CESM2 single anthropogenic greenhouse gas and aerosol forcing large ensembles

CESM Winter 2025 Working Group Meeting

ESPWG/CVCWG Session

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Thanks to: Isla Simpson, Clara Deser, Nan Rosenbloom, Xueying Zhao, Yan-Ning Kuo, Chia-Wei Lan, Min-Hui Lo, and Chun-Chieh Wu

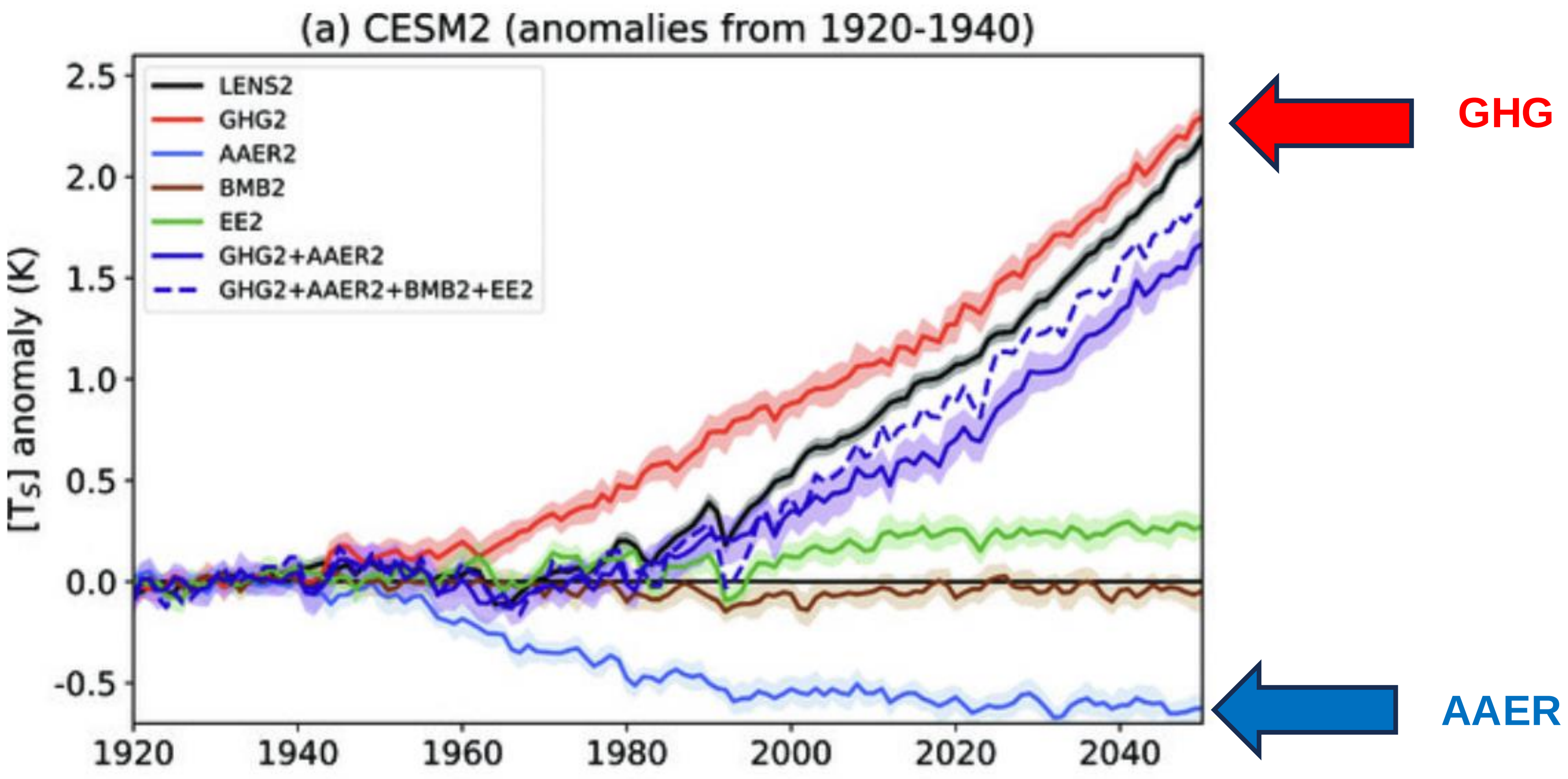
CESM2 Single Forcing Large Ensemble Project

The CESM2 "Single Forcing" Large Ensemble Project is a publicly available set of climate model simulations useful for addressing the roles of individual forcings in historical and future climate change. This simulations use the same model and forcings as the CESM2 Large Ensemble Project and, therefore, can be used to parse the relative roles of different forcings in responses found in that ensemble where all forcings are applied together. The ensemble members are initialized from 1850 from the same initial conditions that were used to initialize the "macro" members of the CESM2 Large Ensemble and they extend to 2050, following CMIP6 historical forcings prior to 2015 and SSP3-7.0 forcings, thereafter. Note that the smoothed biomass burning emissions that were used in the second 50 members of the CESM2 large ensemble are used, so these simulations should be compared with the second 50 members of the CESM2 large ensemble. Four primary ensembles are available in which different forcings are time evolving while all other forcings are held fixed at 1850's values i.e, the "only" method is used. Note that this differs from the CESM1 Large Ensemble which used the "all-but-one" method where all forcings were evolving *except* the one of interest. In the CESM2 ensembles, *only* the forcing of interest is evolving. Four ensembles are available using the following time-evolving forcings:

- GHG = only greenhouse gases evolving (15 members)
- AAER = Only anthropogenic aerosols evolving (20 members)
- BMB = Only biomass burning aersols evolving (15 members)
- EE = everything else evolving i.e., all forcings other than those that are time evolving in GHG, AAER or BMB are time evolving. Greenhouse gases and anthropogenic and biomass burning aerosols are held fixed (15 members)

https://www.cesm.ucar.edu/working-groups/climate/simulations/cesm2-single-forcing-le

"Only method" to quantify the impacts of single forcing - DAMIP



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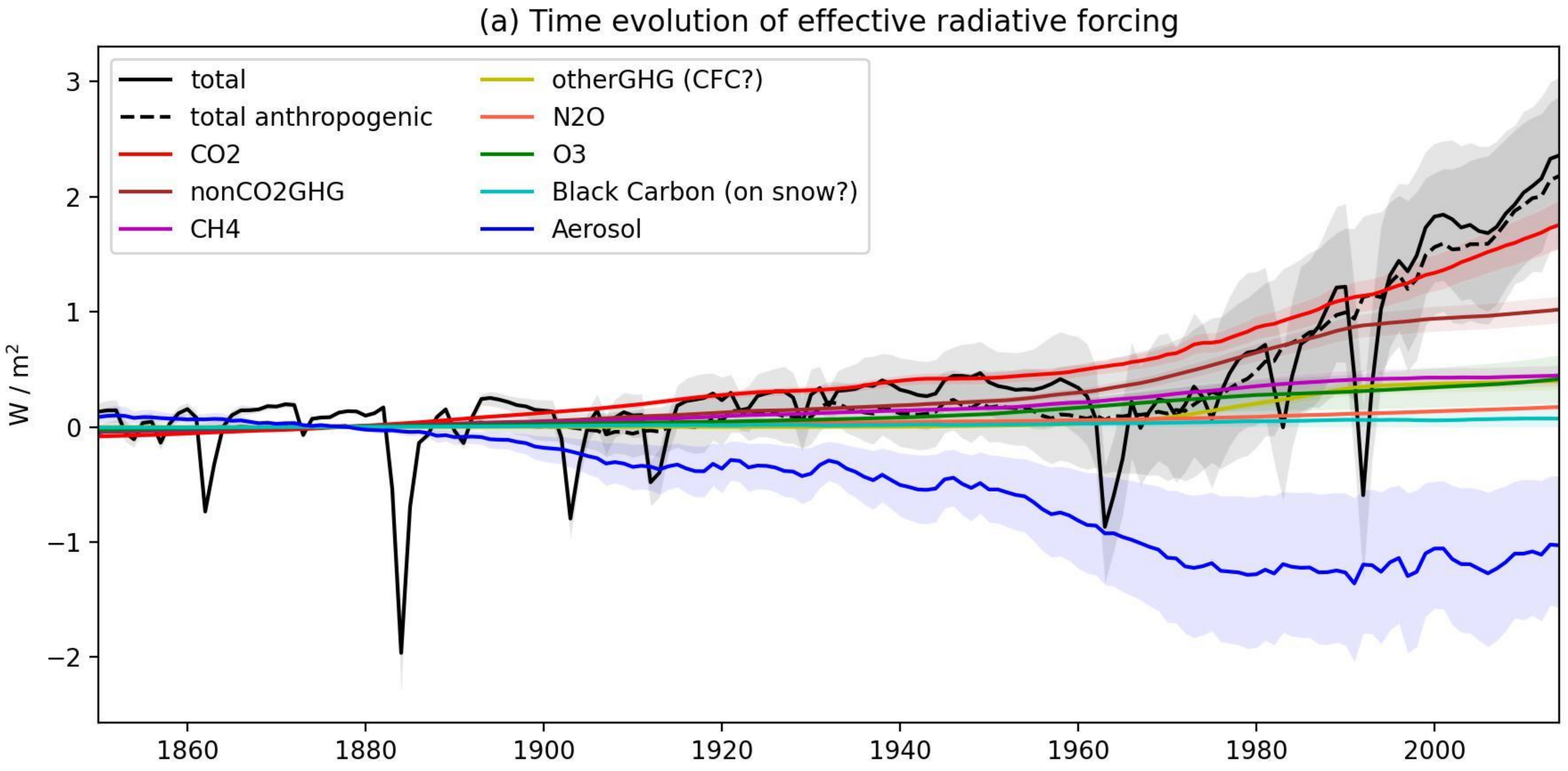
Effective radiative forcing



CMIP6 ERF: https://www.pik-potsdam.de/%3C0303%3Emmalte/rcps

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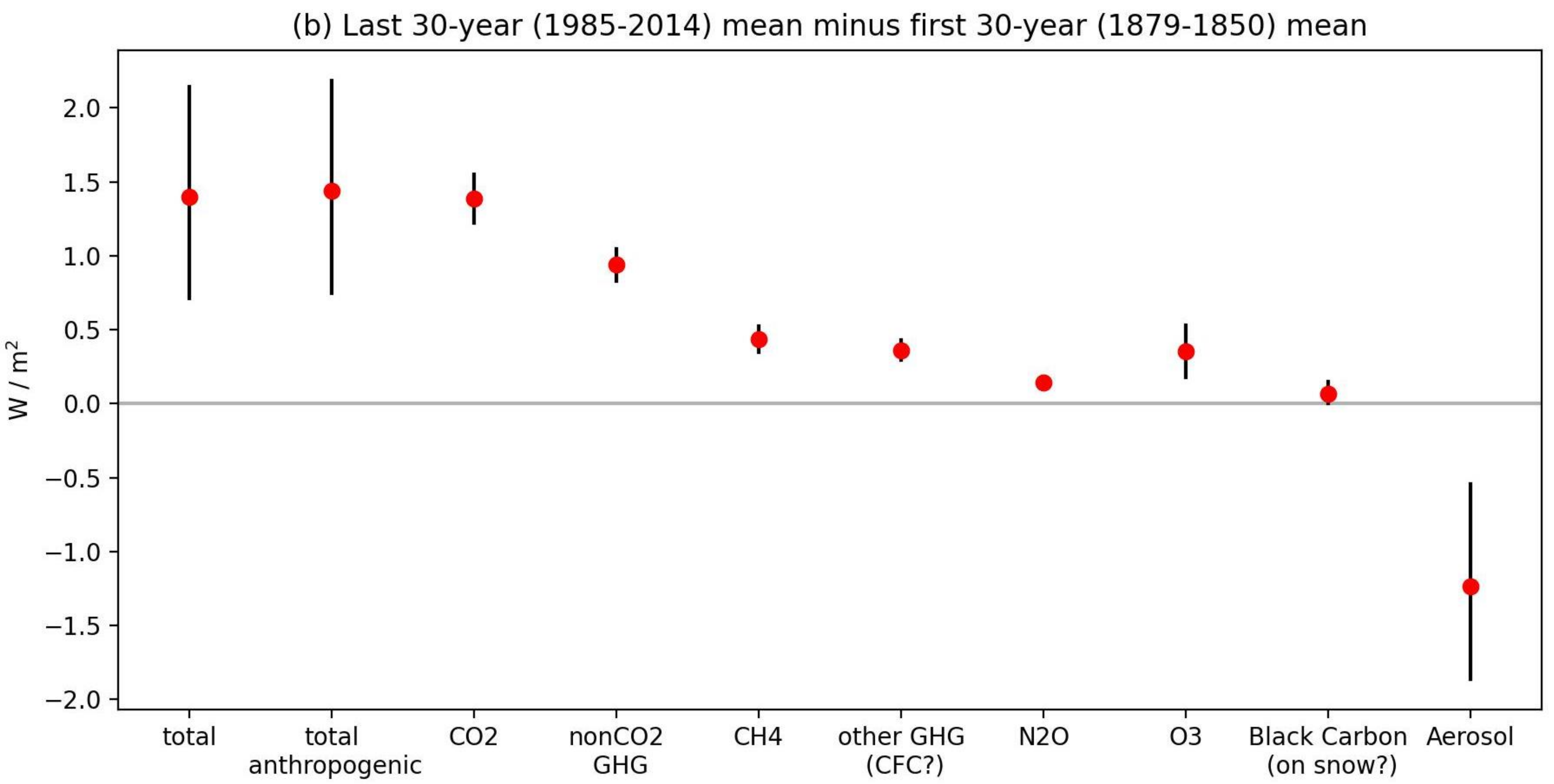

