Anthropogenic aerosols mask increases in US rainfall by greenhouse gases

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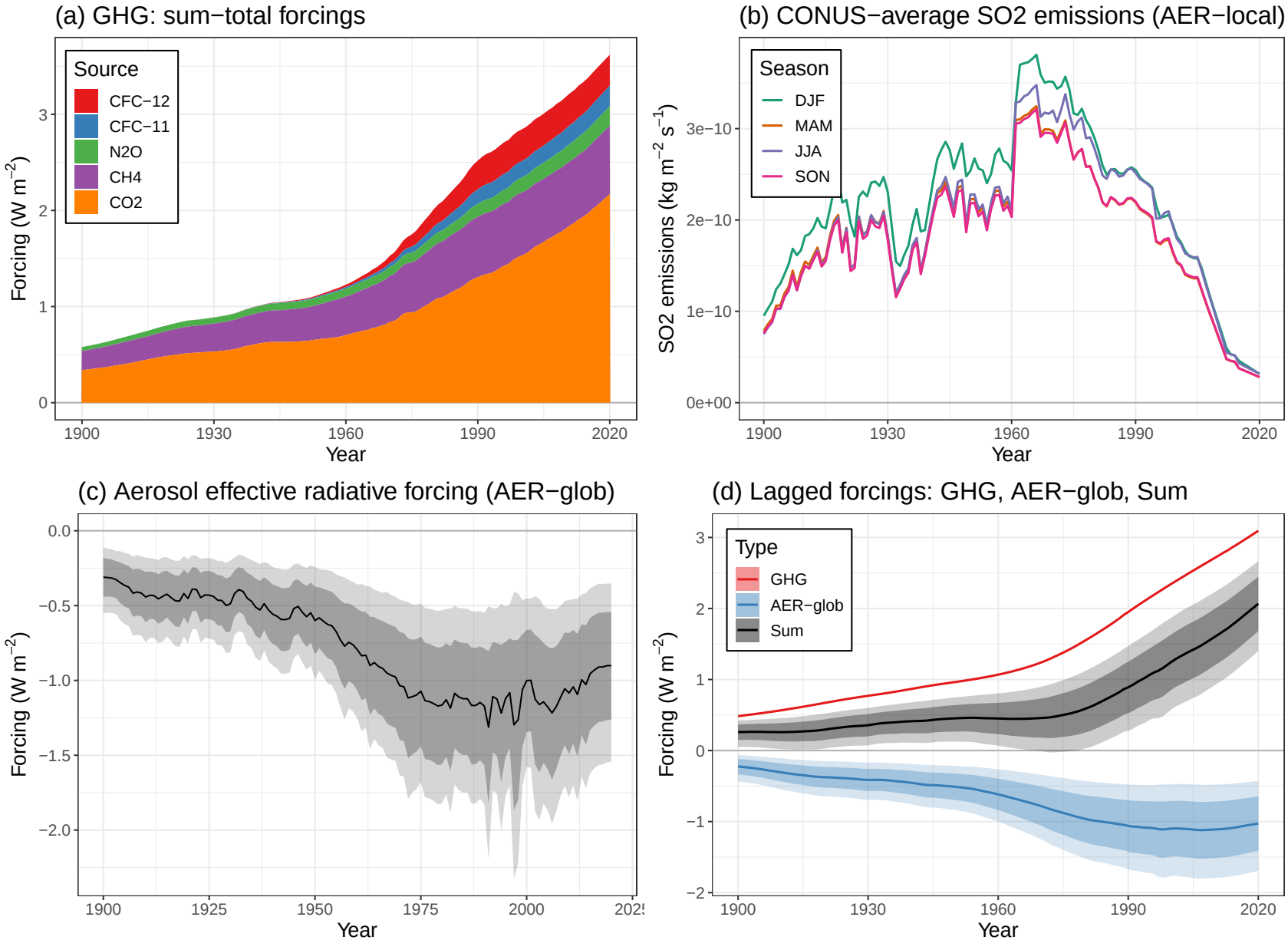
Supported by Department of Energy / Biological and Environmental Research

March 14, 2024

Goals of this study

- Detect systematic trends in observed CONUS-mean precipitation and 20-year return values, if any
- Attribute trends to anthropogenic forcings from GHGs and aerosols
- Compare the results of this framework applied to observations and to CMIP6 ESMs

Time Series of Radiative Forcings



Our philosophy in using model data

- Records of short-lived climate forcers (SLCFs) are uncertain.
- Complicated response of precipitation to SLCFs is uncertain.
- Therefore, traditional "fingerprinting" D&A is ruled out.
- We will use models in perfect-data sense, to test and guide fits applied directly to observations.

