P_0 = P_{fixGHG}^{duration}$ = P(MHW =1 | X_{GHG} = 0)

- Necessary causation = 0.98 –1.00

There is less than 1% chance that the 2019-2021 event with ~3 years duration and 1.6 ℃ intensity could have happened in the absence of GHG forcing.

- Sufficient causation = 0.05

However, this event is extreme, the inclusion of GHG forcing is necessary, but not sufficient.

Barkhordarian et al.
Communications E&E (in review)

Key message

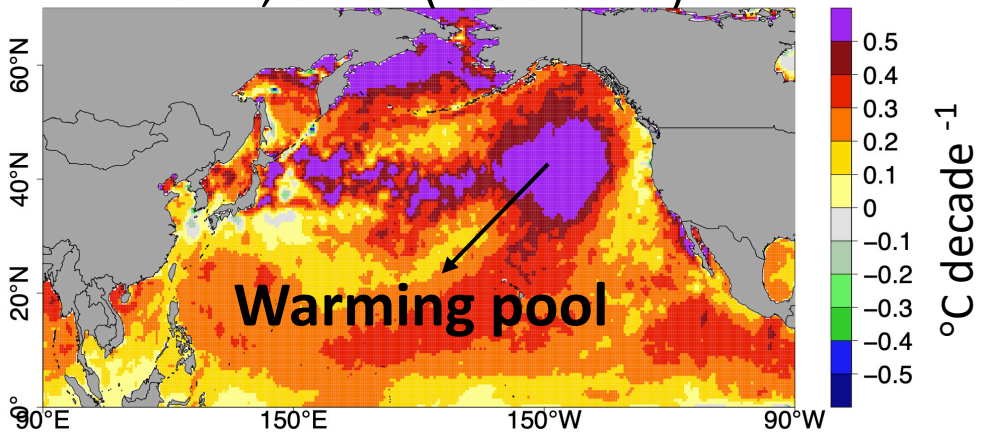
The 2019/2021 marine heatwave requires GHG forcing to occur (with 99% probability), but the inclusion of GHG forcing alone is not enough to guarantee the event's occurrence.

The background long-term trends

[1] Hannart, Pearl, Otto et al. (2016). [2] Stott, et al. (2016)

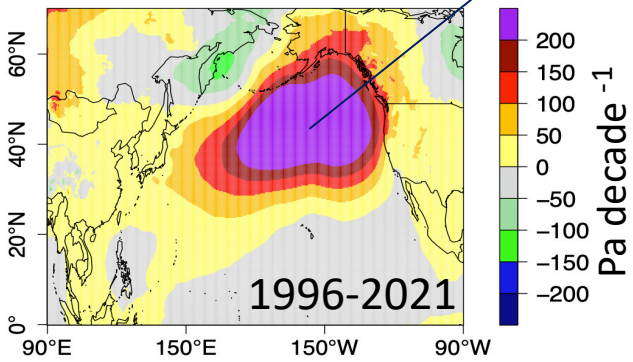
Discovering an outstanding long-term warming pool

Mean SST linear trend
NOAA; OISST (1996-2021)

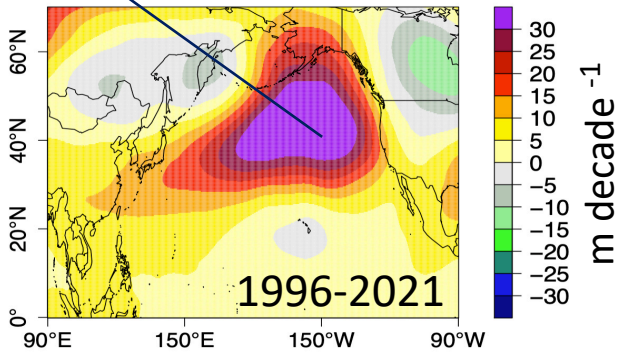


exceeding the preindustrial 98th %-tile

Mean SLP linear trend



500 Gph linear trend



The long-term warming pool is marked by:

- Concurrent and pronounced increase in annual mean, and variance of SSTs. Prominent MHWs occur where mean warming, and higher variance overlap.
- 0.5 °C warmer and shorter winters. 1 °C warmer and 37 days longer summers.
- Decrease in wintertime low cloud's cooling effect [1995-2018; EUMETSAT].
- There is < 2% chance that internal variability is responsible for the observed cold-season strengthening high-pressure system.

