# Distinct anthropogenic greenhouse gas and aerosol driven marine heatwaves

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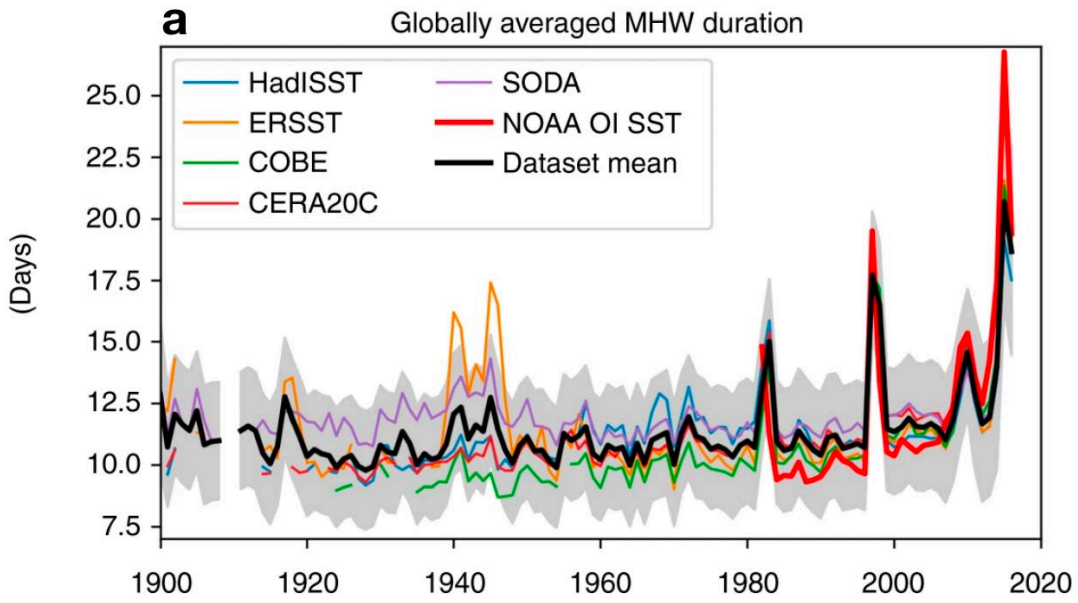
# Marine Heatwaves (MHWs)

- **MHWs** are extreme warm events in which sea surface temperature (SST) is higher than the threshold (the 90th percentile of daily SST climatology), persists for at least five days, with no less than 3 days interval. (Hobday et al., 2016)
- MHWs have significant impacts on ecosystem, fishery,  and economy.
- MHW duration and frequency have been increasing globally under global warming.

