Chemistry-climate interactions from perturbations of anthropogenic and biomass burning emissions

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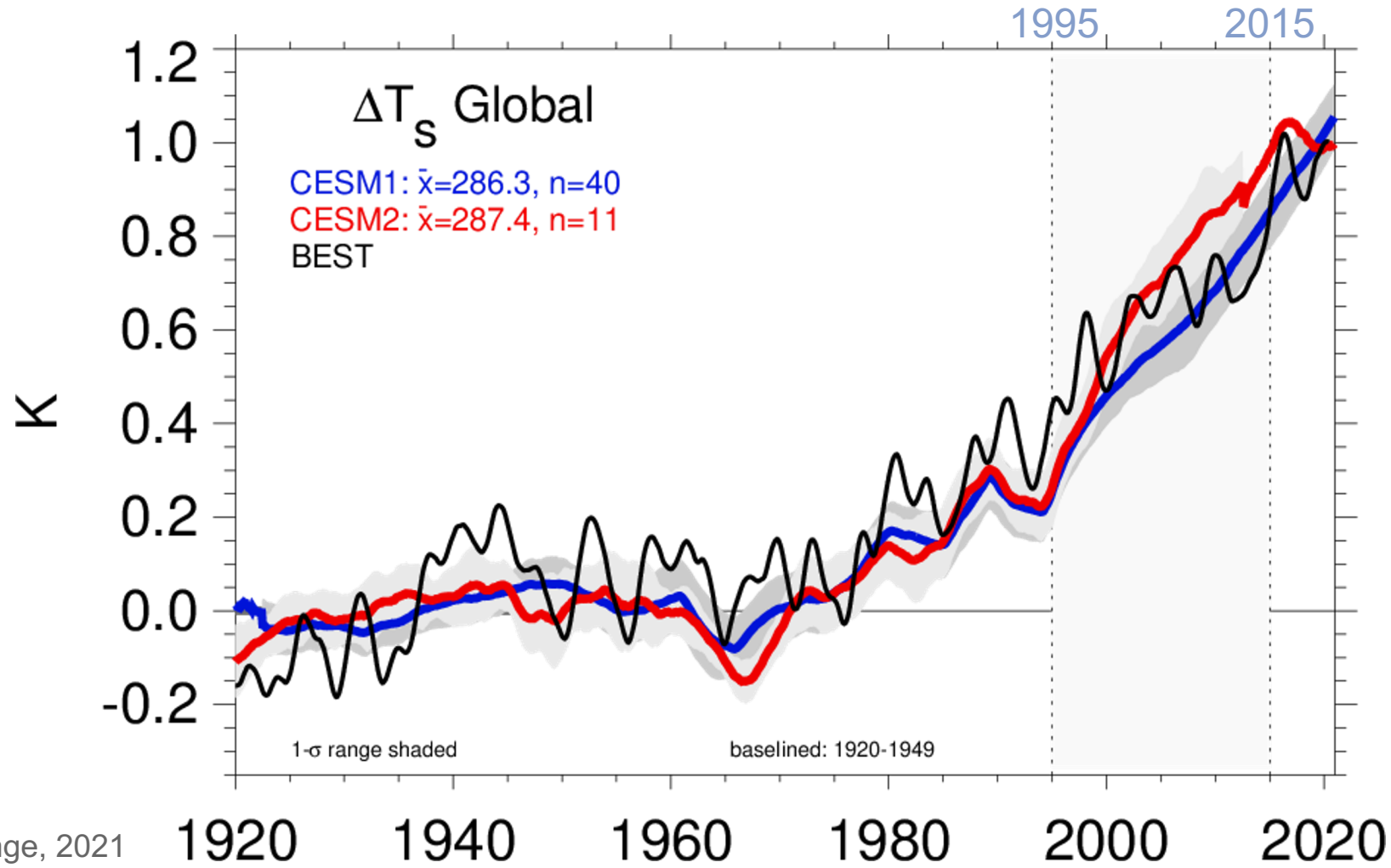
Looking at CMIP6 biomass burning emissions

Recent warming and CMIP6 in CESM2

Key points:

- Agreement with observations (BEST) is good for both CESM1/2



Fasullo et al., Submitted to Nature Climate Change, 2021

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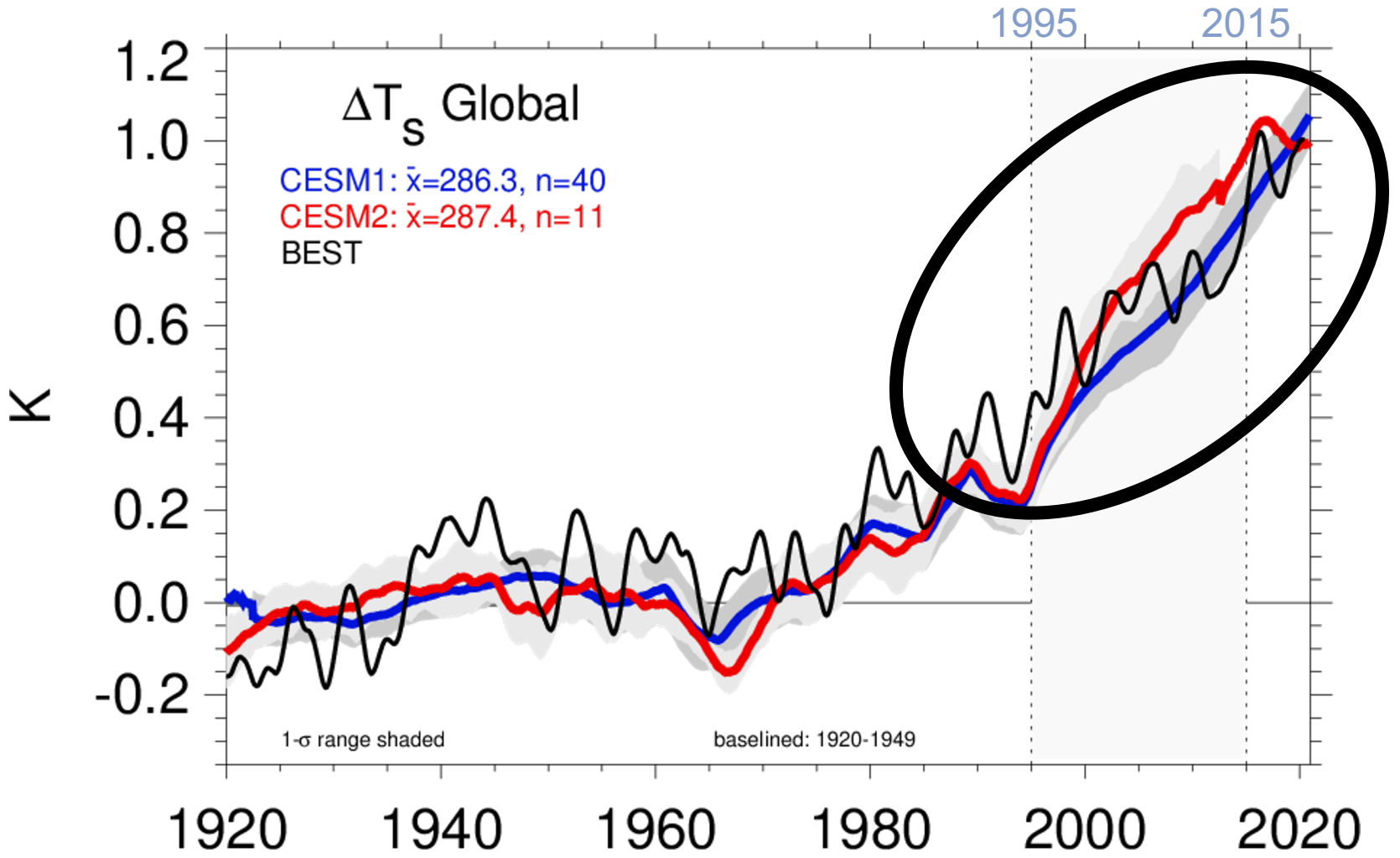

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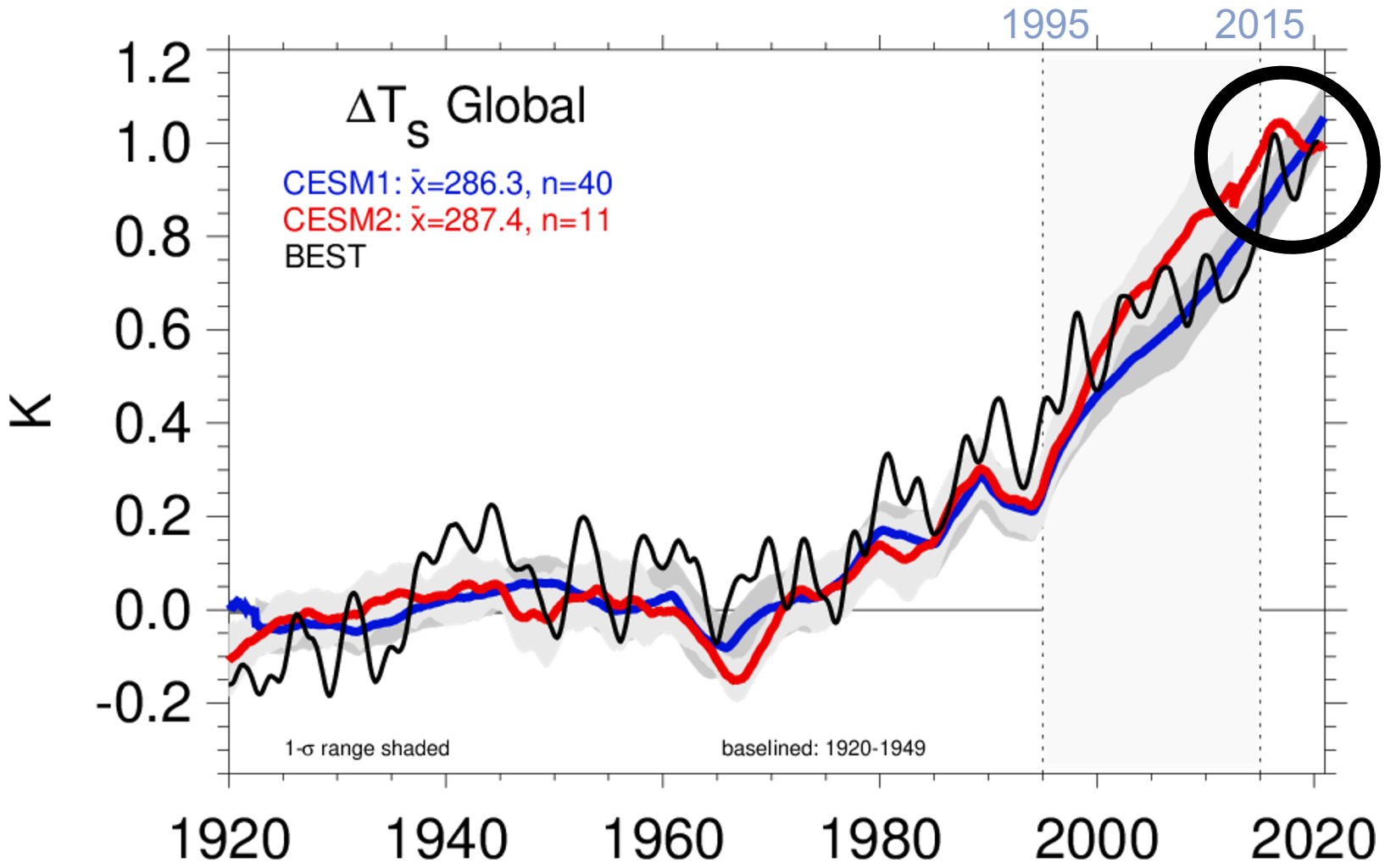

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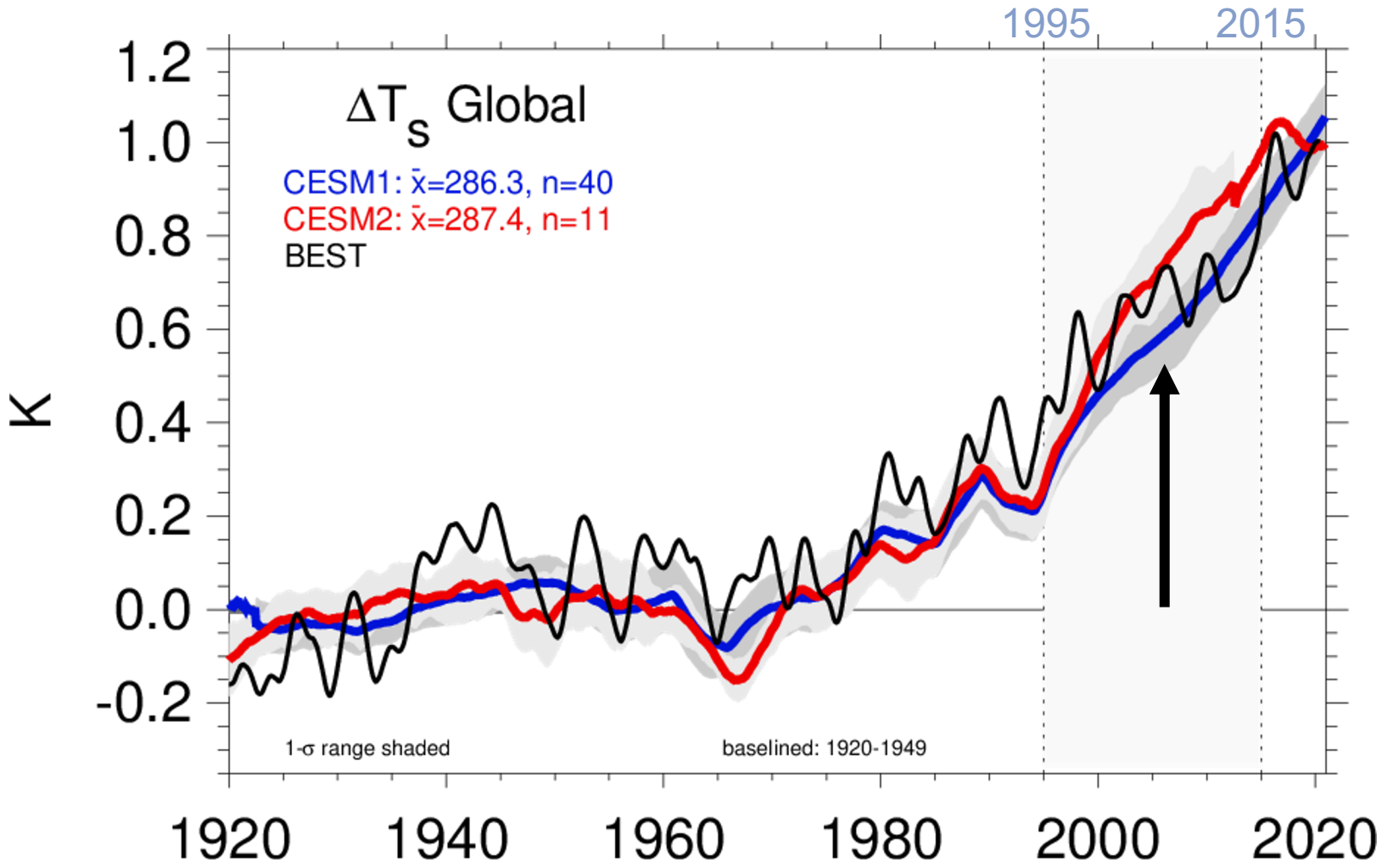
- …but … CESM2 warms more than BEST or CESM1 from 1995-2014, then less than CESM1 through 2025.
- And we have enough ensemble members to show it is not internal variability