Advantage: We can use the diversity of responses to SLCFs, etc. across the CMIP6 MME to help ensure our D&A is insensitive to structural uncertainty.

CMIP6 and C20C+ simulations we use

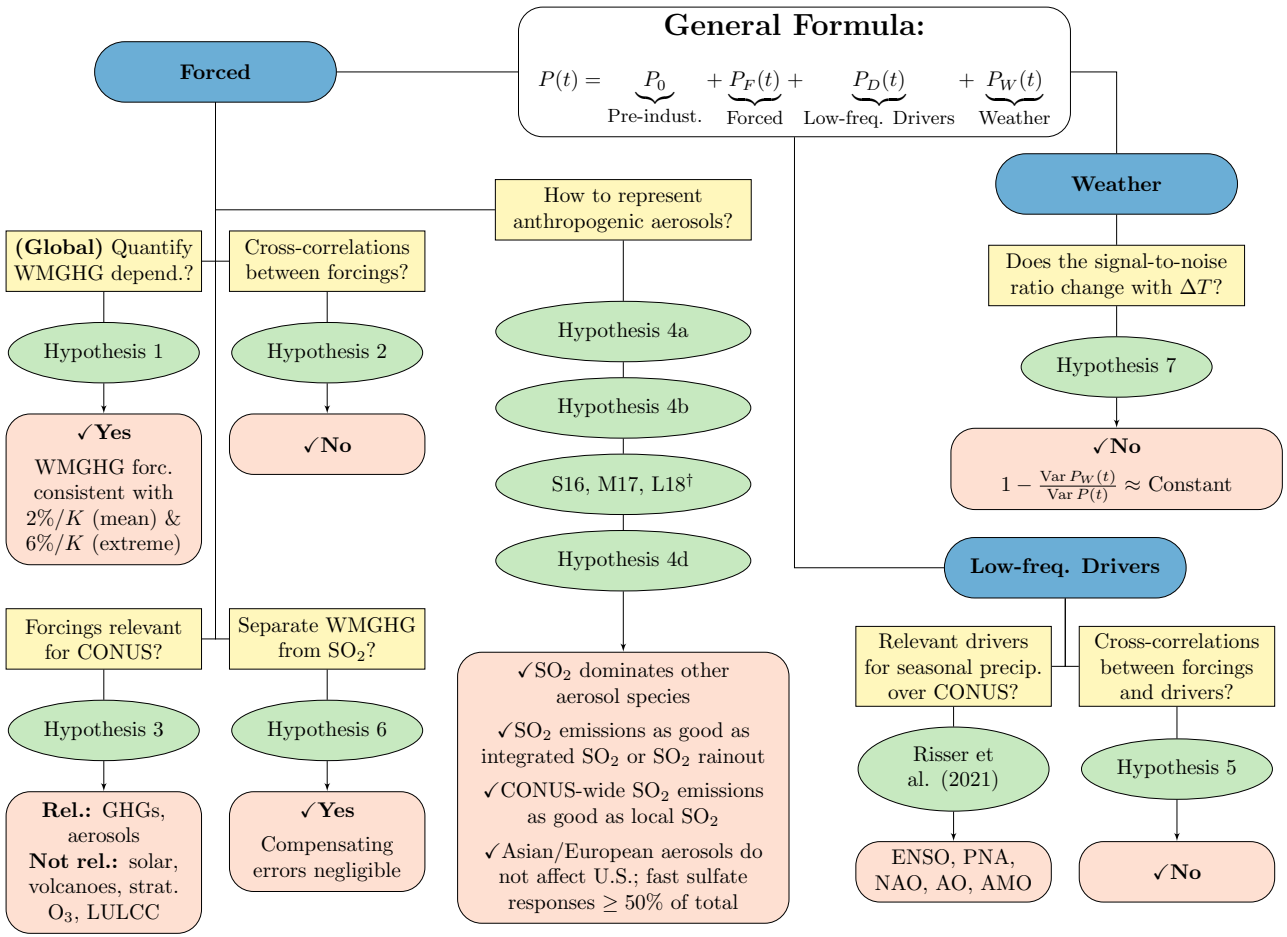
D&A framework outside of aerosols:

- **CMIP6 core DECK:** piControl, historical, 1pctCO2
- **CMIP6 DAMIP:** hist-aer, hist-CO2, hist-GHG, hist-nat, hist-strato3
- **CMIP6 LUMIP:** hist-noLu
- **C20C+:** all-hist, plus15-future, plus20-future