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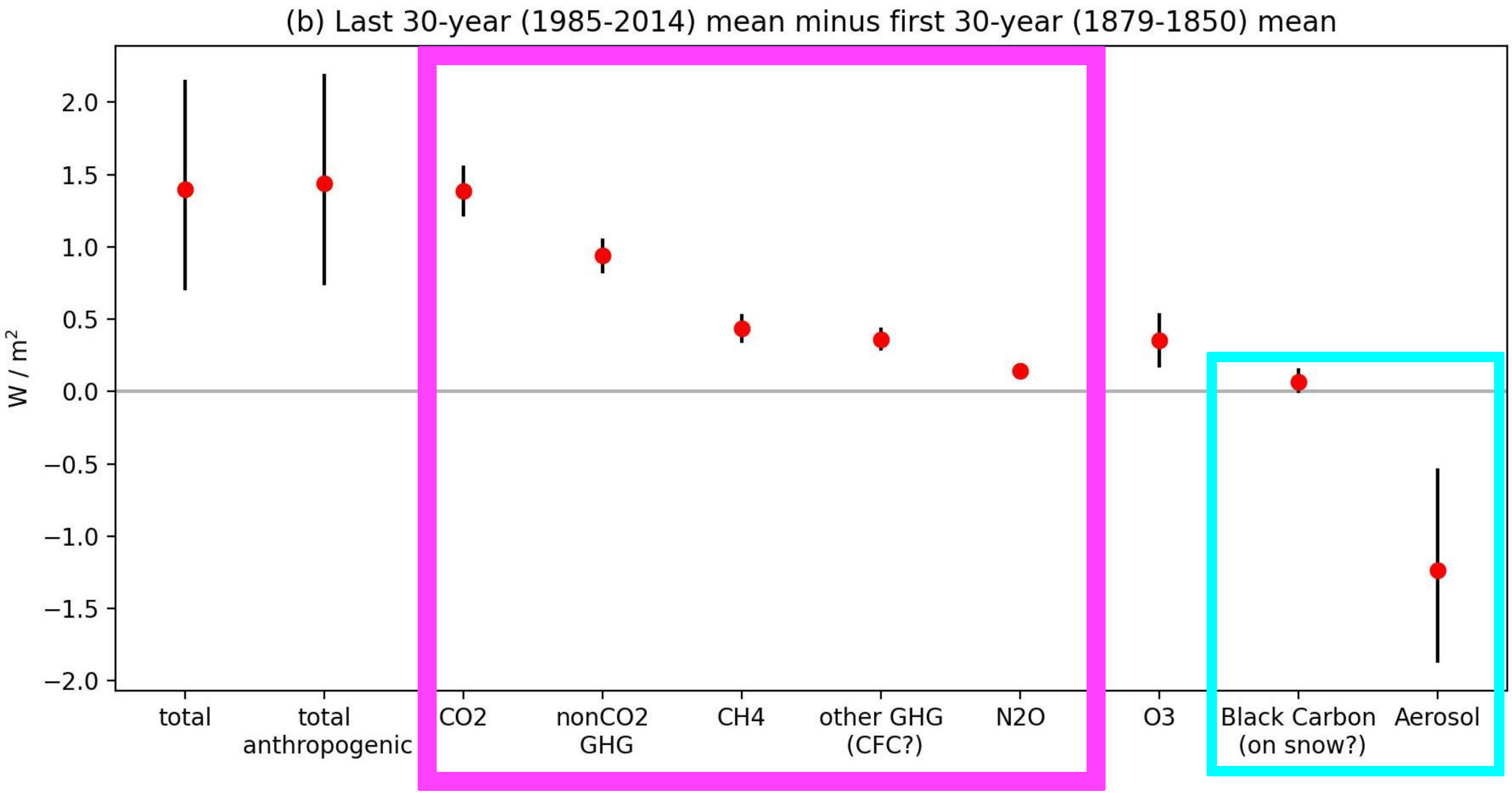
Effective radiative forcing



CMIP6 ERF: https://www.pik-potsdam.de/%3C0303%3Emmalte/rcps

From forcing perspective: GHG

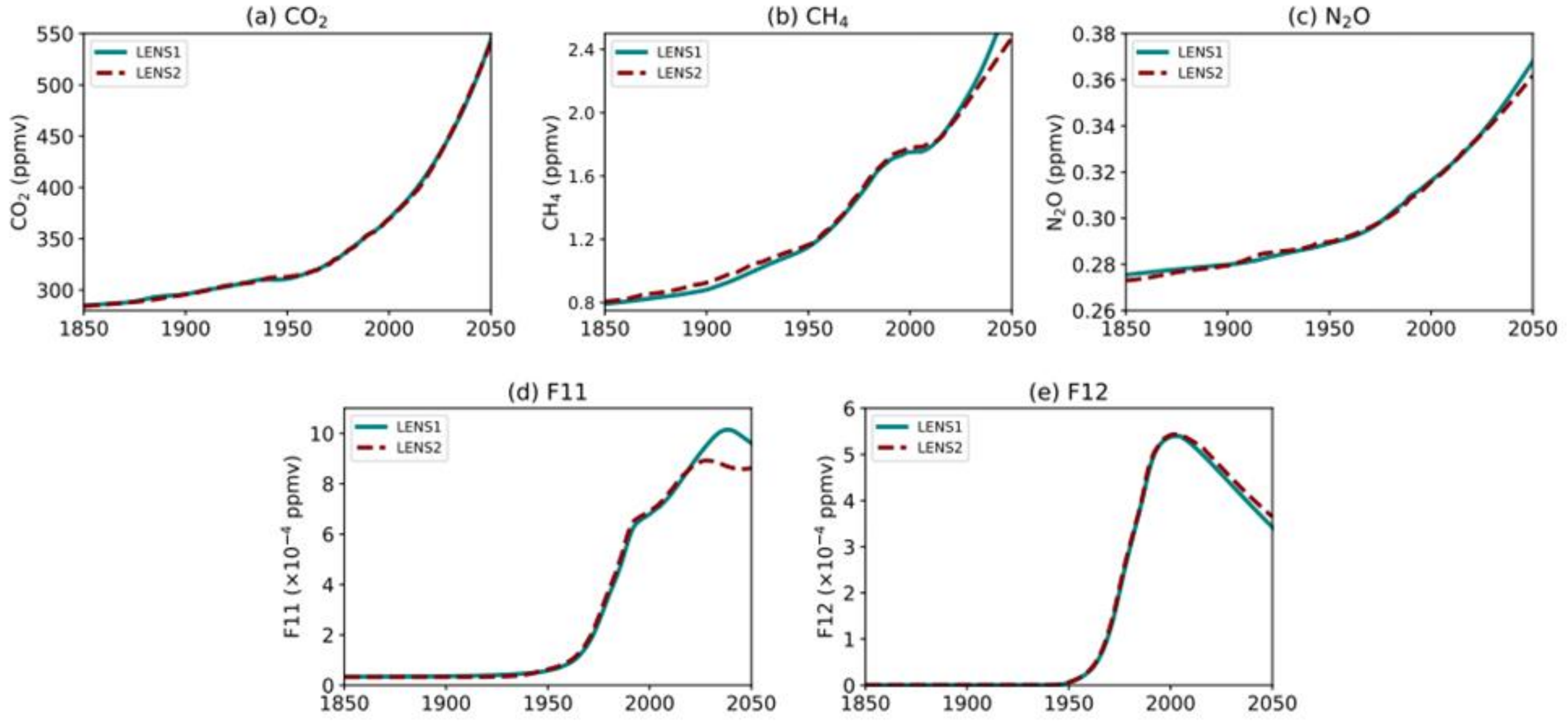


FIG. 2. A comparison of global mean greenhouse gas concentrations between the LENS1 (solid teal) and LENS2 (dashed maroon). (a) CO_2, (b) CH_4, (c) N_2O, (d) F11, (e) F12.

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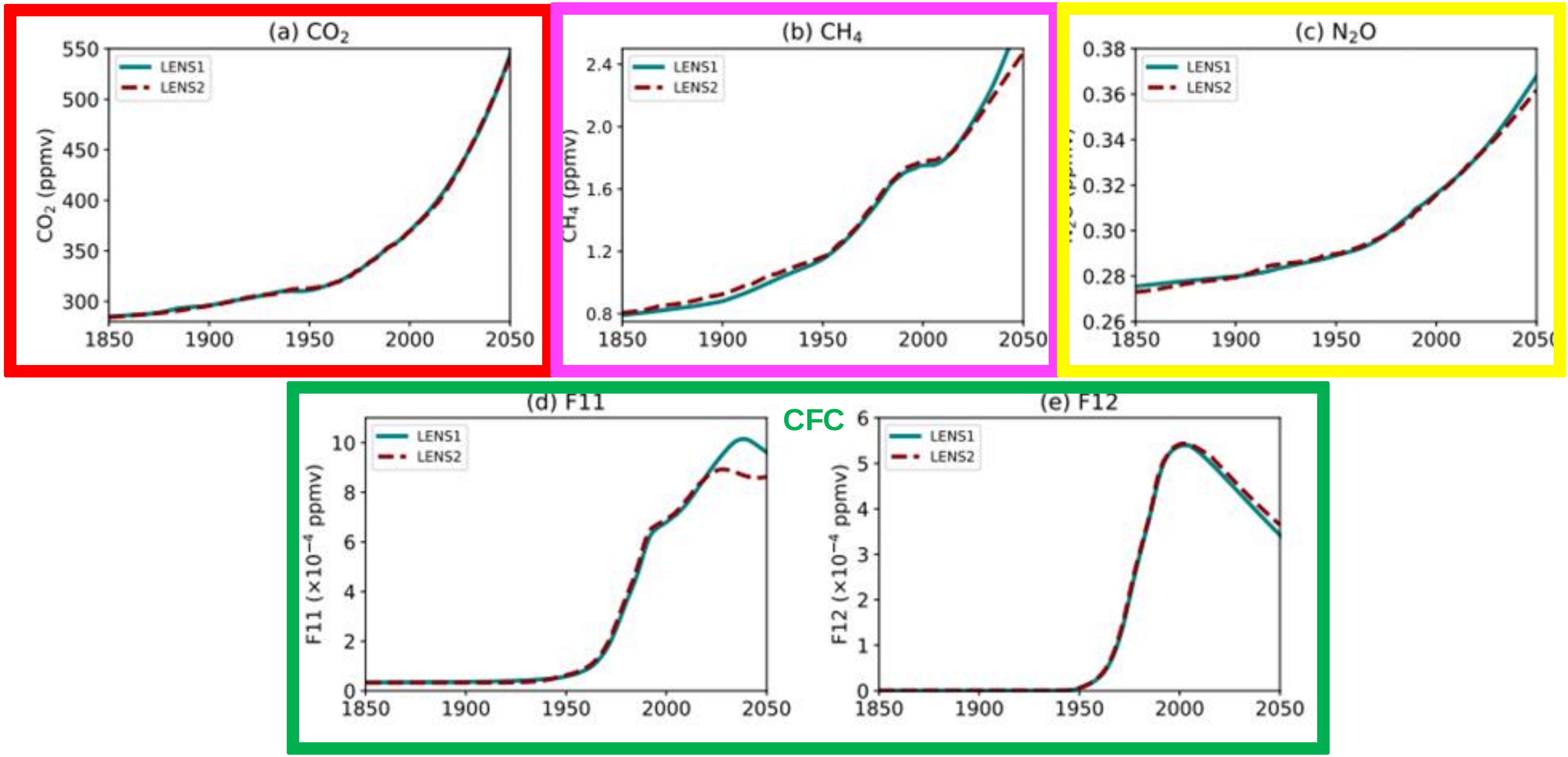
From forcing perspective: GHG



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From forcing perspective: anthropogenic aerosols

