Subsurface Ocean Temperature Responses to the Anthropogenic Aerosol Forcing in the North Pacific

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CESM CVCWG MEETING
Feb 21, 2023

Climate Effects of Anthropogenic Aerosols (AAs):

SST trends from CMIP5 MMM

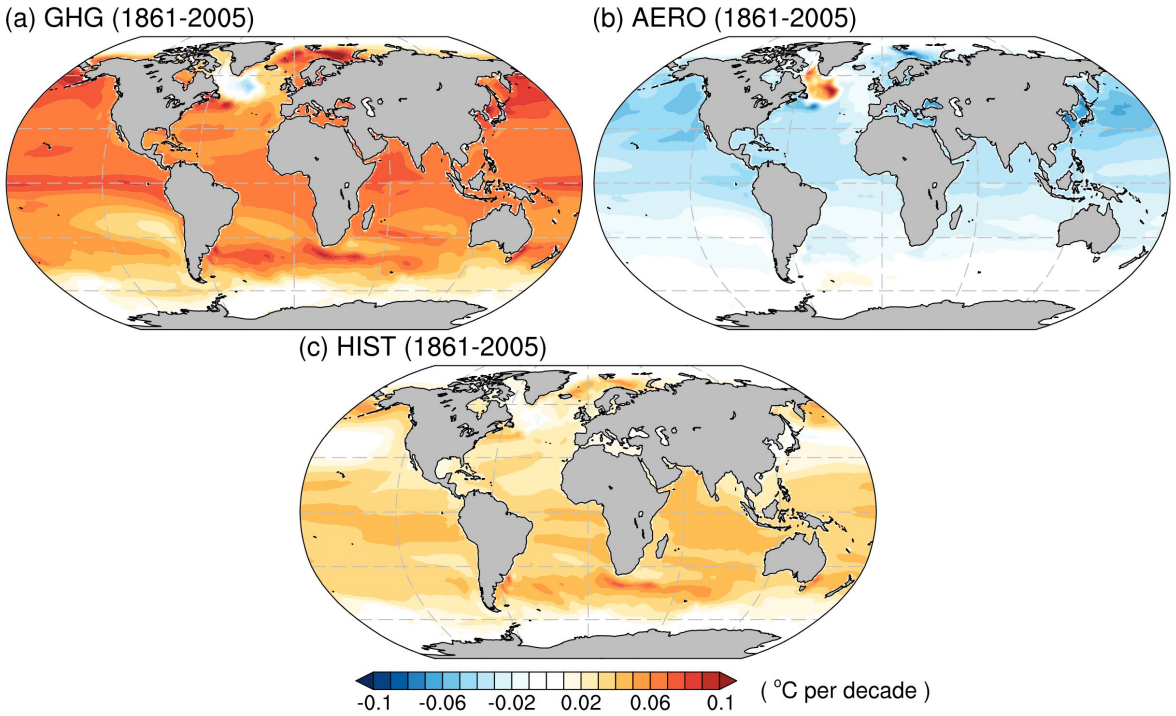
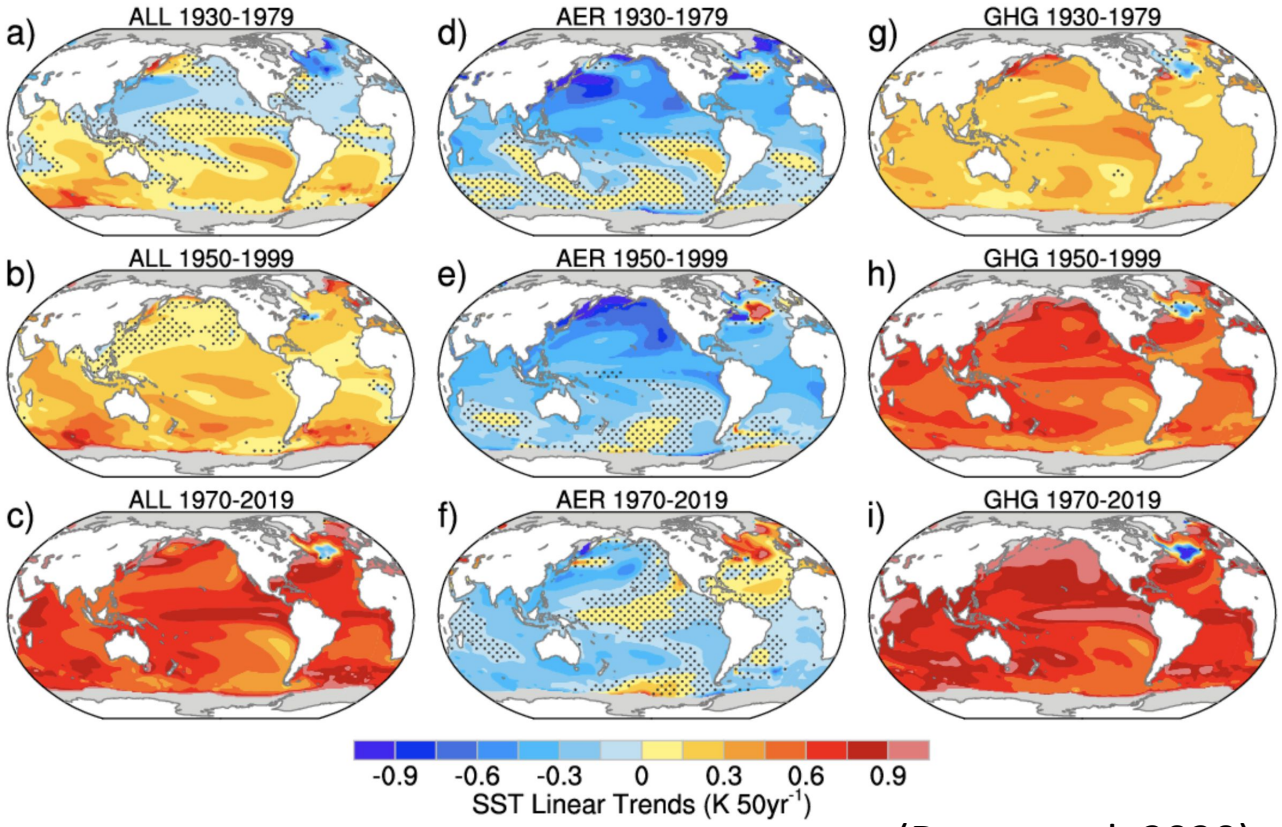


FIG. 2. Trend of SST (°C decade^{-1}) of ensemble mean of 9 CMIP5 models in the (a) GHG runs (1861–2005), (b) AERO runs (1861–2005), and (c) HIST runs (1861–2005). Positive indicates warming of surface seawater.

