

The impact of future climate changes on stratospheric aerosols

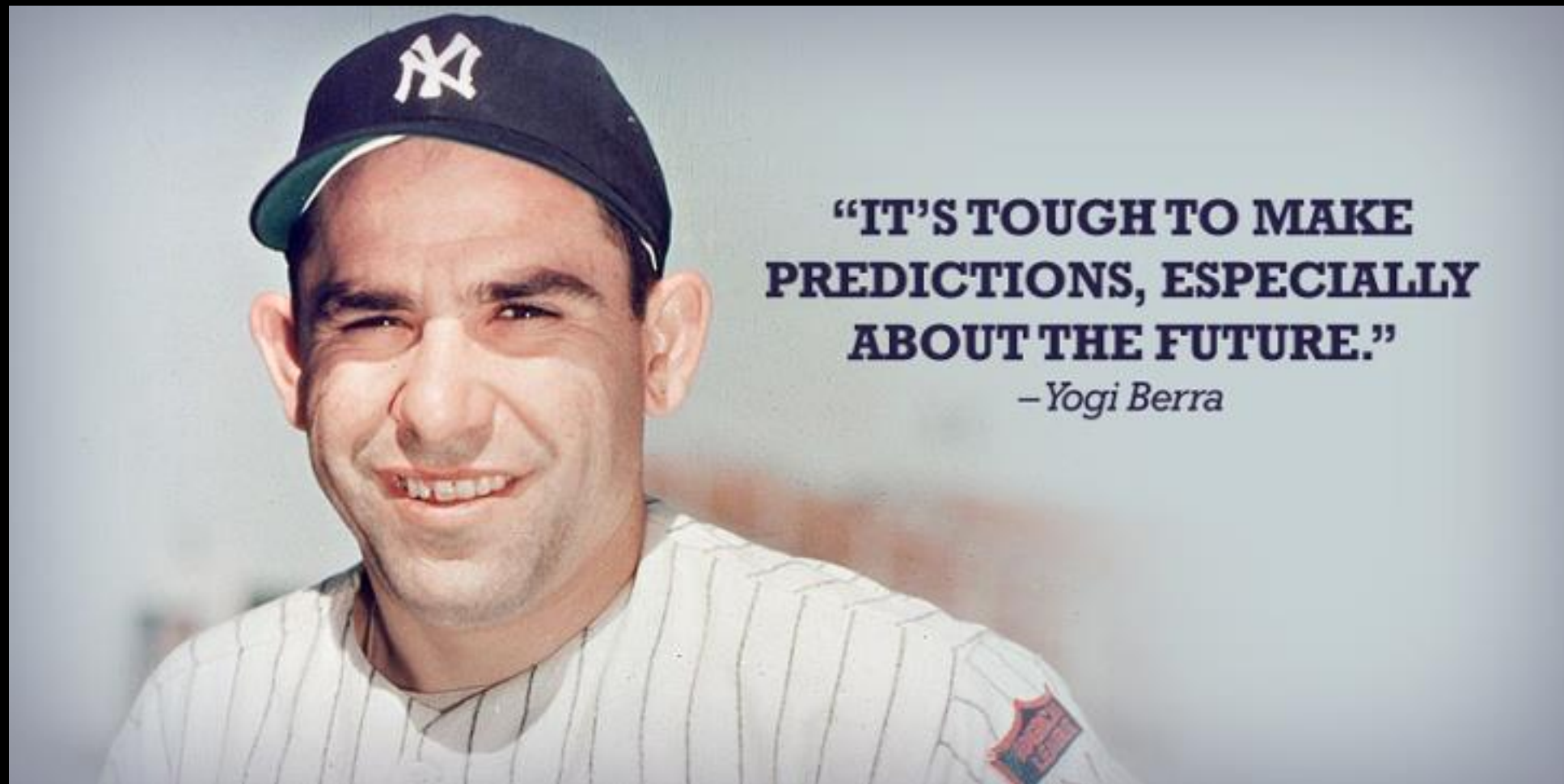
Owen Brian Toon

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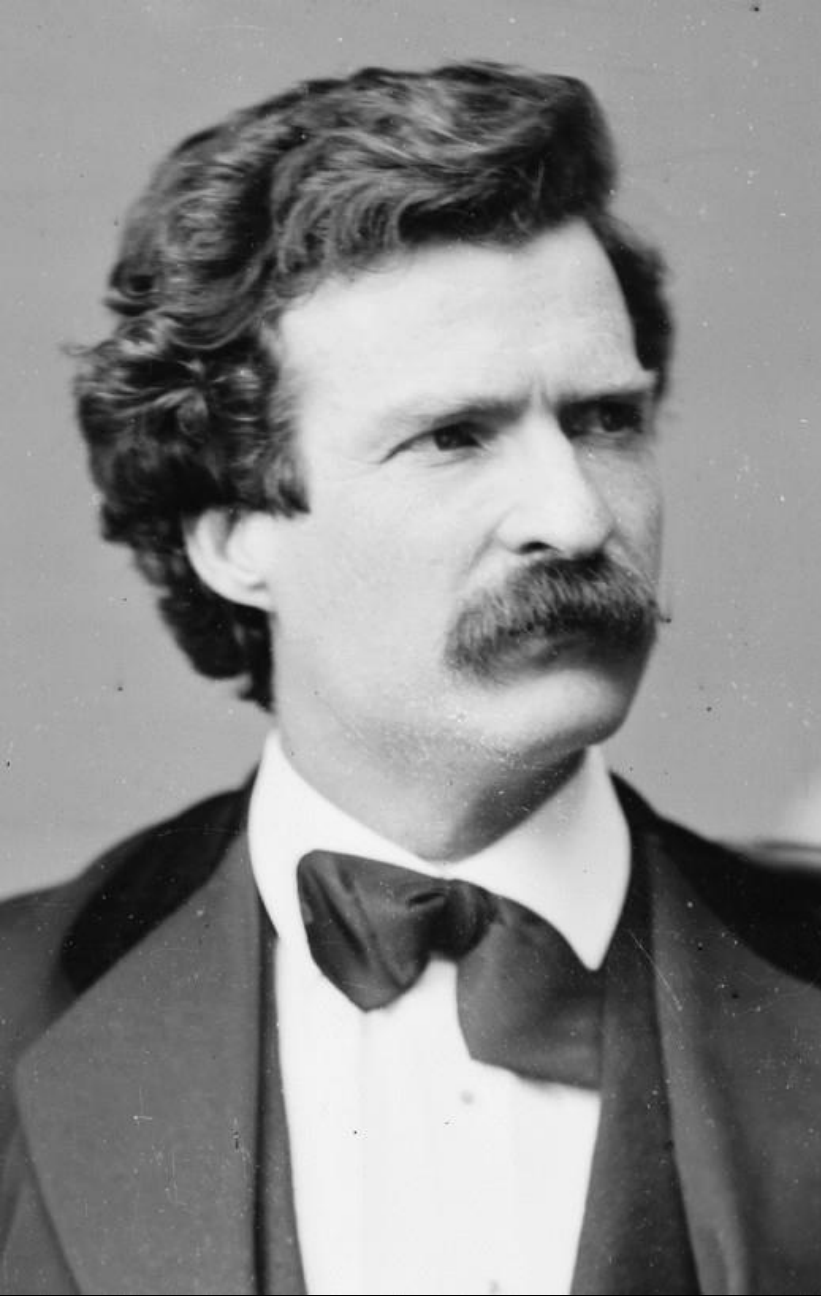
Good luck with that. I think you have the most difficult topic, since, well - what do we know about it? Terry





**“IT’S TOUGH TO MAKE
PREDICTIONS, ESPECIALLY
ABOUT THE FUTURE.”**

—Yogi Berra



...the Lower Mississippi has shortened itself ... an average of a trifle over one mile and a third per year. Therefore, any calm person, who is not blind or idiotic, can see that in the Old Oolitic Silurian Period, just a million years ago next November, the Lower Mississippi River was upwards of one million three hundred thousand miles long, and stuck out over the Gulf of Mexico like a fishing-rod. And by the same token any person can see that seven hundred and forty-two years from now the Lower Mississippi will be only a mile and three-quarters long...There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of fact.