Additional simulations needed for aerosol attribution:

- **CMIP6 AerChemMIP:** histSST, piClim-control, piClim-aer, piClim-SO2, piClim-BC, piClim-OC, piClim-NH3
- **PDRMIP:** (Papers on) Base, Sul×5, Suleur, Sulasia
- **SO_2 Sourcing:** CAM5-MAM runs from Yang et al, 2018

The Flowchart for the Framework



† S16 = Samset et al. (2016); M17 = Myhre et al. (2017); L18 = Liu et al. (2018)

Hypotheses

Label	Hypothesis	Conclusion/confidence	Model data sets used
H1	Can we correctly identify the magnitude of the WMGHG effect?	Yes / *Likely*	DAMIP (hist-GHG); CMIP6 piControl and 1pctCO2
H2	Can we isolate WMGHG dependence in a noisy climate system with all forcings?	Yes / *Very likely*	DAMIP (hist-GHG, hist-aer); CMIP6 historical
H3	Are there meaningful trends due to individual forcing agents?	Yes: GHG & SO_2 / *Likely*	DAMIP (hist-GHG, hist-aer, hist-nat, hist-stratO3); LUMIP (hist-noLu); CMIP6 historical
H4	Are aerosol effects due to local, fast response to SO_2?	Yes / *Likely*$\rightarrow$*Certain*	AerChemMIP and PDRMIP
H5	Do the individual forcing agents influence the relationships between the climate drivers and precipitation?	Yes / *Likely*	DAMIP (hist-GHG, hist-aer, hist-nat, hist-stratO3); LUMIP (hist-noLu); CMIP6 historical
H6	Can we distinguish the WMGHG effect from the aerosol effect?	Yes / *Likely*	DAMIP (hist-GHG, hist-aer); CMIP6 historical
H7	Is the background variability / fast internal variability / weather state dependent?	Yes / *Certain*	C20C+ All-Hist; HAPPI Plus15- and Plus20-Future

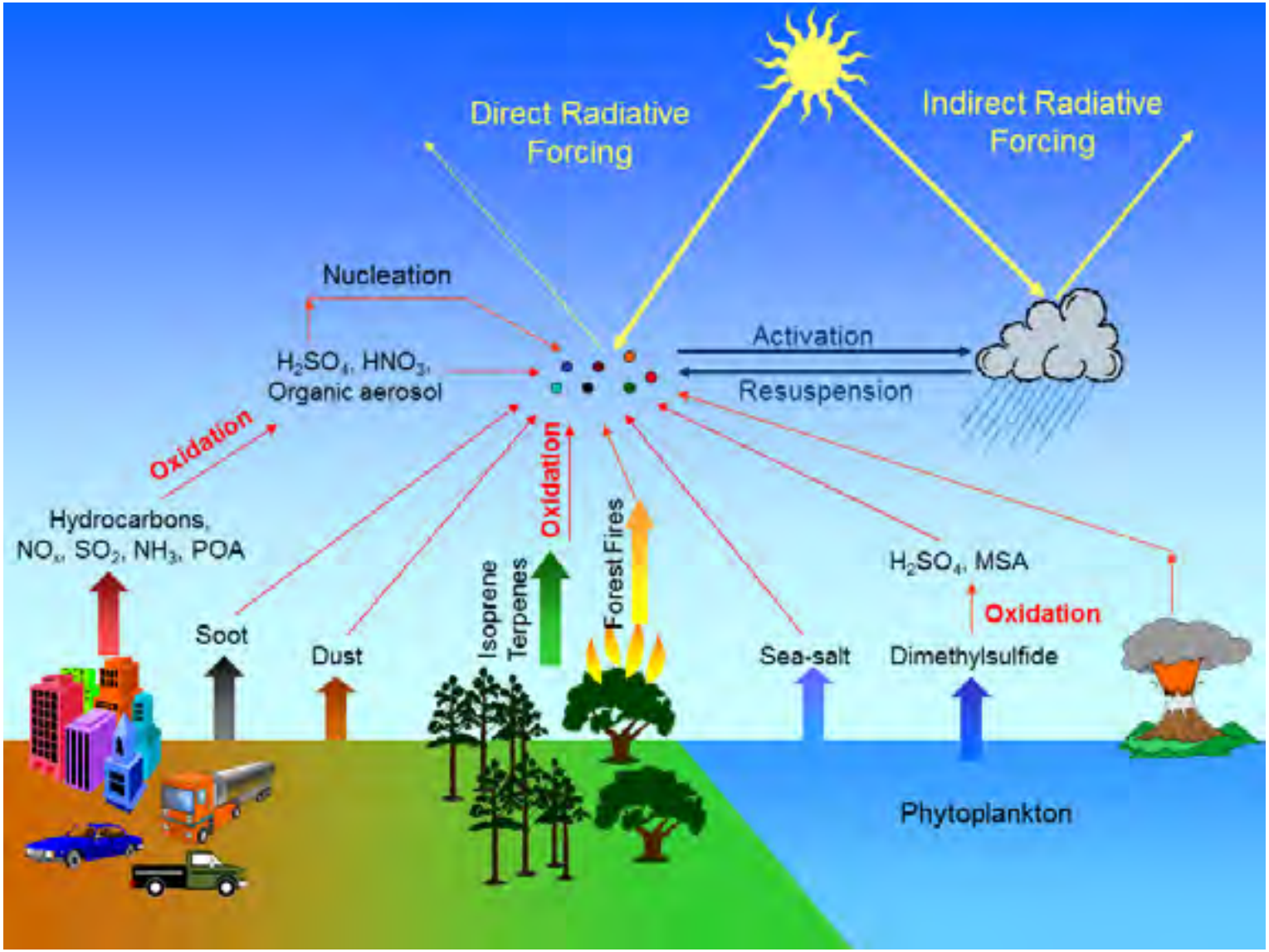
Detection and Attribution Formulae for Precipitation P