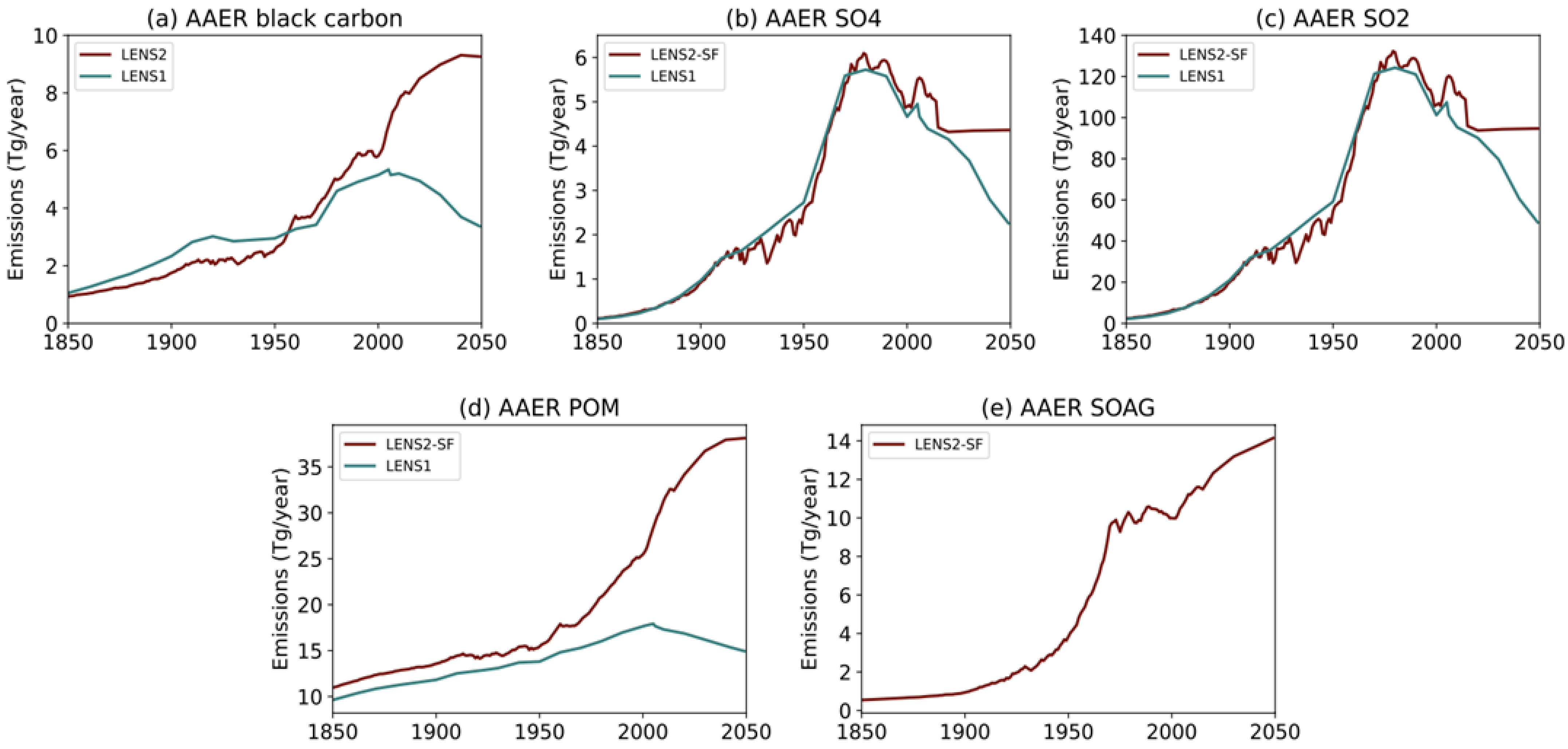

FIG. 3. A comparison of anthropogenic aerosol emissions between LENS1 (teal) and LENS2 (maroon): (a) Black Carbon, (b) SO_4, (c) SO_2, (d) POM, and (e) SOAG.

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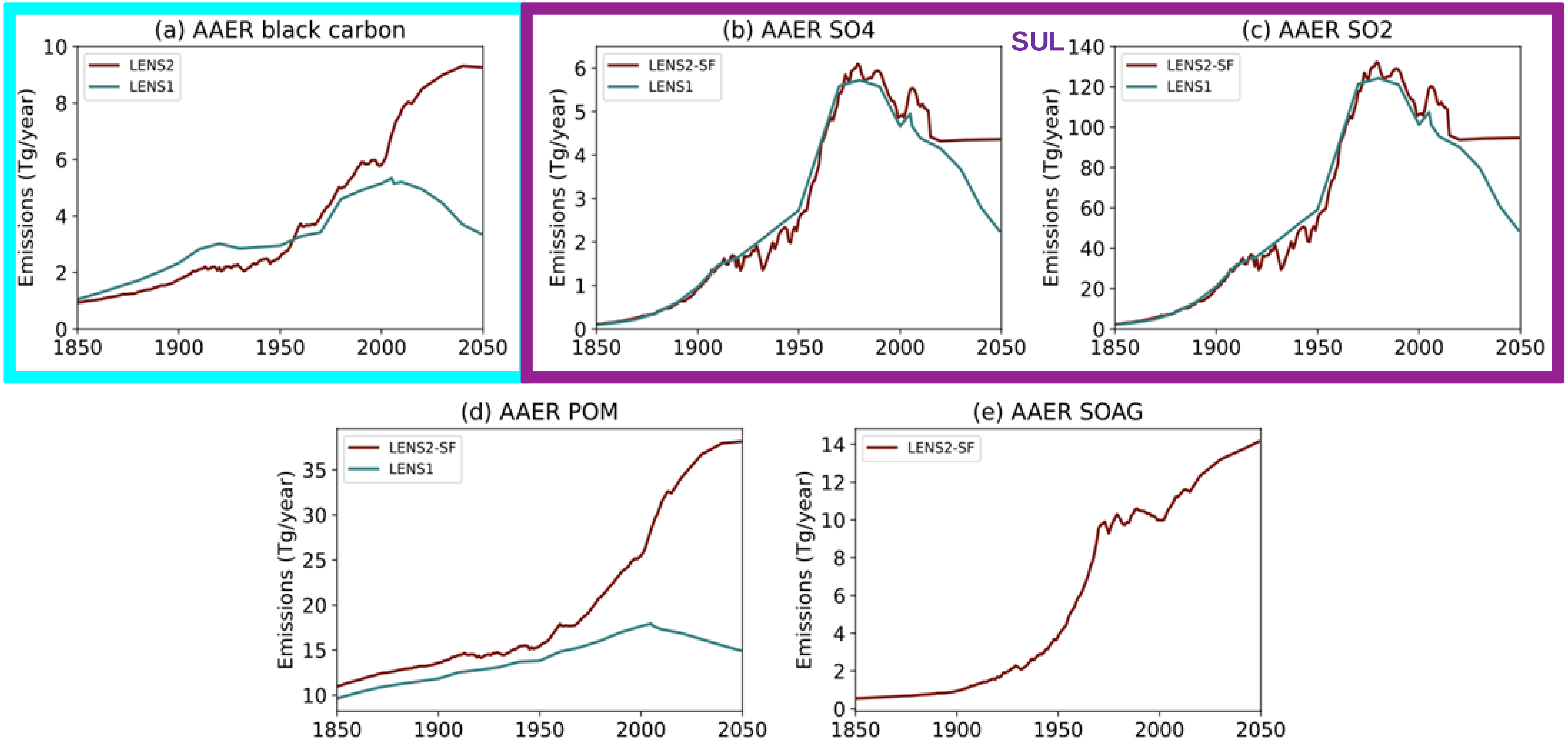
From forcing perspective: anthropogenic aerosols



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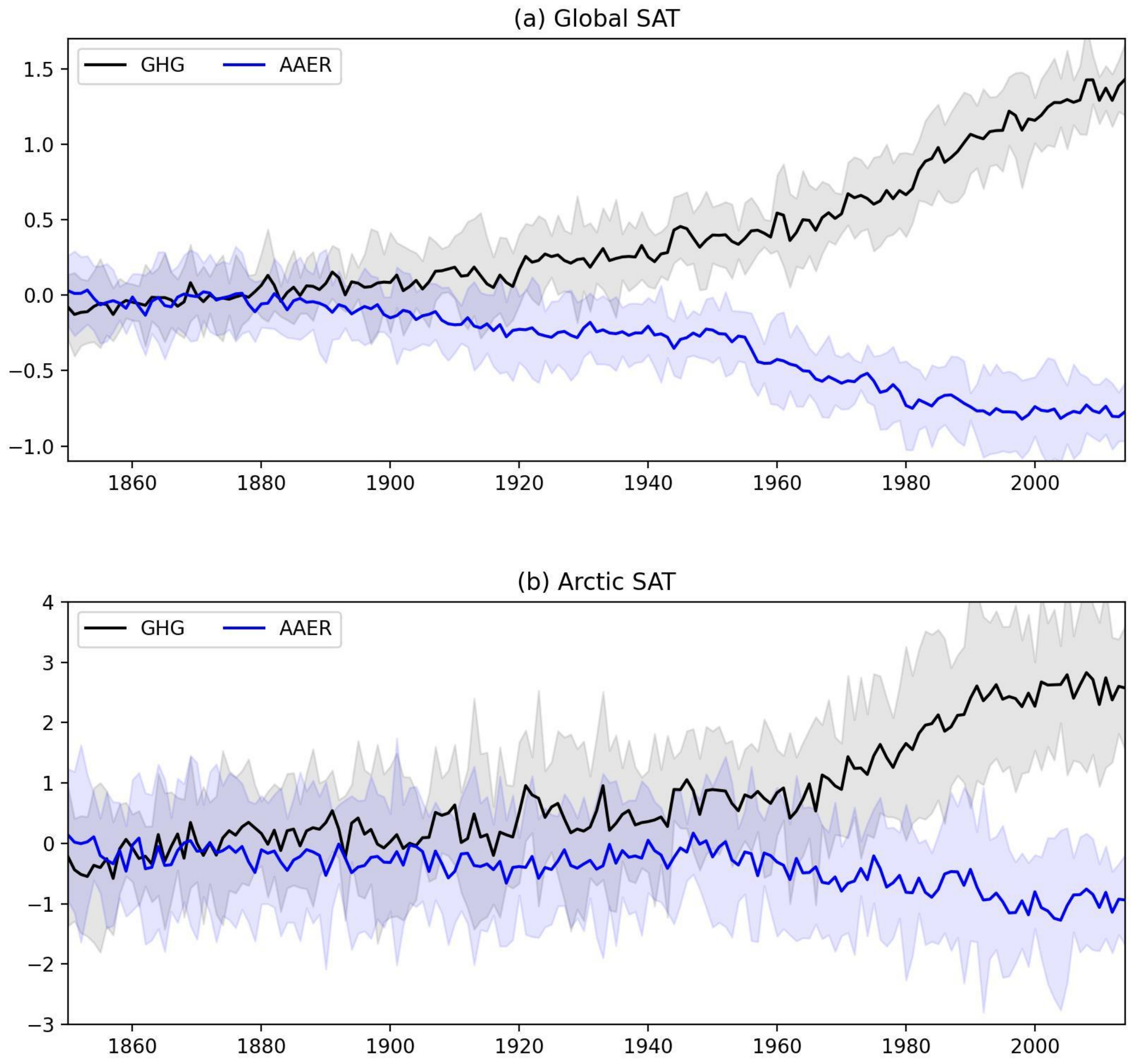
Simpson et al. 2023

Experimental Design – CESM2 single forcing simulations

Experiments	Period	Ensemble member #	Notes
CESM2 CO2-only	1850-2050	10	completed
CESM2 CH4-only	1850-2050	10	completed
CESM2 N2O-only	1850-2050	10	completed
CESM2 CFC-only	1850-2050	10	completed
CESM2 black carbon-only (BLC)	1850-2014	10	completed
CESM2 SO4/2-only (SUL)	1850-2014	10	completed

- We focus on 1850-2014 period.
- “Change” or “response” is defined as the last 30-year mean minus the first 30-year mean;
- “Anomaly” is calculated as the difference with respect to the 1850-1899 mean .