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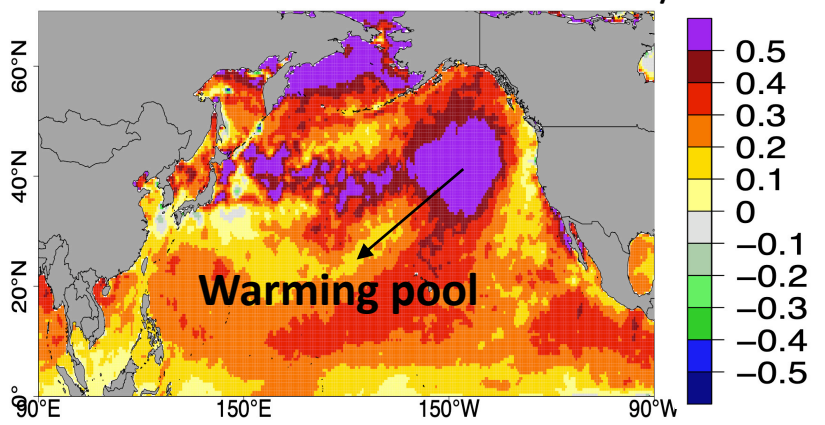
Detection and attribution of the warming pool

The warming pool is systematically-forced

Observed SST trends
(OISSTv2; 1996-2021)

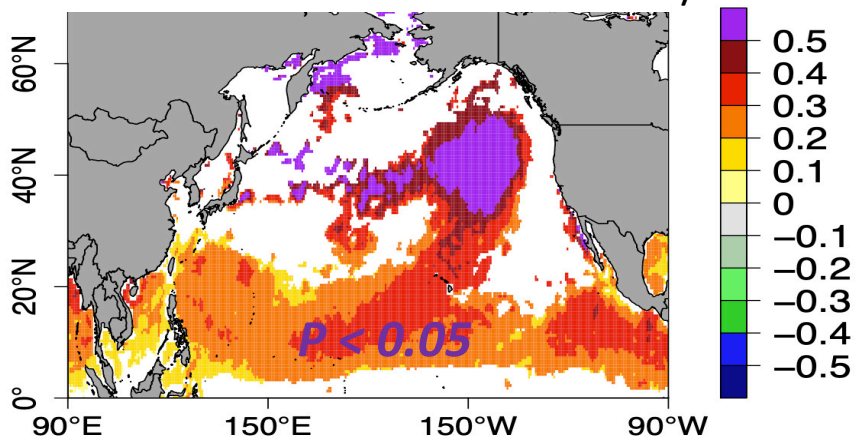


vs. pre-industrial climate
CMIP6 control runs

vs. historical variability
1996-2021, MPI-GE

vs. Paleo simulations
850-1850

Detected forced changes
(OISSTv2; 1996-2021)



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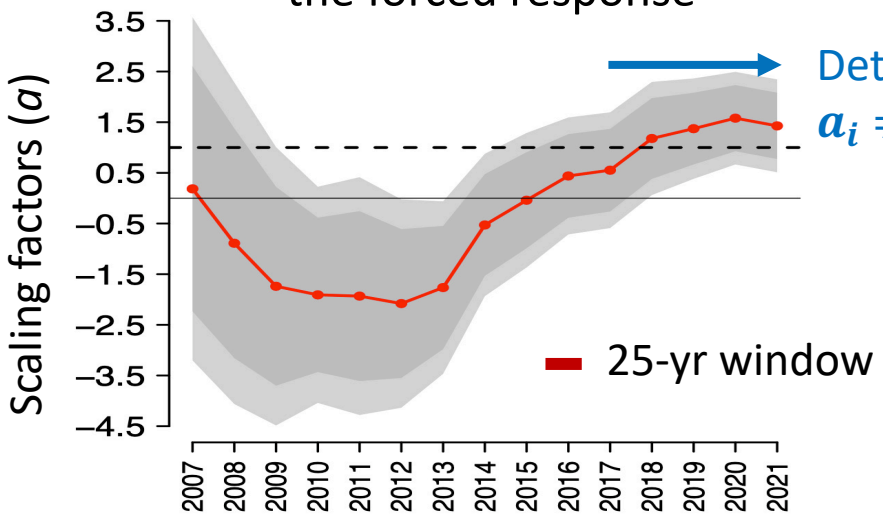
TLS regression of observed SST onto the forced response