$$
\begin{aligned}
P(t) &= P_F(t) + P_D(t) + P_W(t) \\
P_F(t) &\approx P_0 + \beta_{\text{Slow}}\, F_{\text{Slow}}(t, \tau_{\text{Slow}}) + \beta_{\text{Fast}}\, F_{\text{Fast}}(t, \tau_{\text{Fast}}) \\
F_{\text{Slow}}(t, \tau_{\text{Slow}}) &= F_{\text{GHG}}(t, \tau_{\text{Slow}}) + F_{\text{AER-Glob}}(t, \tau_{\text{Slow}}) \\
F_{\text{Fast}}(t, \tau_{\text{Fast}}) &= F_{\text{AER-local}}(t, \tau_{\text{Fast}})z \\
P_D(t) &\approx \sum_{d=\text{ELI,AO,NAO,PNA,AMO}} \beta_d\, d(t)
\end{aligned}
$$

$$
1 - \frac{\operatorname{Var} P_W(t, \Delta T)}{\operatorname{Var} P(t)} \approx 1 - \frac{\operatorname{Var} P_W(t, 0)}{\operatorname{Var} P(t)} = \frac{S}{N} \approx \text{Constant}
$$

- P_F is the forced response, and the focus of this talk.
- P_D is the response due to internal interannual variability.
- P_W is weather noise.

For historical CONUS rainfall, SO_2 is the dominant aerosol



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How to measure SO_2 forcing given lack of observations?