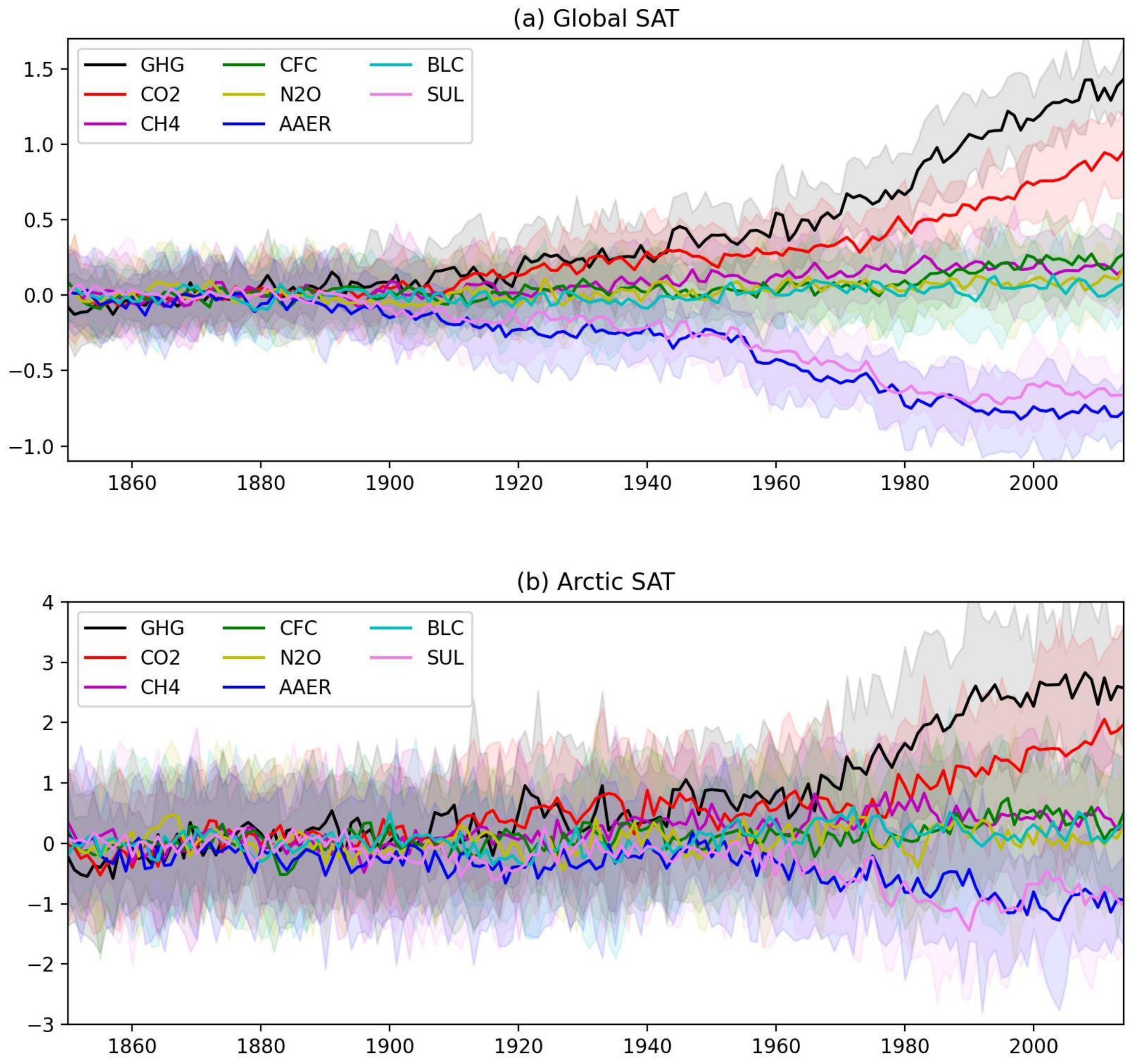
Surface air temperature



Existing GHG runs

Existing AAER runs

Surface air temperature

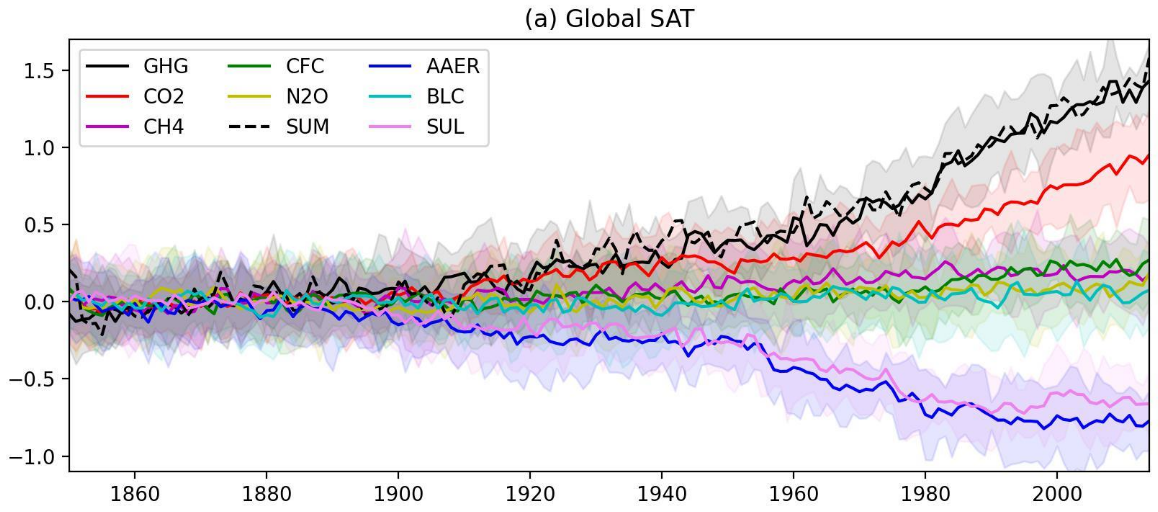


CO2 single forcing runs

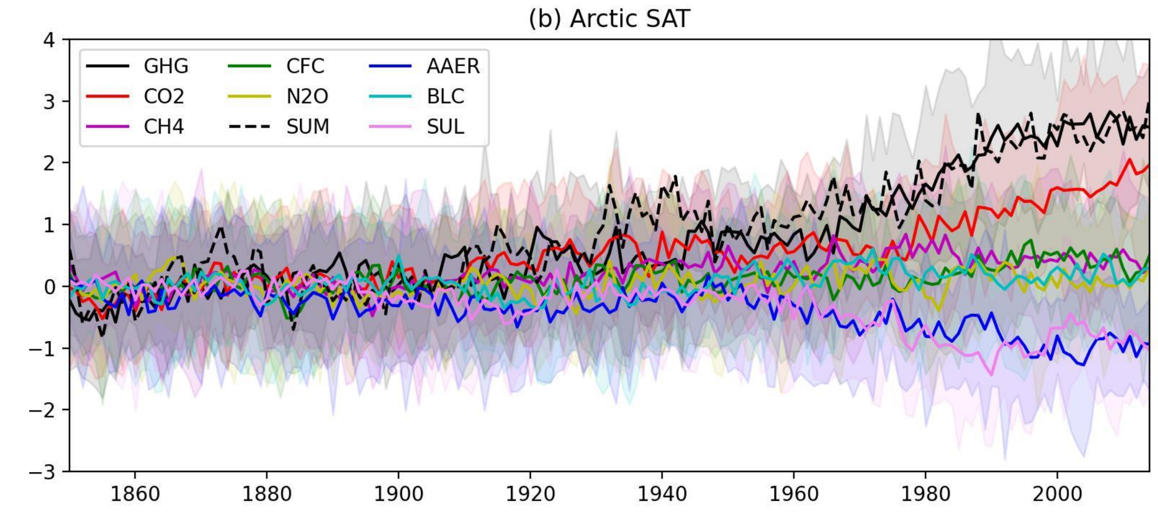
CH4, CFC, N2O, BLC single forcing runs

SUL single forcing runs

Surface air temperature

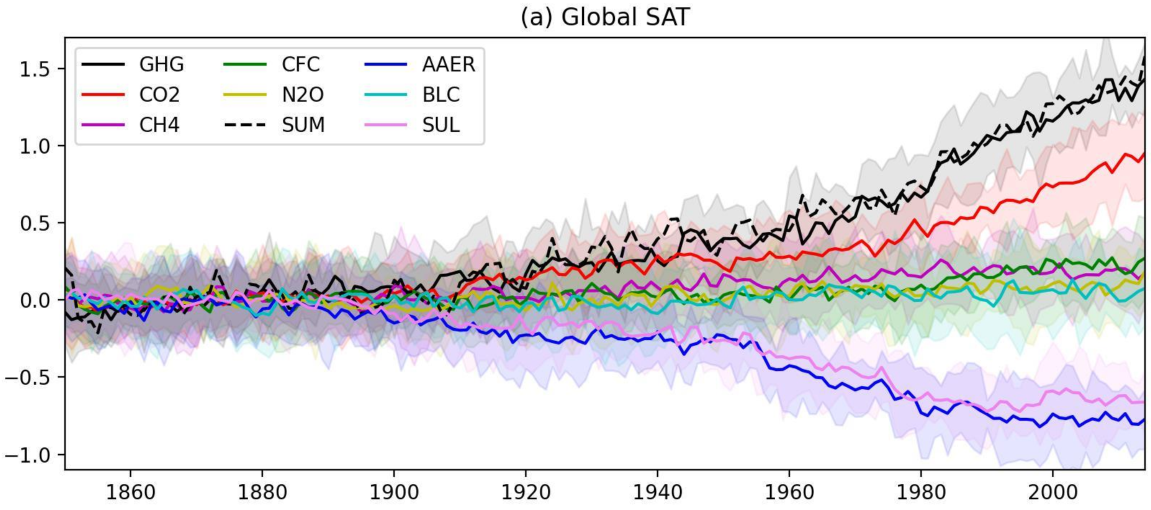


SUM = CO2 + CFC + CH4 + N2O

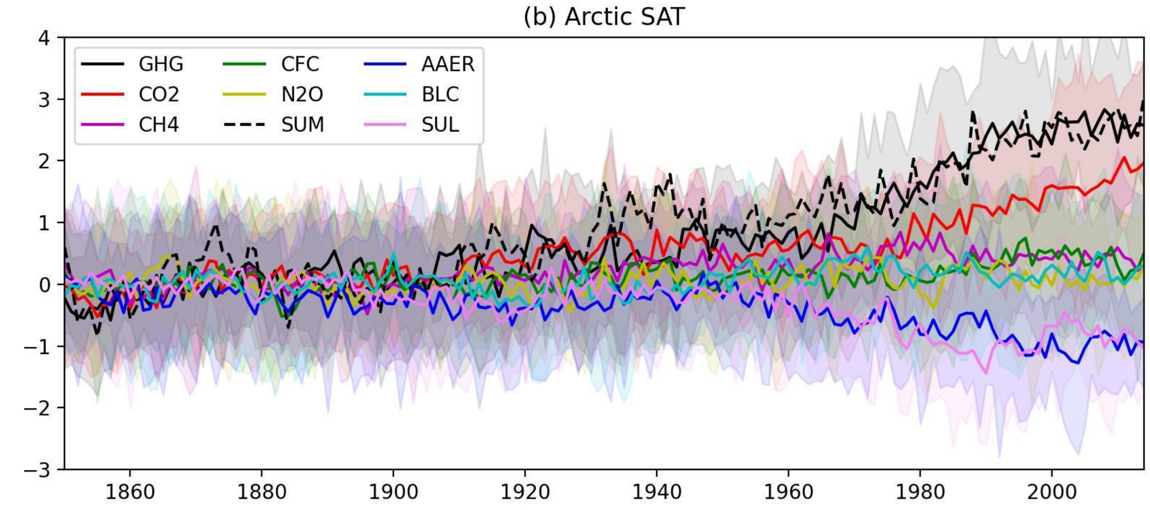


SUM = CO2 + CFC + CH4 + N2O

Surface air temperature

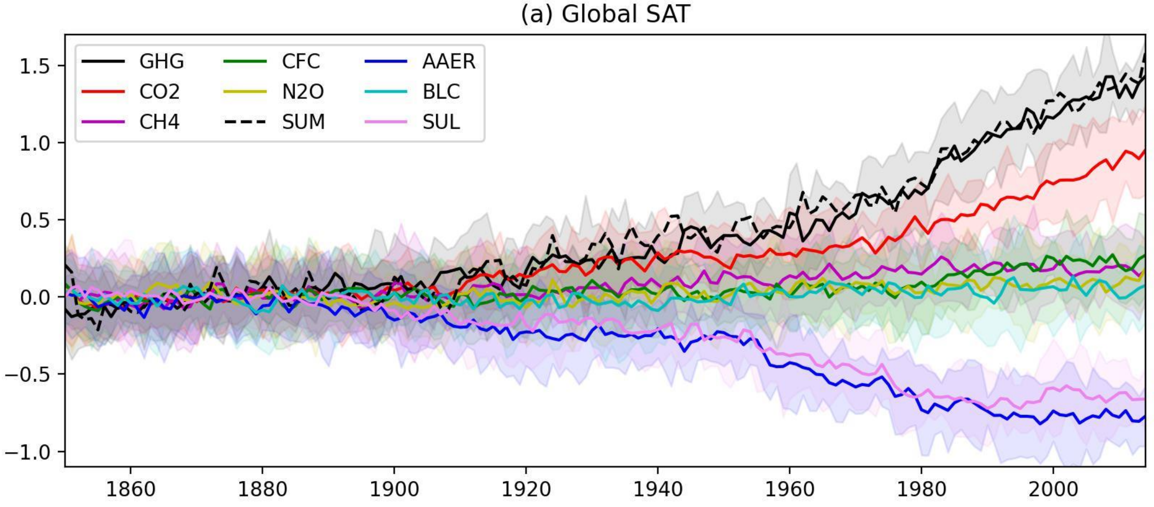


SUM is close to GHG
→ linearly additive?



SUM is close to GHG
→ linearly additive?

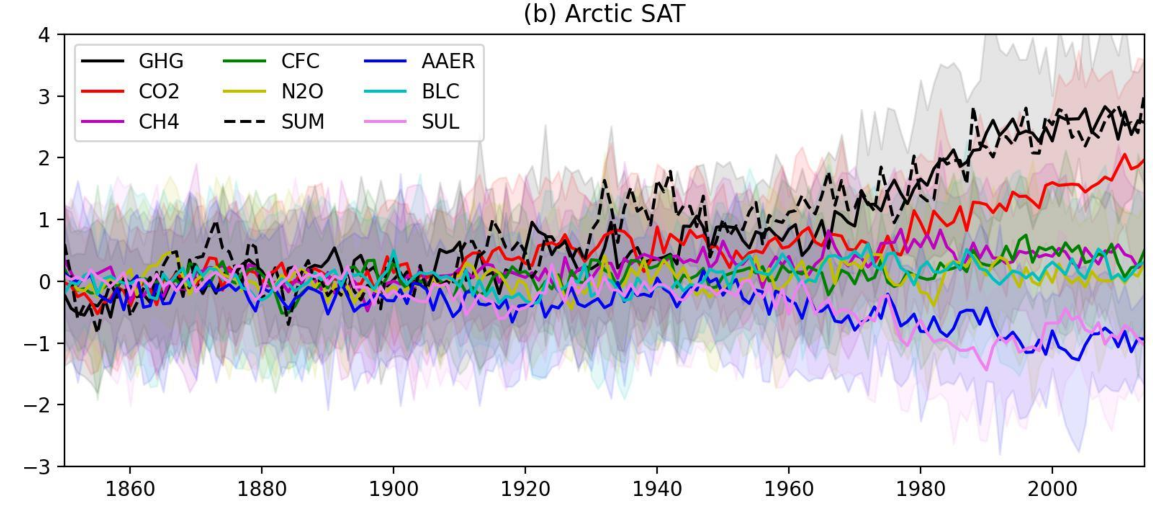
Scientific questions?



Test if the response is linearly additive?

→ The response to climate forcing may not be linearly additive.

→ What is the origin of the nonlinearity, based on a process-level understanding?



What is the role of black carbon in affecting global and regional climate?

Scientific questions?

- What are thee relative importance and comtribution of single GHG to global and regional climate changes?

- The response to climate forcing may not be linearly additive. What is the origin of the nonlinearity, based on a process-level understanding?

- What is the role of black-carbon in affecting global climate?