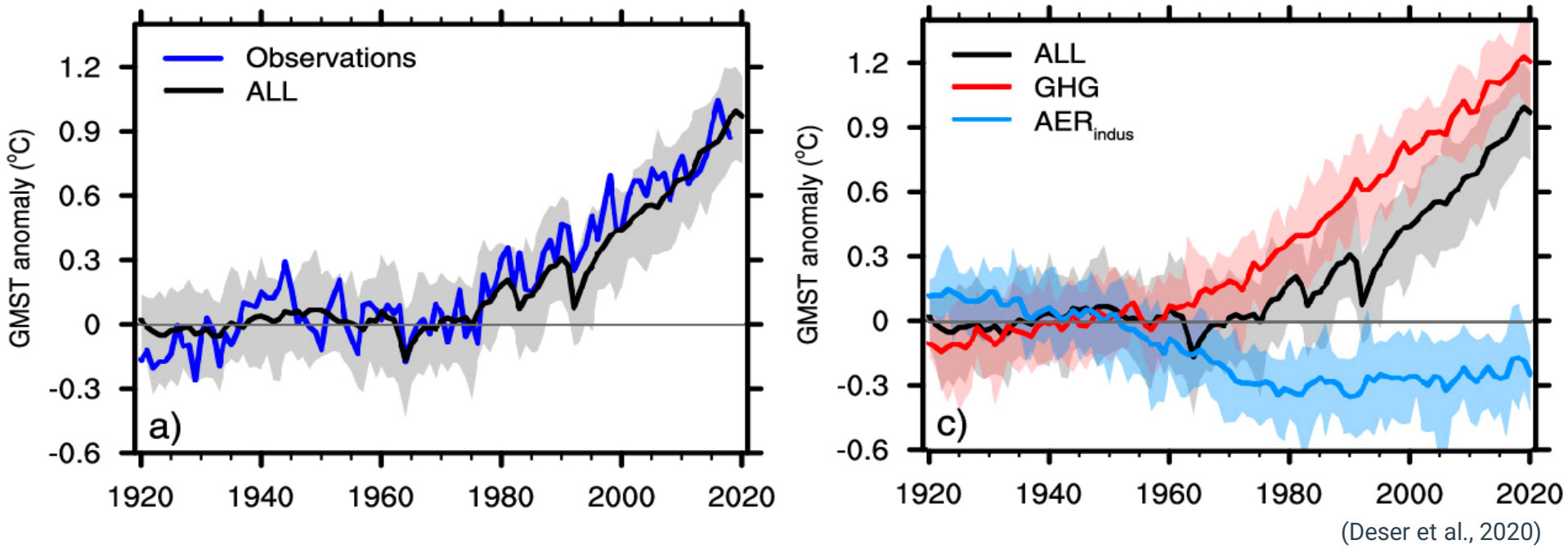

A marine heatwave off the west coast of Australia decimated kelp populations.
Image credit: Thomas Wernberg (University of Western Australia).




(Oliver et al., 2018)

# Motivation and Scientific Questions

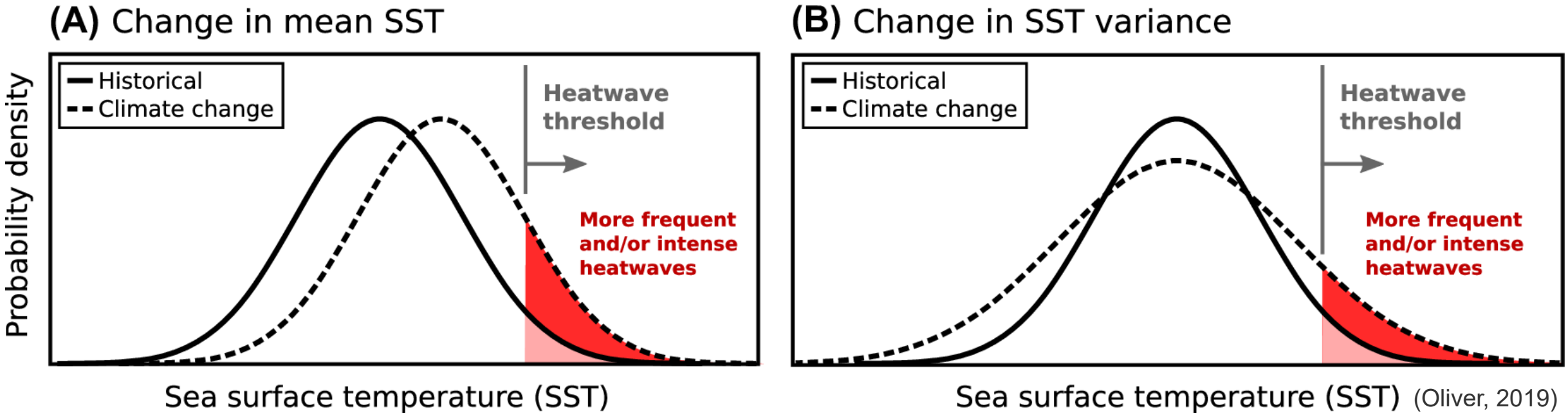
- **Greenhouses (GHGs) ↑ positive**
- **Anthropogenic aerosols ↓ negative**




(Deser et al., 2020)

**How do anthropogenic aerosols and GHGs affect MHWs?**

# Motivation and Scientific Questions



(Oliver, 2019)