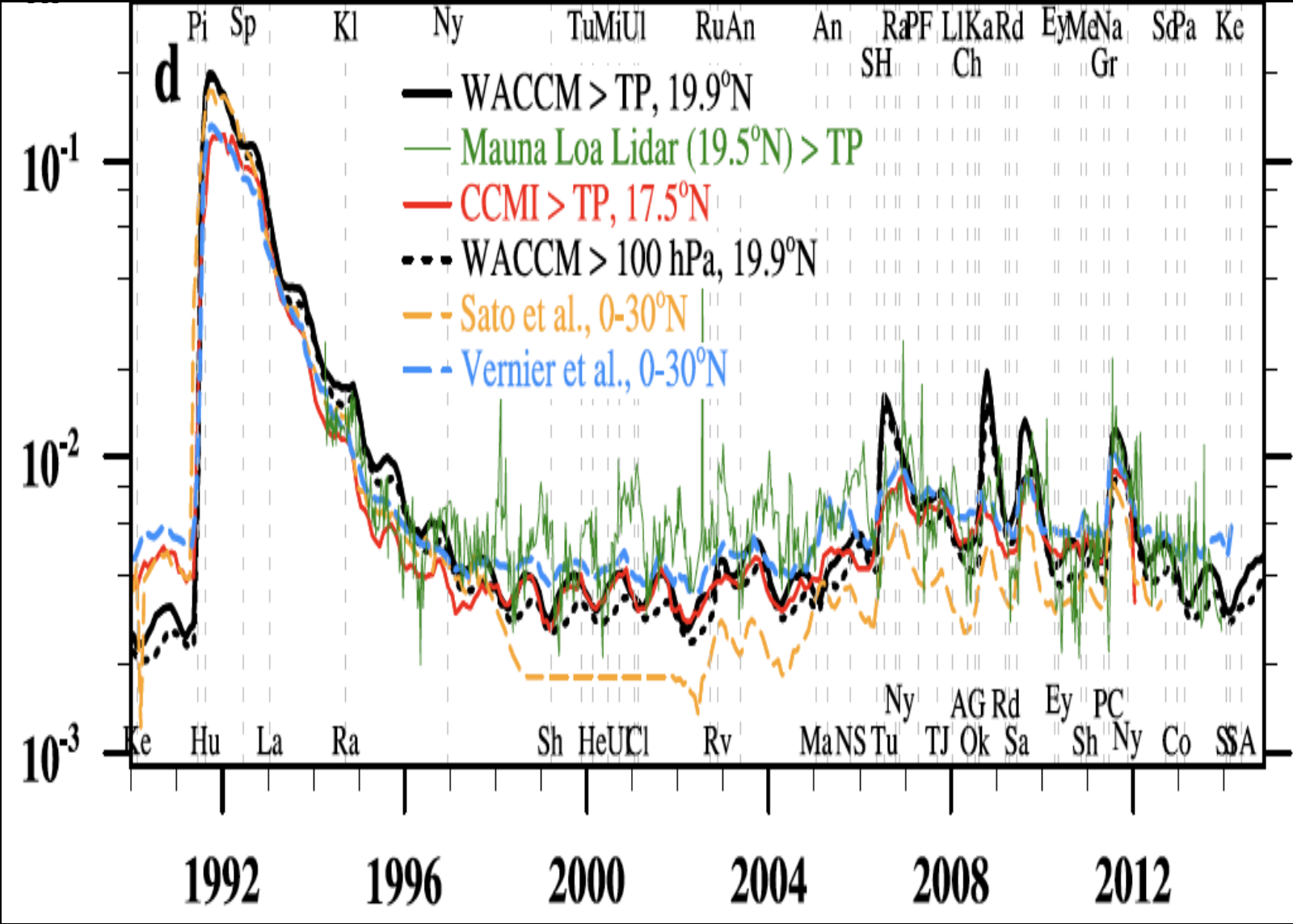
- *Life on the Mississippi*

Data say “background” stratospheric aerosols haven’t changed in the past 30 yrs



Dave Hofmann

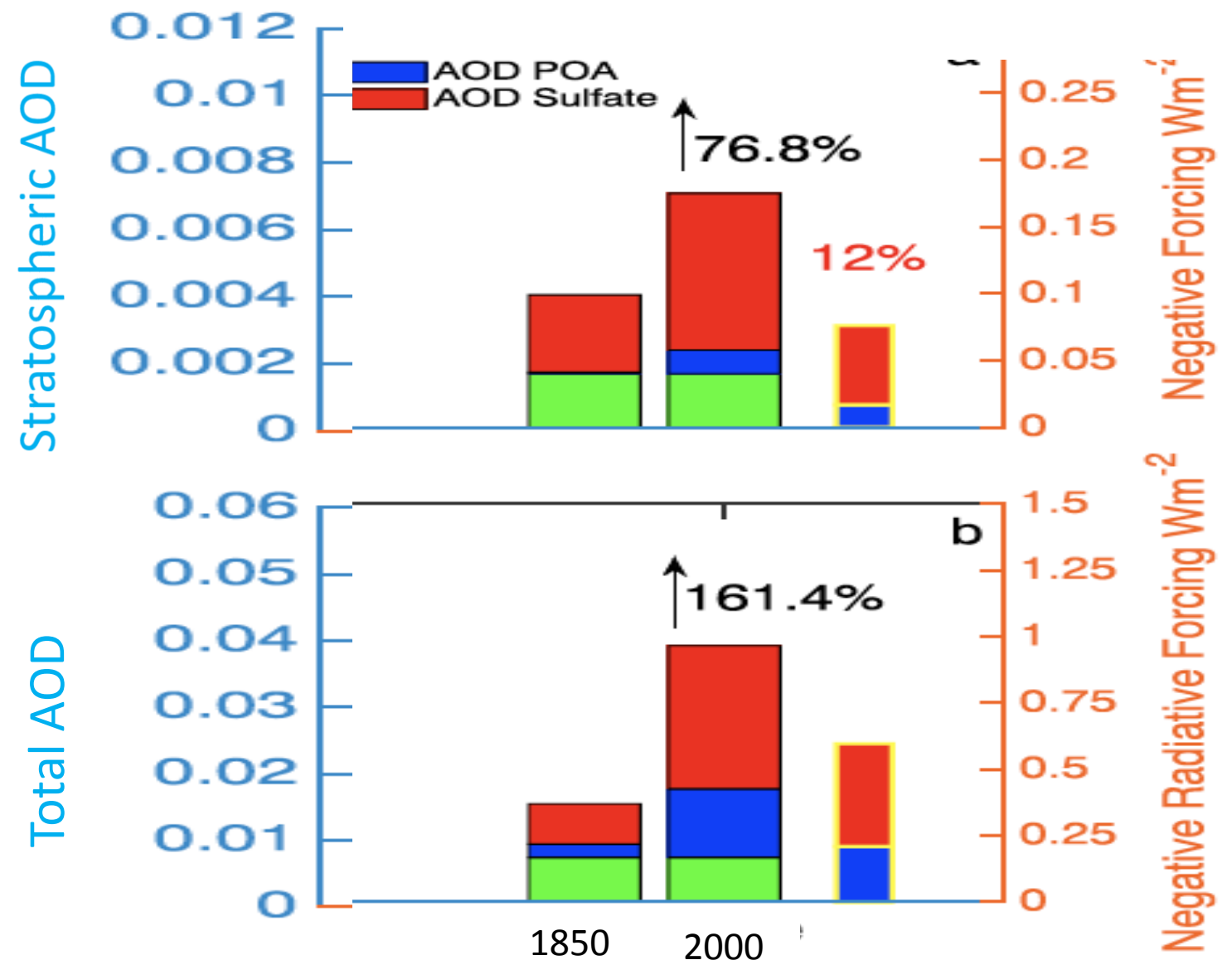
Aerosol Optical Depth, visible



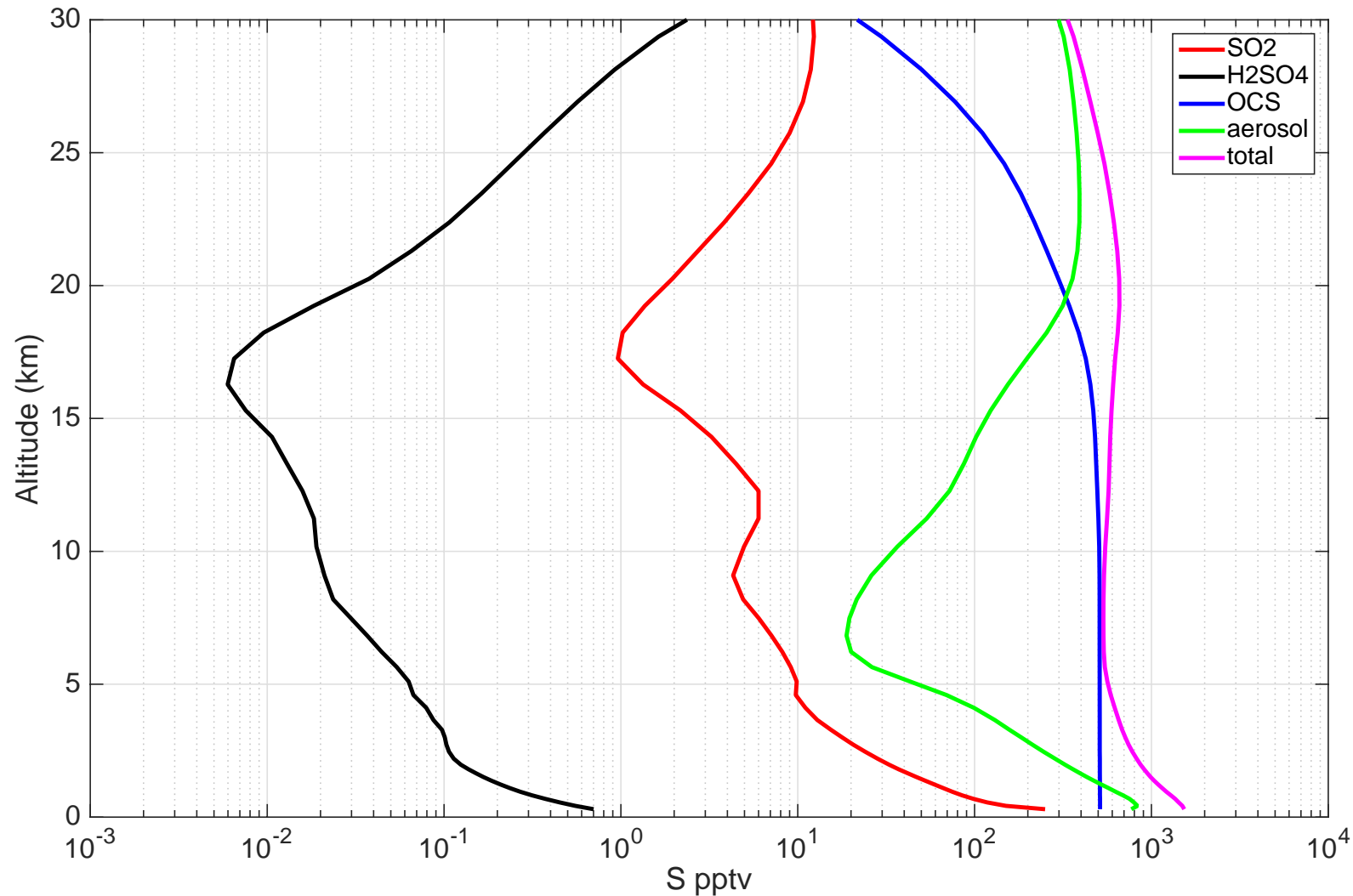
Models say “background” stratospheric aerosols changed in the past 150 years