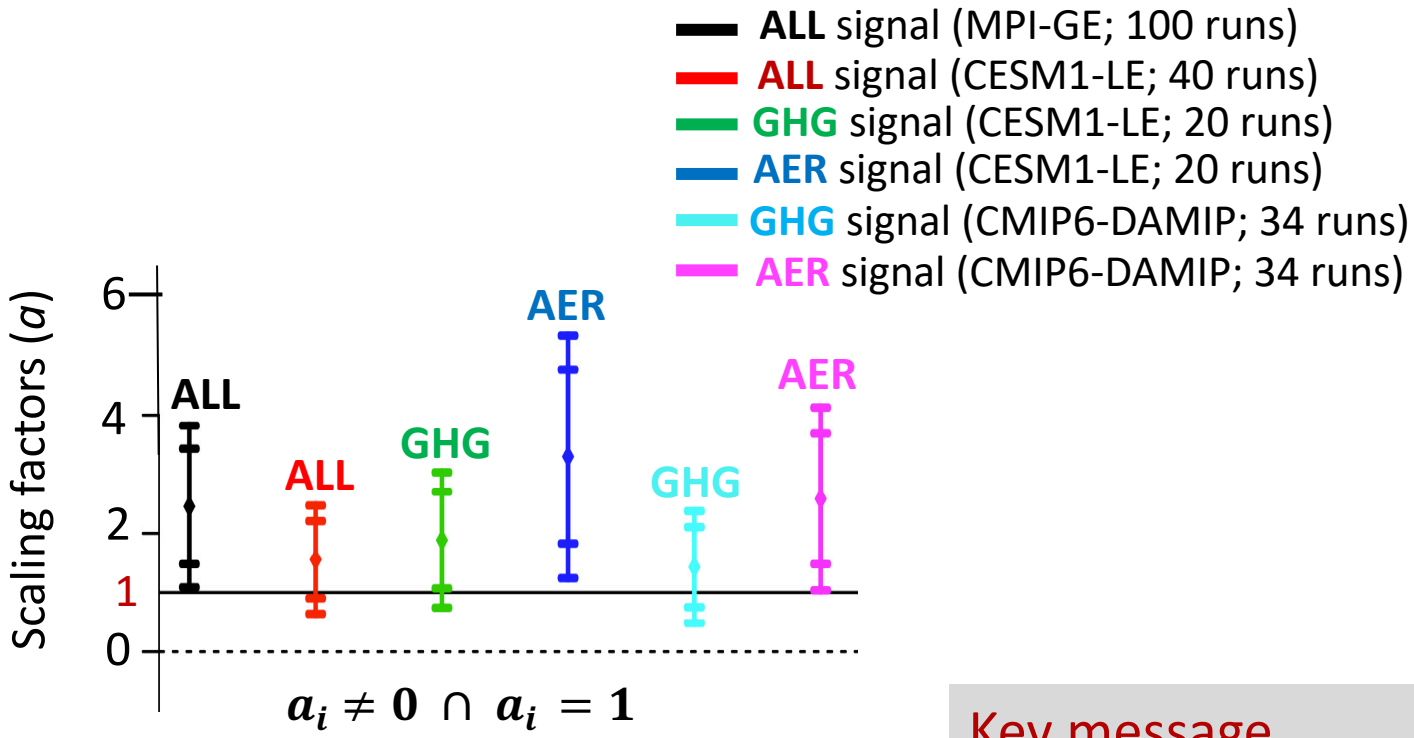
Detection of external forcing signal
$a_i \neq 0 \cap a_i = 1$

Key message

The anthropogenic signal has recently emerged from the natural variability of SST over the warming-pool (P < 0.05).