**Anthropogenic GHGS and aerosols can shift the mean-state SST to modulate MHWs.**

**In addition to this mean-state shift, can they alter the shape of SST probability distribution to modulate MHWs?**

# Methods and Materials

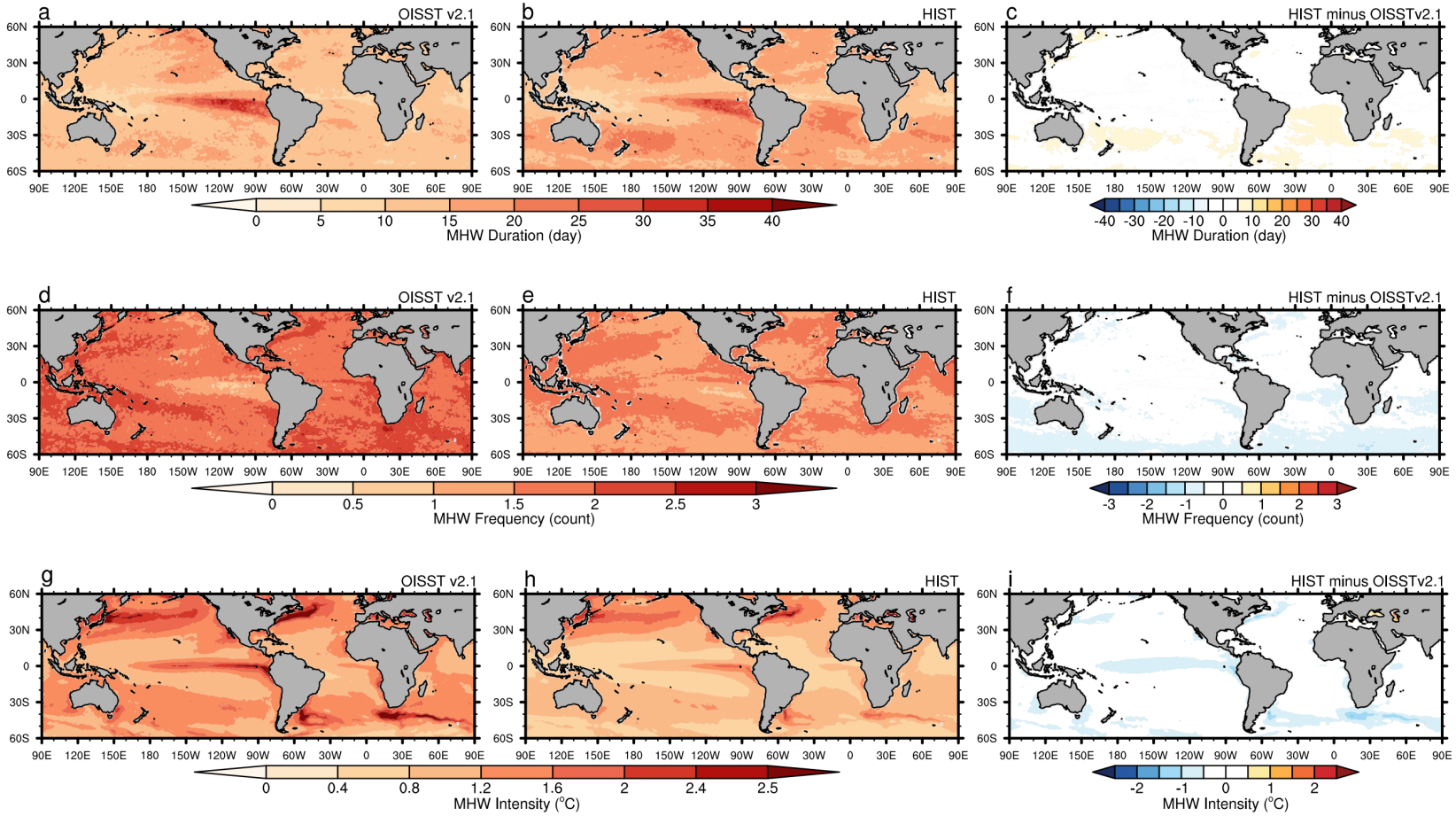
- Observation: OISST V2.1 1982-2020
- 10 CMIP6 fully coupled climate models (ACCESS-CM2, ACCESS-ESM1-5, BCC-CSM2-MR, CNRM-CM5-1, CESM2, CanESM5, HadGEM3-GC31-LL, IPSL-CM6A-LR, MRI-ESM2-0, and NorESM2-LM)

  a) **Historical simulation:** driven by the historical variations of all climate forcings, including anthropogenic GHGs and aerosols (HIST+SSP245)
  b) **Single forcing simulation:** solely driven by anthropogenic GHGs (HIST-GHG) or aerosols (HIST-AER)

**The daily SST climatology is distinct among the HIST, HIST-GHG and HIST-AER simulations. For each simulation, the daily SST climatology is calculated. Hence, our methodology eliminates the effect of mean-state SST differences on MHWs.**