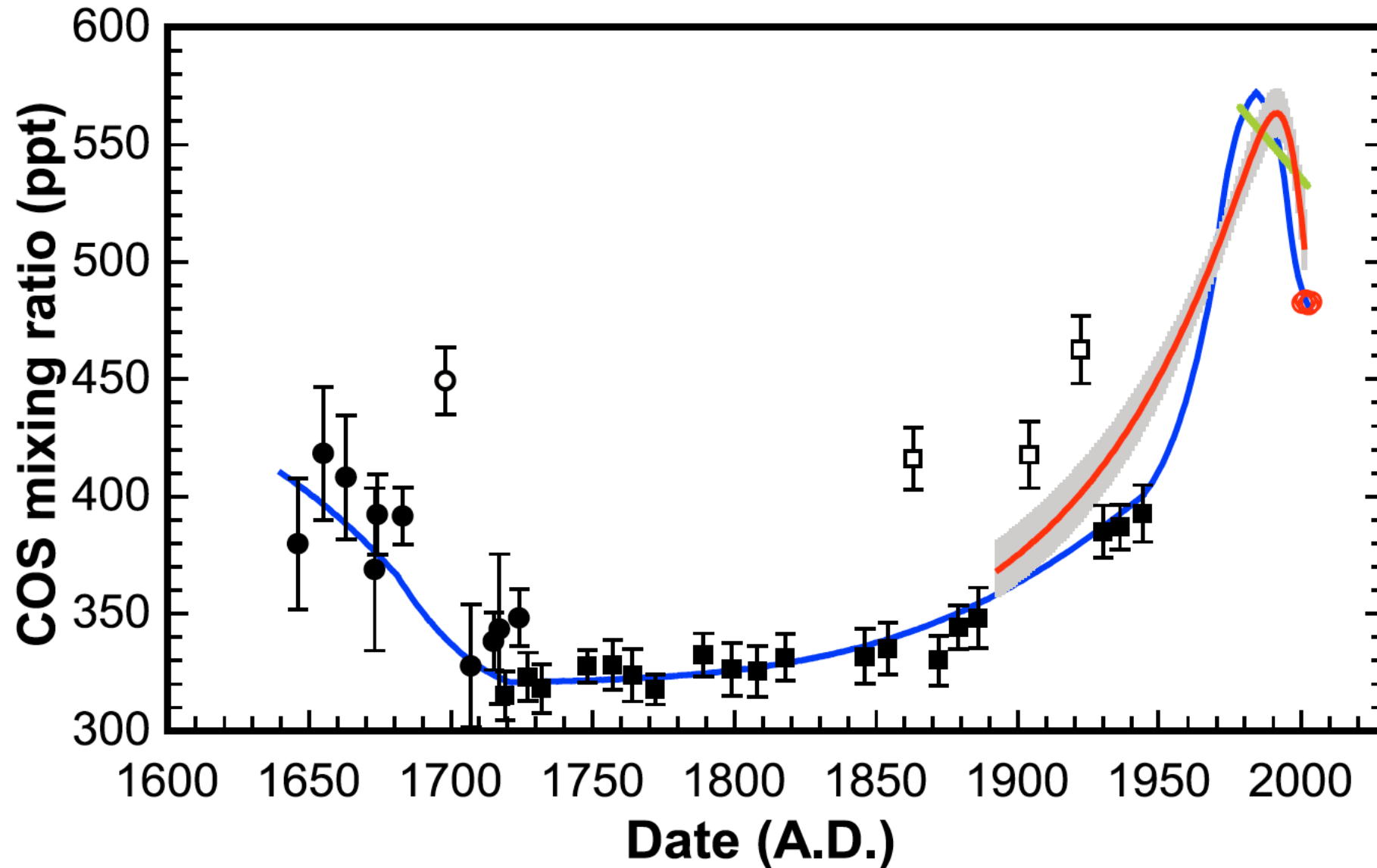
Pengfei Yu



The stratospheric aerosol budget is controlled by COS and tropospheric aerosols, not SO₂