Surface air temperature

GHG

CO2

AAER

BLC

CH4

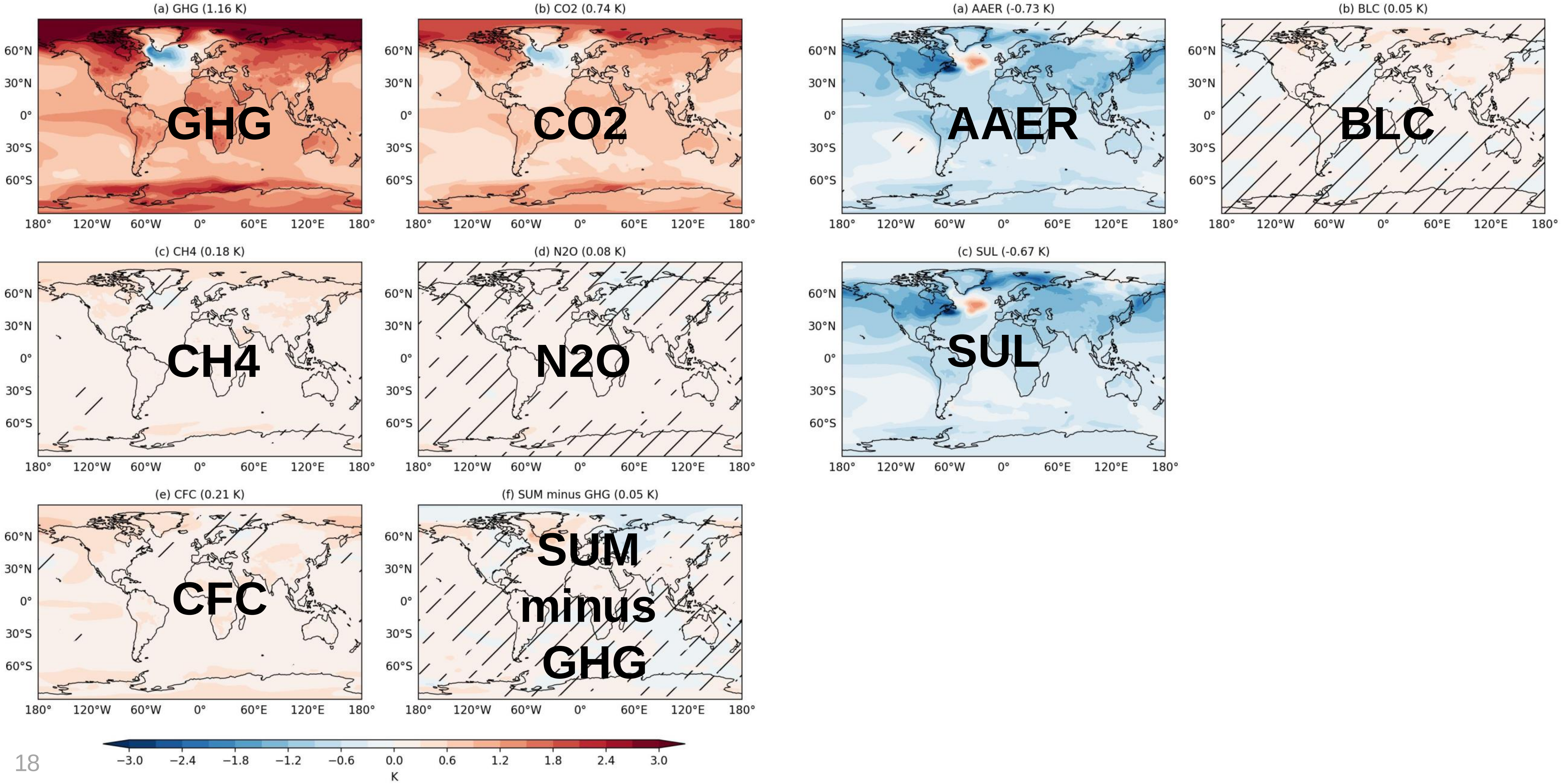
N2O

SUL

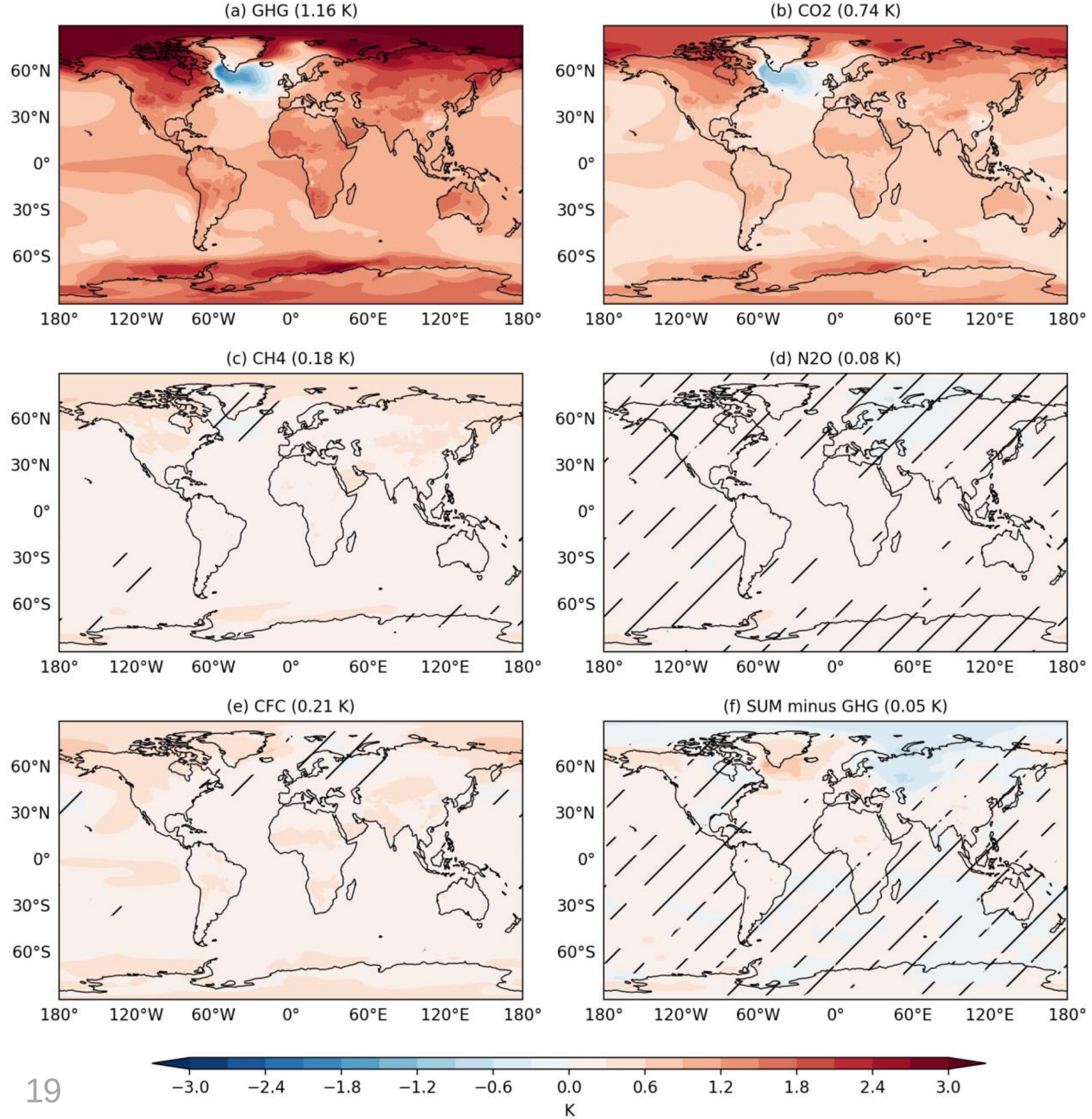
CFC

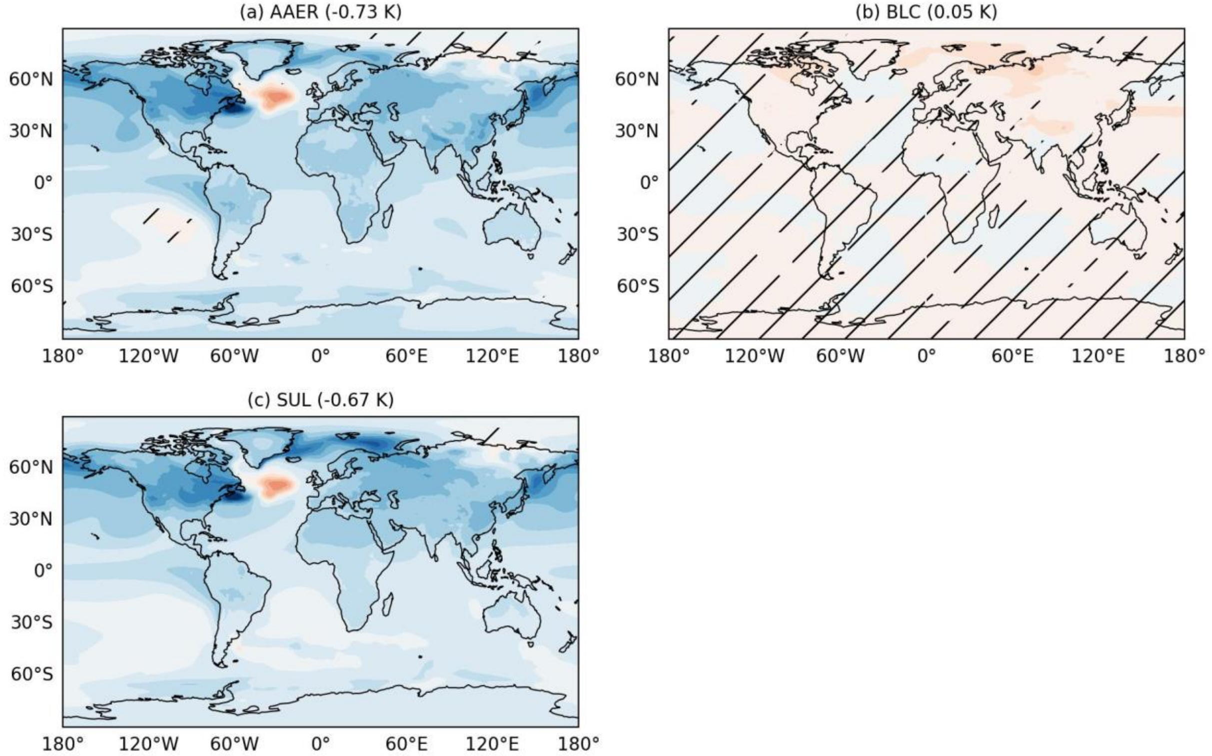
SUM
minus
GHG

Surface air temperature

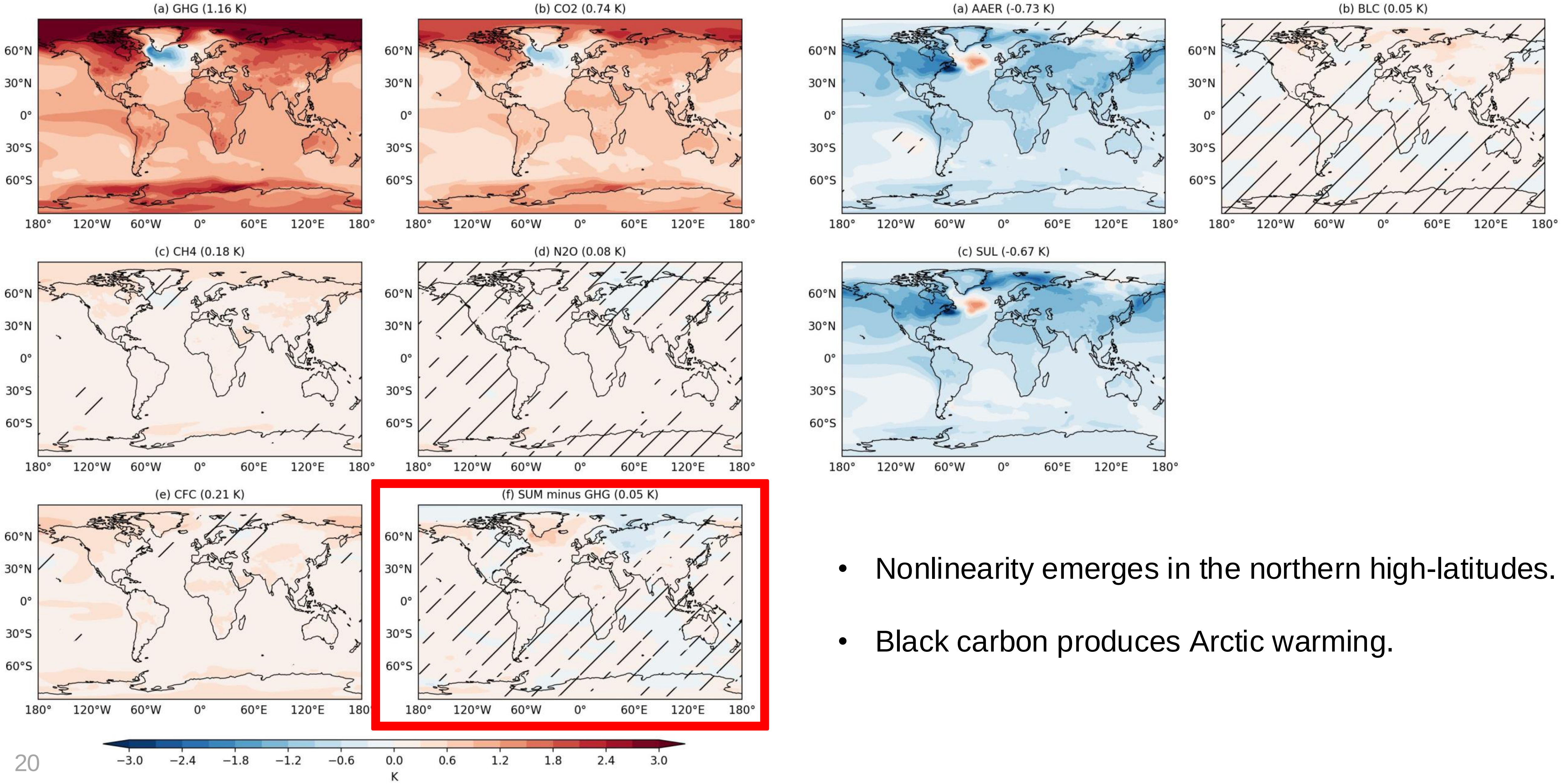


Surface air temperature



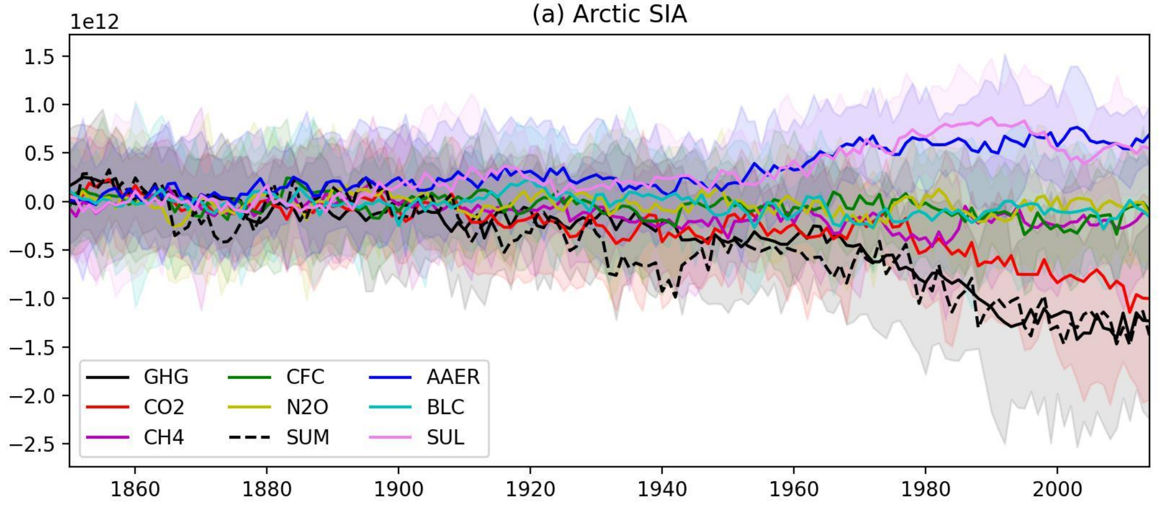


Surface air temperature – SUM minus GHG

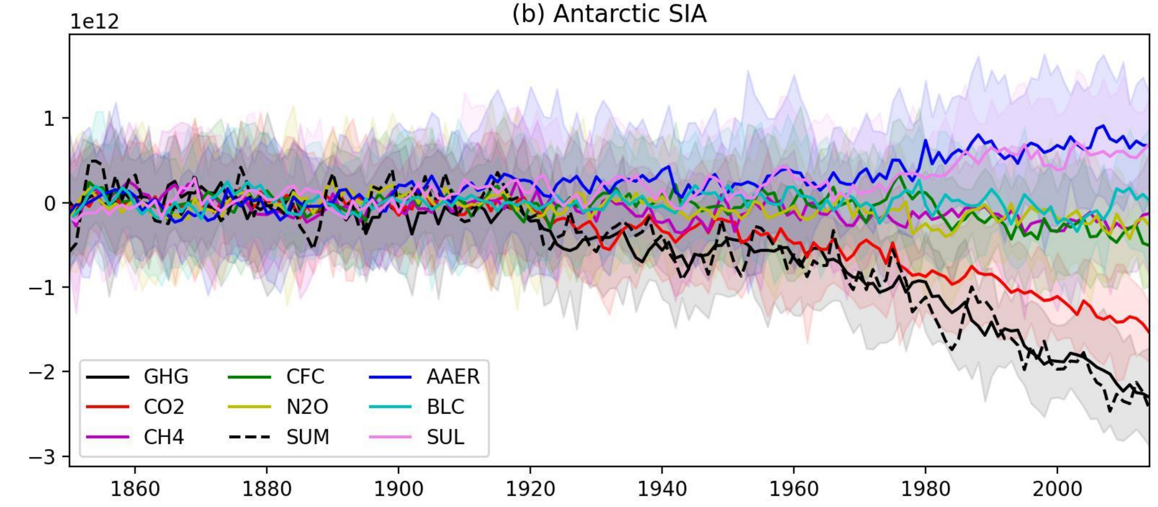


- Nonlinearity emerges in the northern high-latitudes.