# Observed and simulated Marine Heatwaves

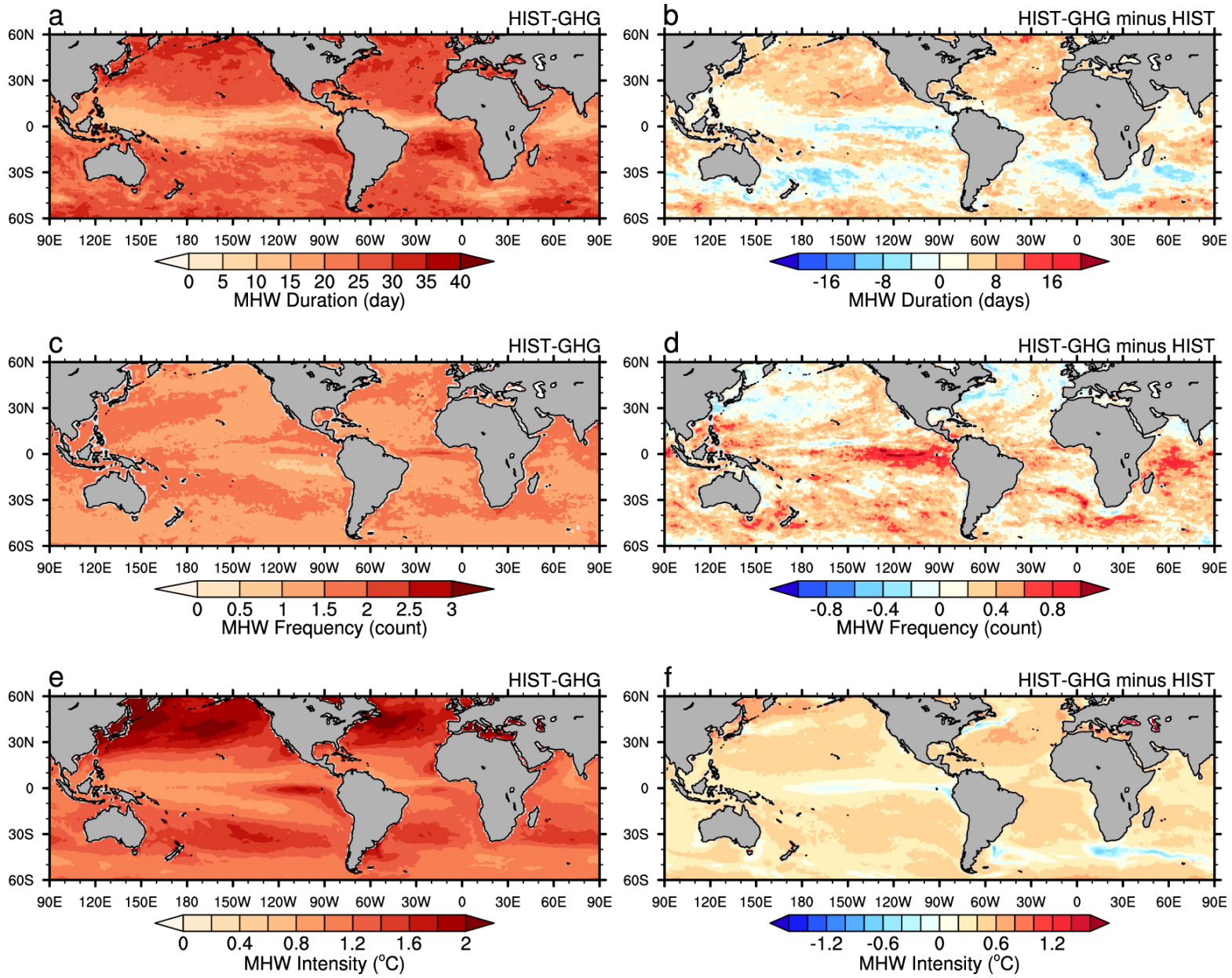
- Strongest and most persistent MHWs → eastern tropical Pacific.
- Short but strong MHWs → Gulf Stream and Kuroshio extensions.
- The difference in MHW between observations and model simulations is **negligible**.




**The main distribution patterns of observed MHWs are well captured by model historical simulations over the past four decades.**