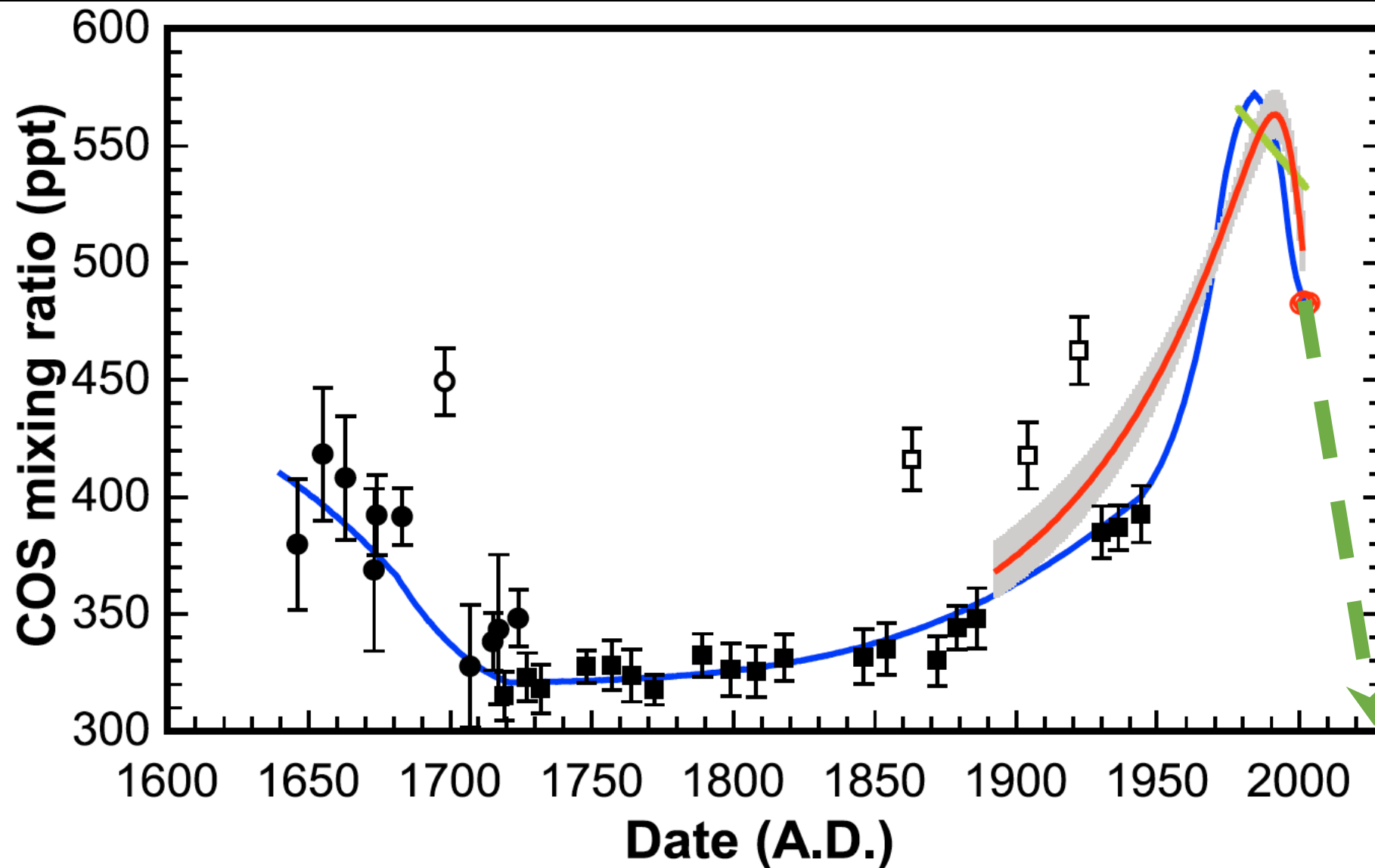


COS variations show exciting trends



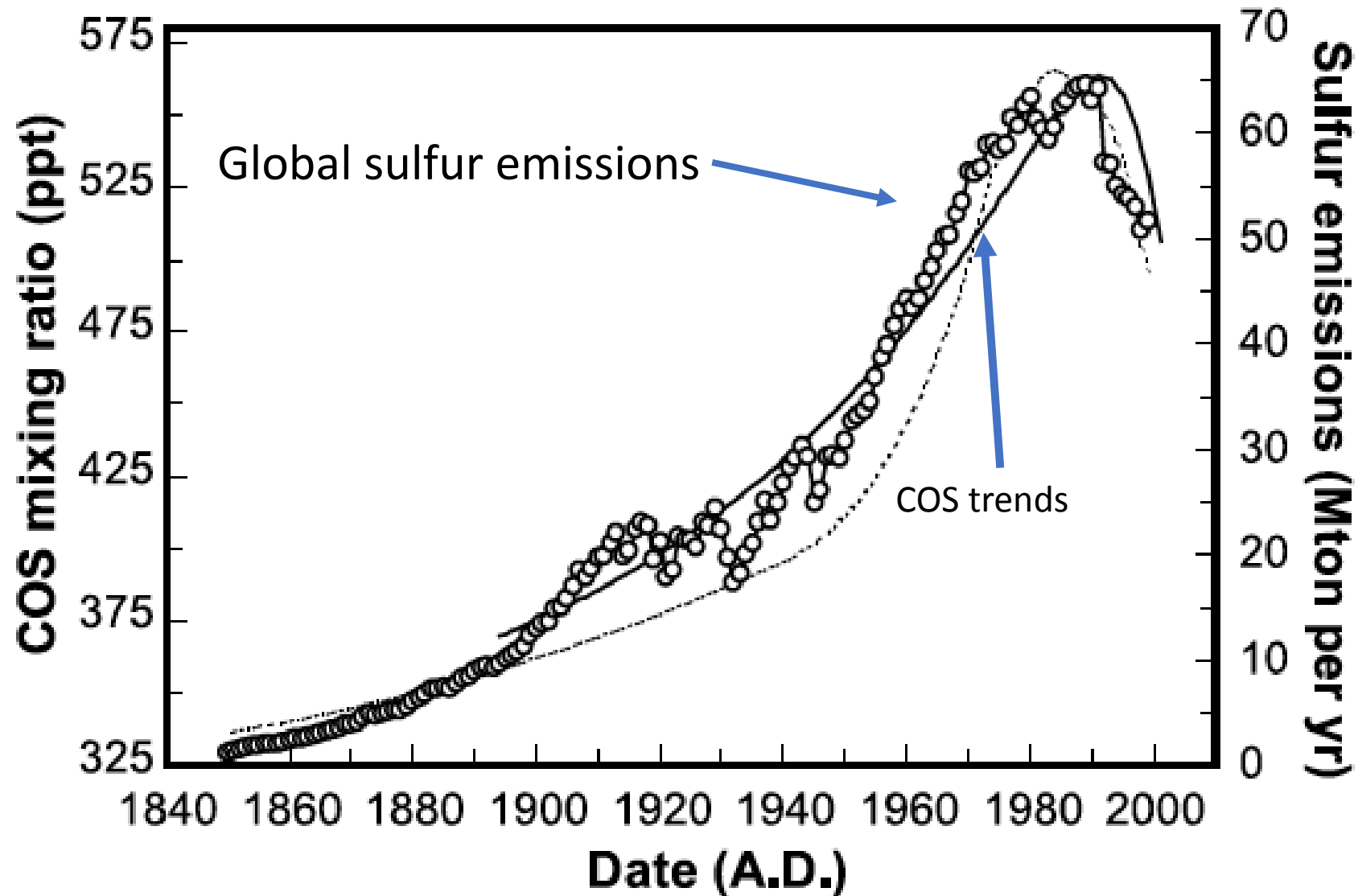
Montzka, et al., JGR,
109 2004

COS variations show exciting trends



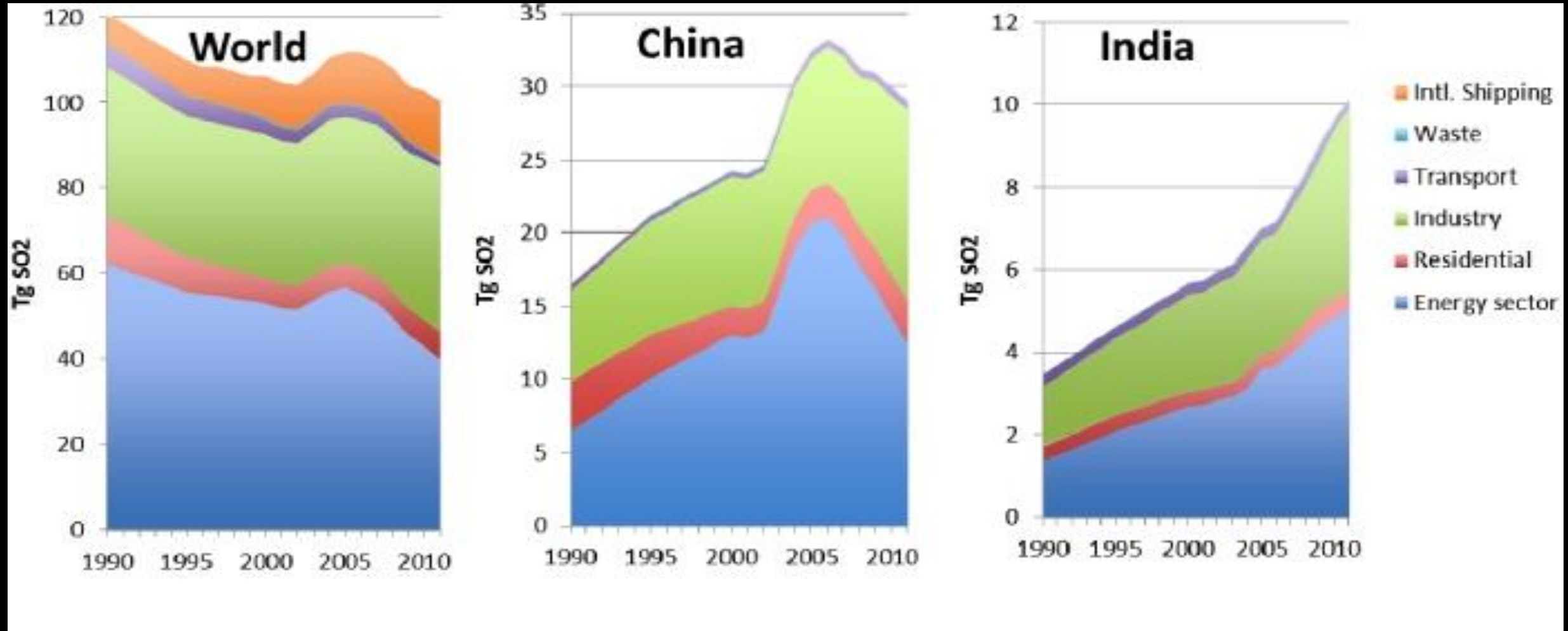
Montzka, et al., JGR,
109 2004

COS budget is not closed. We do not know if sources are falling or sinks are rising. However, COS may track S emissions