(Shi, Xie and Talley. 2018)

SST trends from CESM1 Large Ensemble (LENS)



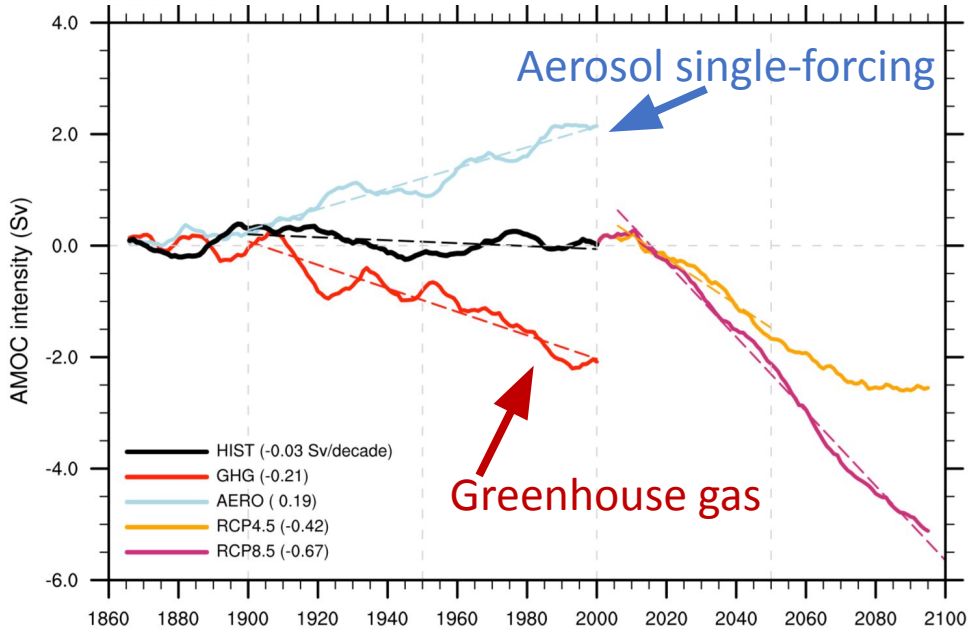
(Deser et al. 2020)

Climate Effects of Anthropogenic Aerosols (AAs):

Lots of previous studies focused on the **surface and atmospheric responses** to AA-forcing.

Importantly, AA-forcing can also give rise to **substantial changes within the ocean**. For example:

Atlantic Meridional Overturning Circulation (AMOC) responses (CMIP5 MMM)



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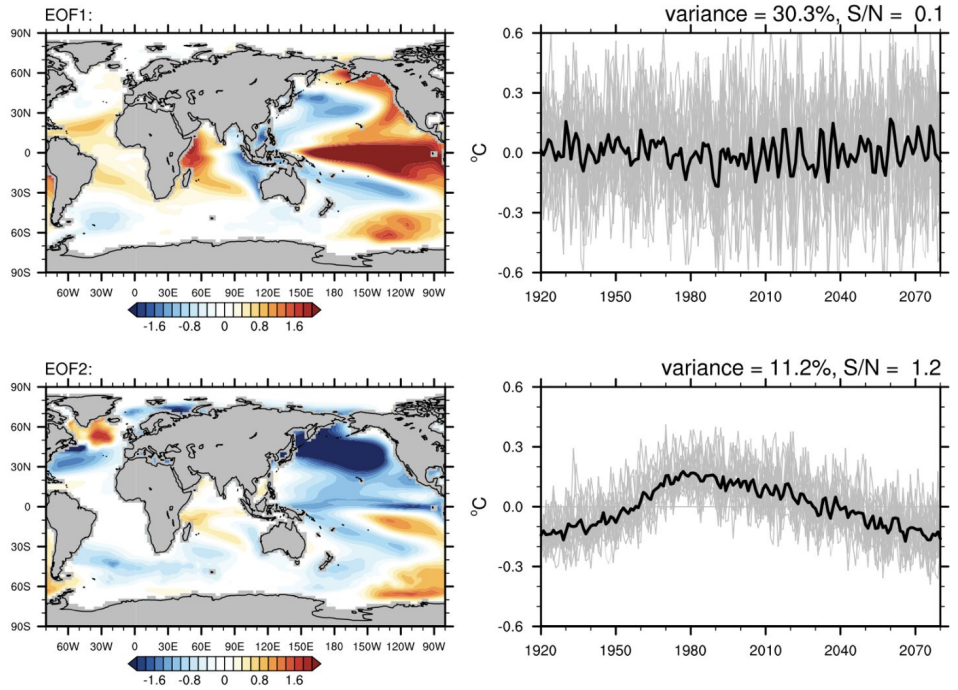
EOFs on SST from CESM1 AA-forcing ensemble



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In this study:

How do the aerosols affect the subsurface temperature change in the N. Pacific?

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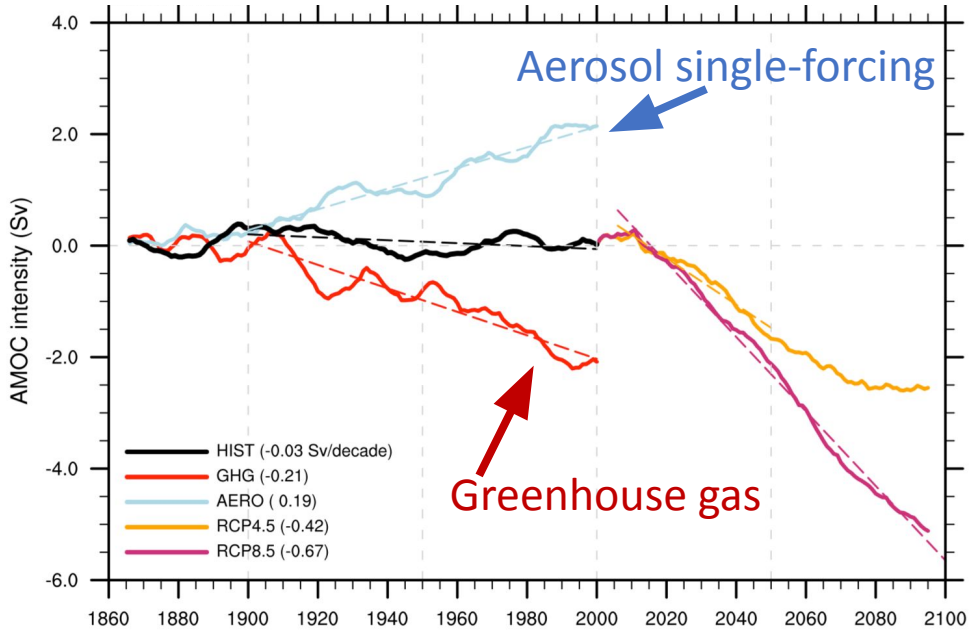