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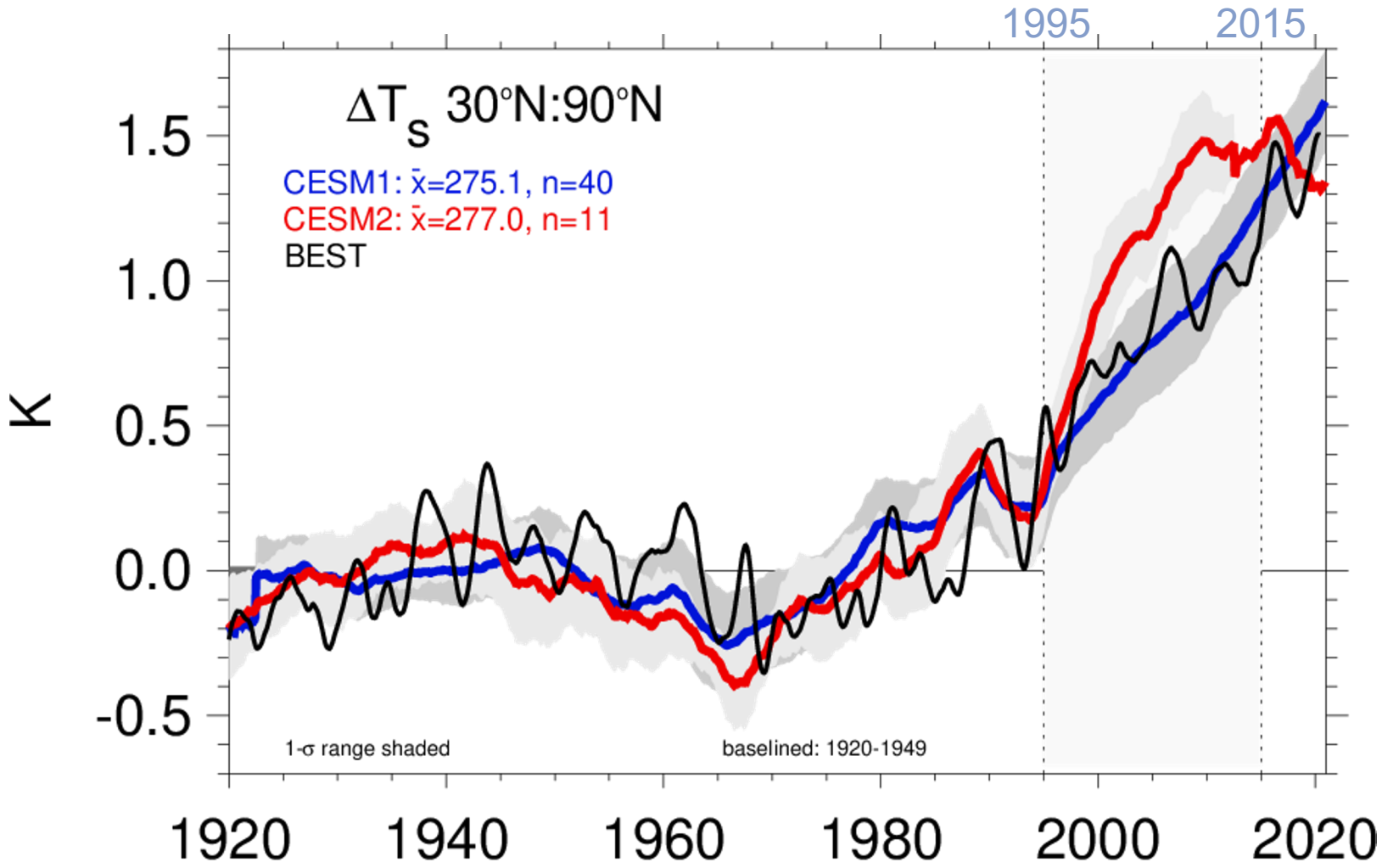
- And it is primarily over 30-90ºN



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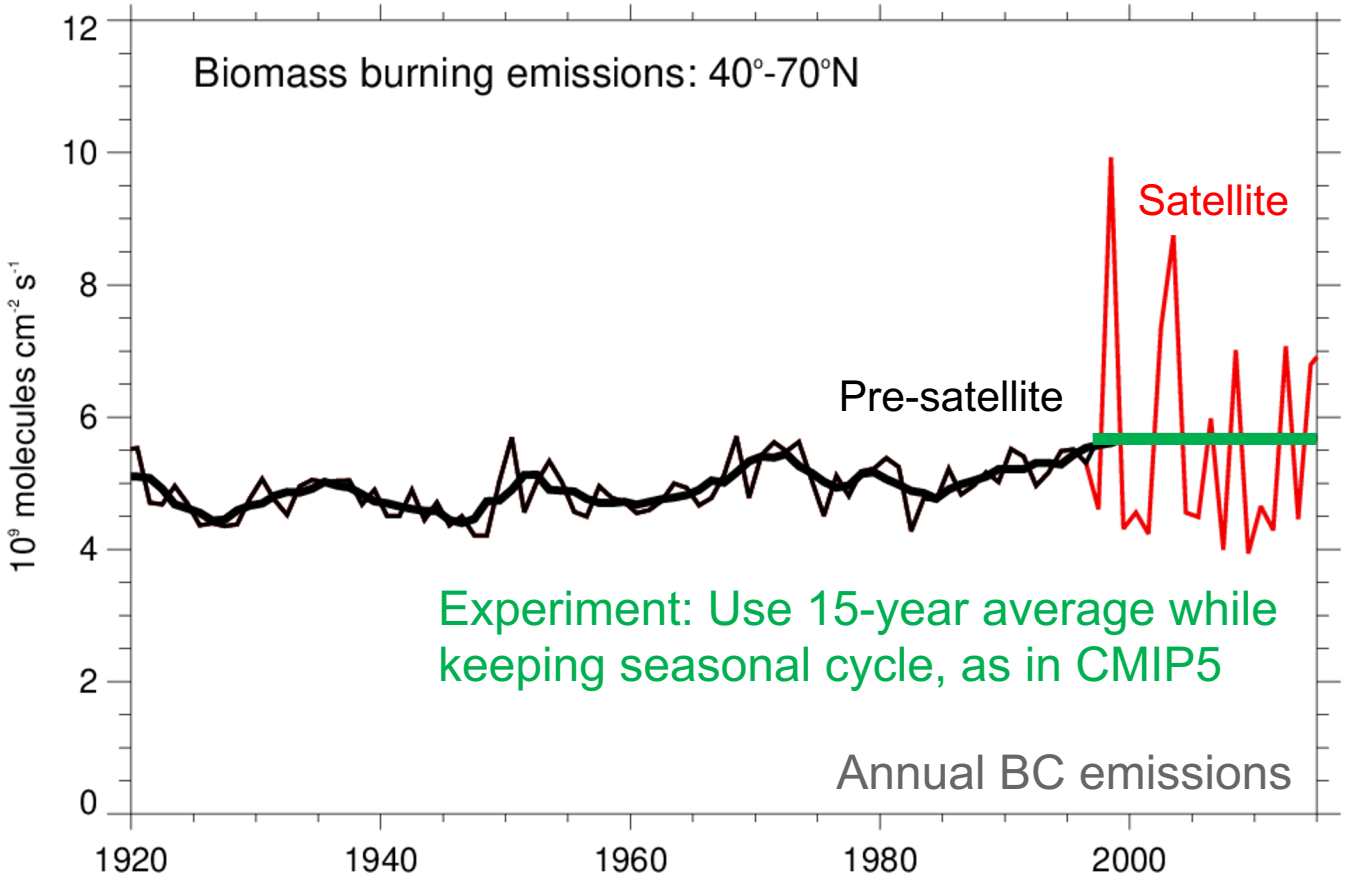

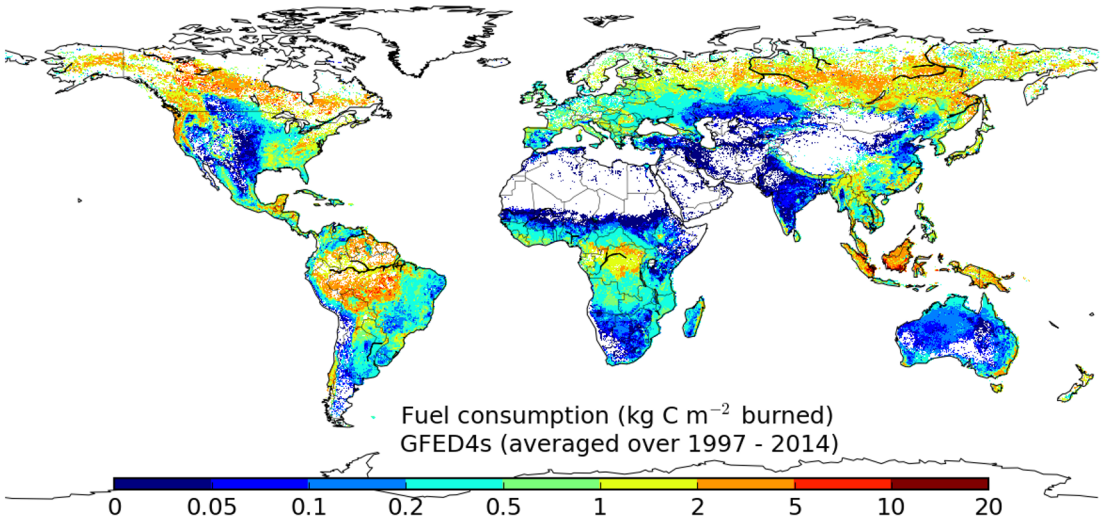

Because of the way it was constructed, the CMIP6 prescribed biomass (BB) emissions show a large increase in variability 1997-2014 (satellite based)

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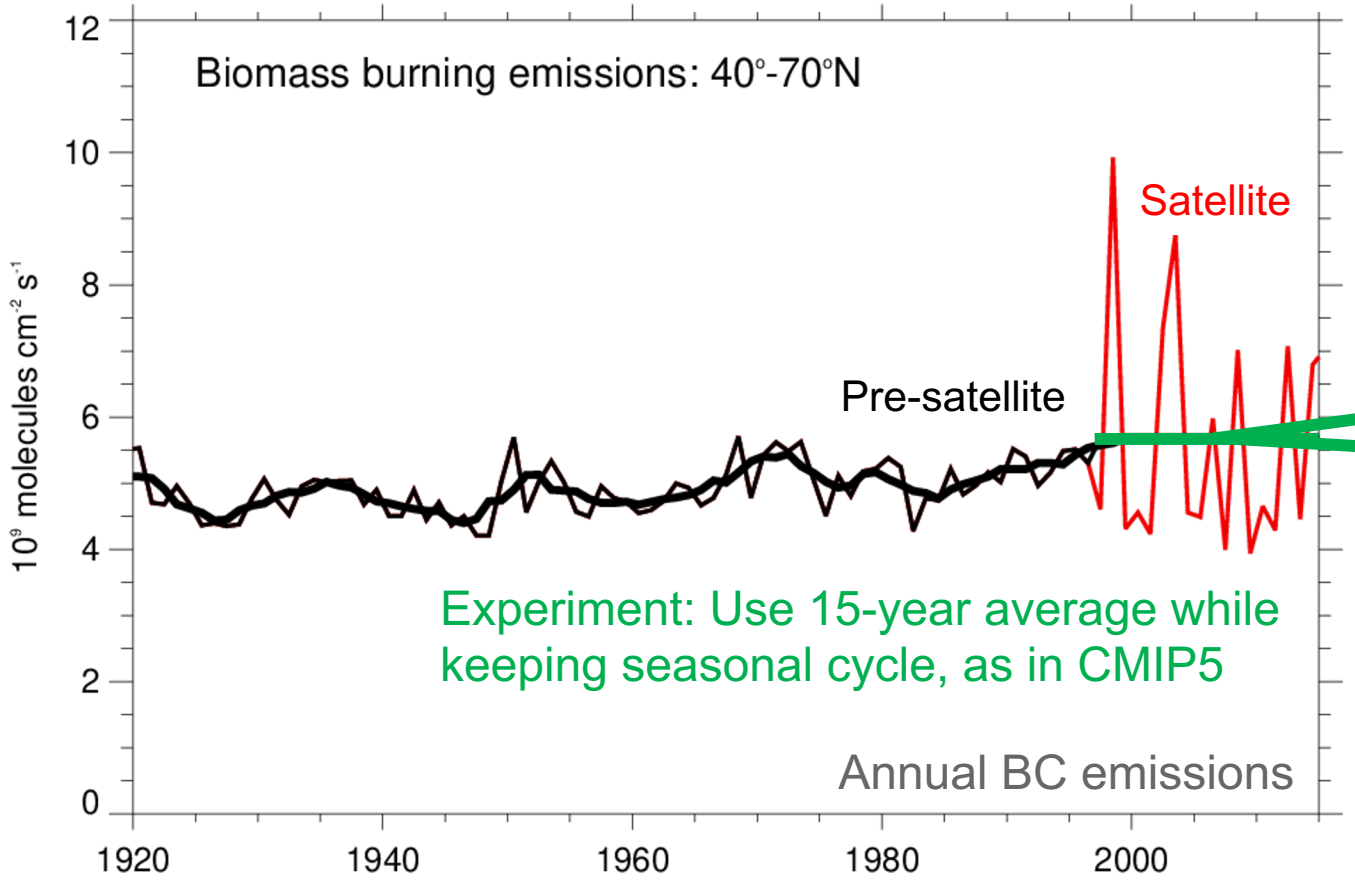