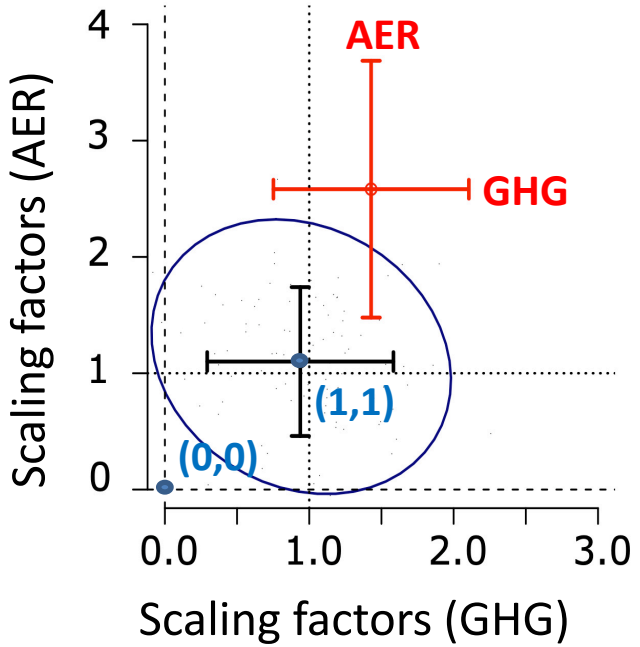
Attributing the warming-pool to anthropogenic forcing

Univariate attribution of observed SST trends (1996-2021)



ALL= Anthropogenic + Natural
GHG= Greenhouse gases
AER= Industrial aerosols

Bivariate signal attribution (1996-2021)



Key message

Forcing by elevated GHG levels and recent industrial aerosol-load decrease are identified as key causes for the here-detected Pacific warming pool ($P < 0.05$).