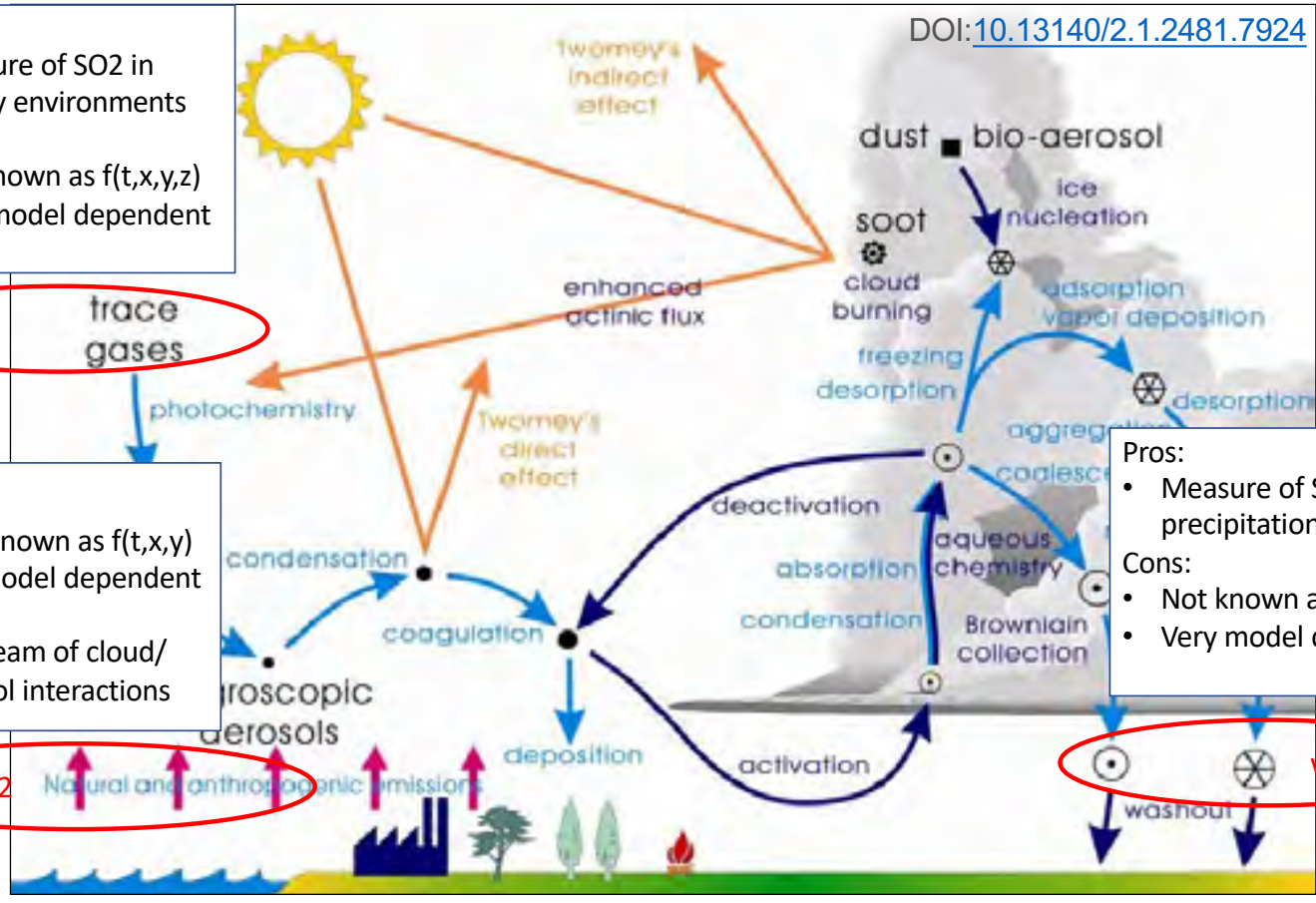
Pros:
- Measure of SO2 in cloudy environments