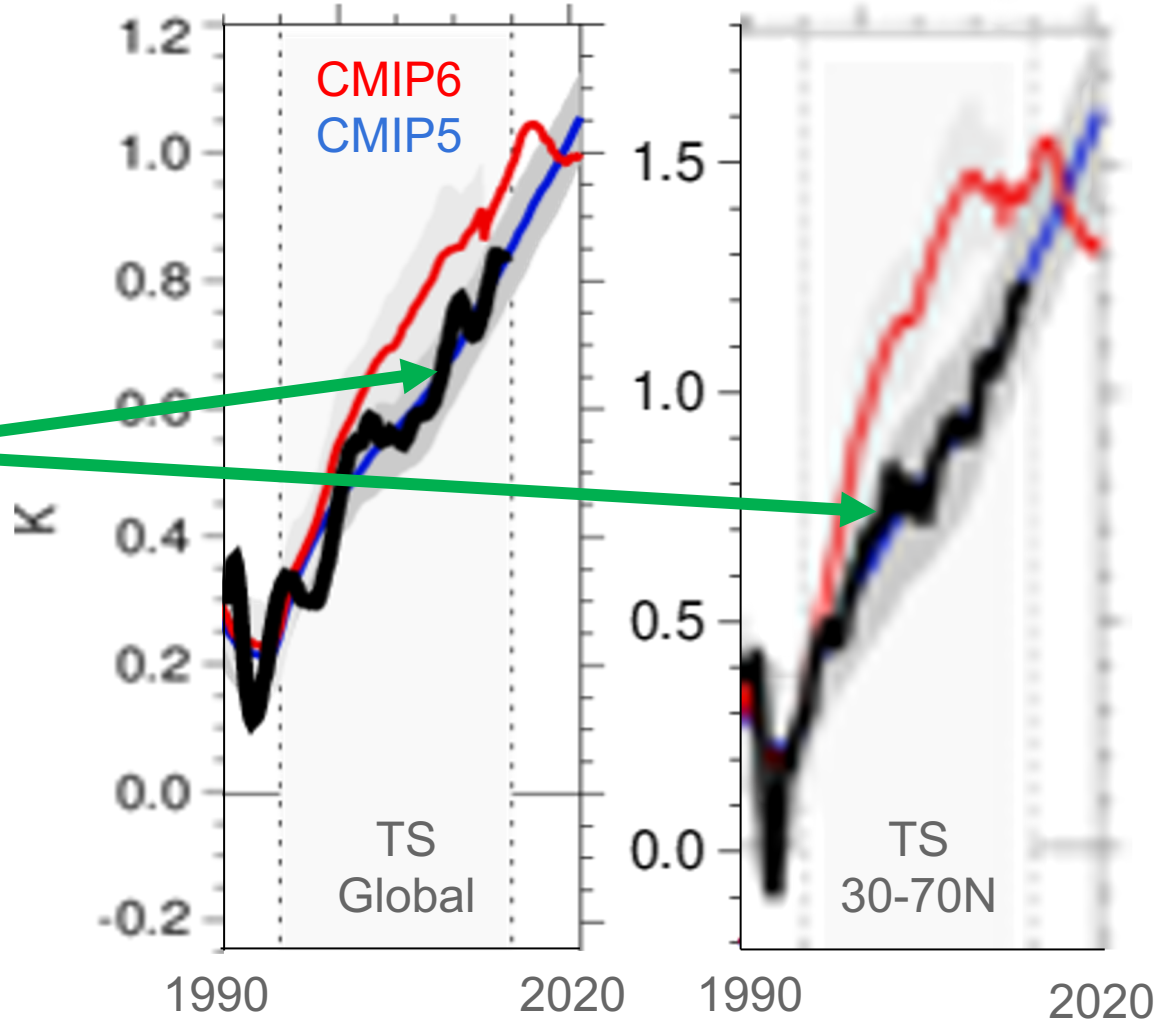

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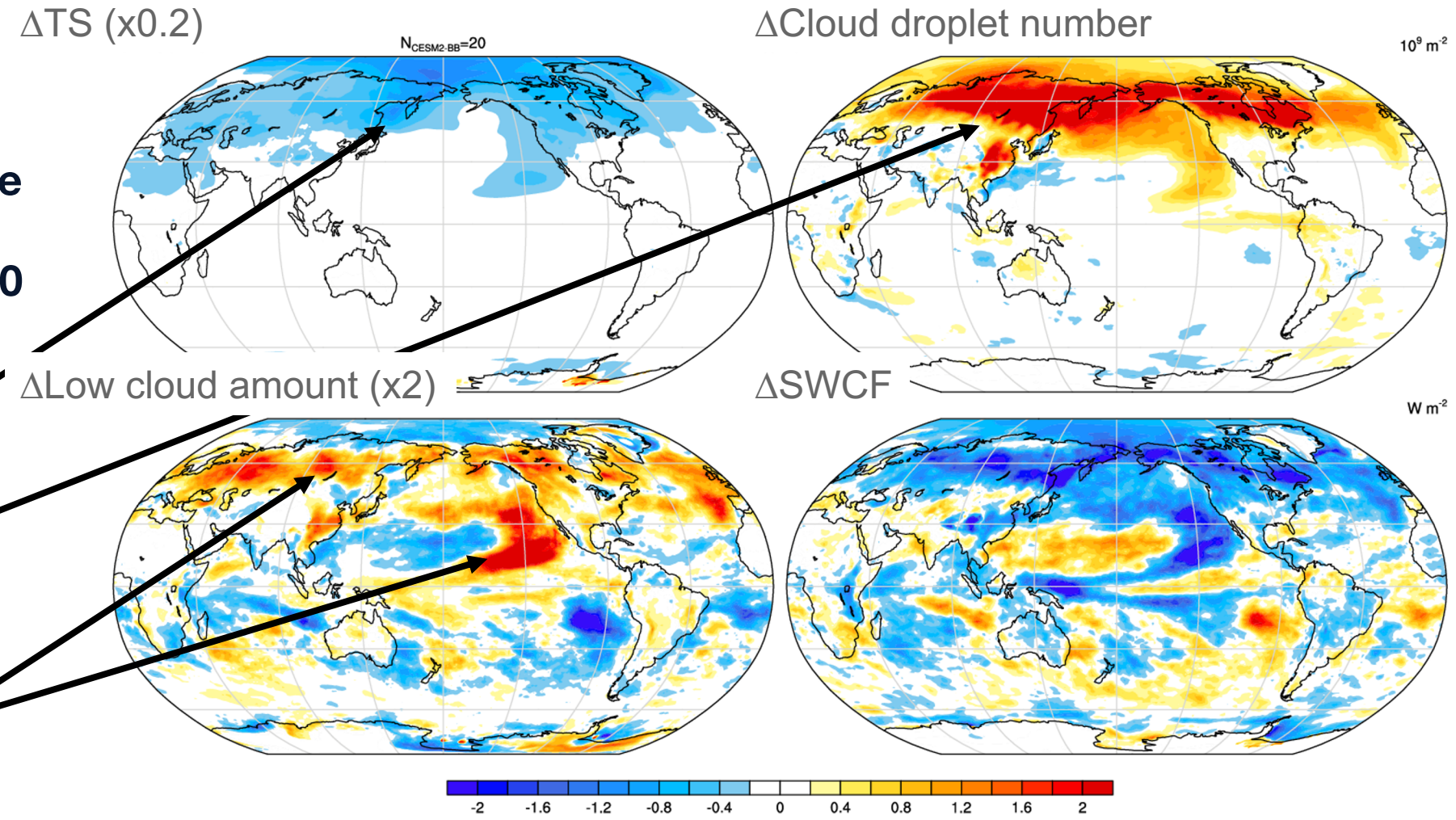
Recent warming and CMIP6 in CESM2

Patterns of Response
CESM2BB-CESM2
Δ 1995-2014 | 1970-90

- Constant emissions result in NH cooling.
- Cloud drop number increases in the high latitudes.
- Local and downstream effects are apparent in the low cloud (↑) and radiation (↓) fields.



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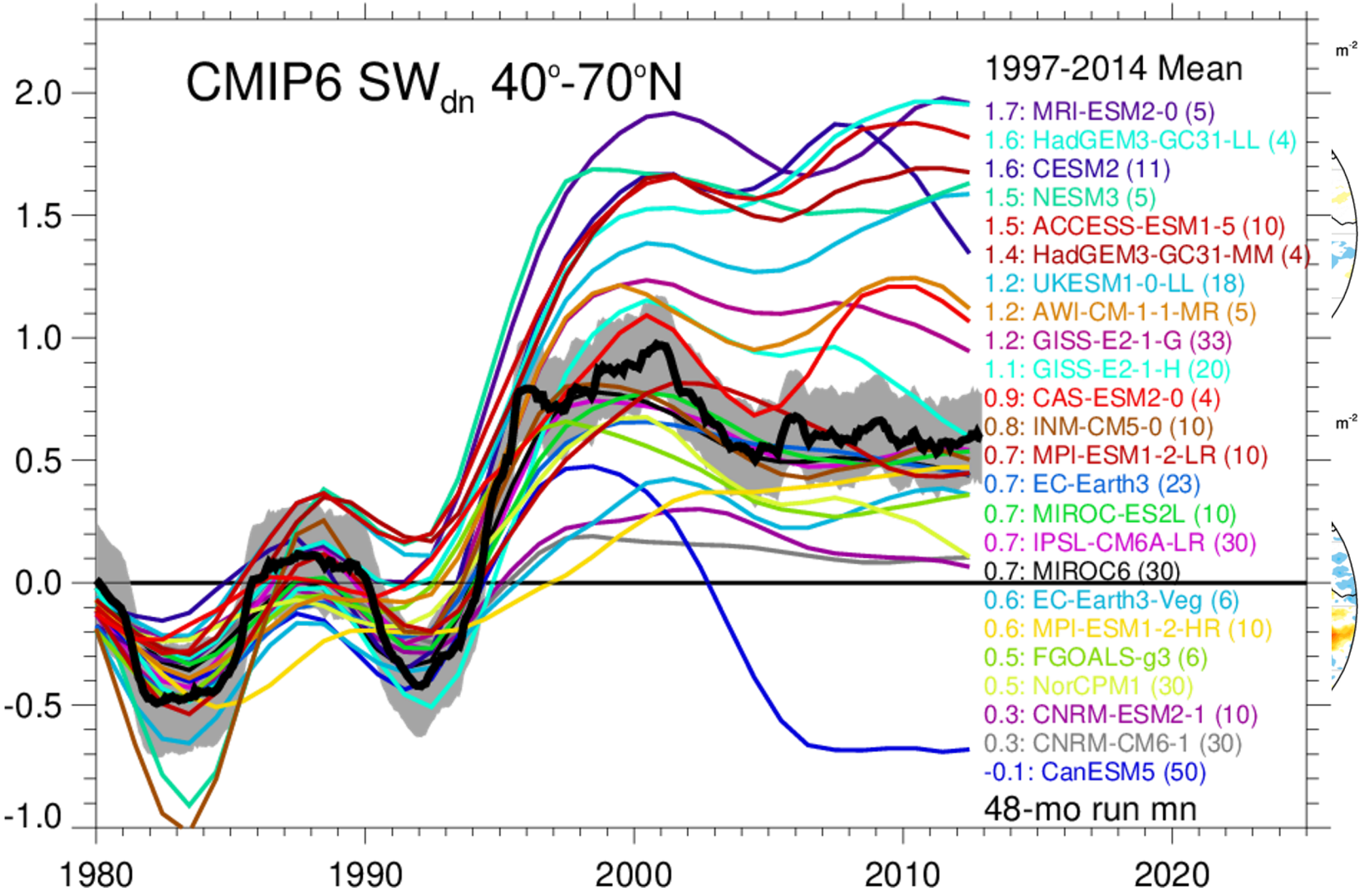
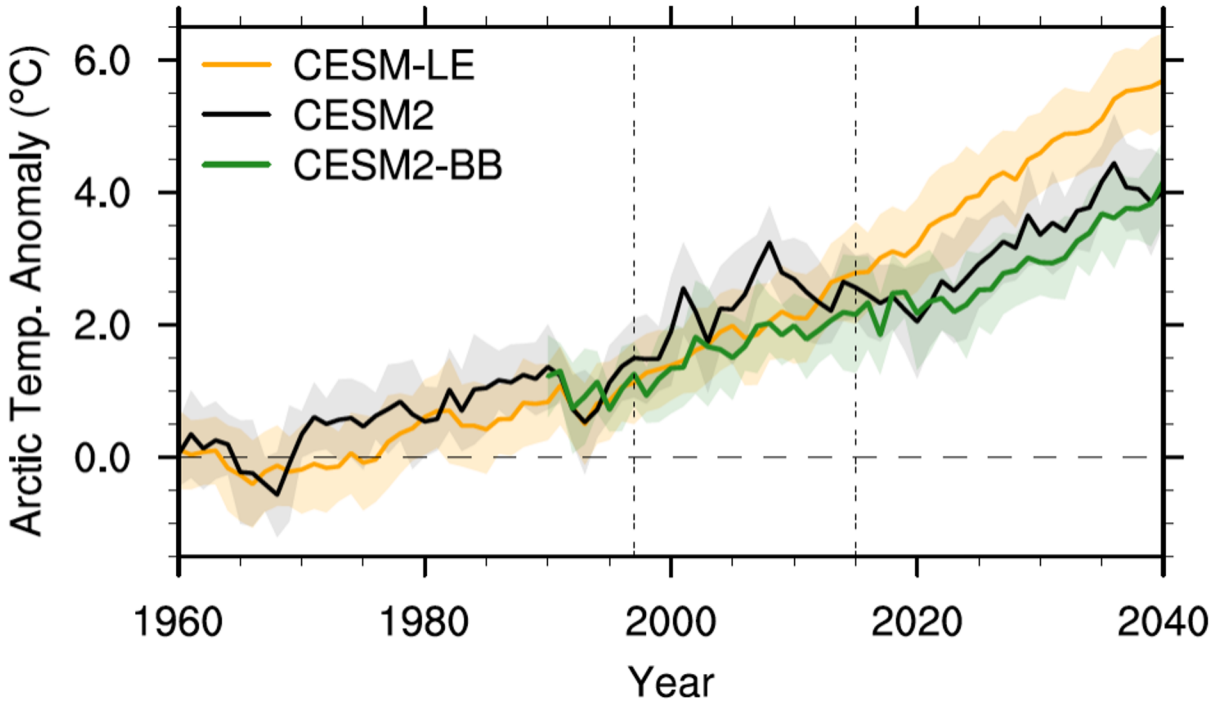
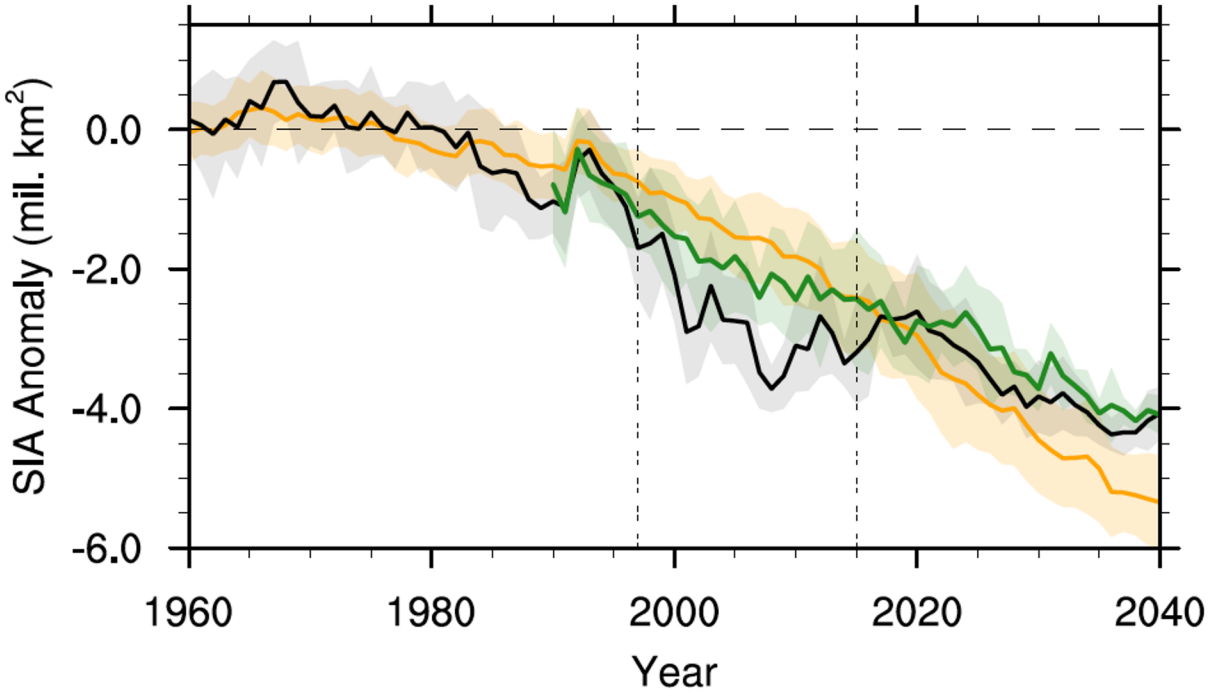