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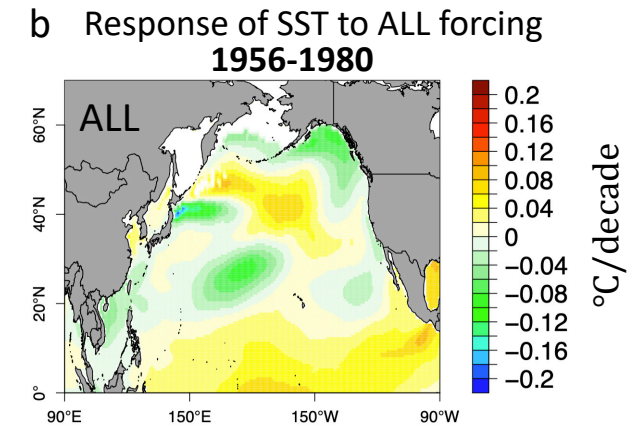
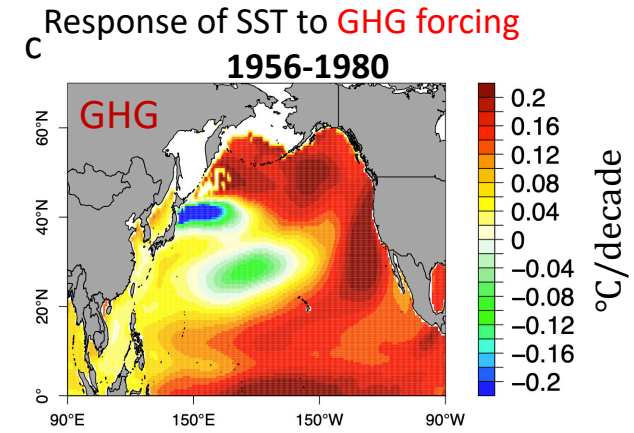
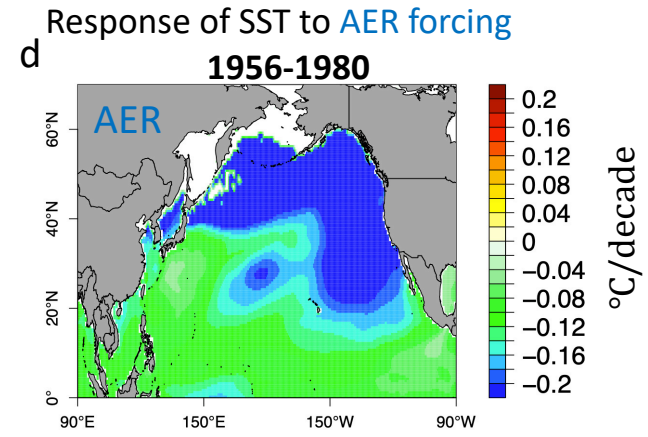
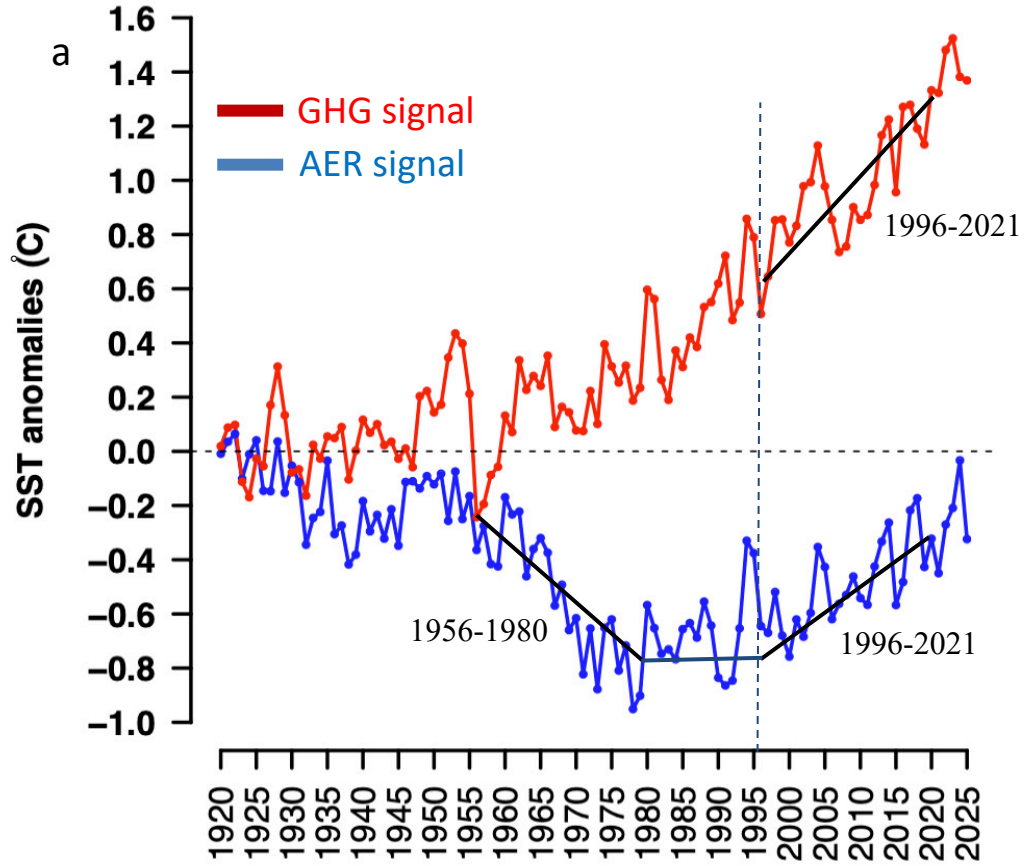
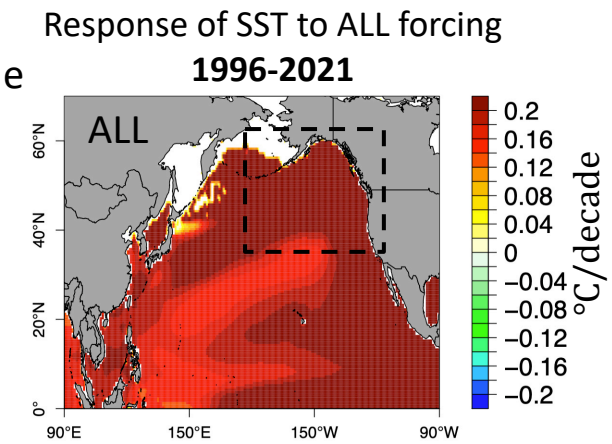
Evolving roles of GHG and anthropogenic aerosols (AER) in driving **annual SST** over the northeast Pacific (black box)