Cons:
- Not known as f(t,x,y,z)
- Very model dependent

iso2

Pros:
- Well known as f(t,x,y)
- Not model dependent

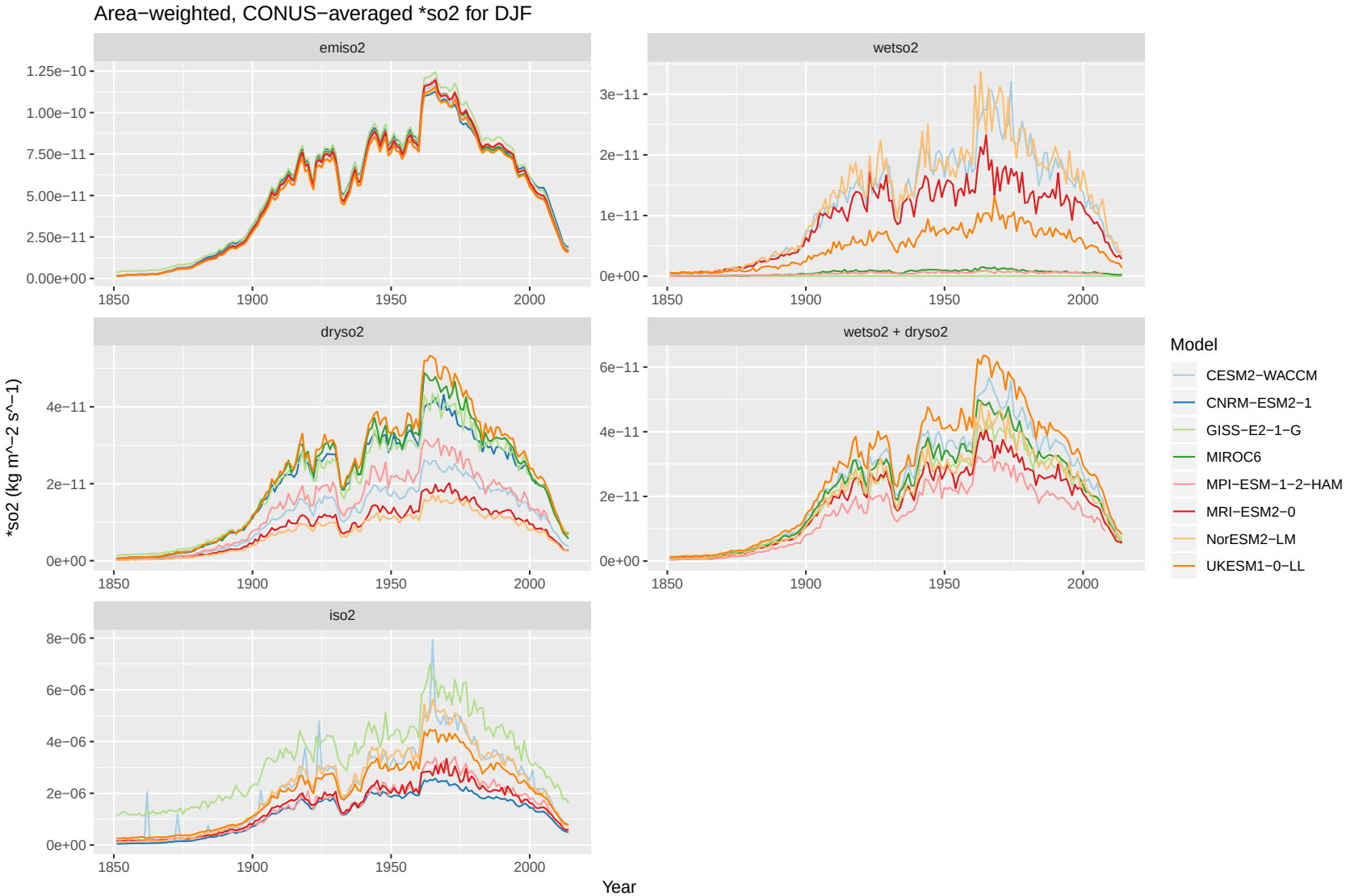
Cons:
- Upstream of cloud/ aerosol interactions



Pros:
- Measure of SO2 in precipitation

Cons:
- Not known as f(t,x,y,z)
- Very model dependent

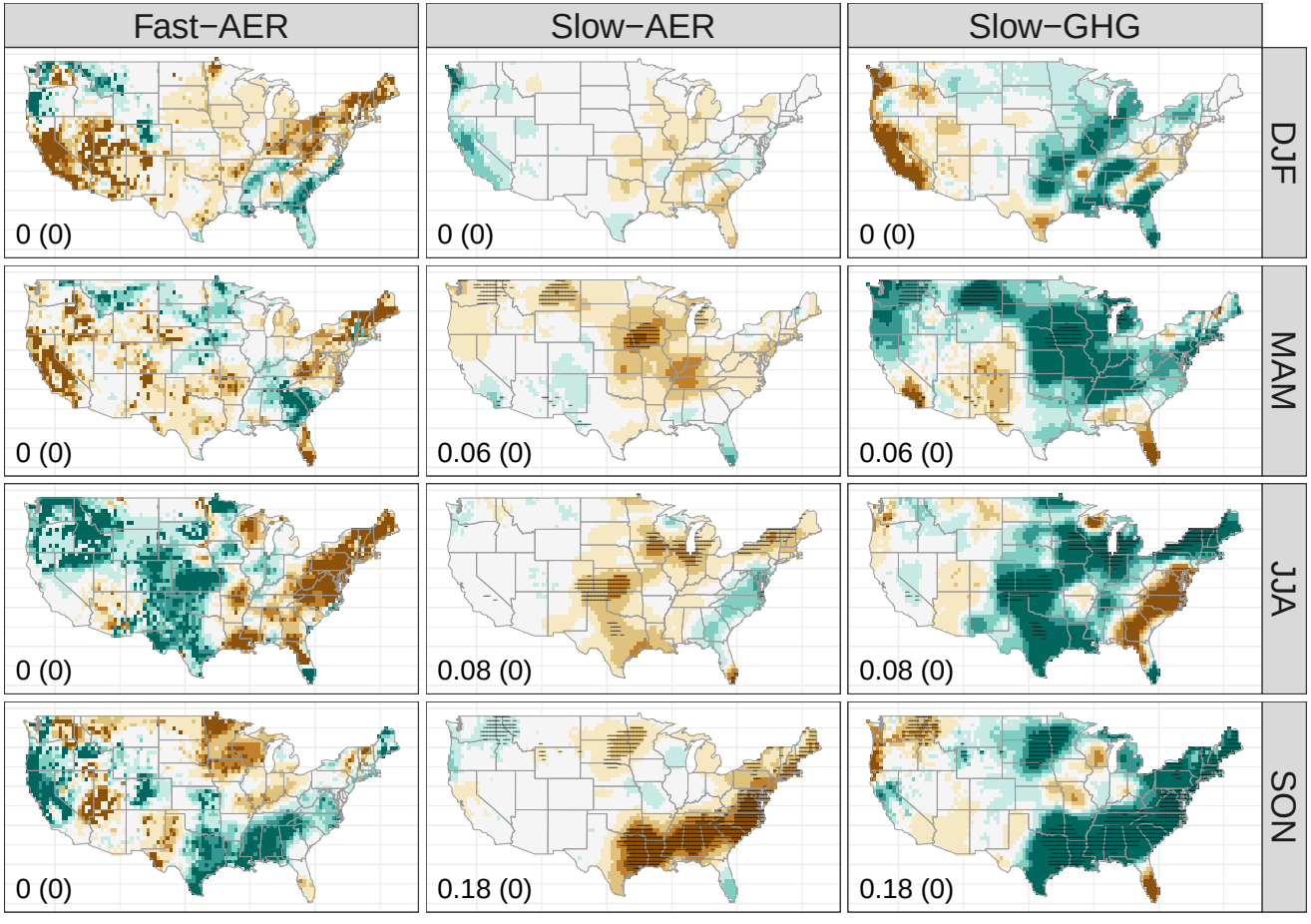
Ad hoc solution: Use SO_2 emission due to CMIP6 diversity