Impact on sea-ice trends





De Repentigny et al., submitted to Nature Climate Change, 2021

Partial conclusion

- We have identified a strong signature of biomass burning in the Arctic
- While the variability in the biomass burning emissions as observed during the satellite era is obviously realistic, the consequence of the results shown here is that the lack of variability in the pre-industrial control biomass burning emissions is limiting our understanding of the role of biomass burning emissions
- Tuning will need to take into account this variability
- Highly variable (interactive?) biomass burning emissions should be considered for all simulations (PI, historical, future)

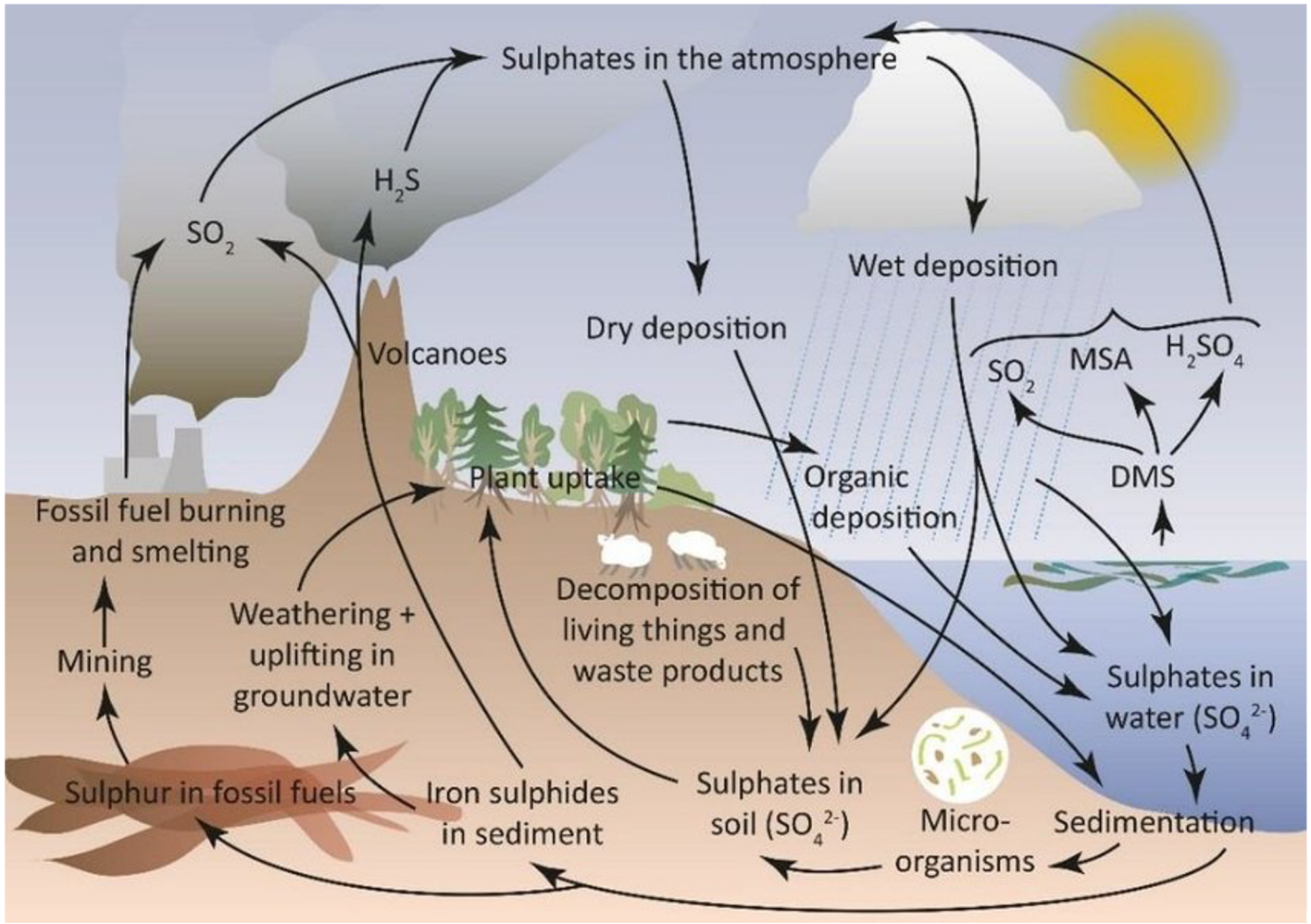
Looking at CMIP6 anthropogenic emissions

CMIP6 Analysis of sulfate deposition

Sulfate lifetime = 3-4 days
Main sources (SO2)

- Volcanoes
- Power plants

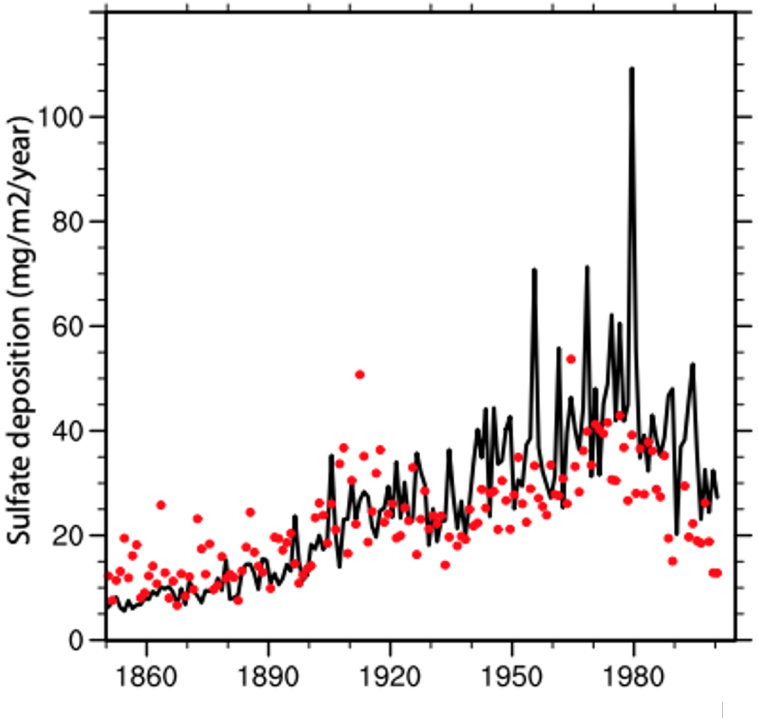
Chemistry (simplified)
SO2 + oxidants -> SO4