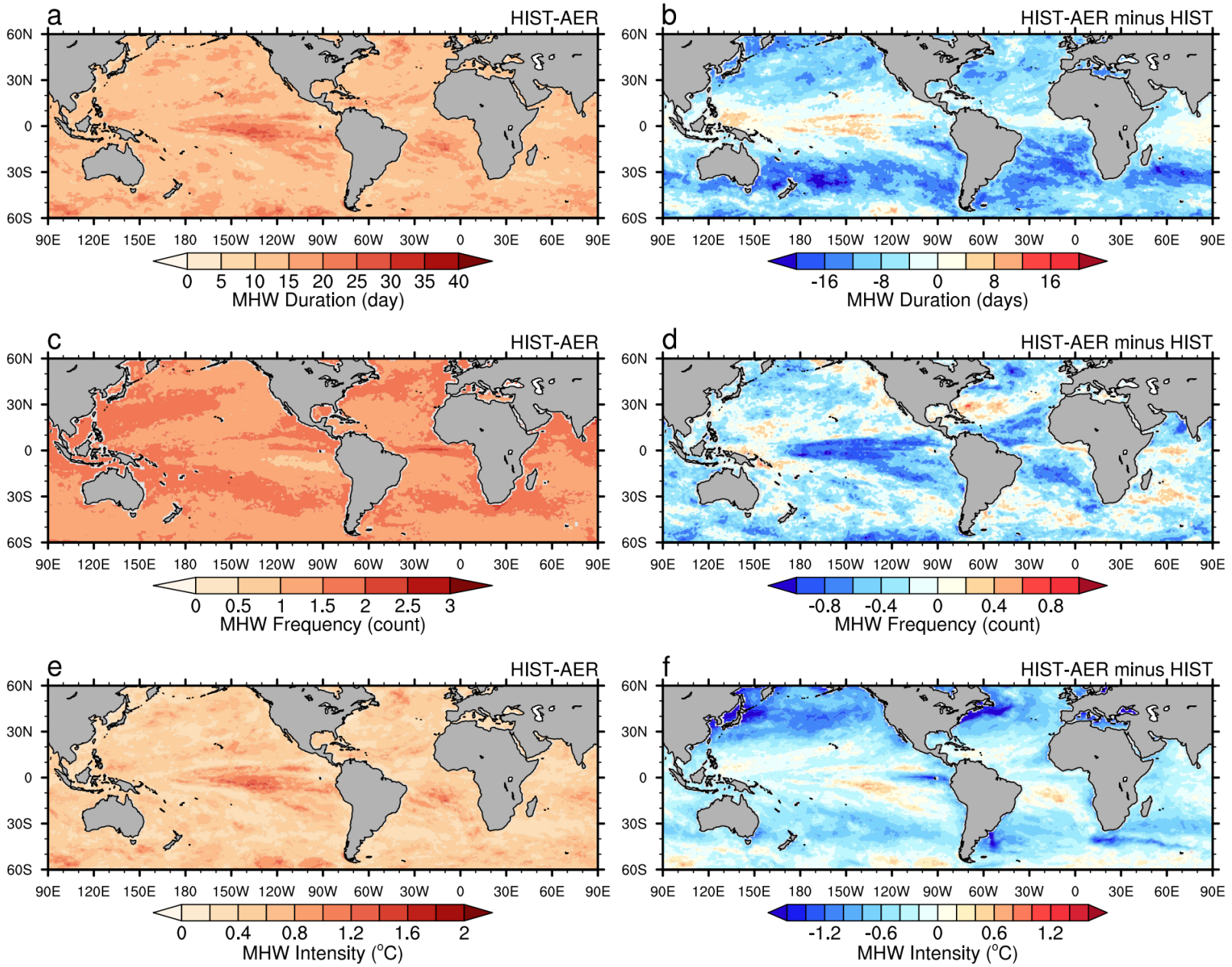
# Global MHWs driven by GHGs alone

When only the effects of anthropogenetic GHGs are taken into account, more persistent and intense MHWs are expected to occur more frequently over most of the global ocean compared to historical simulations.