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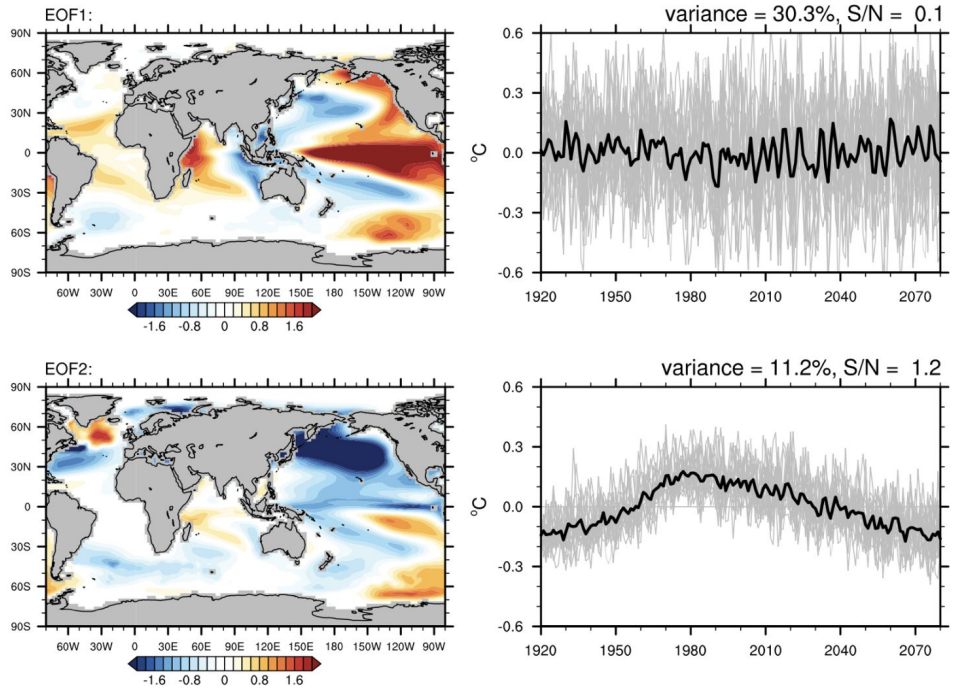

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In this study:

How do the aerosols affect the subsurface temperature change in the N. Pacific?

Is the "fingerprint" driven by aerosols identifiable from the background noise?

Data

CESM1 Large Ensemble Simulations:

- **CESM1 all forcing runs, LENS**: Historical & RCP8.5, 40 members with identical radiative forcing and different initial conditions.
- **CESM1 all-but-one-forcing runs, XAER**: Same with LENS but without industrial-AER forcing, 20 members (1920-2080).

Based on method in Deser et al. 2020, anthropogenic aerosol single-forcing ensemble (**AER**) is calculated as:

$$AER_i = (XAER_i - XAER_{em}) + (LENS_{em} - XAER_{em})$$

CanESM5 Large Ensemble Simulations:

- **CanESM5 aerosol single-forcing runs**: AAs are the only time varying forcing agent, 15 members.

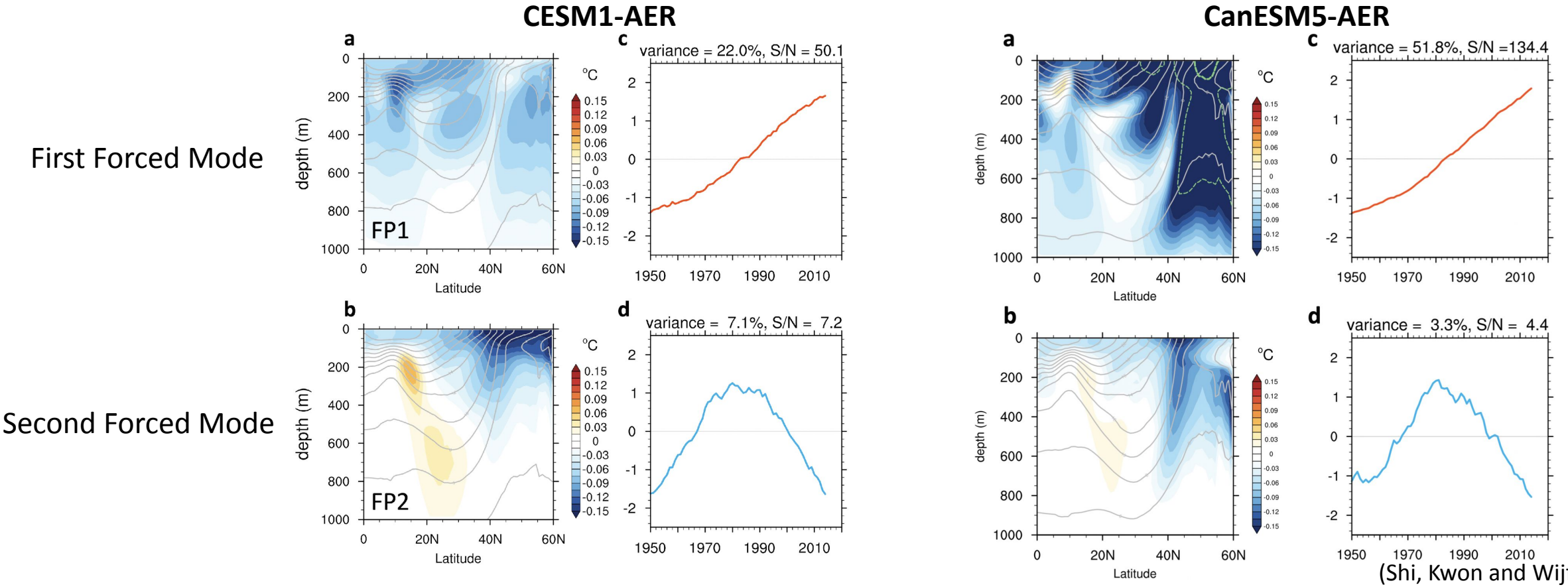
Upper 1,000 m temperature change in the North Pacific (0° to 60°N), from 1950 to 2014.

Subsurface Fingerprints due to AA-forcing:

Signal-to-noise maximizing pattern analysis finds patterns (linear combinations of EOFs) that maximize the signal-to-noise ratio.

In this method, the extracted patterns are associated with the maximization of the **ratio of signal (e.g., variance of ensemble mean) to the total variance (from all ensemble members)** (Déqué 1988; Schneider & Griffies 1999; Ting et al. 2009; Wills et al. 2020).