Lappalainen et al., ACP, 2016

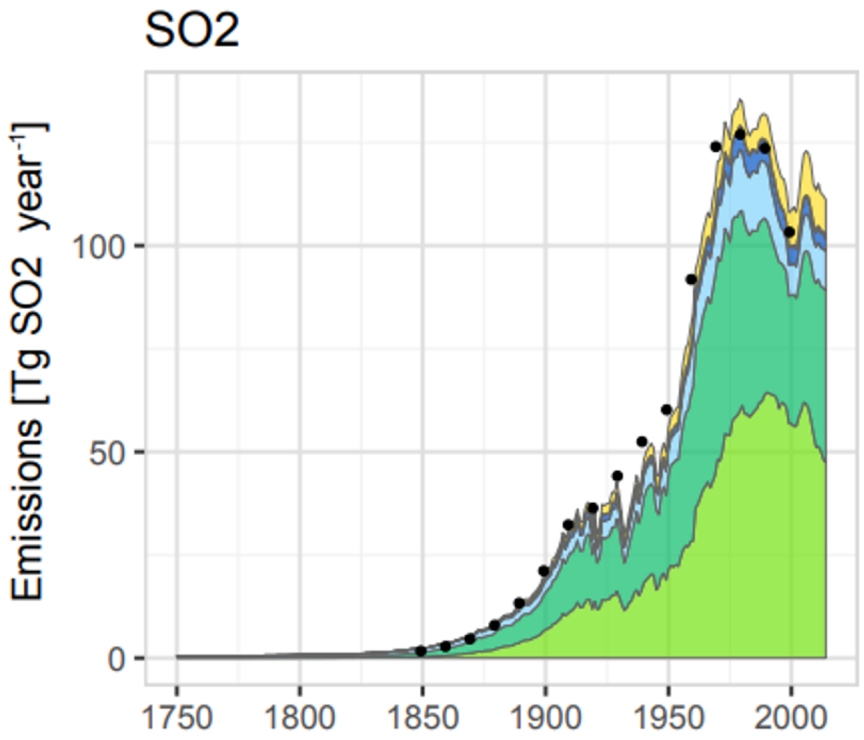
CMIP6 Analysis of sulfate deposition

Greenland: D4 site



Lamarque et al., 2010: CMIP5 results

Global anthropogenic emissions



Hoesly et al., ACP, 2018

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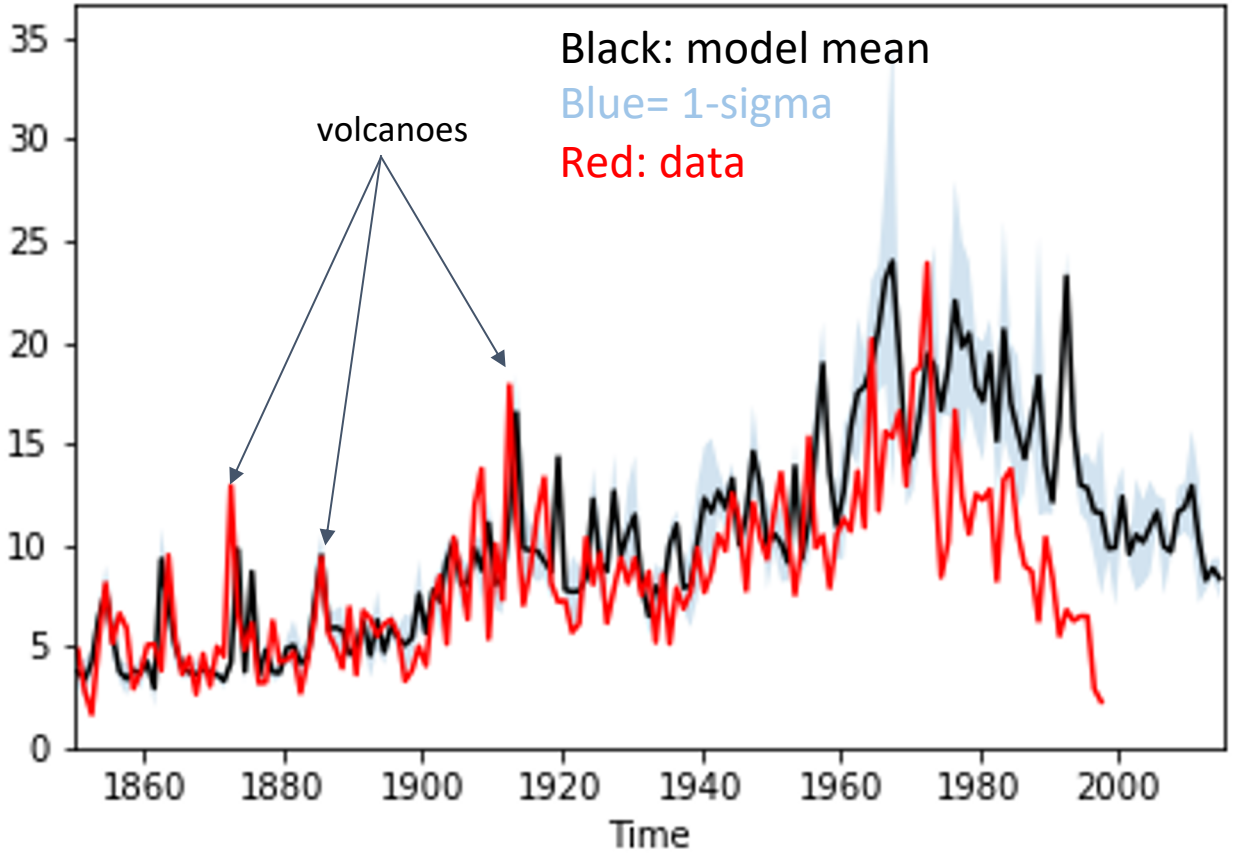
WACCM6 (3 members)



Lamarque et al., in preparation

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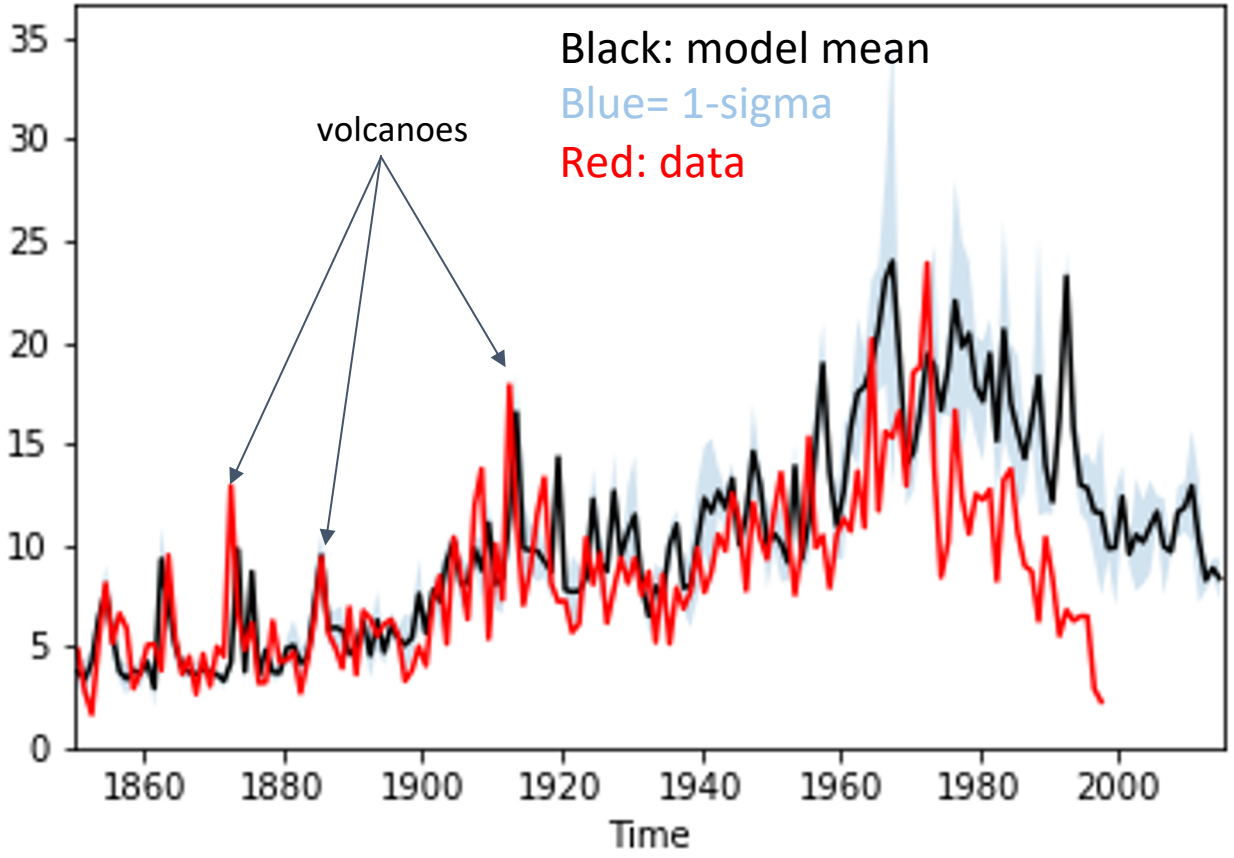
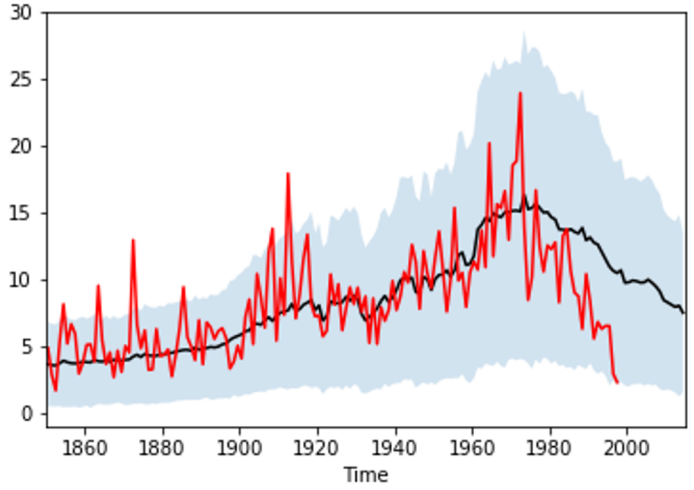


Multi-model (15) mean



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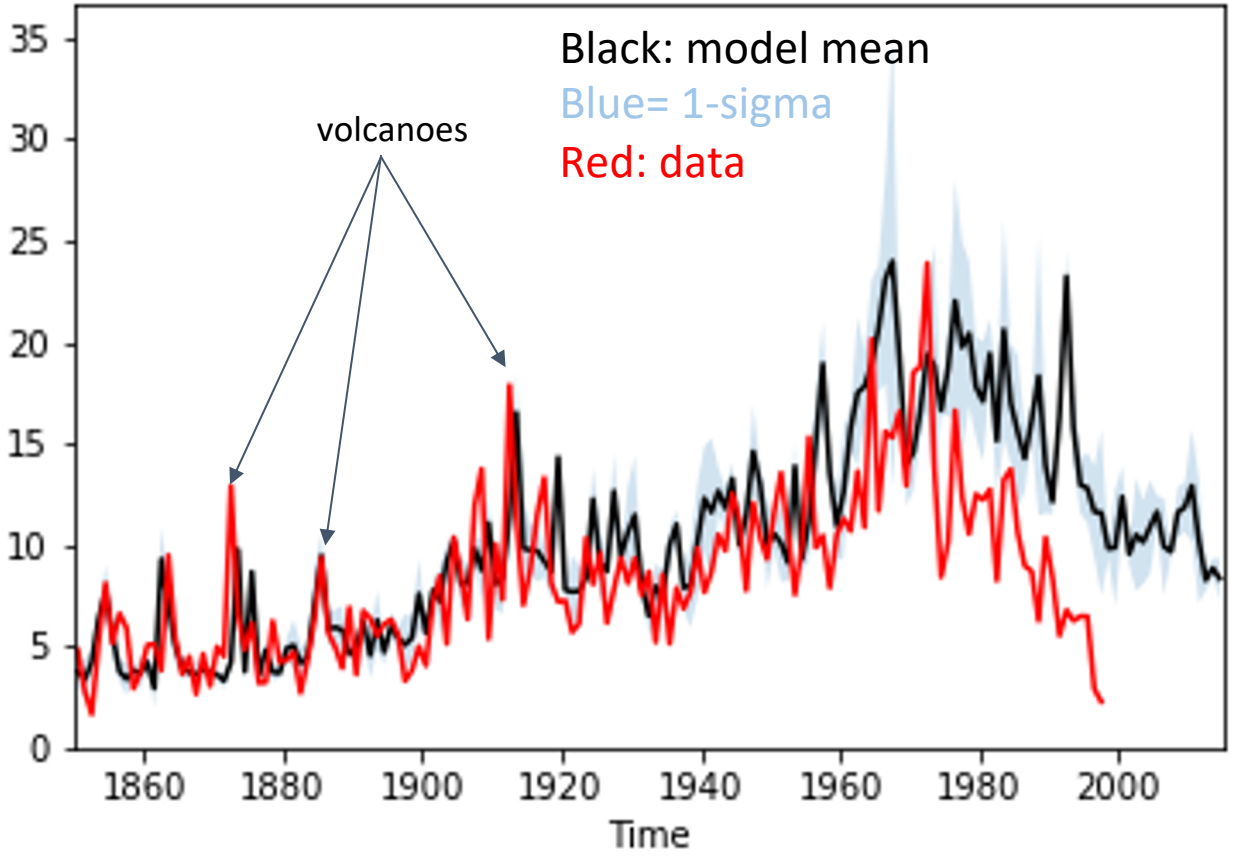

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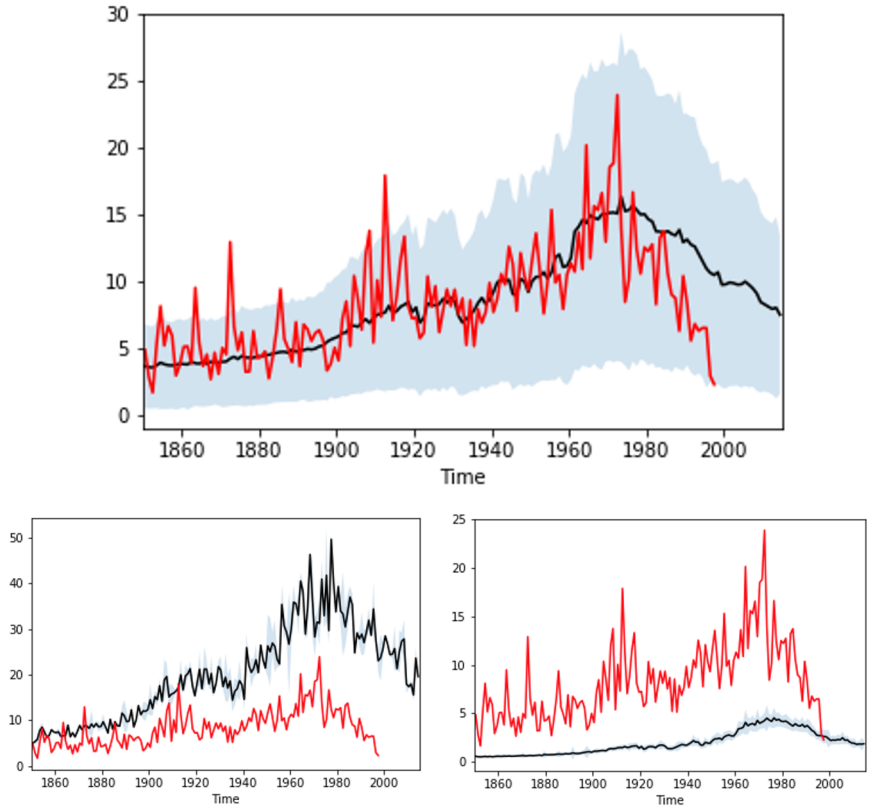