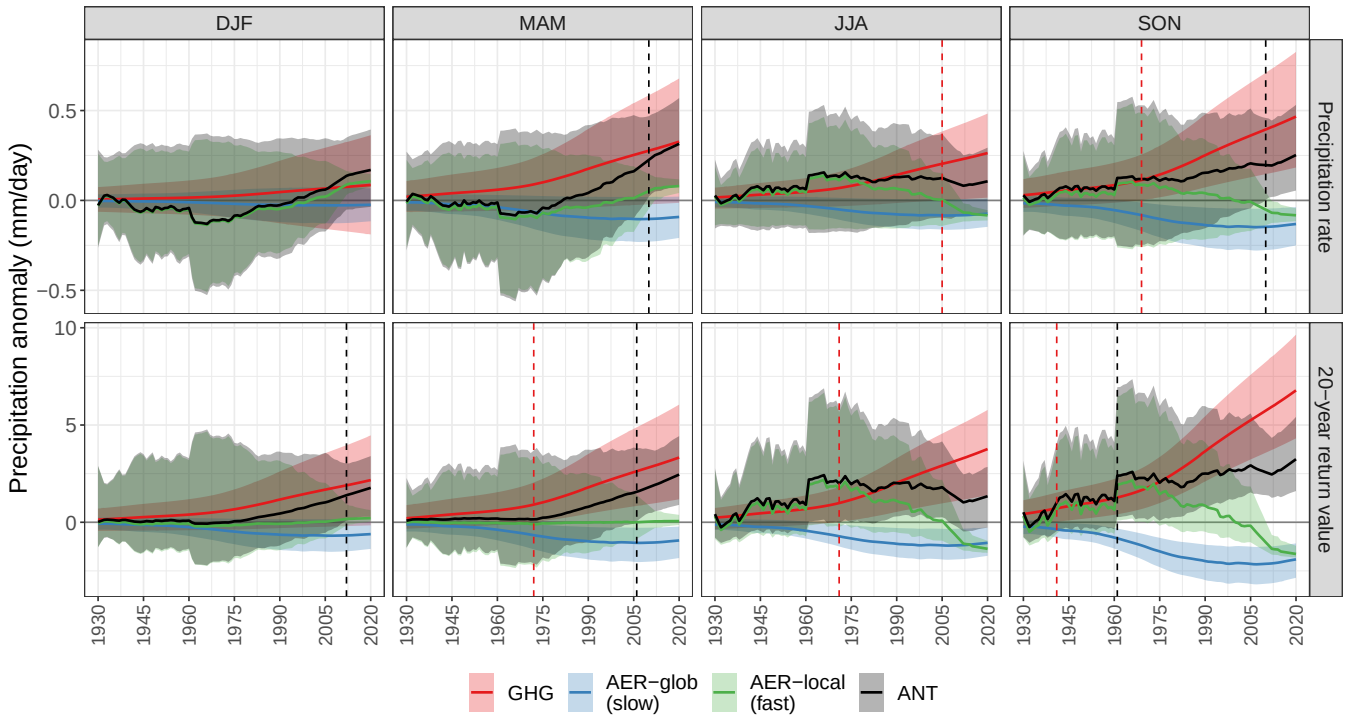
Response of precipitation to anthropogenic forcings