- Black carbon produces Arctic warming.

Sea ice area (SIA)

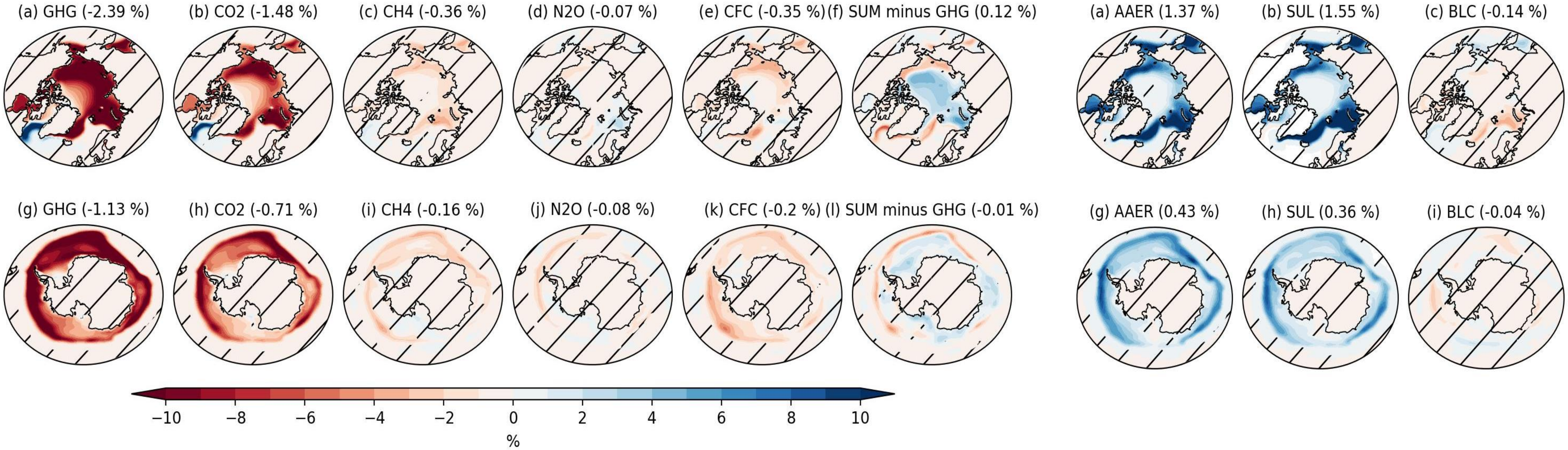


SUM is close to GHG
→ linearly additive

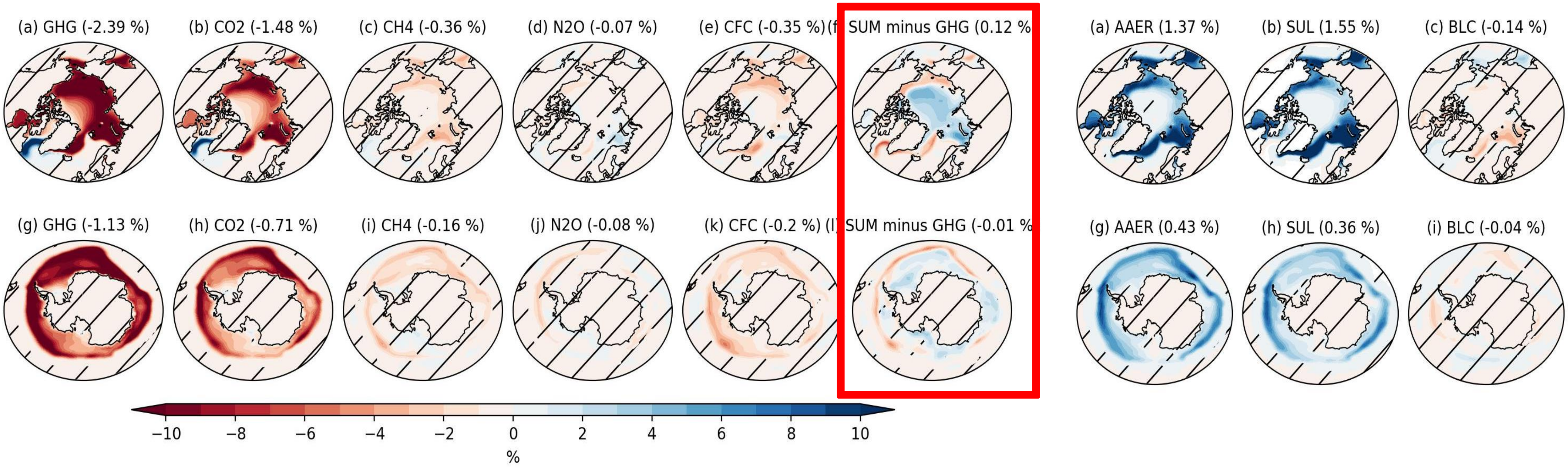


SUM is close to GHG
→ linearly additive

Sea ice concentration (SIC)



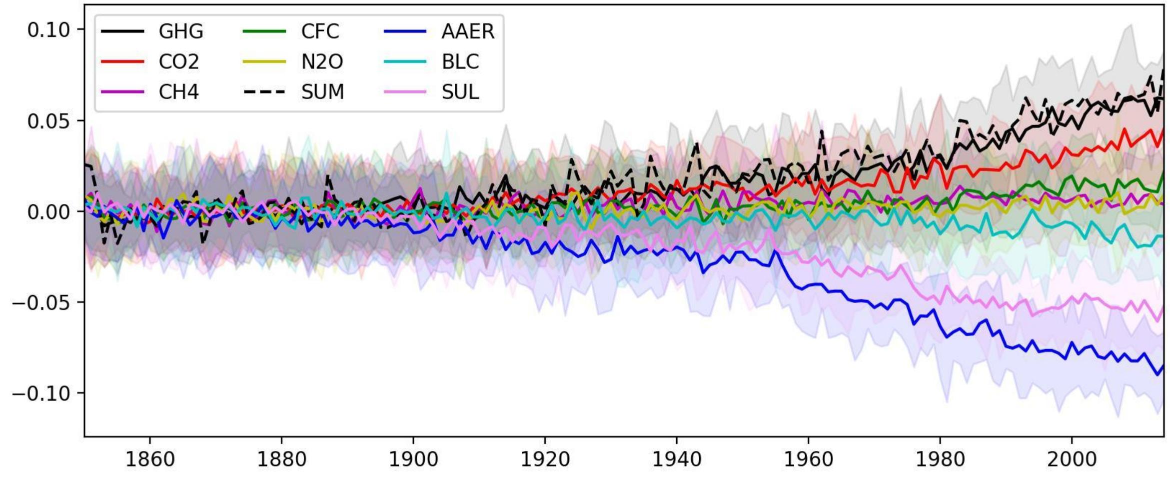
Sea ice concentration (SIC) – SUM minus GHG



- Nonlinearity emerges in the sea ice concentration in both Arctic and Antarctic.
- SUM overestimates SIC in the sea-ice edge, while underestimate SIC in interior sea ice.