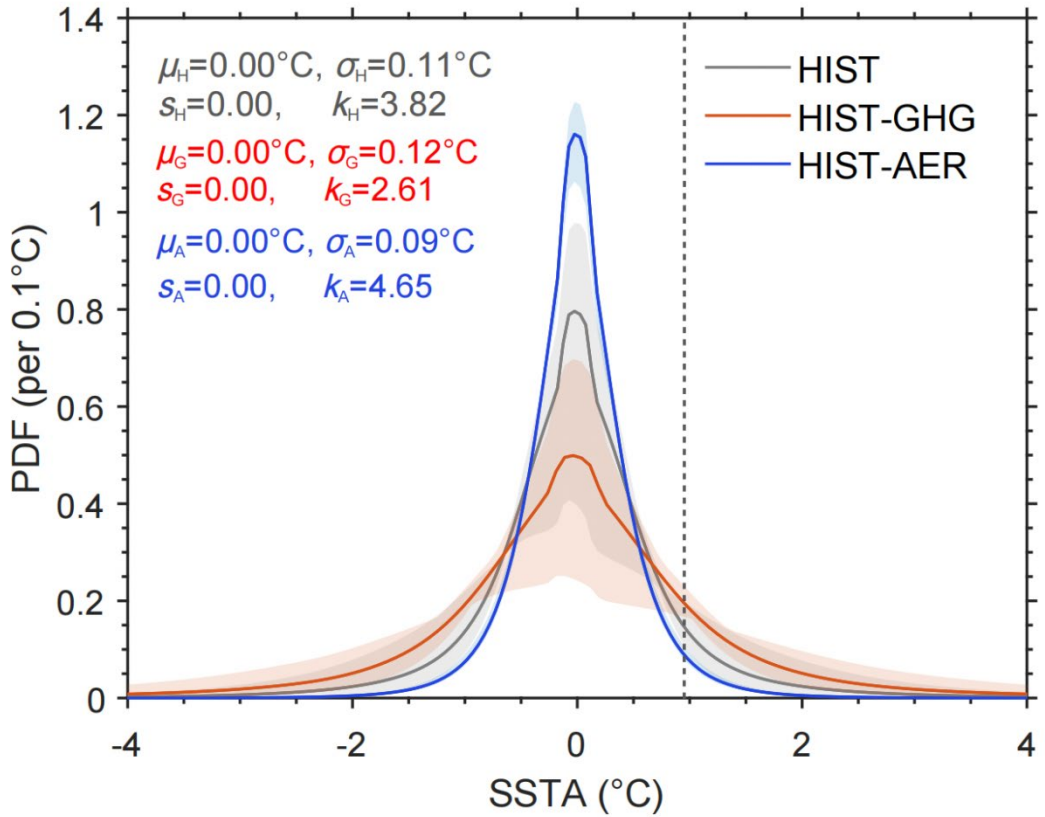


# Global MHWs driven by aerosols alone

When only the effects of anthropogenetic aerosols are considered, weaker and shorter MHWs are expected to occur less frequently over global oceans compared to historical simulations.



# Probability Density Function (PDF)




- Compared to HIST, HIST-GHG and HIST-AER show smaller and larger kurtosis, respectively, which implies GHGs (aerosols) alone foster (inhibit) the occurrence of climate extremes such as MHWs.
- According to the strong kurtosis changes, anthropogenic GHGs or aerosols alone can also exacerbate or mitigate cold climate extremes (the left-hand tail of probability distribution) like marine cold spells.

Kurtosis -> +0.25 ◦C (HIST-GHG) & -1.35 ◦C (HIST-AER), for 99$^{th}$ percentile SSTA, relative to HIST

Mean-state shift -> +0.48 ◦C (HIST-GHG) & -0.70 ◦C (HIST-AER), relative to HIST