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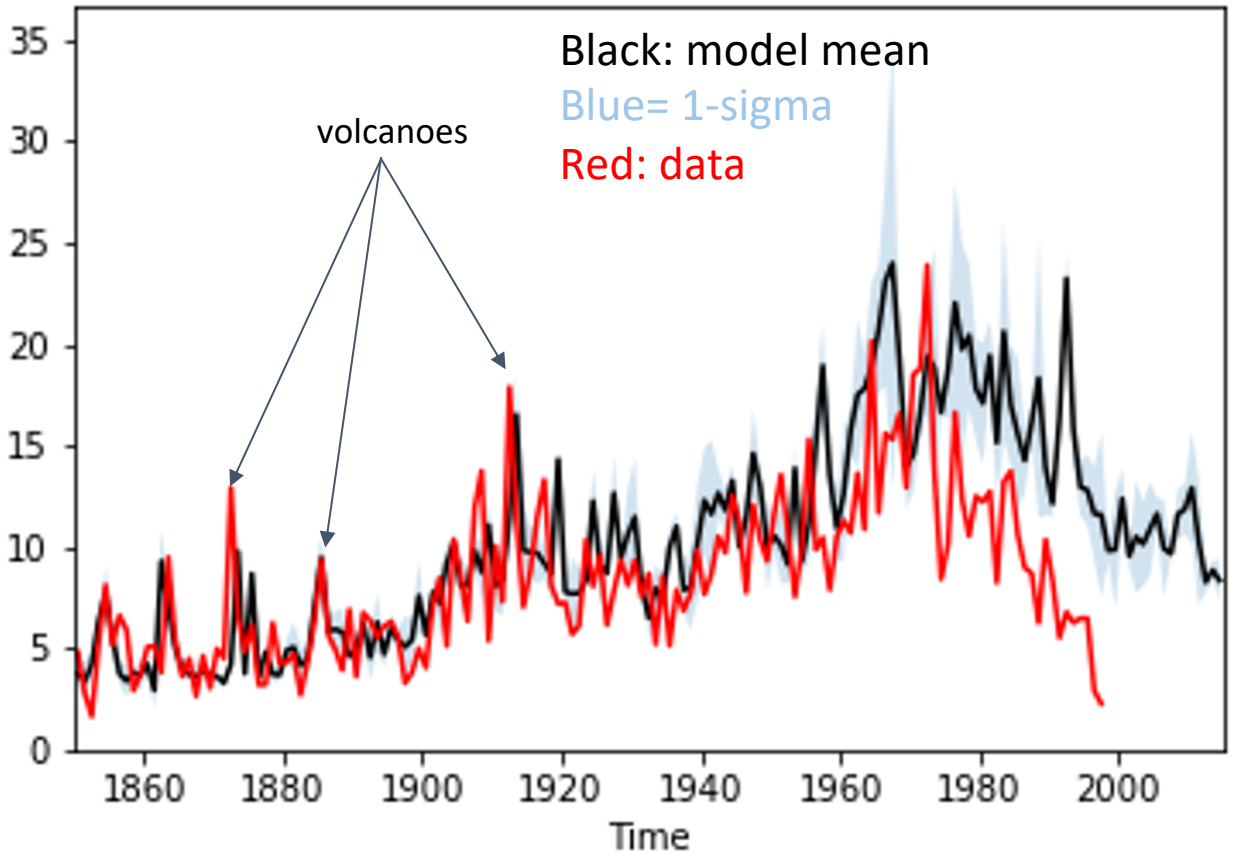
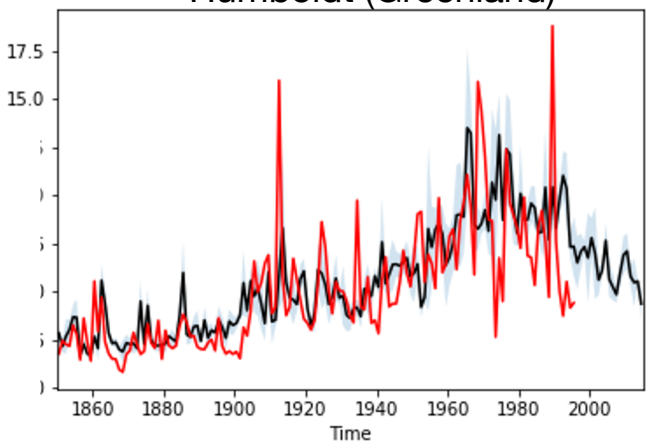
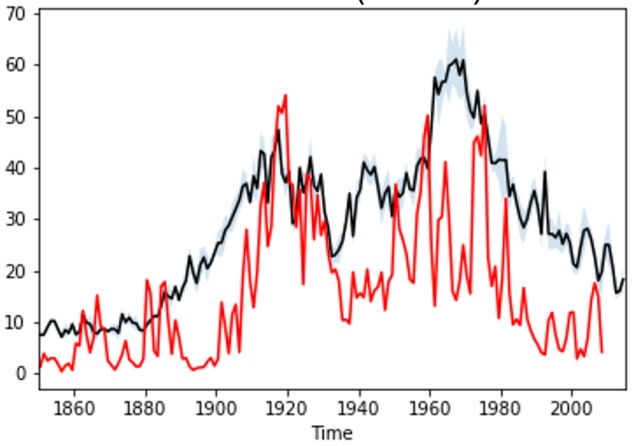


Humboldt (Greenland)



McCall (Alaska)



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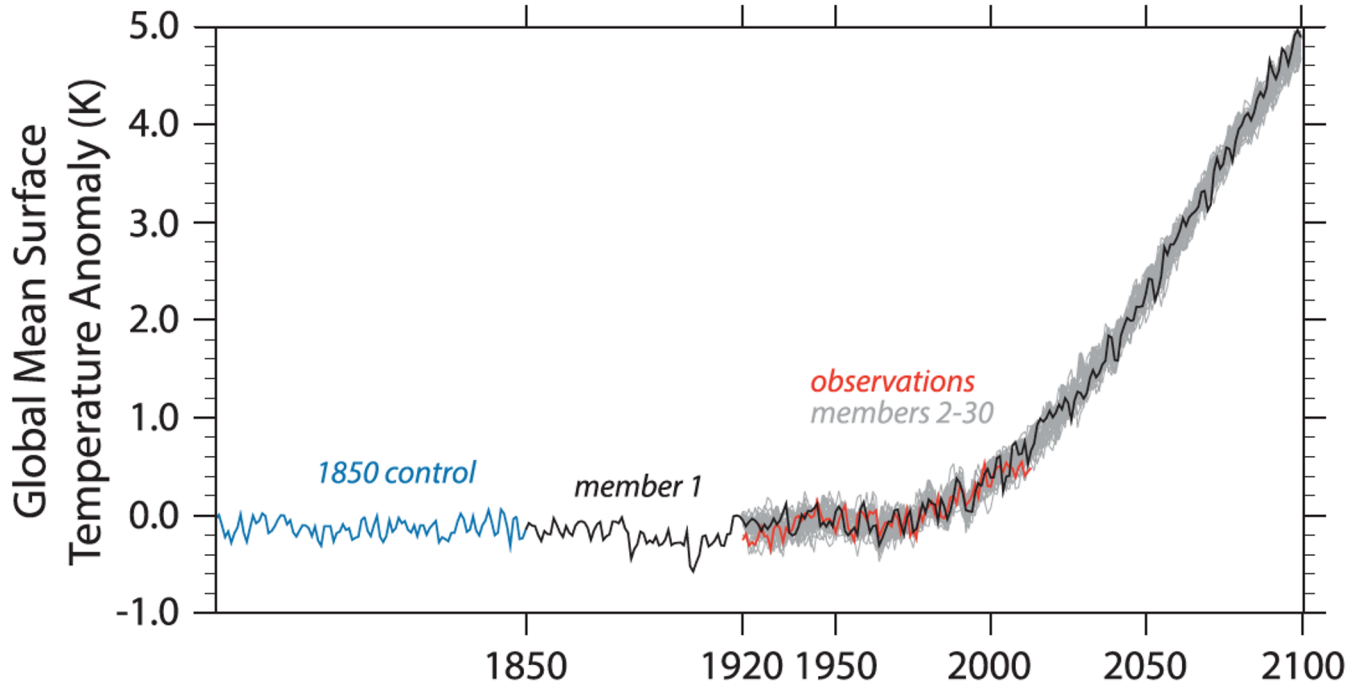
WACCM6 Large Ensemble

Purpose:

-> Large ensembles are critical for understanding the role of forced response vs unforced variability



Kay et al., BAMS, 2015

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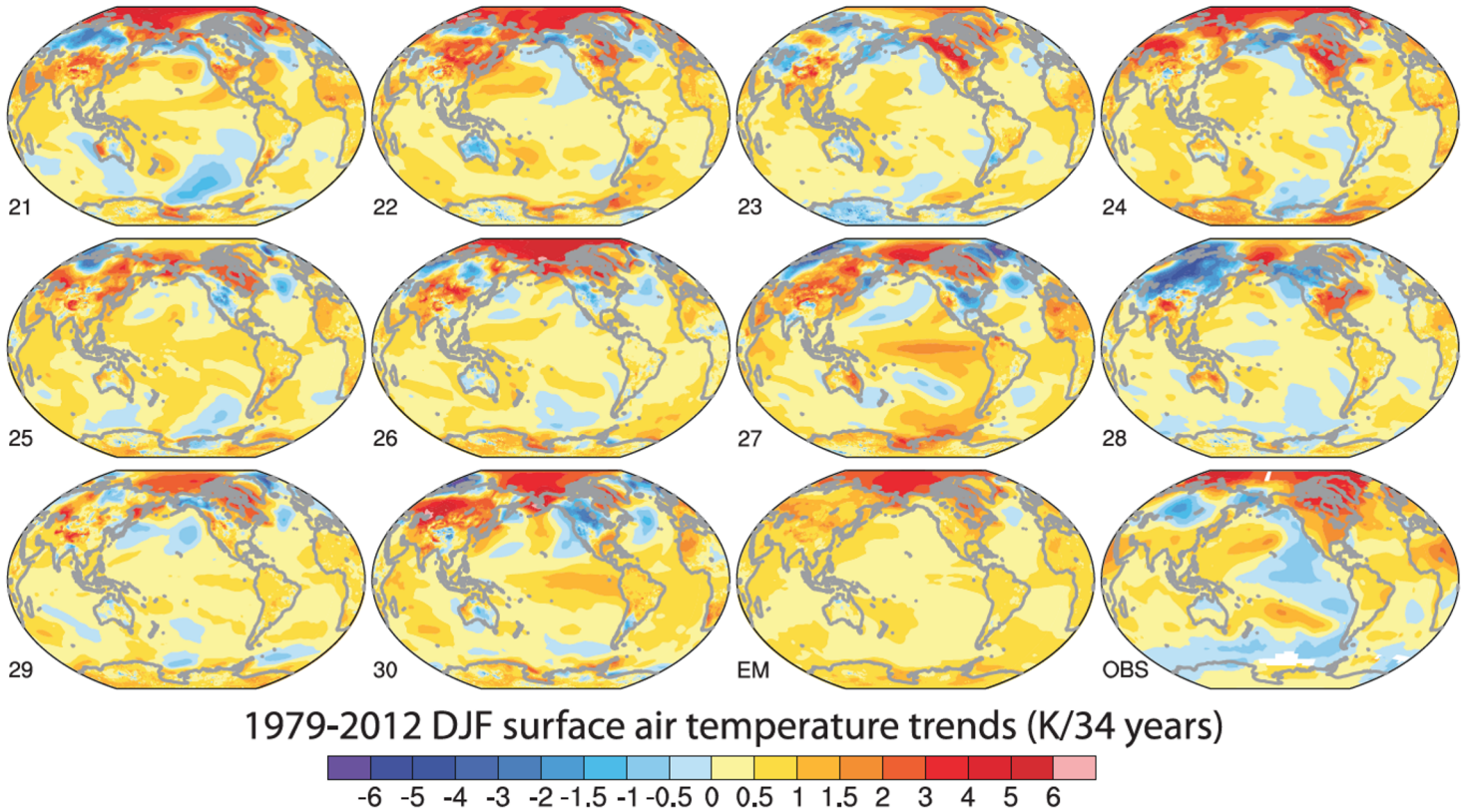

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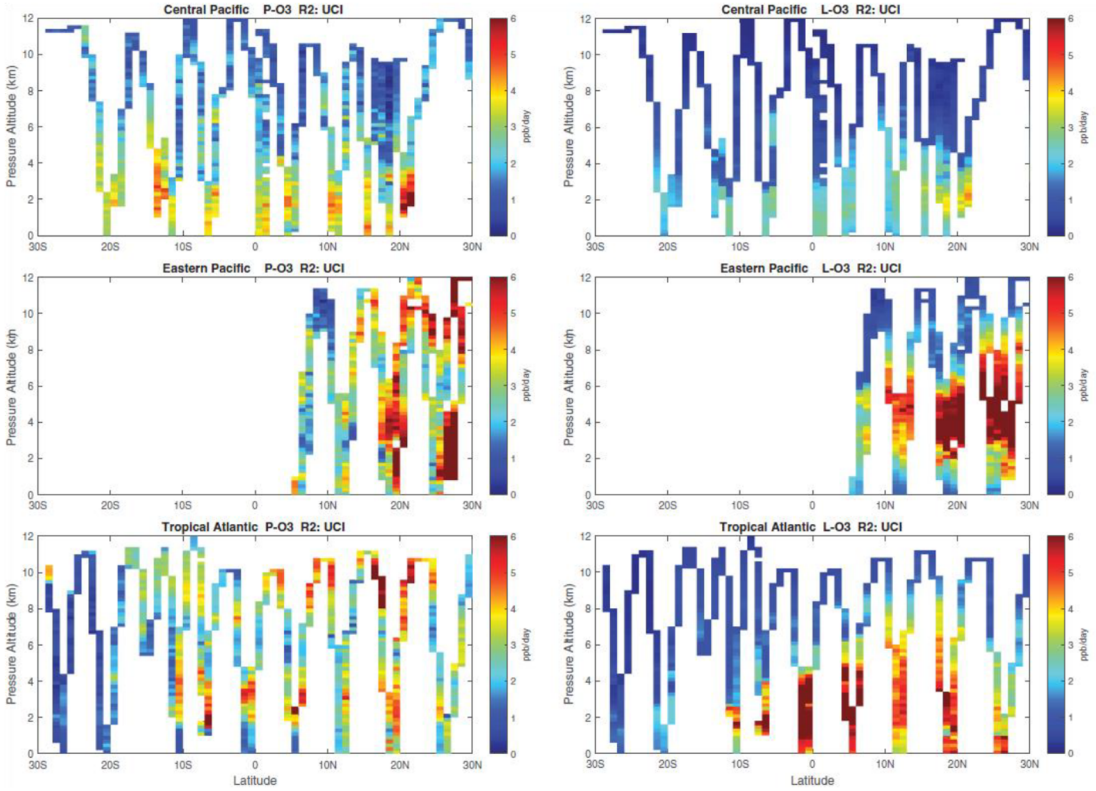
Atmospheric composition variability (ATom)



Hao et al., submitted to PNAS, 2021

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-> Protocol (in collaboration with Arlene Fiore, LDEO/Columbia):

- Full chemistry WACCM6 (1-degree, 70L, ~230 tracers)
- Fully-coupled CMIP6 historical version
- Focus on the recent 1950-2014 period
- Micro-macro initialization
- All forcings identical to CMIP6 historical, including emissions (anthro, bb, volcanoes, …)
- Targeting additional 15+ ensemble members to existing 3
- Runs are on-going