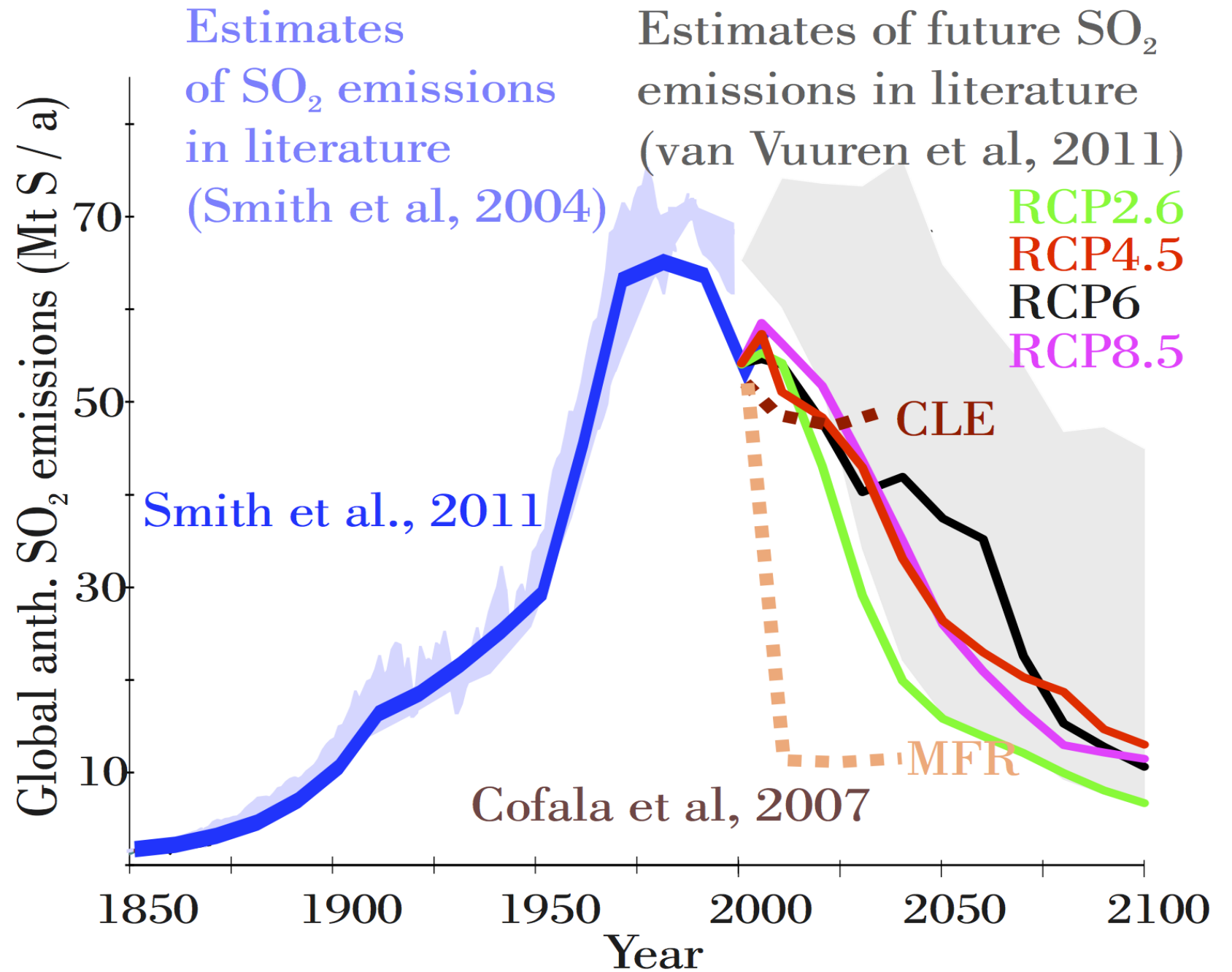


Montzka, et al., JGR,
109 2004

Sulfur emissions are dropping globally



Sulfur emissions decline after 2010



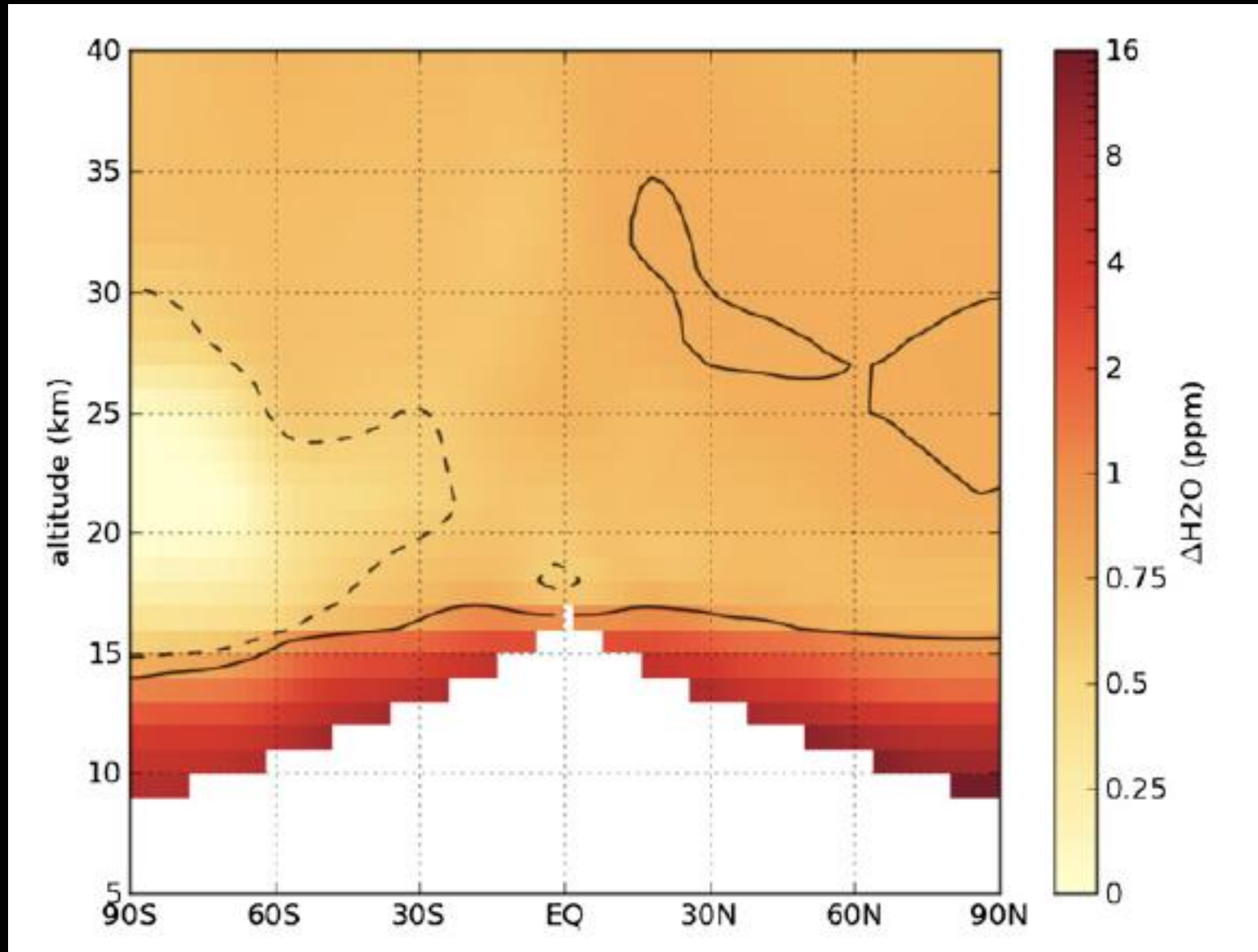
The Garden of Eden scenario for background stratospheric aerosols



SO₂ and COS return to preindustrial levels.

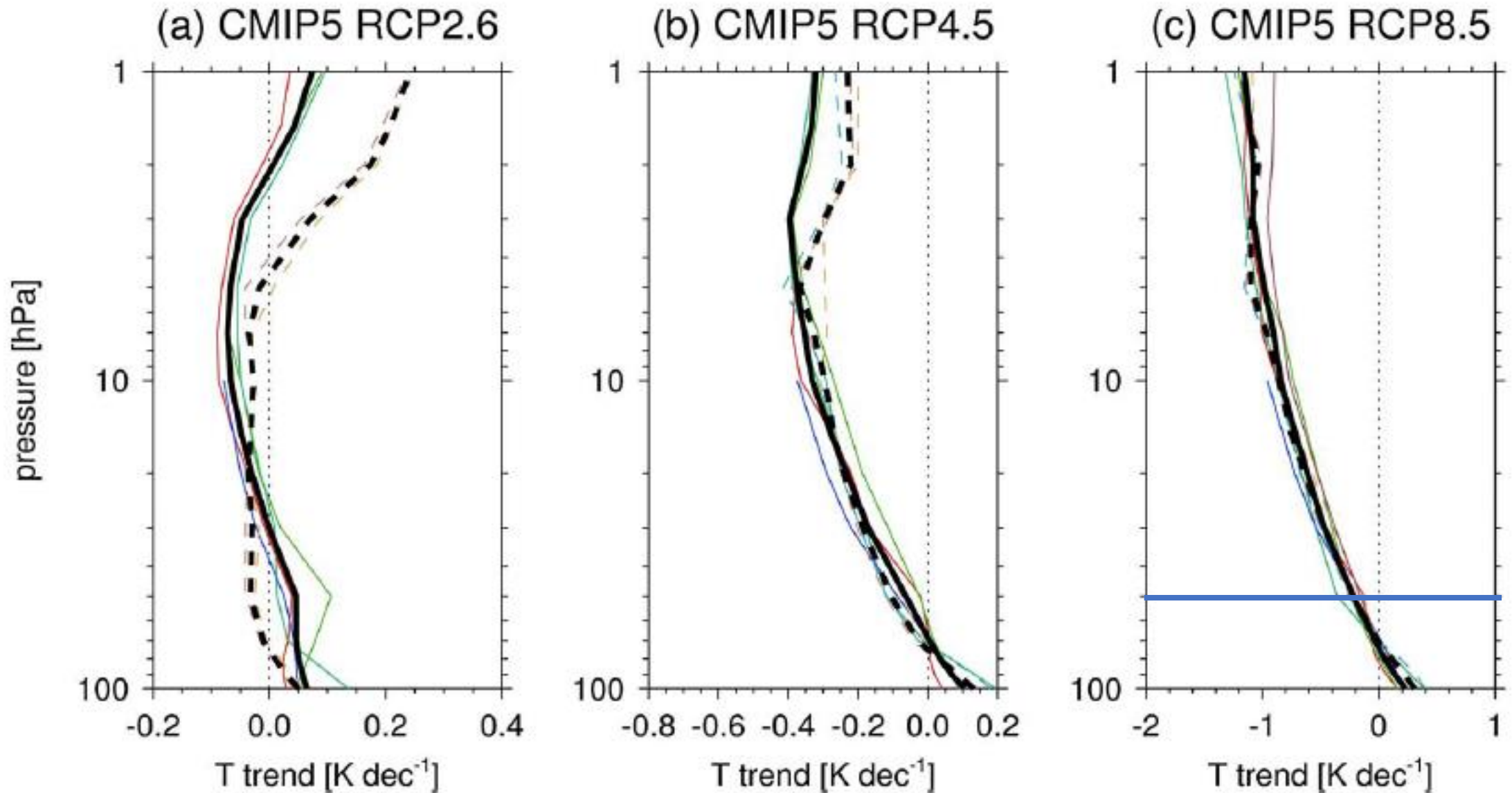
Stratospheric AOD falls by ~ 0.03 (40%), radiative forcing of $+0.075 \text{ Wm}^{-2}$ occurs.

Changes in stratospheric-H₂O: up 0.2-1ppmv in 21st century



A. Dessler et al., PNAS, 110, 18087, 2013

21st century changes in stratospheric T small CO_2 \downarrow O_3 \uparrow

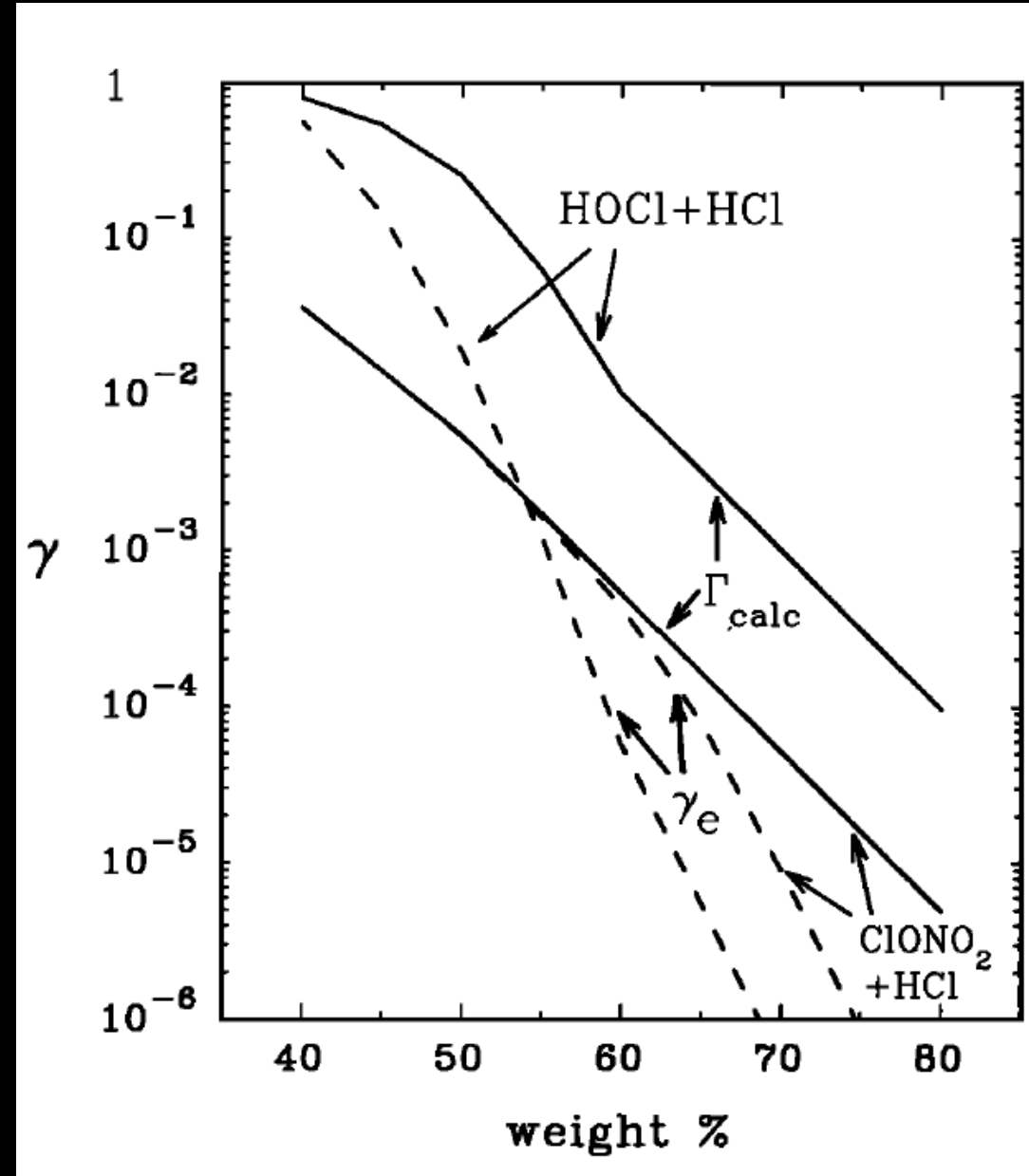


21st century changes T ($\leq 2\text{K}$), water ($< 1\text{ppm}$) will:

- *Lower sulfuric acid concentration about 2%
-size increase probably not observable against changes in source gases

- *Increase reactivity of aerosols, might double reaction rates

Hanson et al., JGR, 99,3615,1994



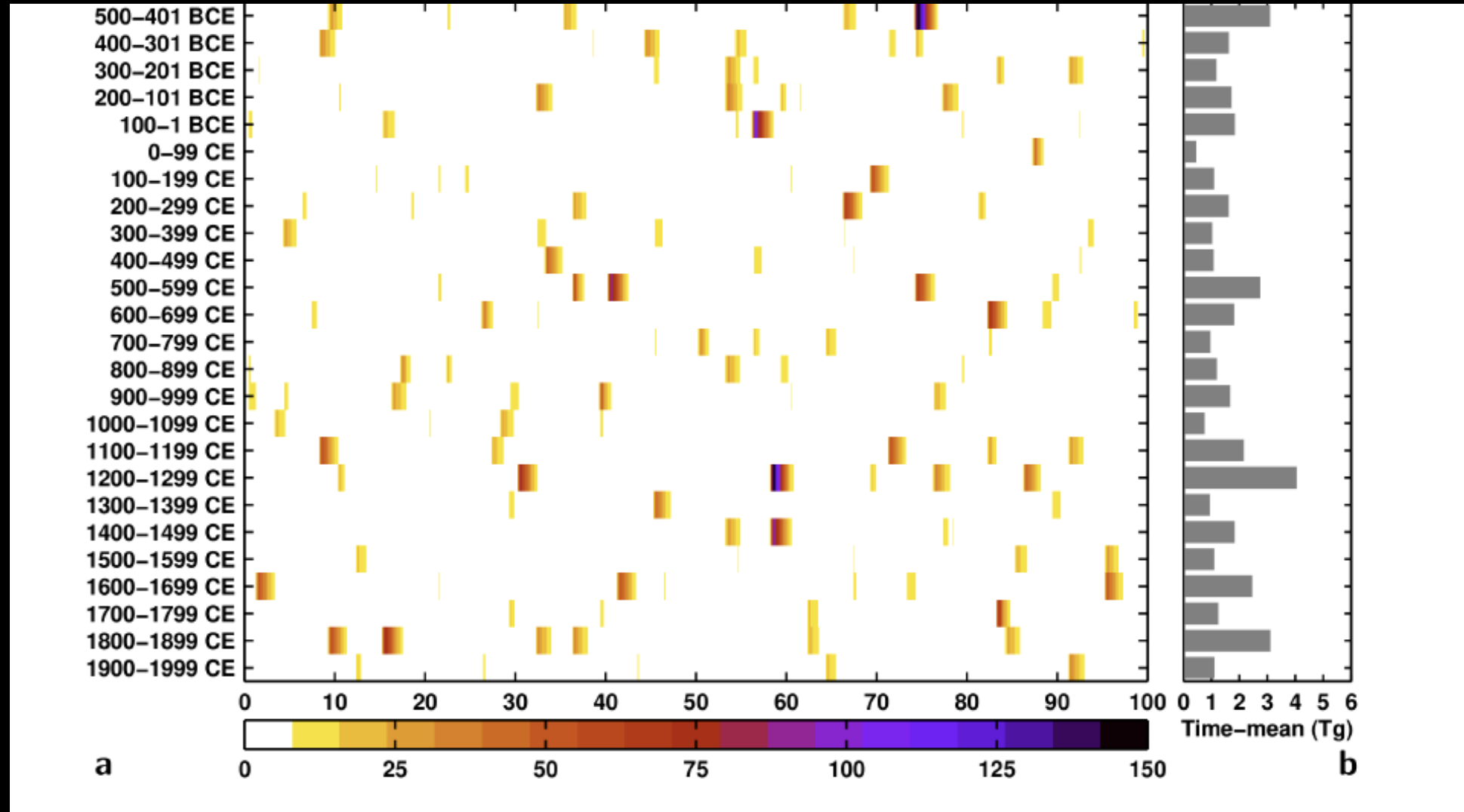
Probability of volcanic forcing $> 1 \text{ W/m}^2$ rises above 3%/yr