Precipitation

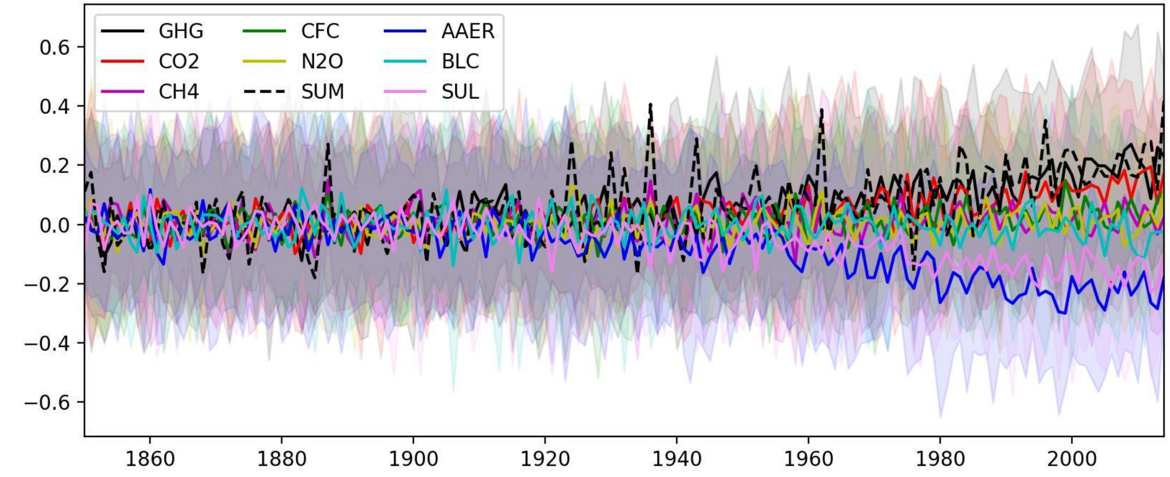
(a) Global PRECT



SUM is close to GHG
→ linearly additive

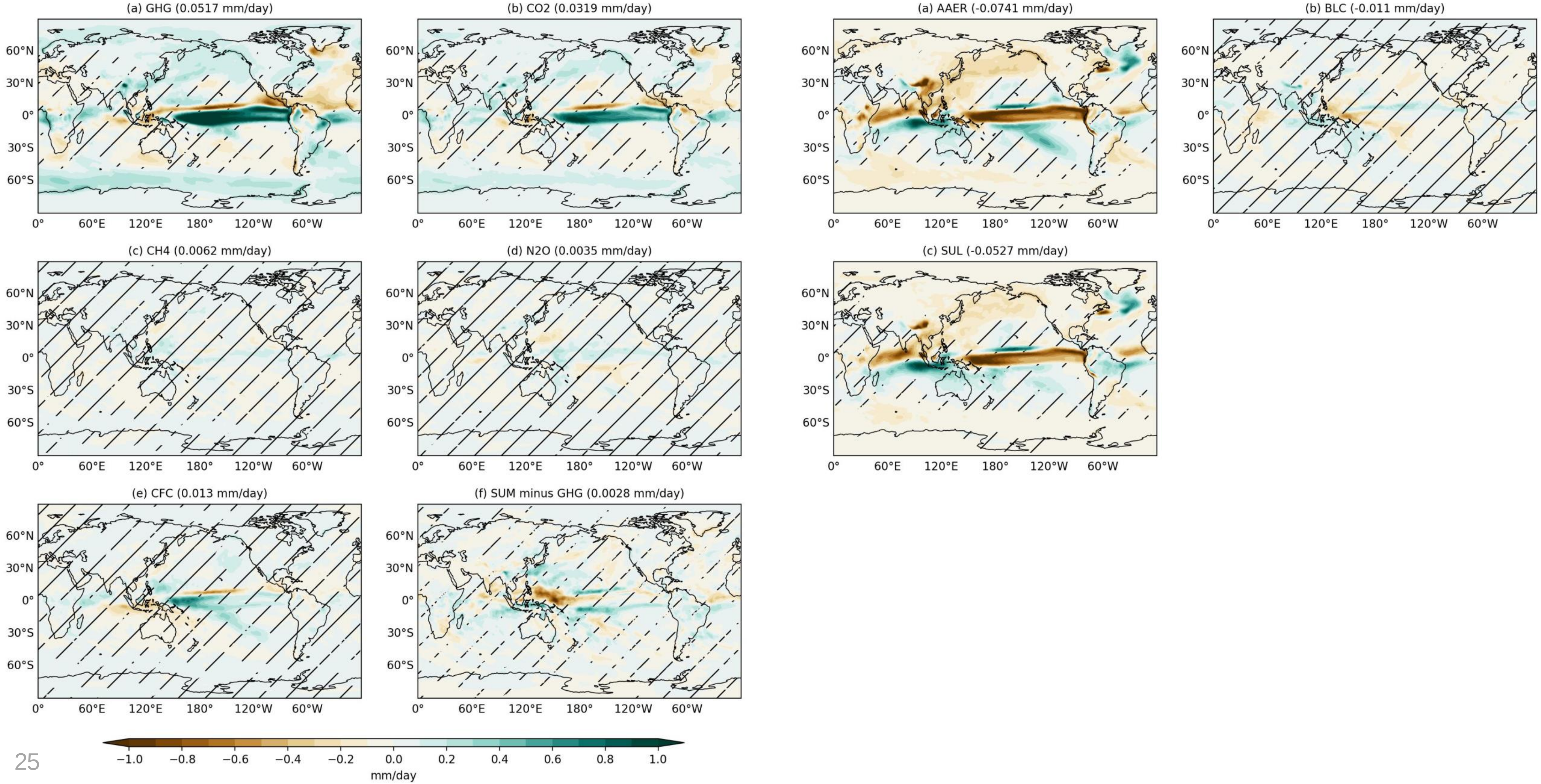
Black carbon decreases global precipitation

(b) Tropical PRECT

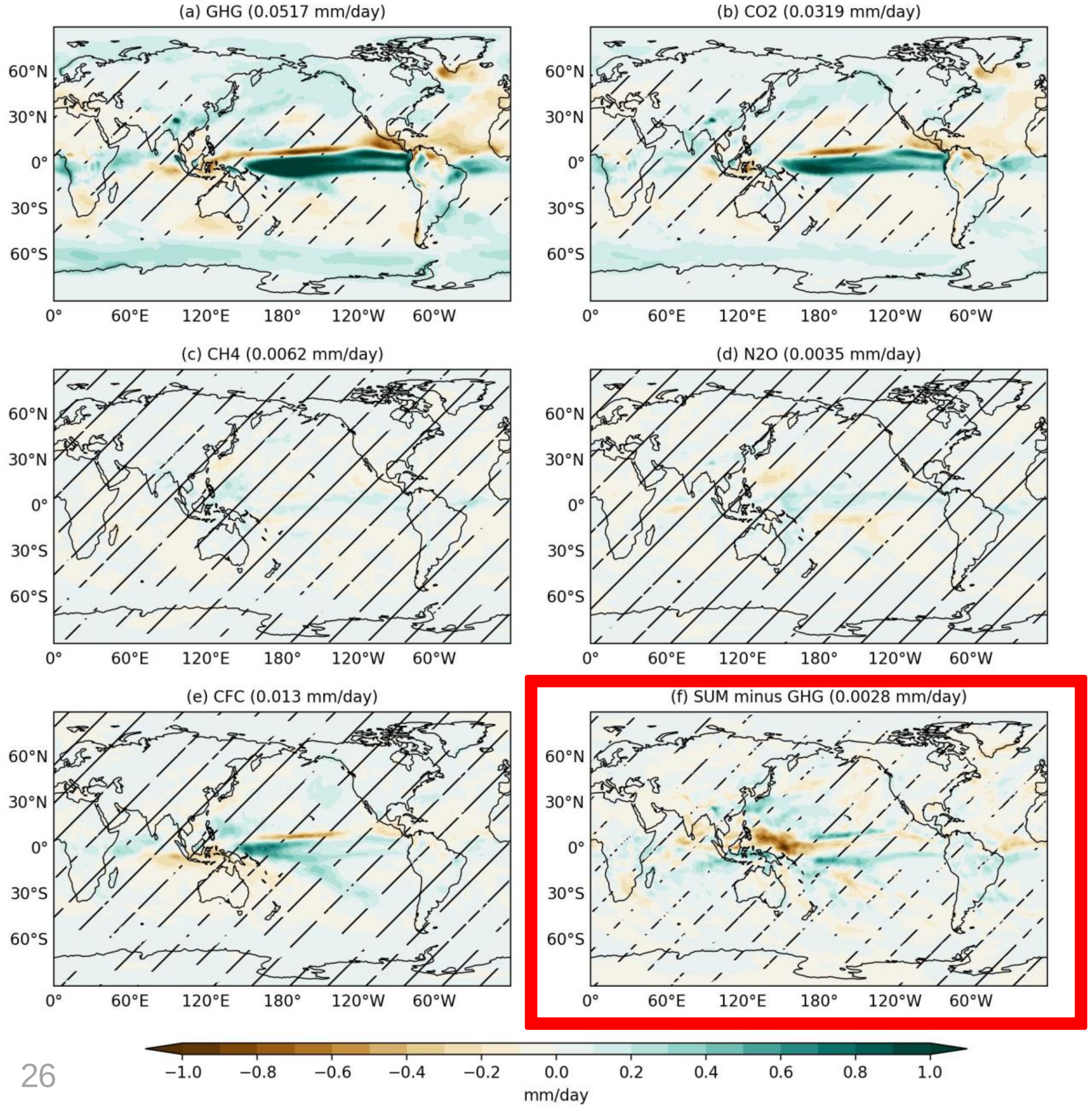


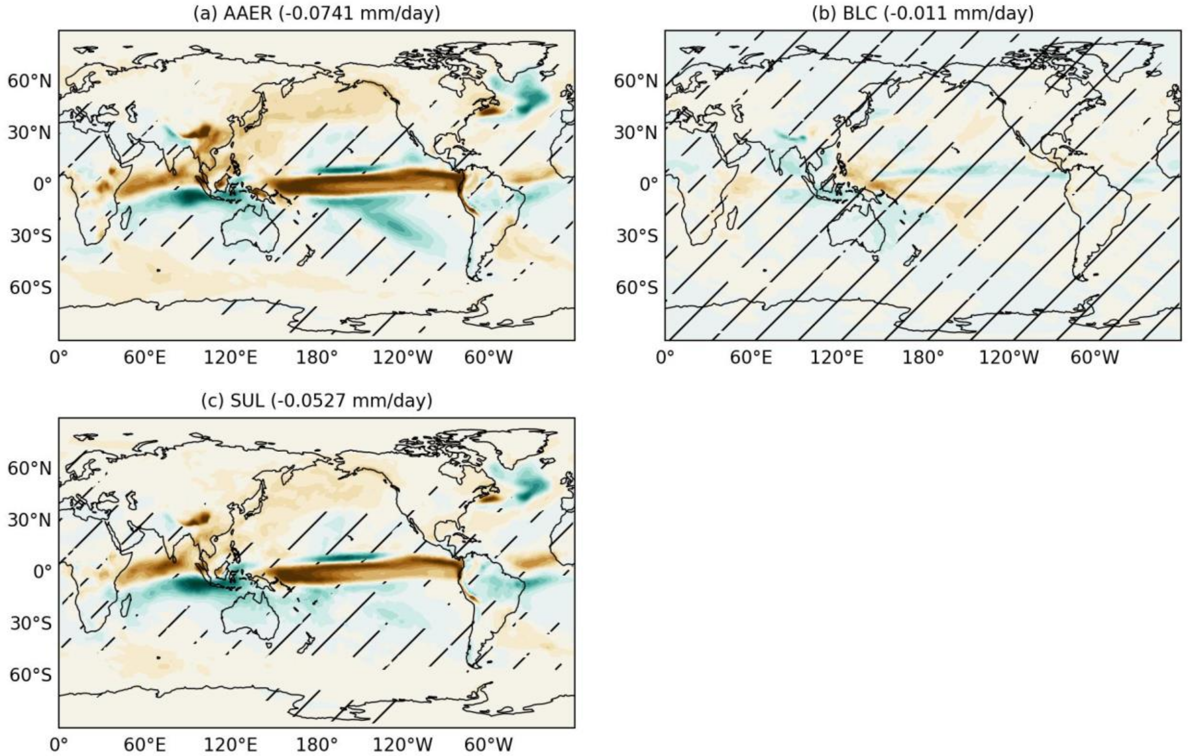
SUM is close to GHG
→ linearly additive

Precipitation



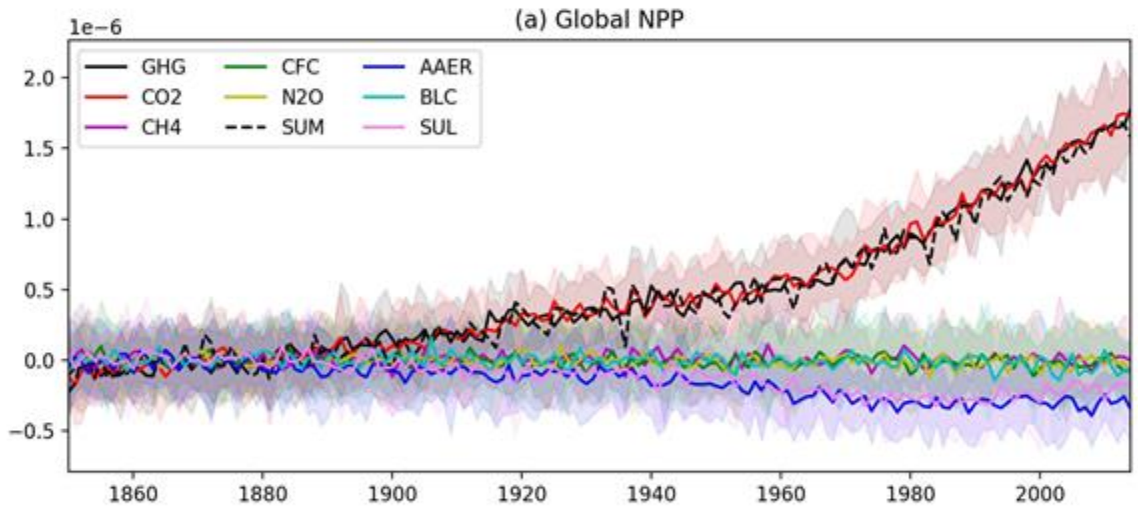
Precipitation – SUM minus GHG



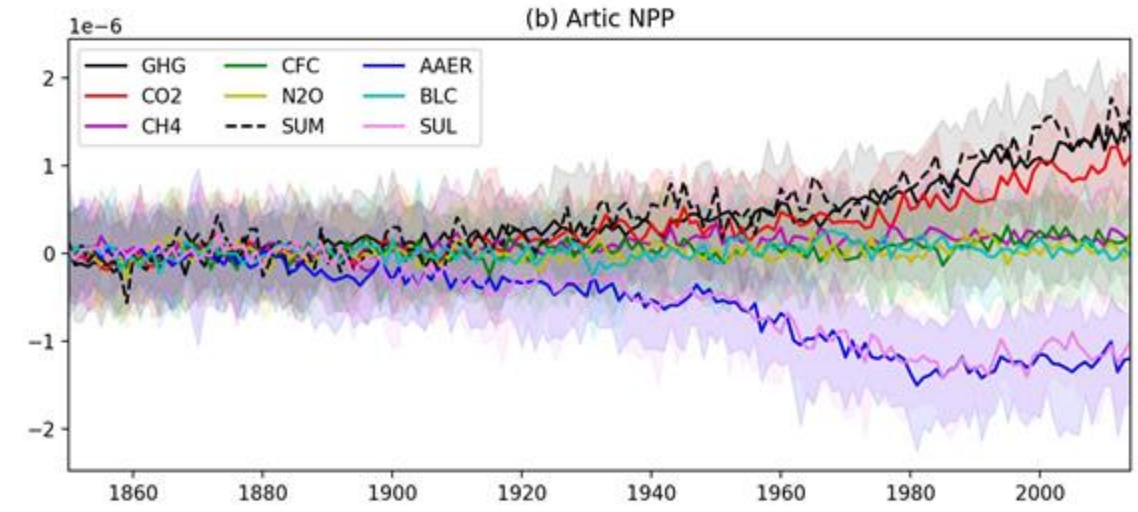


- Nonlinearity emerges in the tropics.
- Black carbon produces equatorial wetness and off-eqautorial dryness.