No Clean Air Act simulations

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-> Identify the composition and climate impacts of the US Clean Air Act

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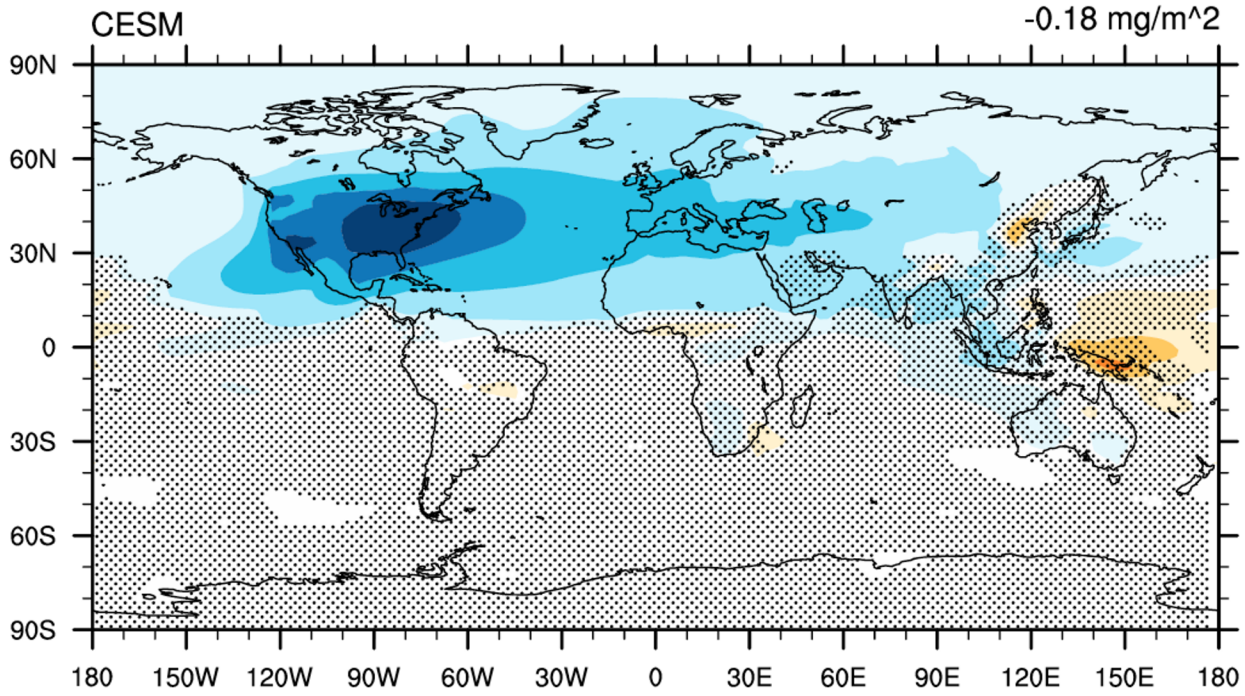

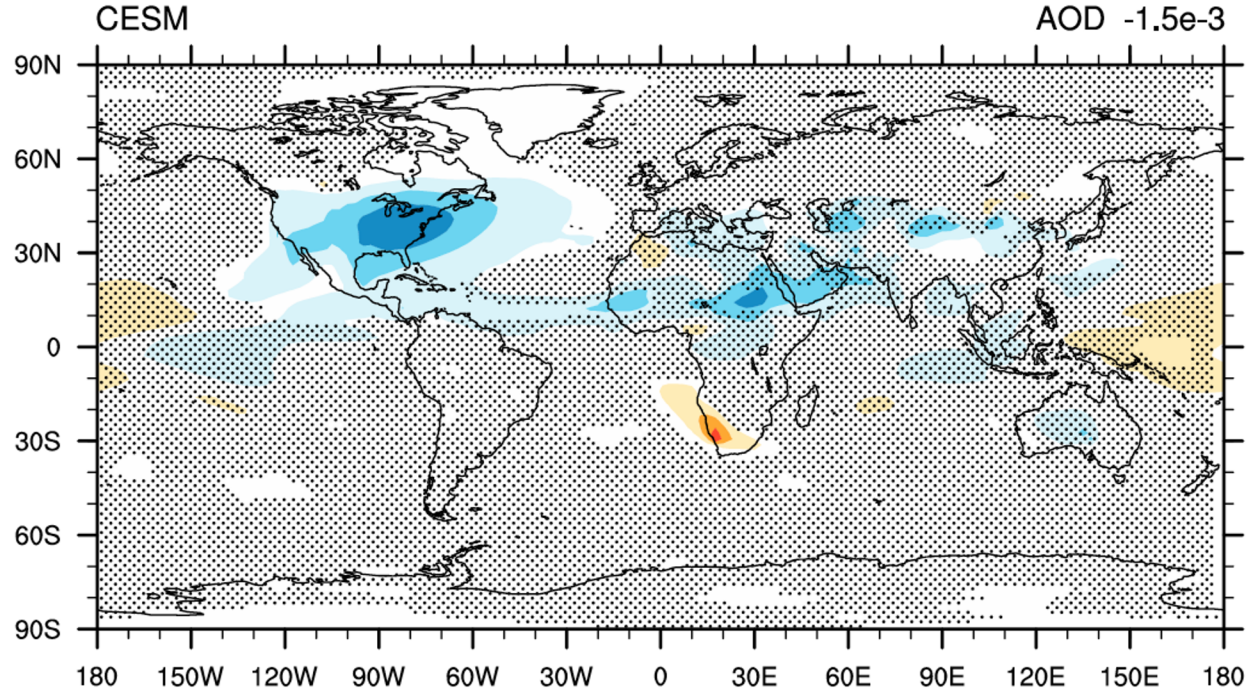

Conley et al., JGR, 2018

Impact of removing SO2 2000 emissions over the US

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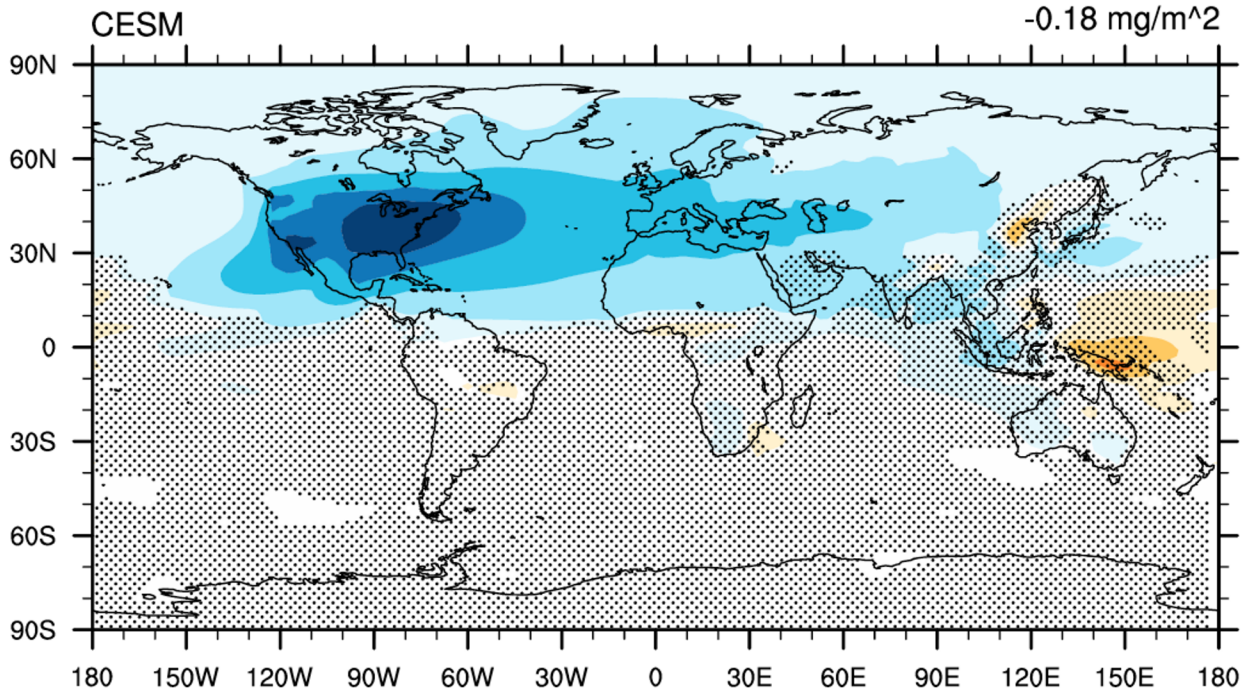

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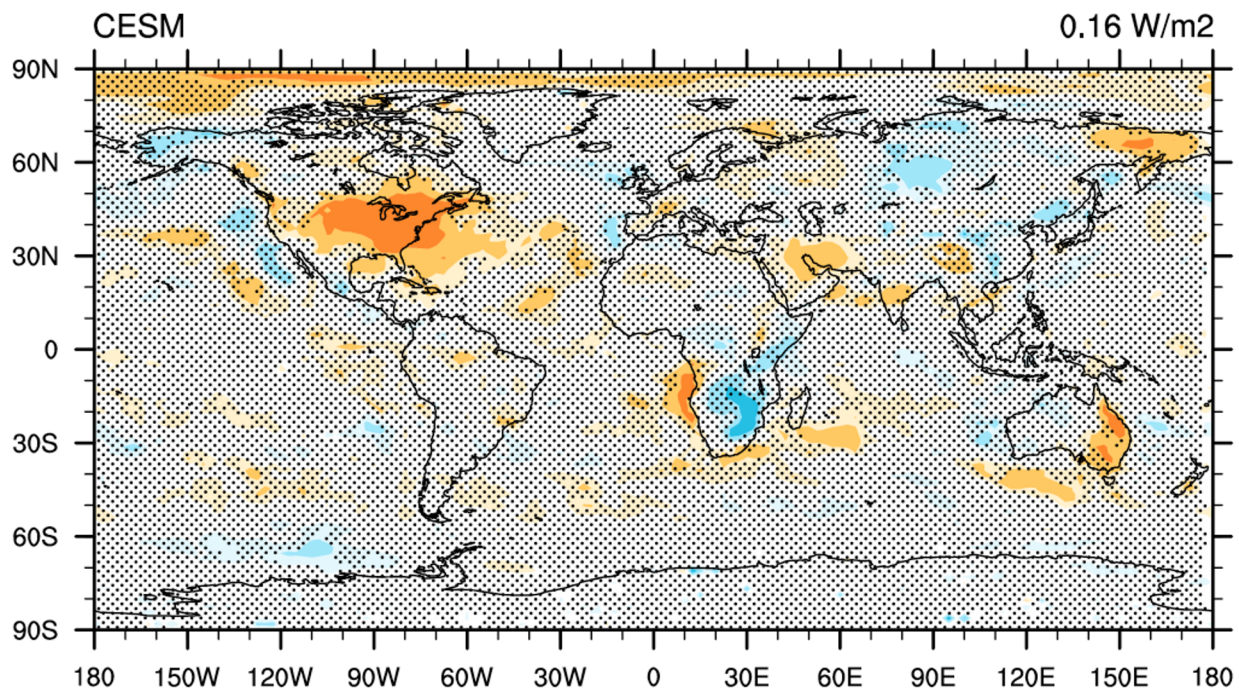

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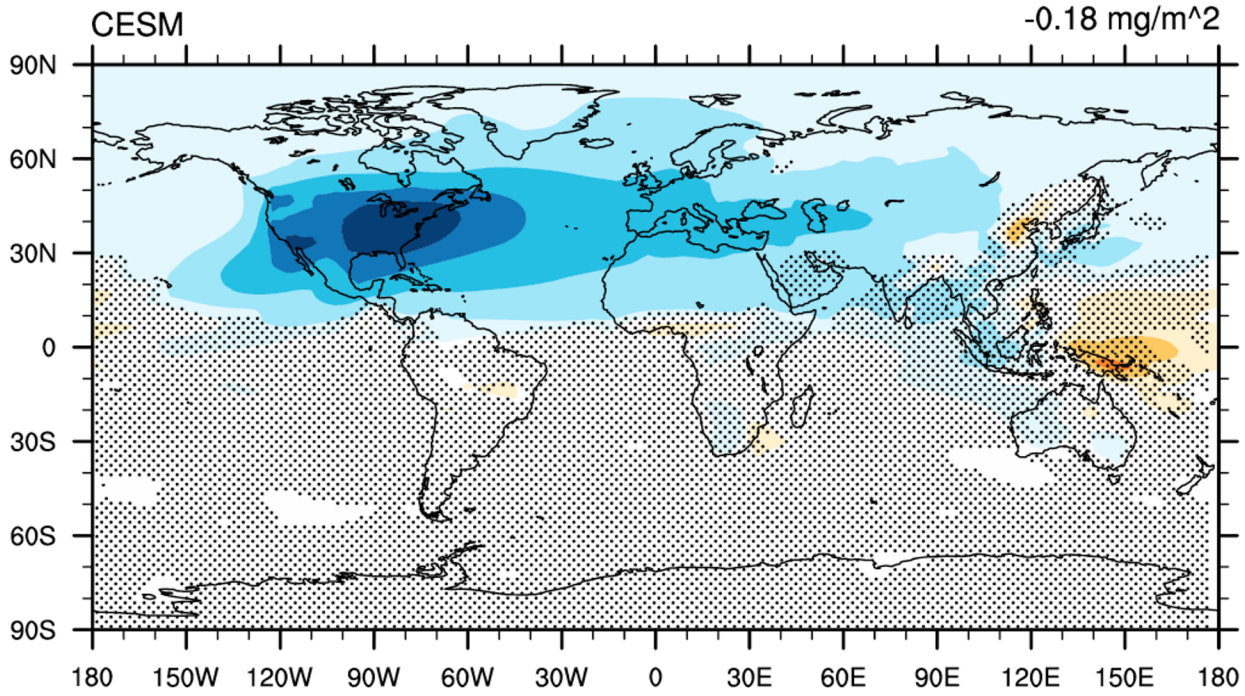