**The effect of Kurtosis on MHWs is comparable to that by mean-state change.**

# Conclusion

- Compared to historical simulations, global MHWs show larger (smaller) frequencies, intensity and durations under anthropogenic GHGs (aerosols) alone scenario.
- Compared to historical simulations, global SST probability distribution has expanded (contracted) tails under anthropogenic GHGs (aerosols) alone scenario, indicating the promotion (reduction) of extreme climate phenomena such as MHWs.
- The effect of kurtosis on climate extremes is comparable in magnitude to that of mean-state change.

**Ren, X., Liu, W., allen, R. J., & Song, S. (2024). Distinct Anthropogenic Greenhouse Gas and Aerosol Induced Marine Heatwaves. Environmental Research: Climate, 3(1). https://doi.org/10.1088/2752-5295/ad13ac**

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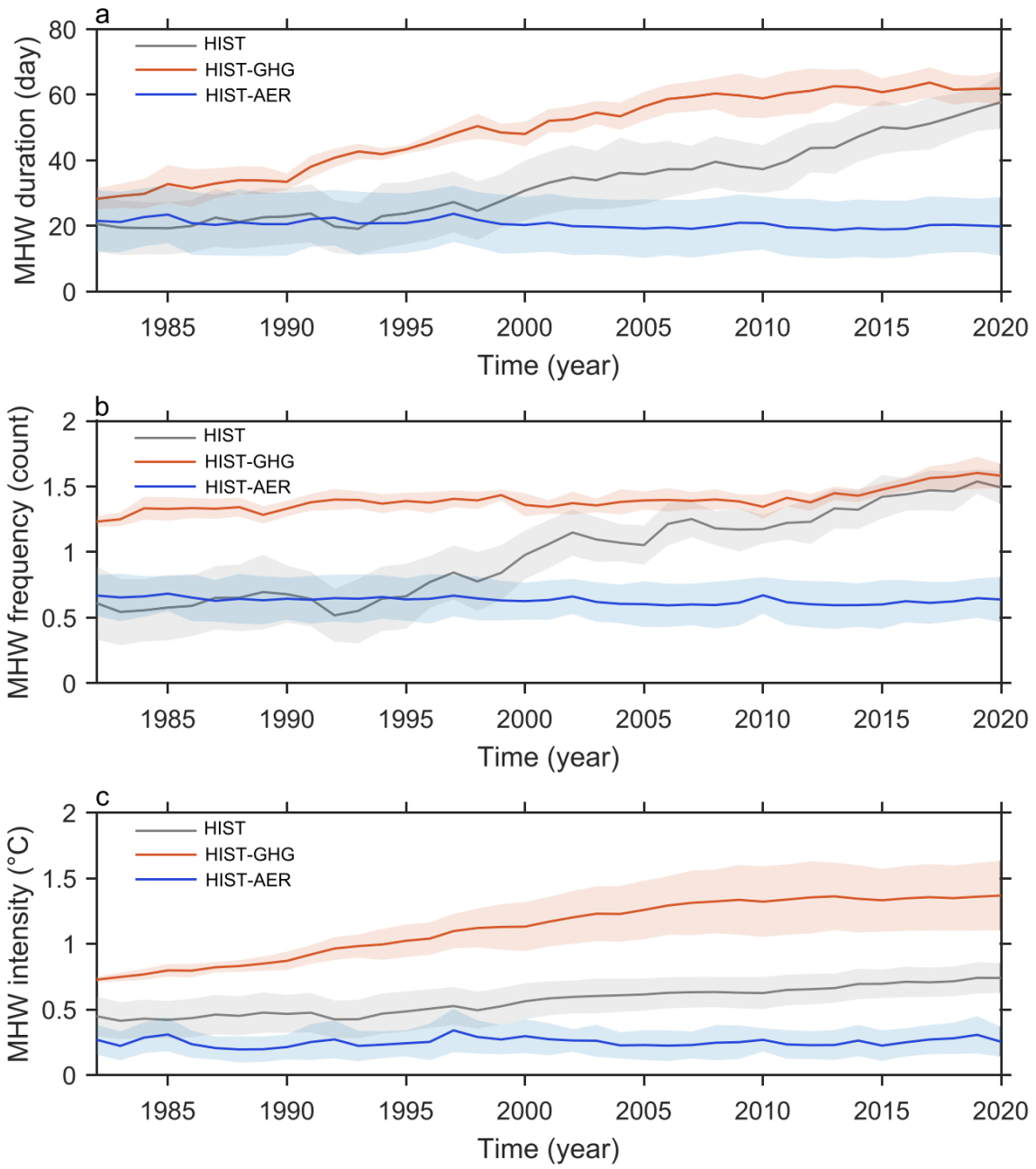
# MHW metrics time series