Net primary productivity (NPP)



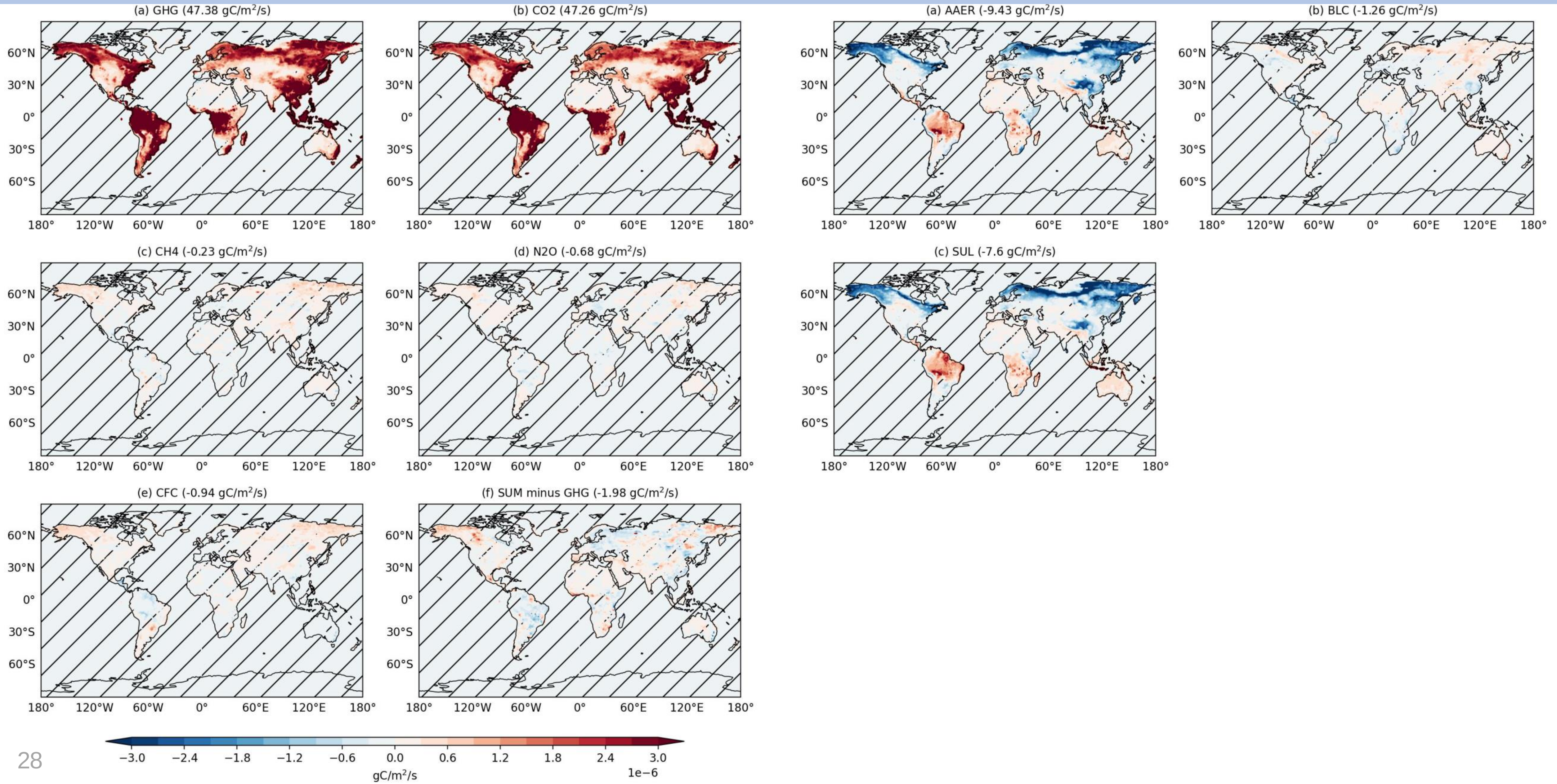
SUM is close to GHG
→ linearly additive
→ CO2 contributes to all NPP repsonses



CO2 contributes most but not entirely in Arctic

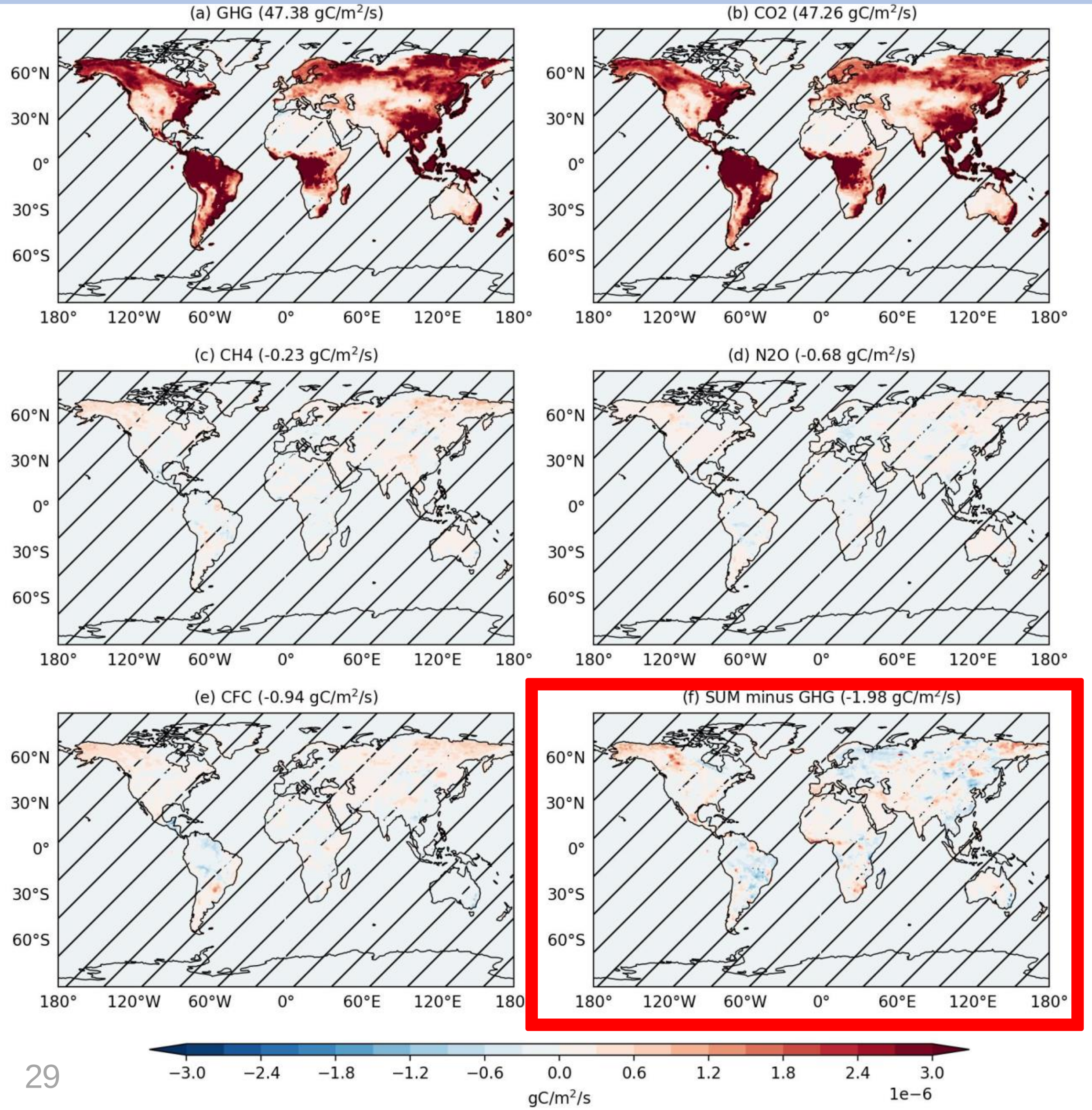
Net primary productivity (NPP)

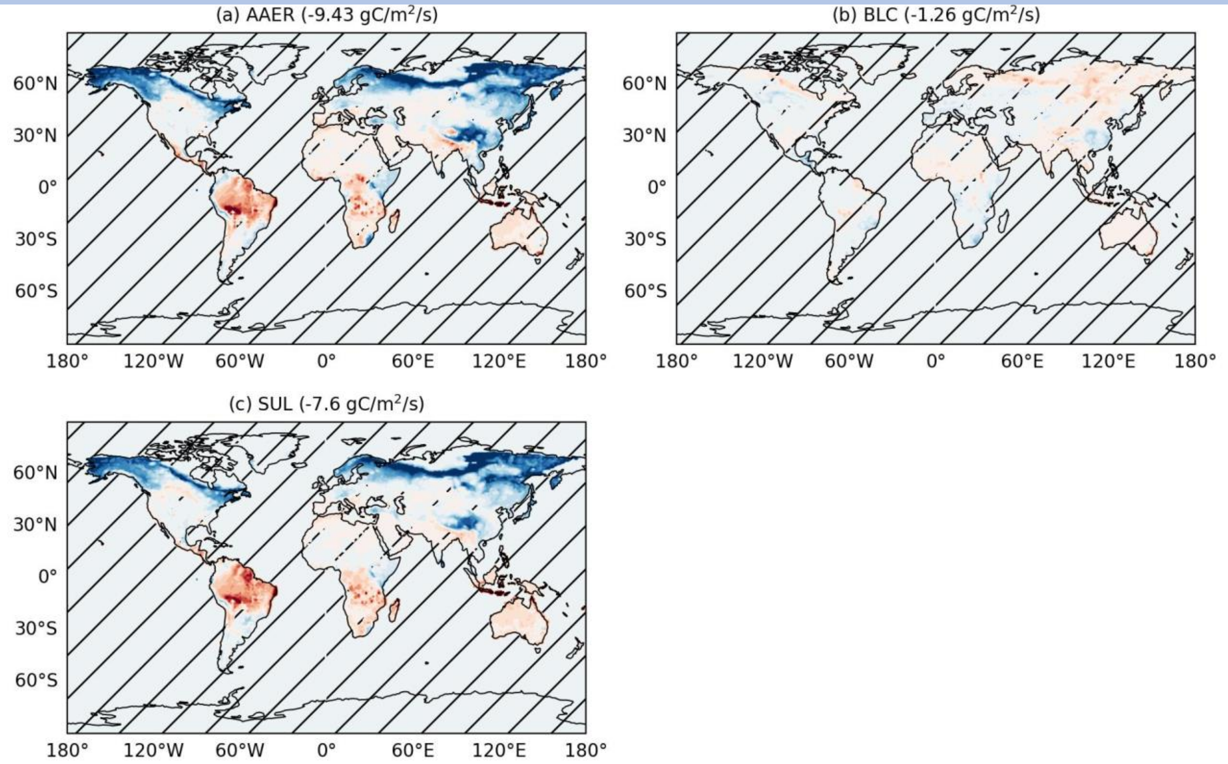
1x10^8



Net primary productivity (NPP) – SUM minus GHG

1x10^8





- Nonlinearity emerges in the many sectors.
- Sulfate aerosols produce sharp interhemispheric contrast.

Discussion

- Nonlinearity emerges in many regional sectors: sea ice, tropical precipitation, NPP.
- What does the nonlinearity mean for detection & attribution analysis?
- The role of black-carbon, non-uniform spatial distribution, in affecting/warming global and regional climate is something relatively new and different from GHGs.
- Personally, I am interesting in polar climate, including Arctic maplification and sea-ice loss. But other perpectives or topics (e.g., ITCZ or tropical precipitation) with broader implications are possible and welcome from CESM community!!!
- If you would like to look at the output, please let me know (**yuchiaoliang@ntu.edu.tw**) or fill in the google doc (here).

Discussion – other experiments?

Experiments	Period	Ensemble member #	Notes
CESM2 CO_2-only	1850-2050	10	completed
CESM2 CH_4-only	1850-2050	10	completed
CESM2 N_2O-only	1850-2050	10	completed
CESM2 CFC-only	1850-2050	10	completed
CESM2 black carbon-only	1850-2014	10	completed
CESM2 SO4/2-only	1850-2014	10	completed
??			
??			
??			

Discussion – other experiments? Priority?

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CESM2 black carbon-only	1850-2014	10	completed
CESM2 SO_4/2-only	1850-2014	10	completed
CESM2 AAER+GHG?			
CESM2 tropospheric O_3-only?			
CESM2 stratospheric O_3-only?			

We thank to National Center for High-performance Computing (NCHC) in Taiwan for providing computational and storage resources.