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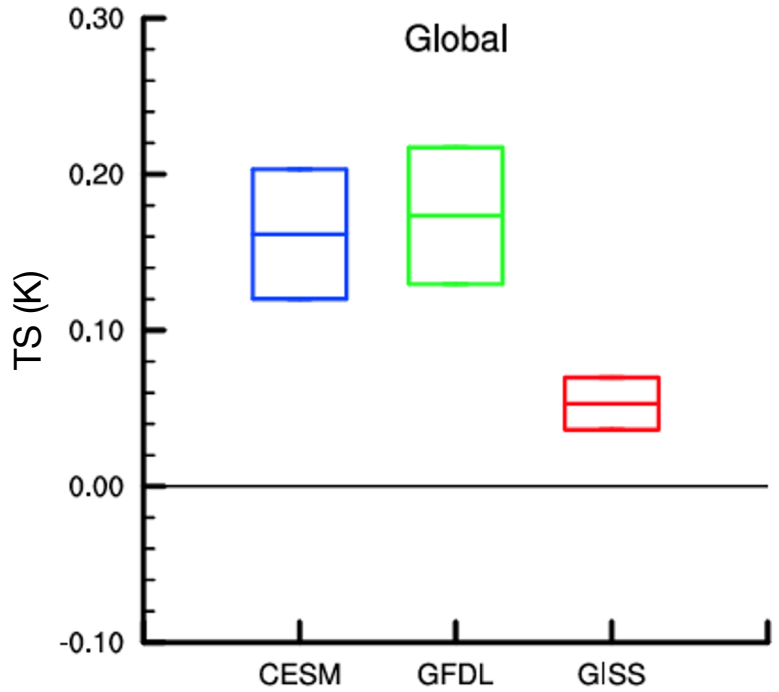

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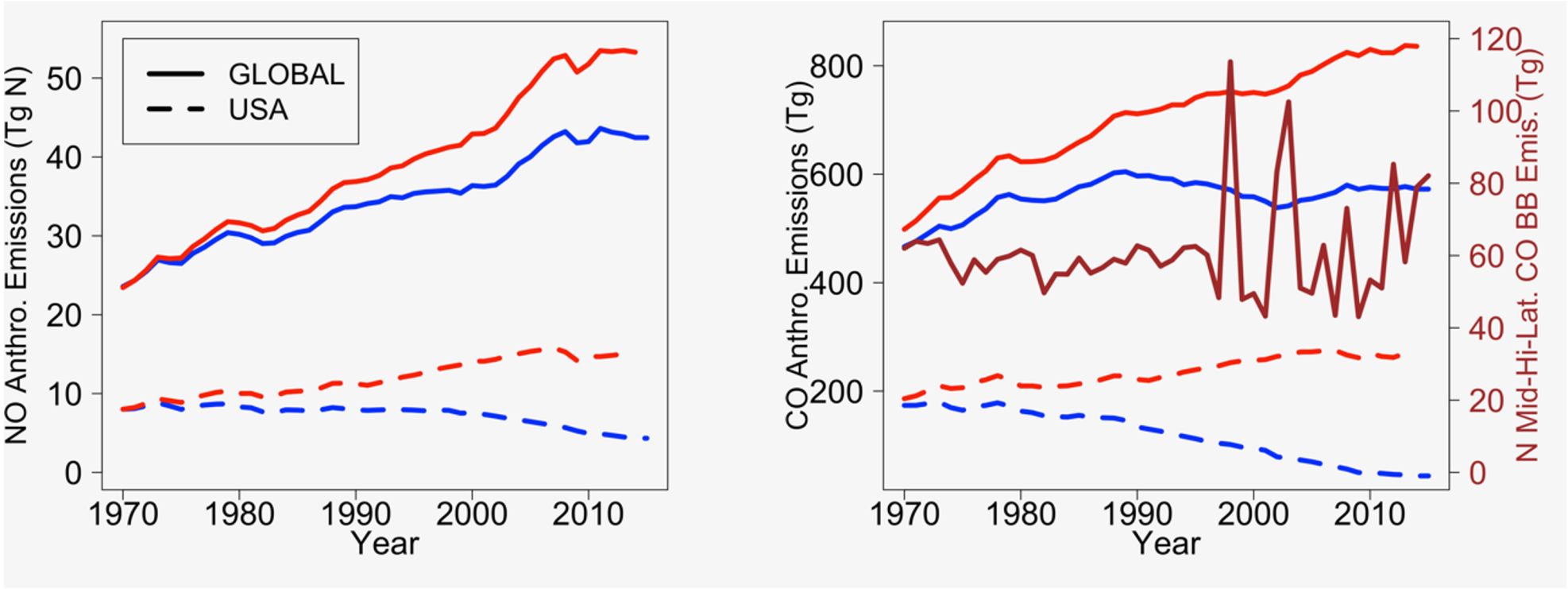
-> Use CEDS to create new dataset, consistent with CMIP6 (S. Smith, JGCRI)



Figures courtesy of A. Fiore

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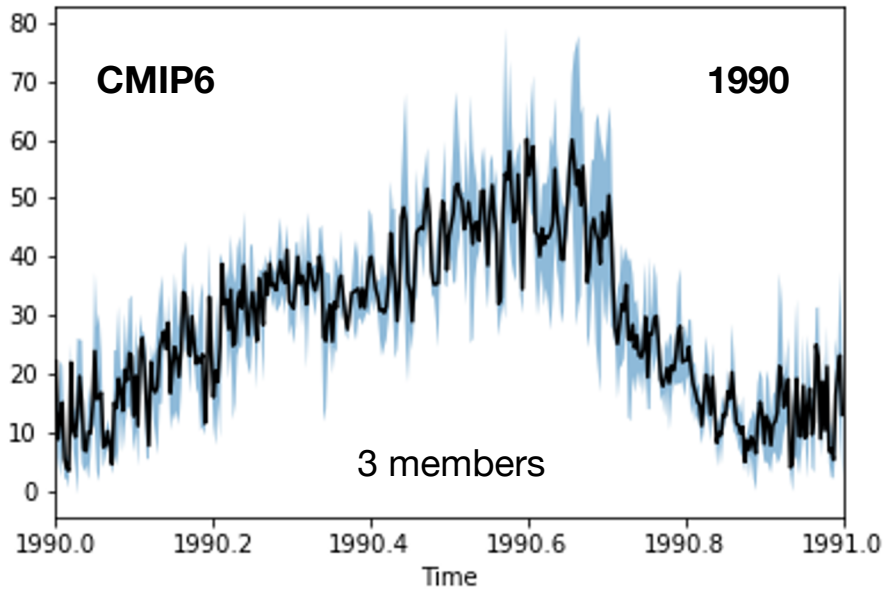

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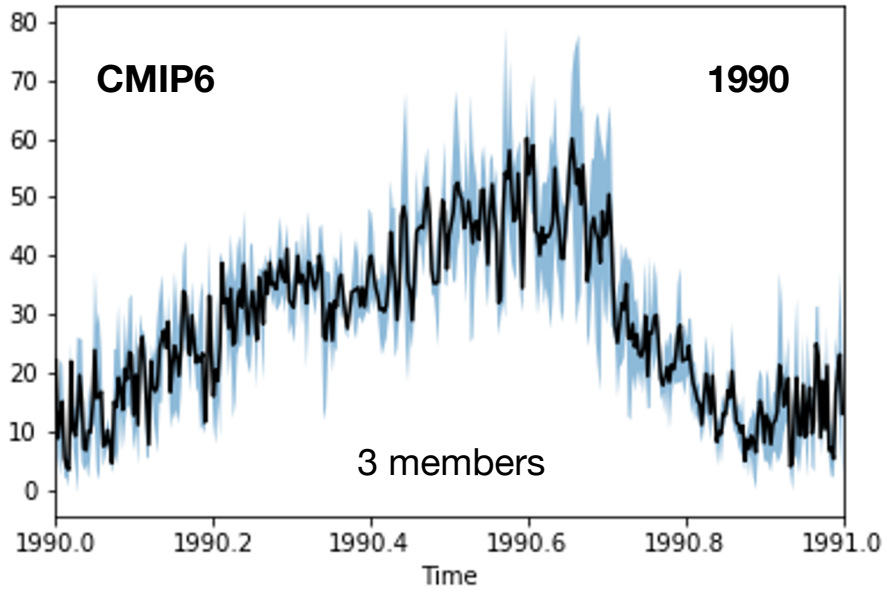

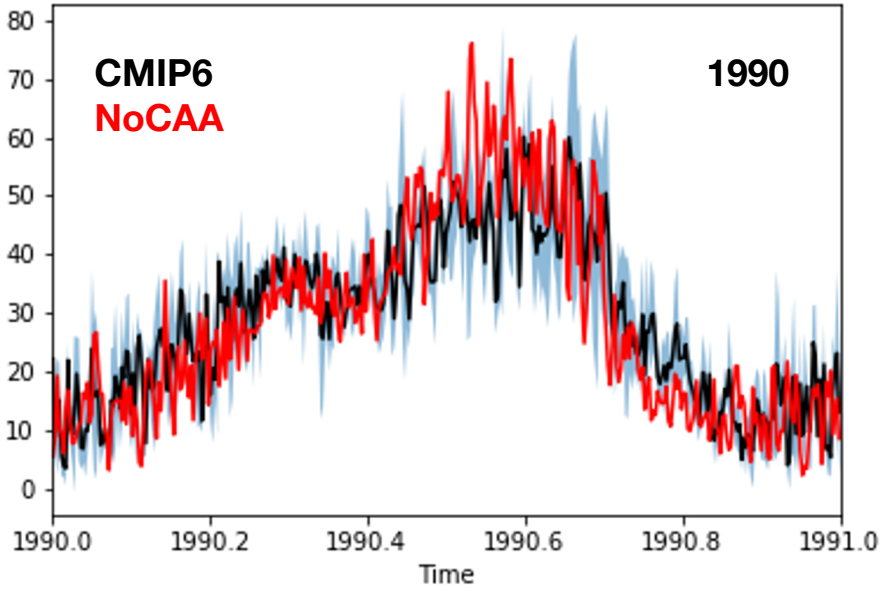

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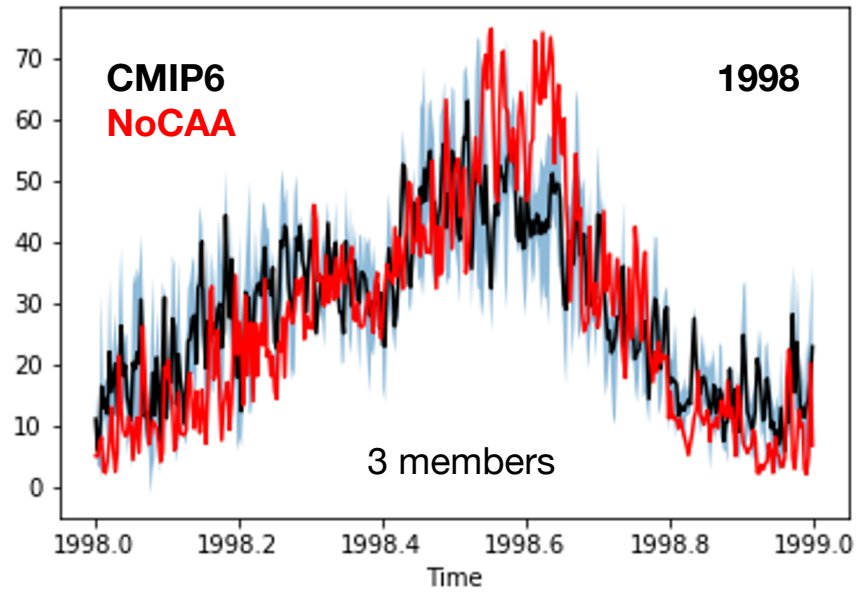

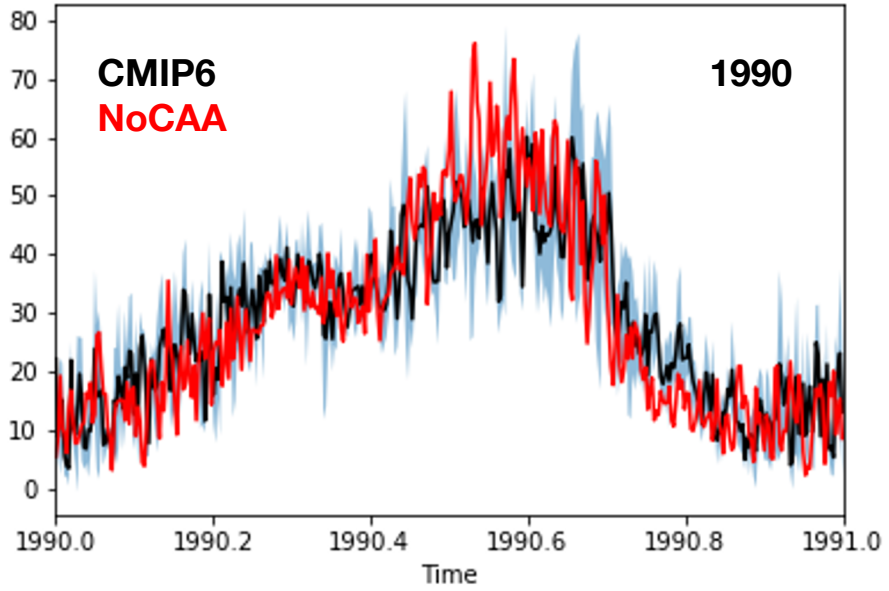

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-> NoCAA simulations will be (are?) performed by E3SM, GISS and GFDL

-> Analysis will include

- Health impacts (PM2.5 and ozone)
- Nitrogen/sulfur deposition
- Climate forcing and impacts
- ...

Partial conclusions (2)

- Designing and performing first large ensemble for in-depth chemistry analysis
- Will provide background information on observed long-term trends (deposition, ozone sondes, surface measurement, …)
- Ensemble large enough to look at extremes
- Will complement analysis from Emissions-MIP (led by Steve Smith)
- No-Clean Air Act complement simulations will provide a multi-model comprehensive look at the role of regional emissions on climate and composition

Thank you!