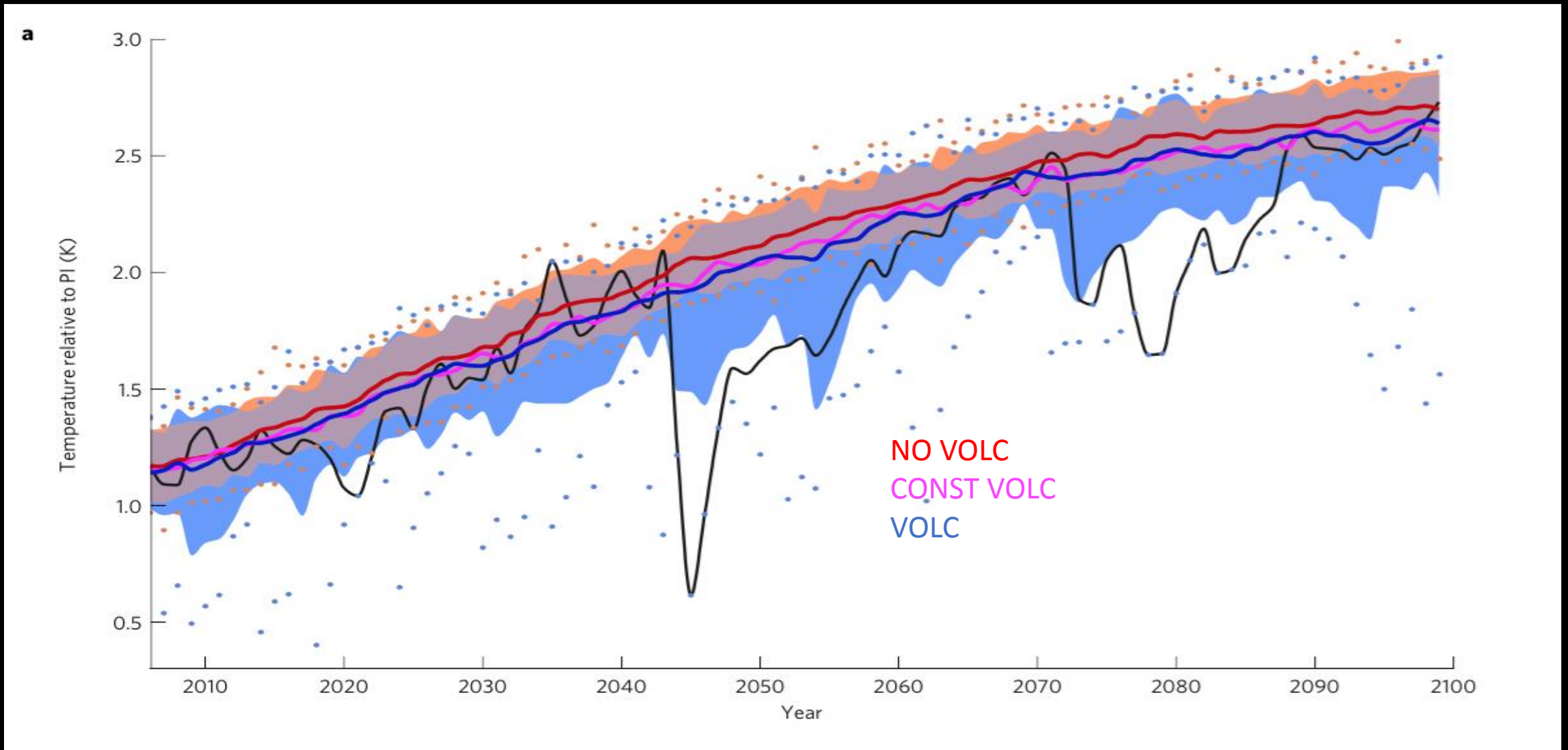
ERTA ALE - GATEWAY TO HELL
REPENT, ALL YE CROOKED POLITICIANS,
OR BURN IN HELL

Yusuf Khashim
© 2014

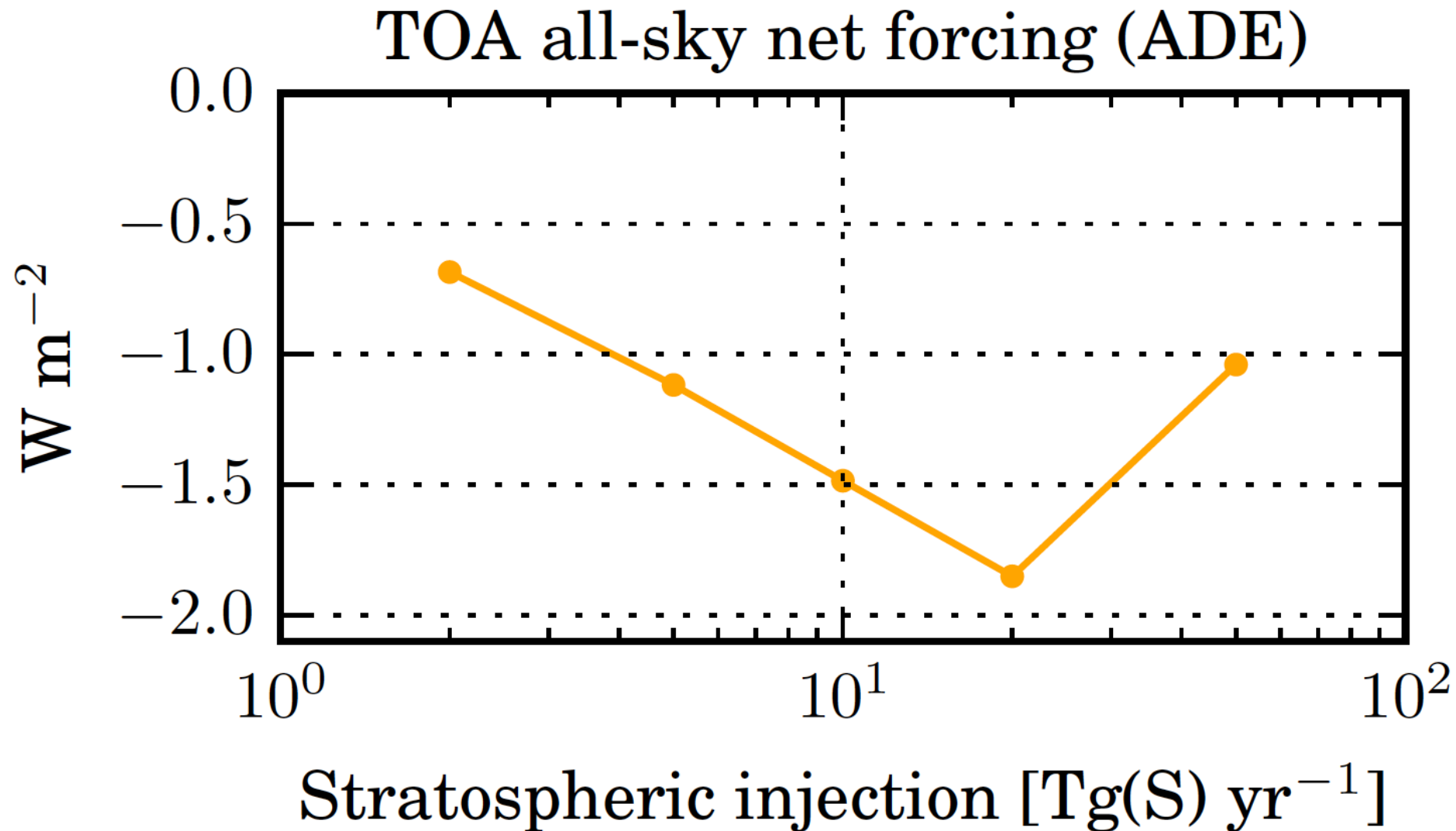
Volcanic eruptions will impact the next century, the 20th century may have been relatively benign



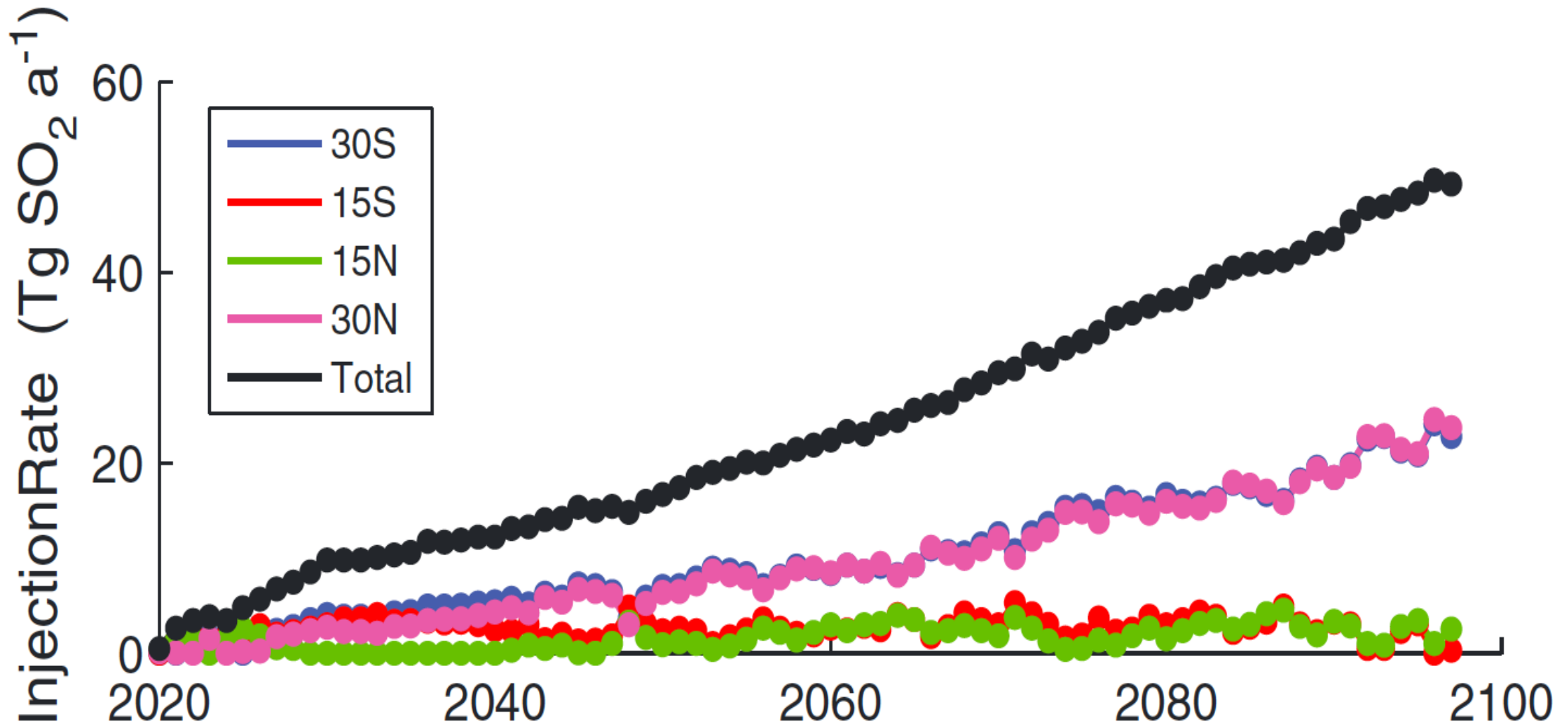
Future temperature anomalies depend on how volcanic forcings occur



Geoengineering modifies stratospheric aerosol, but efficacy declines with increasing injection



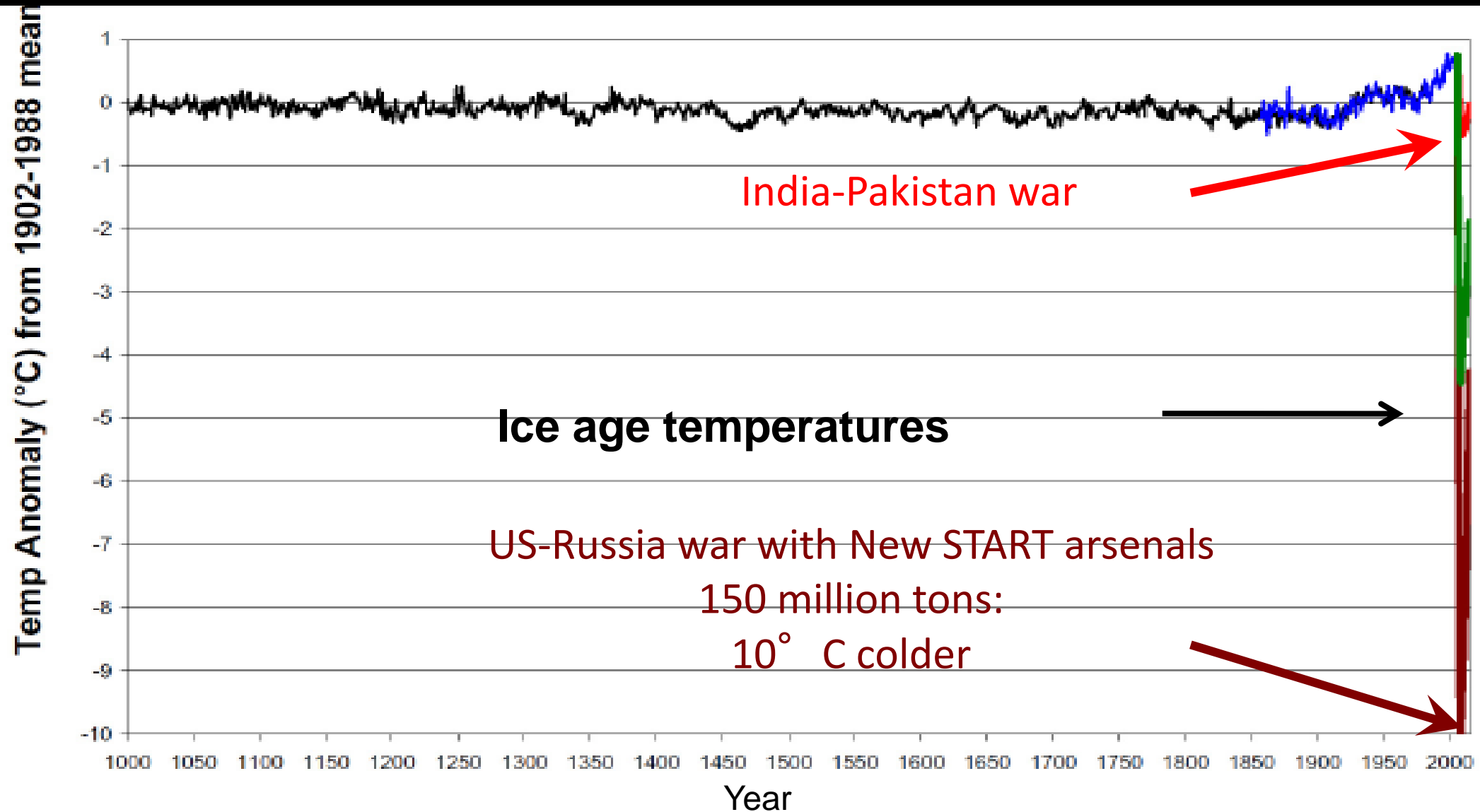
Keeping global temperature constant to end of century requires a lot of SO_2 , probably not achievable



Nuclear war may flood the stratosphere with ~ 150 Tg soot



Surface temperature declines after global conflict to ice age conditions





"Give me a
one-handed economist!
All my economists
say, On the one
hand on the other."