Zonal-mean patterns of N. Pacific temperature and time series, 1950-2014



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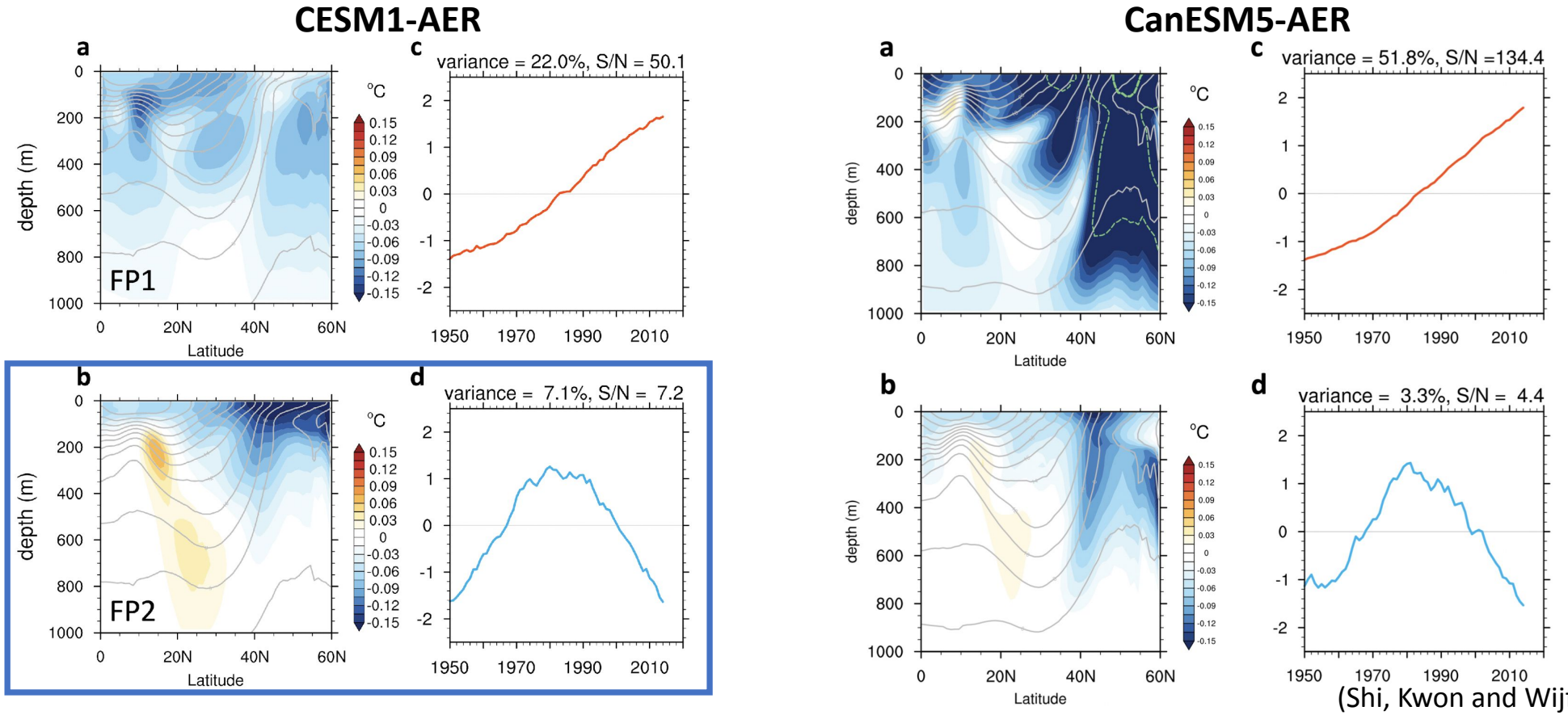

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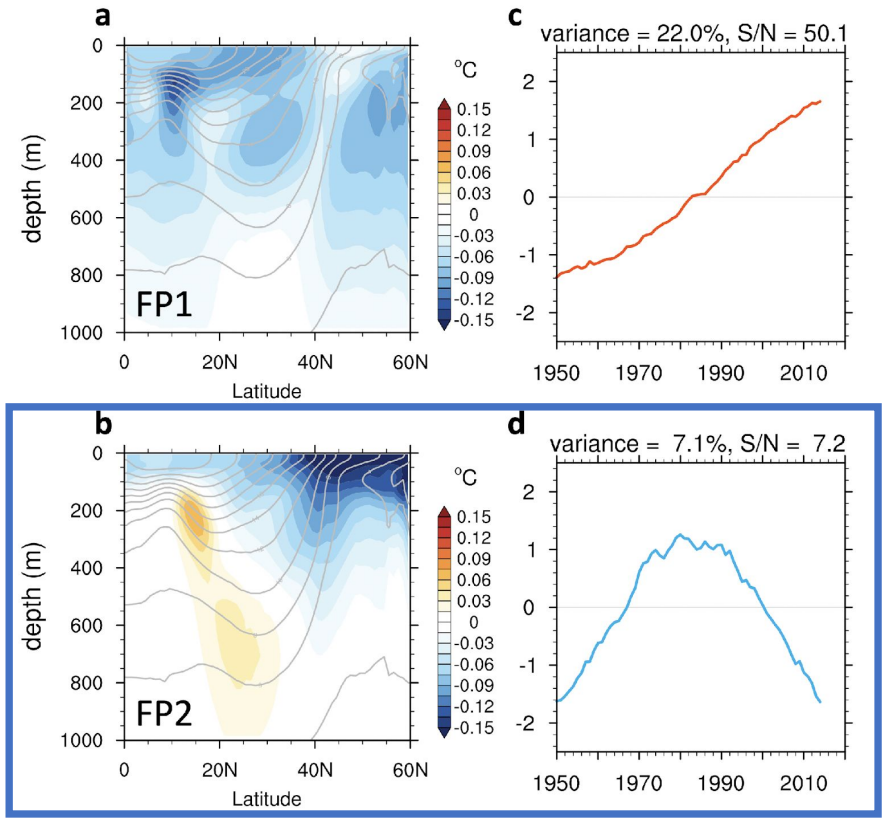
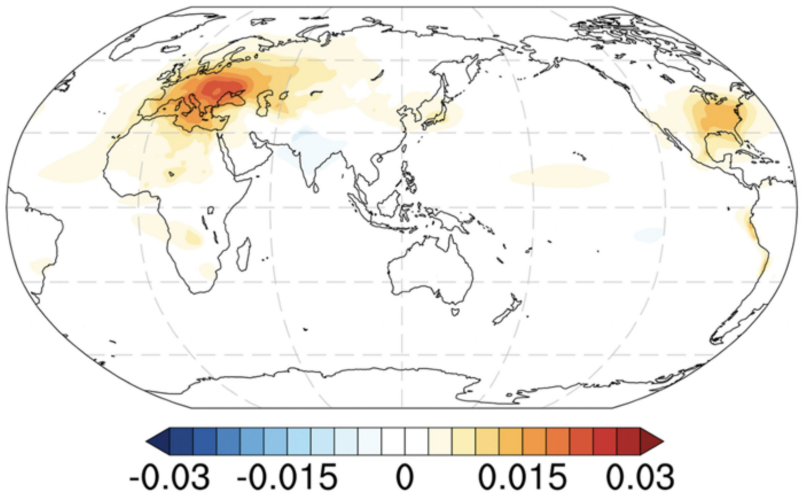
CESM1-AER