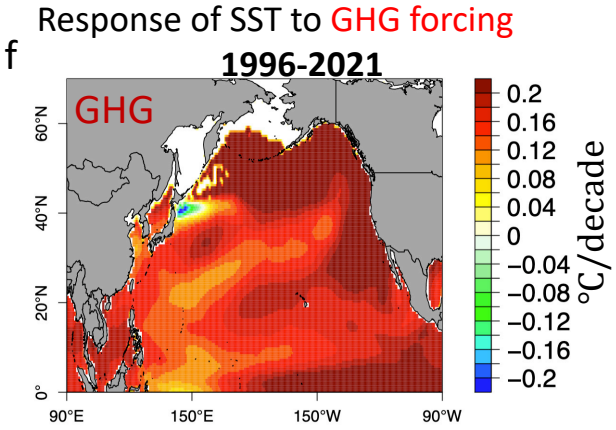


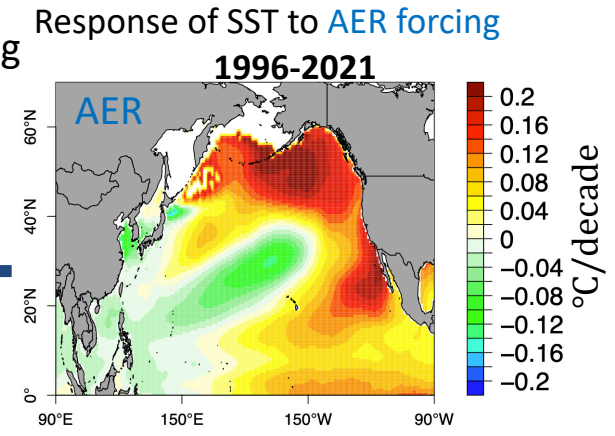


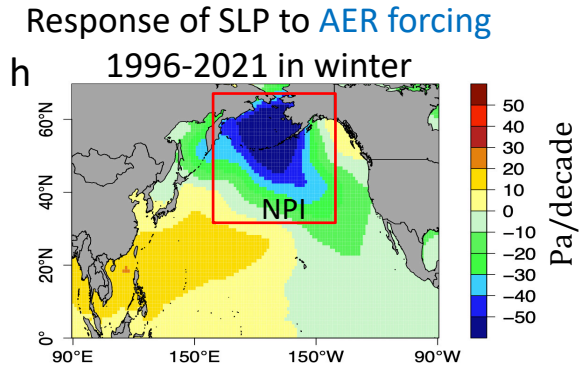












Conclusions

- Forcing by elevated **GHG levels has virtually certainly caused** the multi-year persistent 2019/2021 (2014/2015) marine heatwave, in a necessary causation sense.
- We discover an **outstanding warming pool co-located with the Blob-like** SST anomalies, which we attribute to GHG forcing and the recent industrial aerosol-load decrease ($P < 0.05$)
- The warming pool is associated with **a powerful strengthening ridge** that has recently emerged from the natural variability, indicating that it will provide **conducive conditions for even more severe marine heatwave** events in the future.

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