- GHG variations lead to longer-lasting, more frequent, and intense MHWs.
- Anthropogenic AER markedly curb the intensity and growth of MHWs.

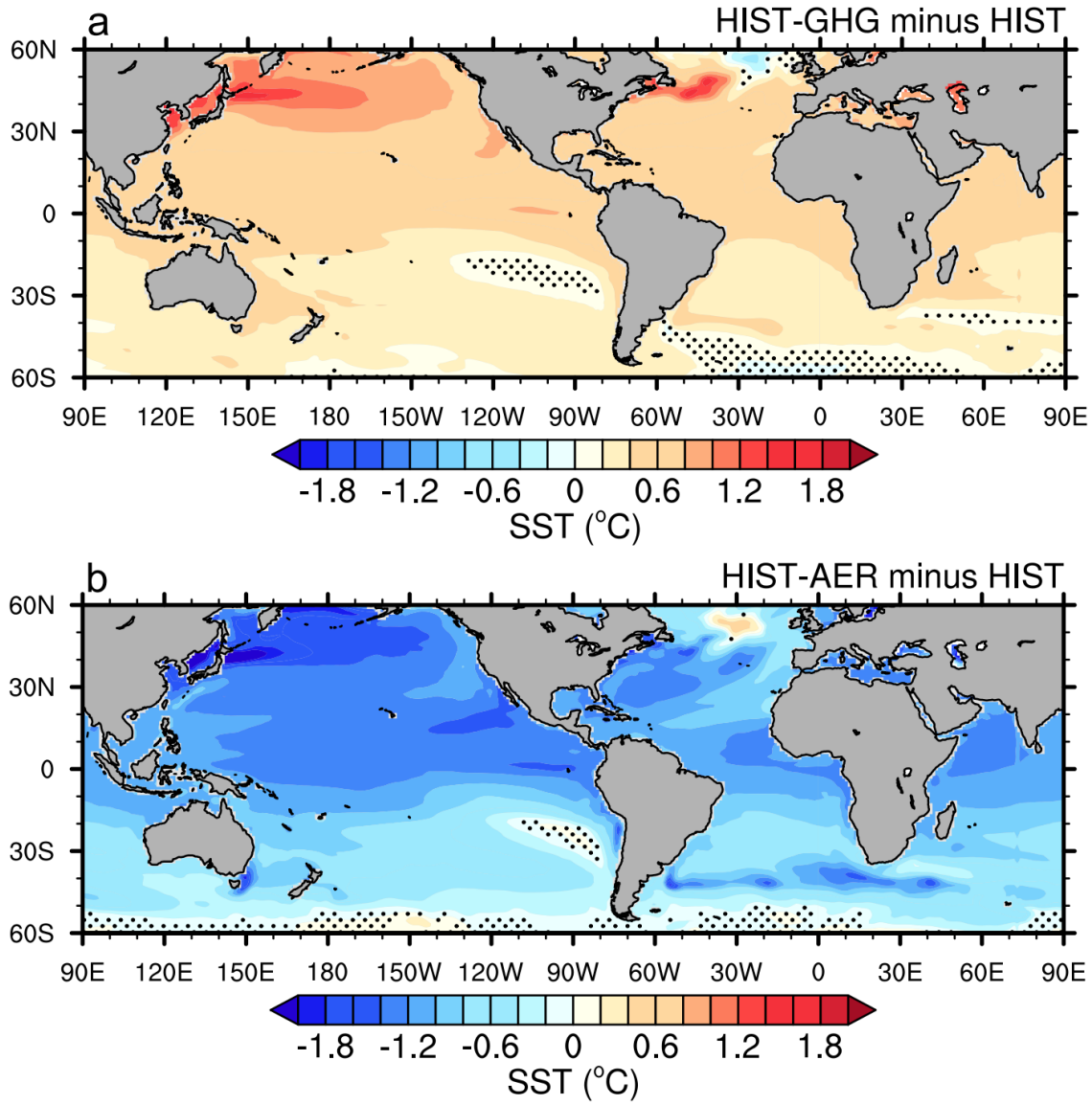


# SST mean state change

HIST-GHG → Anomalous global SST warming,
PDF shift ↑ **0.48** ℃

HIST-AER → Anomalous global SST cooling
PDF shift ↓ **0.70** ℃

The aerosol- and GHG- induced mean-state shifts → PDF shifts



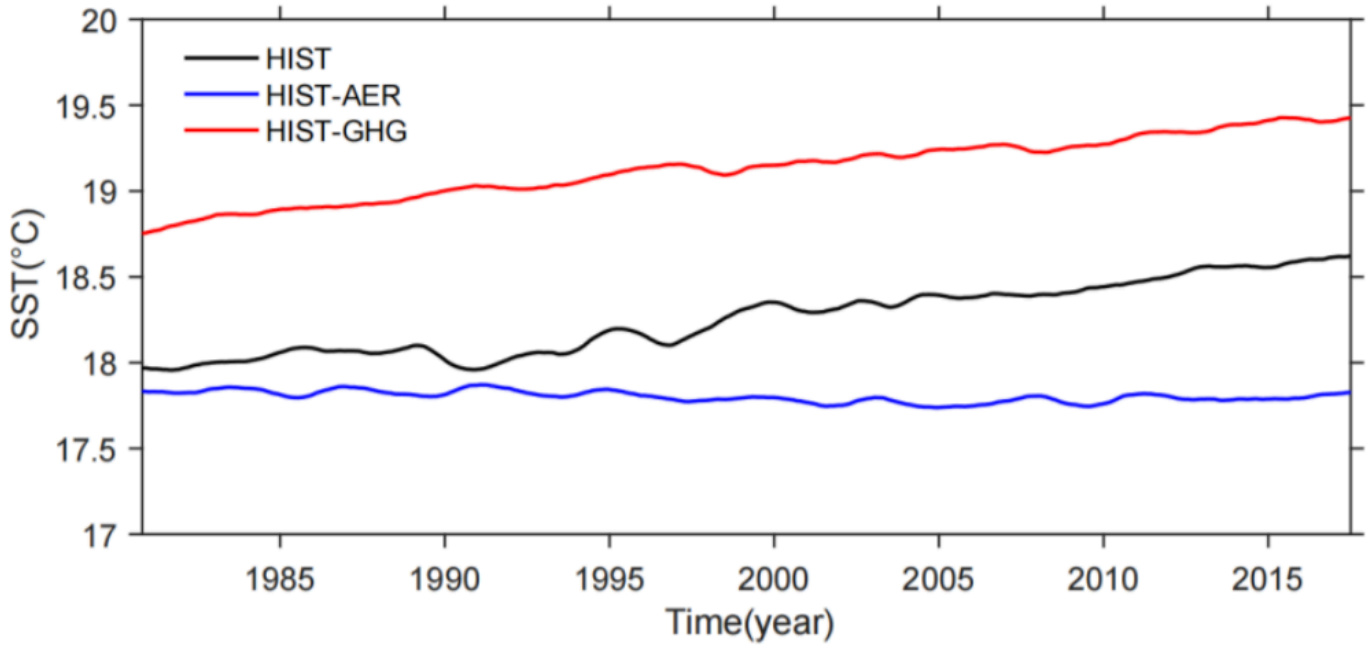



**Figure R2.** Time series of globally (60°S-60°N) averaged annual mean SST for the HIST, HIST-GHG and HIST-AER simulations during 1982–2020.