First Forced Mode

Second Forced Mode

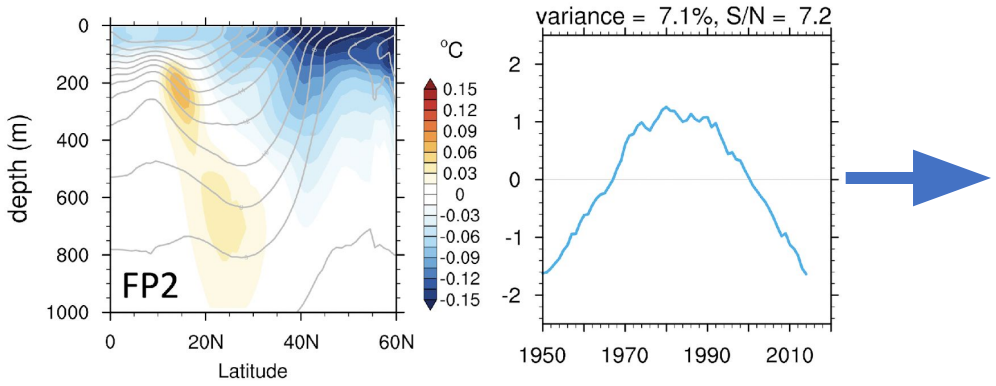


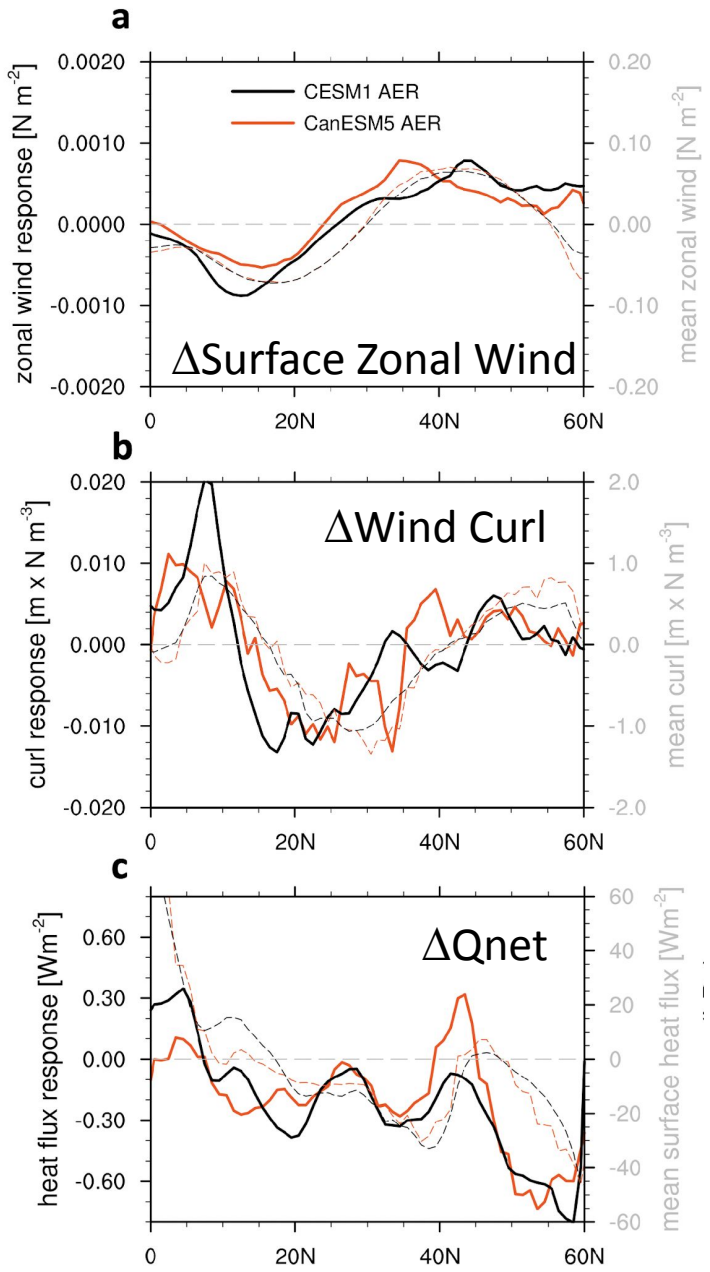
Regression of Aerosol Optical Depth on FP2 series

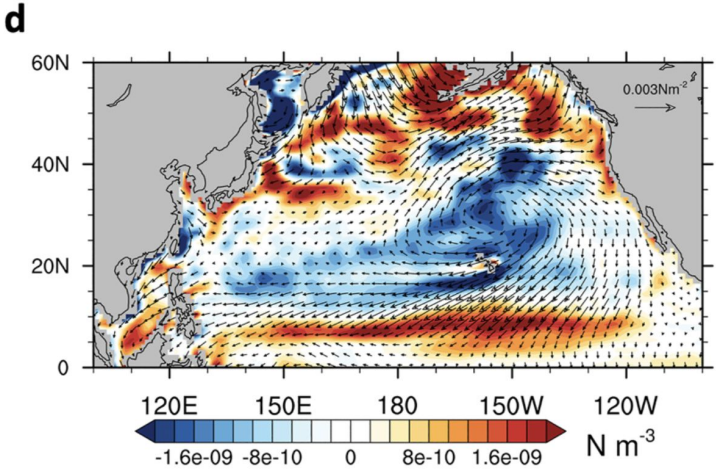


Subsurface Fingerprints due to AA-forcing:

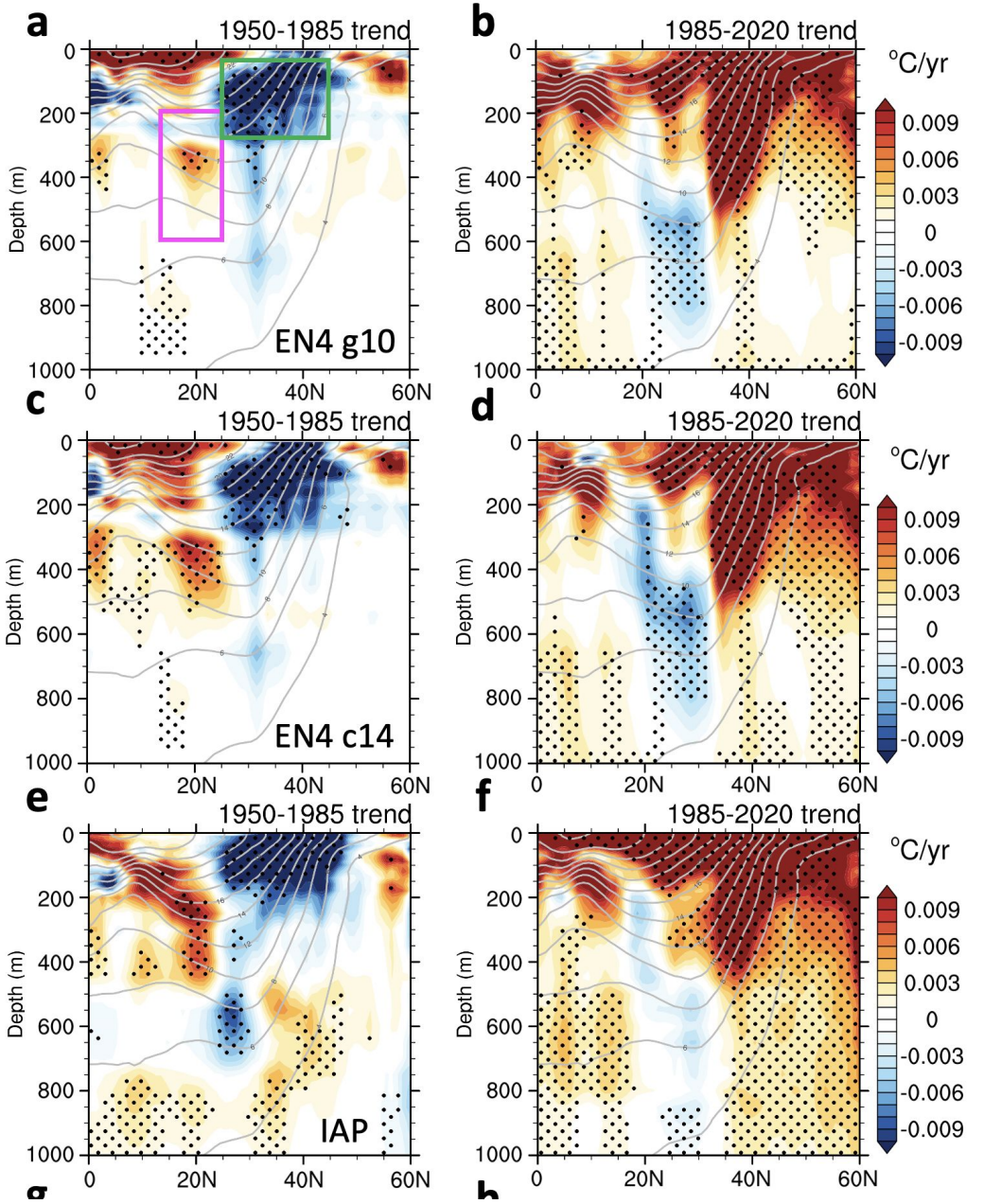
More regression analysis

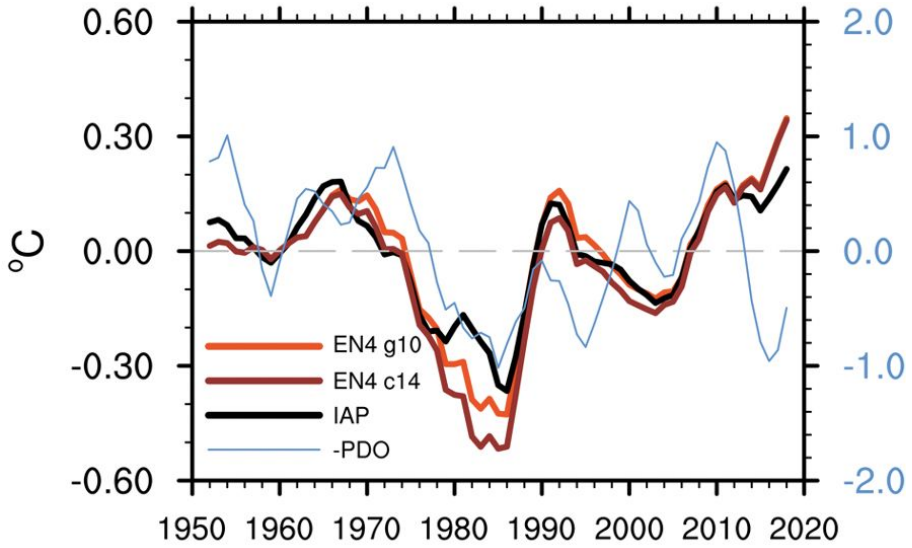


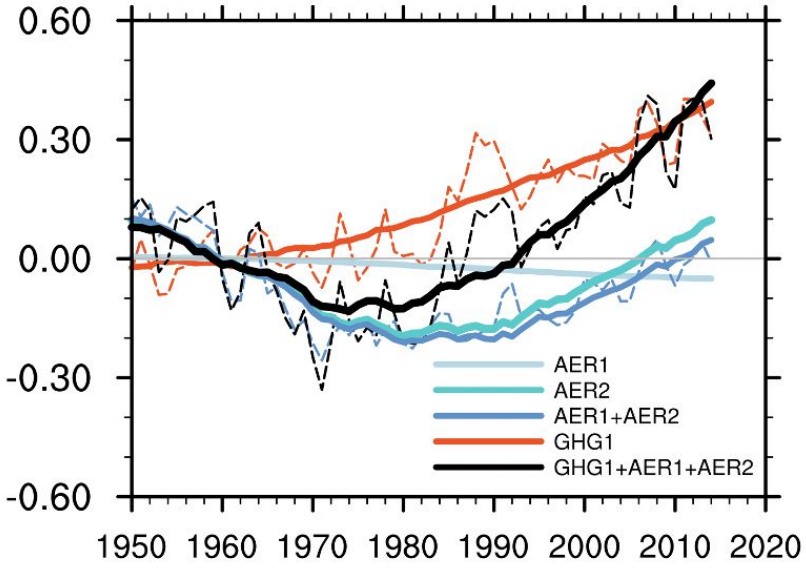




Observed Zonal Mean Changes:

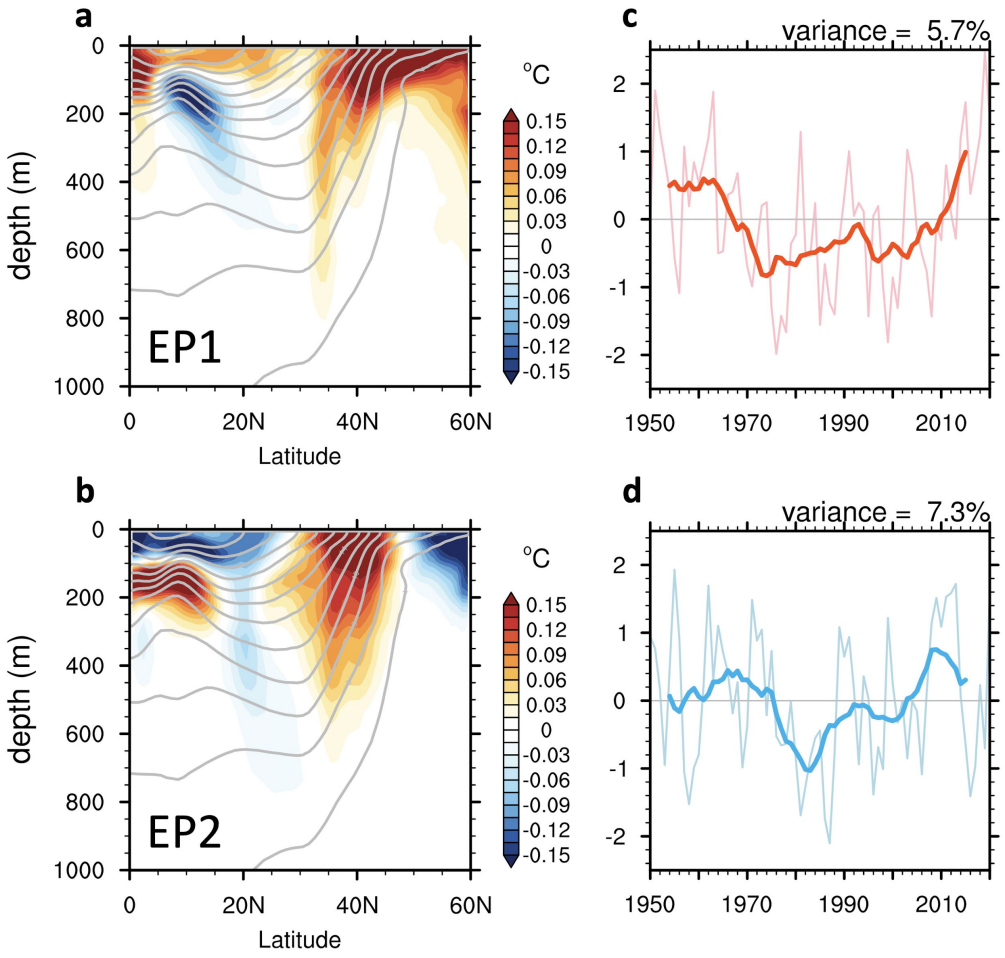




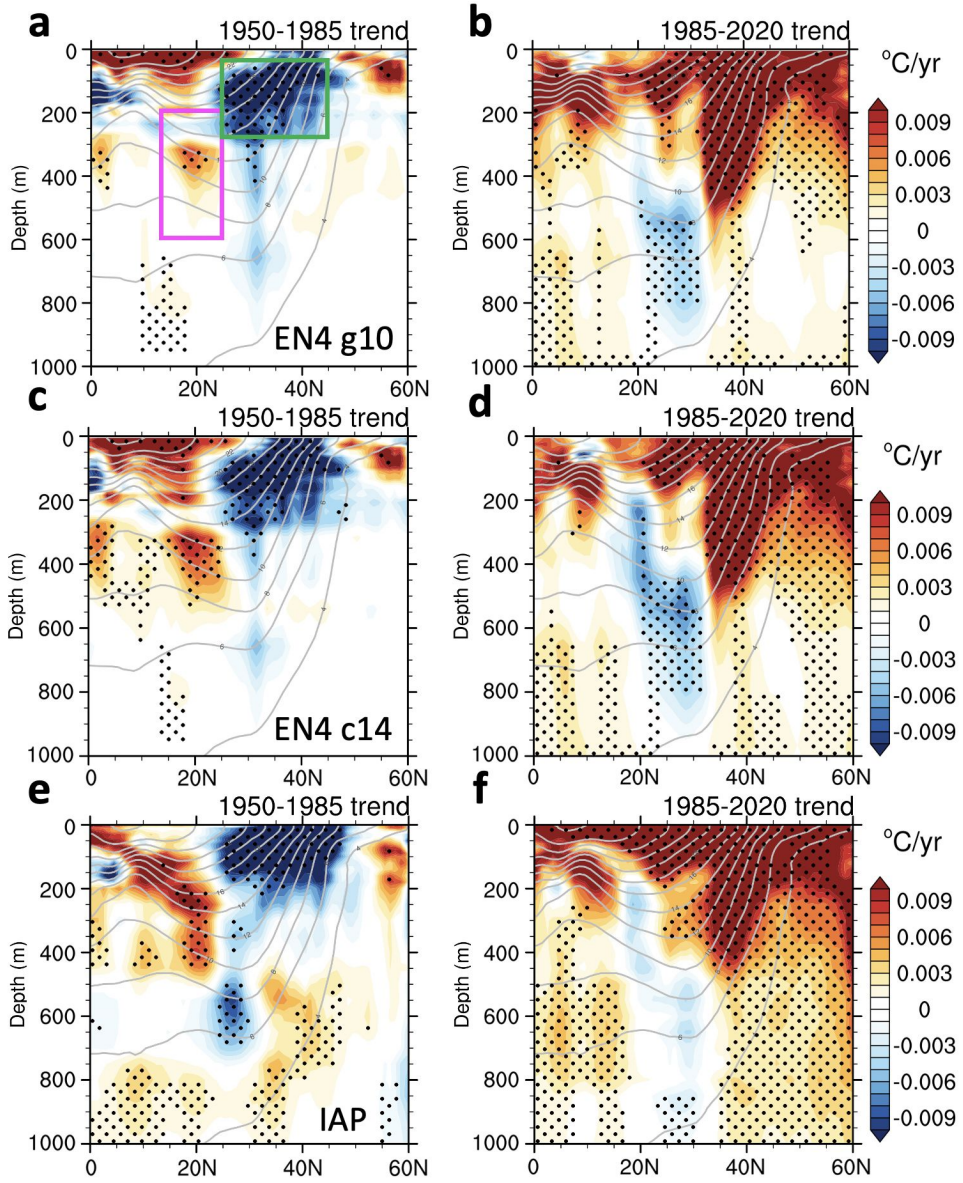


Observed Zonal Mean Changes:

Extracted Pattern (EP) from Observations, 1950-2020
(detrended before the pattern recognition analysis)



Temperature trends from observations



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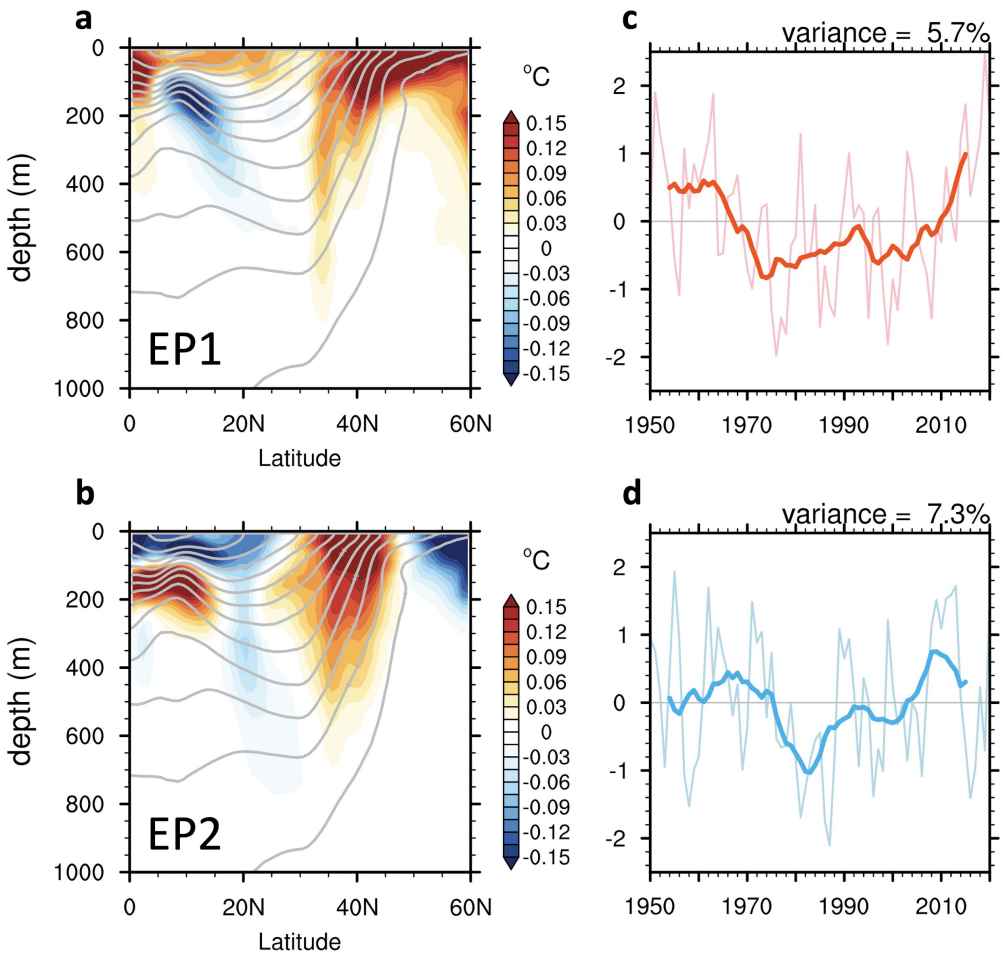
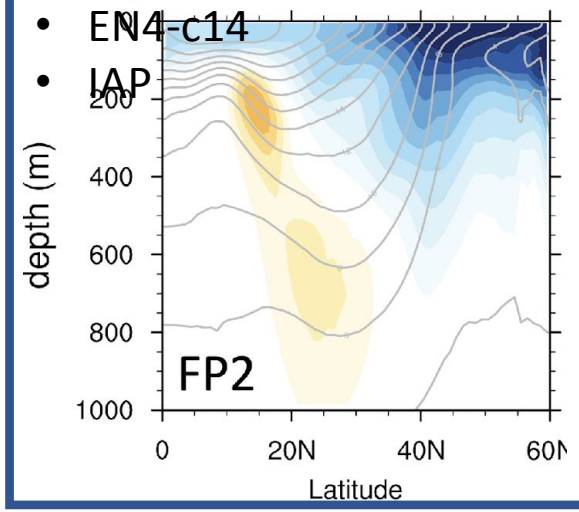