Hatching = statistically significant attribution
for moderate (−) and strong (+) significance

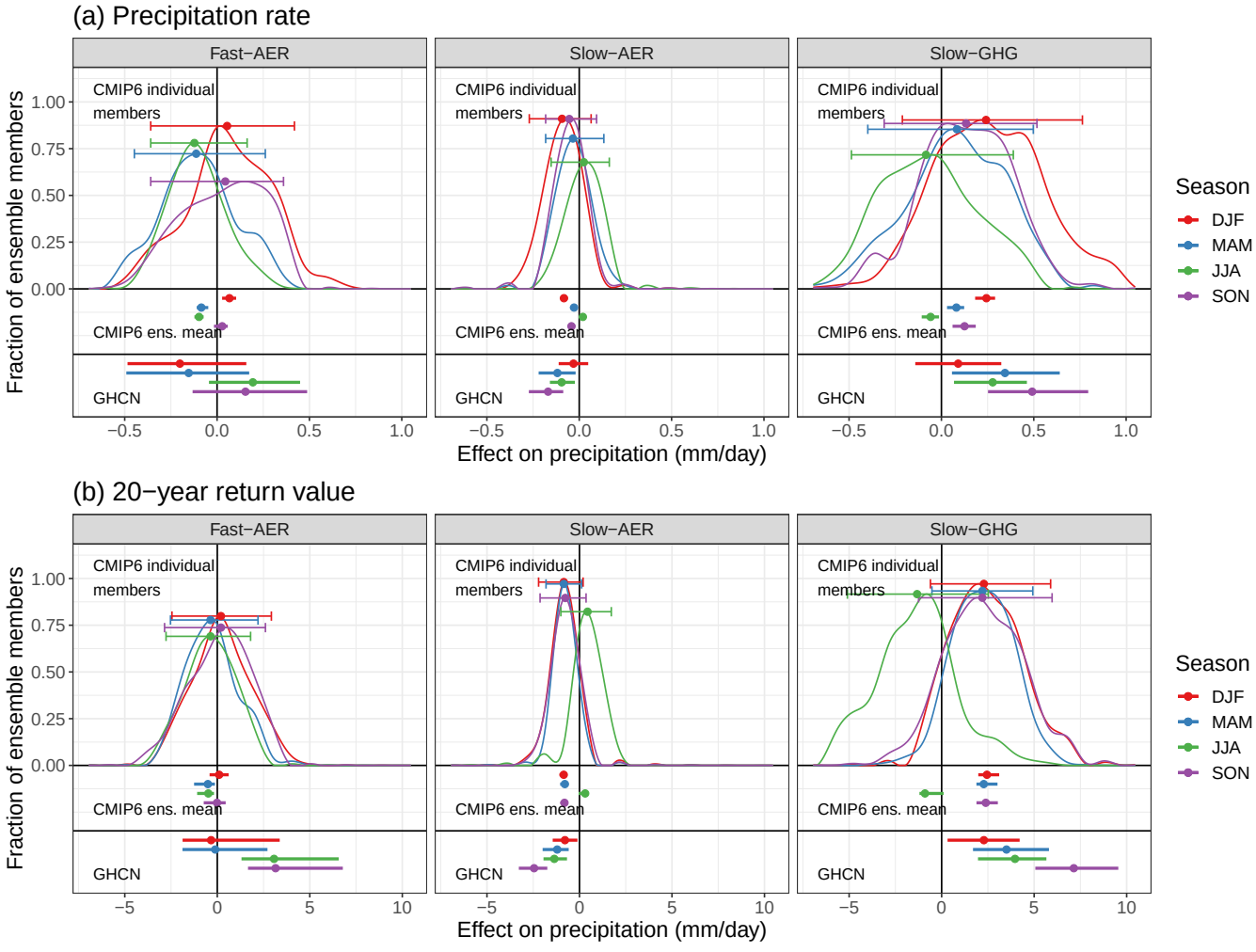
(a) Grid−box attribution: mean precipitation response



Time to emergence of CONUS-wide averages



Heterogeneous attribution signals across CMIP6



- The sign and magnitude are determinate across the MME.

Thank you for attending

Questions?