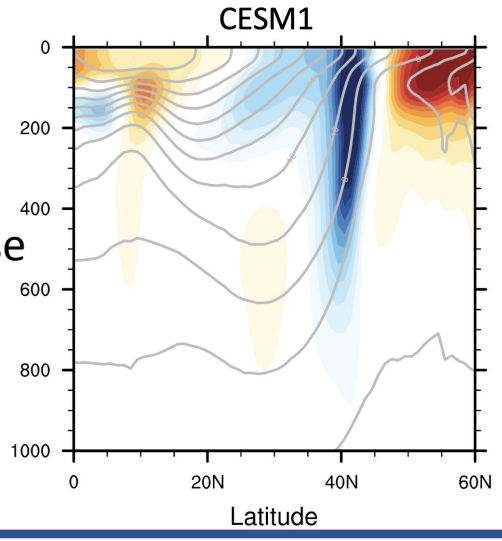
FP2 from CESM1-AER runs

- EN4-g10
- EN4-c14
- IAP



Signal vs. Noise

PDO-related pattern from the pre-industrial control run.



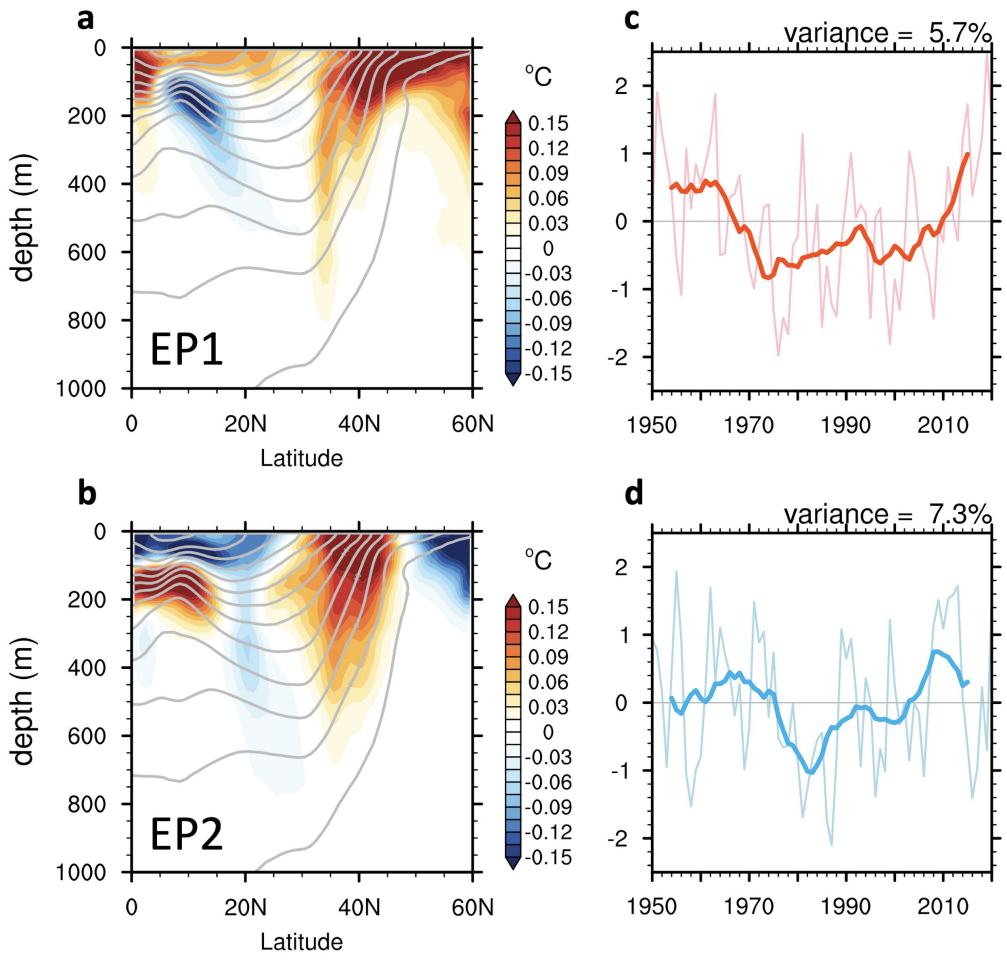
Pattern Correlations

Observed patterns	FP2 from CESM1-AER	FP2 from CanESM5-AER
EP1	**0.80**	**0.64**
EP2	0.18	0.23
EP3	0.07	0.08
EP4	0.28	0.19
EP5	0.04	0.09

Observed patterns	PDO pattern from CESM1 PI	PDO pattern from CanESM5 PI
EP1	0.13	0.25
EP2	**0.64**	**0.63**
EP3	0.15	0.23
EP4	0.39	0.31
EP5	0.01	0.03

Observed Zonal Mean Changes:

Extracted Pattern (EP) from Observations, 1950-2020
(detrended before the pattern recognition analysis)



Take-home points:

1. Anthropogenic aerosols do leave their "fingerprints" within the ocean.

2. The characteristic spatial pattern and non-linear feature of aerosol effects can be extracted from the strong background noise (i.e. internal variability).

3. The extracted forced responses are useful to understand the recent observed changes and improve future projections.

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References:

J.-R. Shi, Y.-O. Kwon, S. Wijffels. "Subsurface Ocean Temperature Responses to the Anthropogenic Aerosol Forcing in the North Pacific". *Geophys. Res. Lett.* (2023). https://doi.org/10.1029/2022GL101035.

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Thank you!