Henry F. Truman

Brian's one handed conclusions

- Background stratospheric aerosol optical depth falls as COS and SO₂ decline
- Weight percent acid declines as T falls, H₂O goes up
- Volcanic eruptions may be more intense/common
- By 2100 Geoengineering requires all current SO₂ emissions go to stratosphere
- Nuclear war could put 150 Tg of soot into stratosphere, destroying civilization

COS budget is not closed

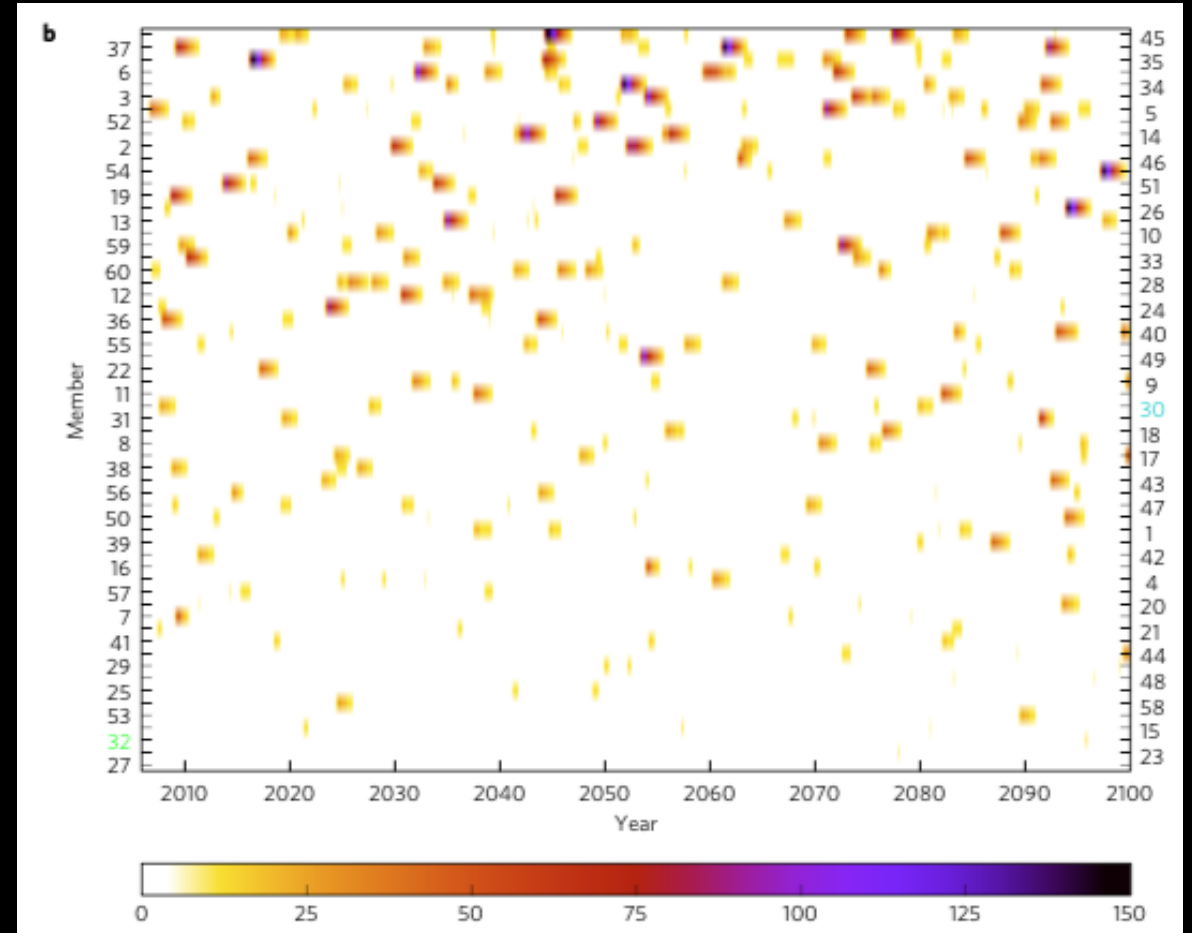
Brühl et al., ACP 2012

Table 1. Global atmospheric budget of COS after Watts (2000).

Sources	Annual flux (Mt yr ⁻¹)
Open ocean	0.10 ± 0.15
Coastal ocean (incl. salt marshes, estuaries)	0.20 ± 0.10
Anoxic soils	0.02 ± 0.01
Wetlands	0.03 ± 0.03
Volcanism	0.05 ± 0.04
Precipitation	0.13 ± 0.08
DMS oxidation	0.17 ± 0.04
CS ₂ oxidation (50 % anthropogenic)	0.42 ± 0.12
Biomass burning	0.07 ± 0.05
Anthropogenic (direct)	0.12 ± 0.06
Total source	1.31 ± 0.25
Sinks	
Oxic soils	0.92 ± 0.78
Vegetation	0.56 ± 0.10
Reaction with OH	0.13 ± 0.10
(this work)	0.245 ± 0.035
Reaction with O	0.02 ± 0.01
(this work)	0.016 ± 0.001
Photodissociation	0.03 ± 0.01
(this work)	0.047 ± 0.006
Total sink	1.66 ± 0.79
(this work)	1.79 ± 0.79
Total imbalance	0.35 ± 0.83
(this work)	0.48 ± 0.83

How can we predict the volcanic impact on future climate projections, when we can't predict volcanic events?

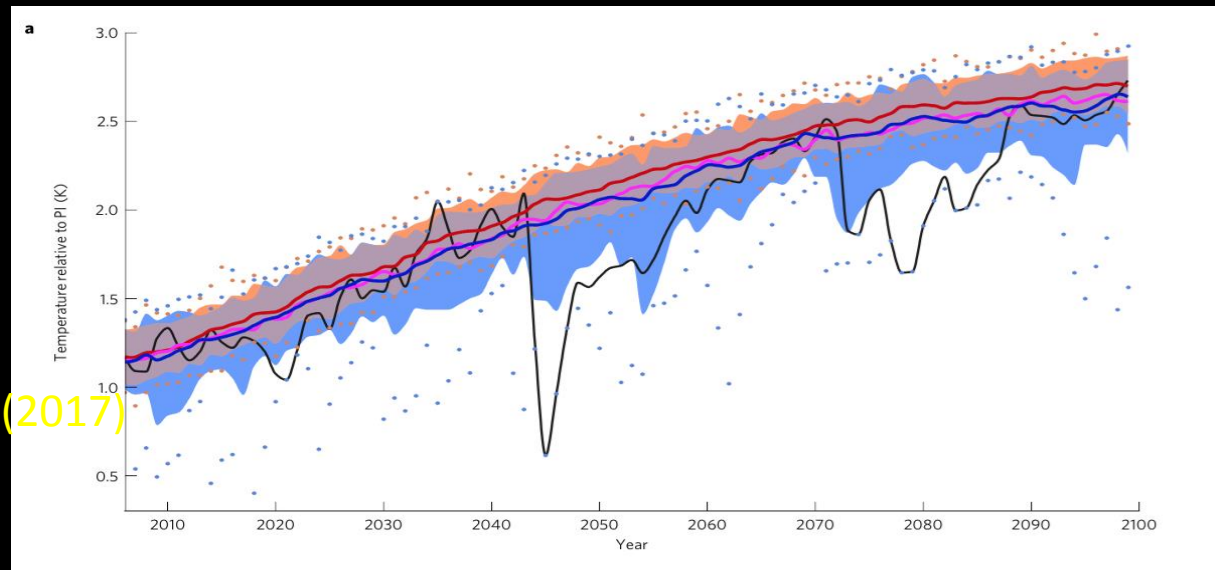
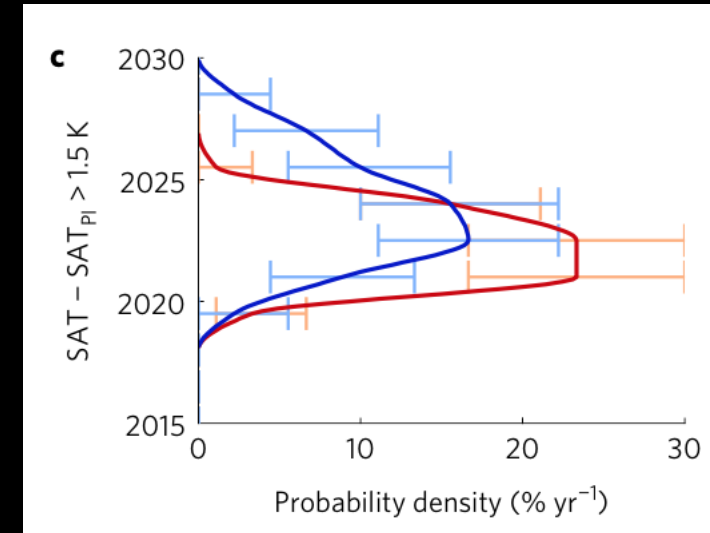
Ingo Bethke, et al Nature Climate Change (2017)



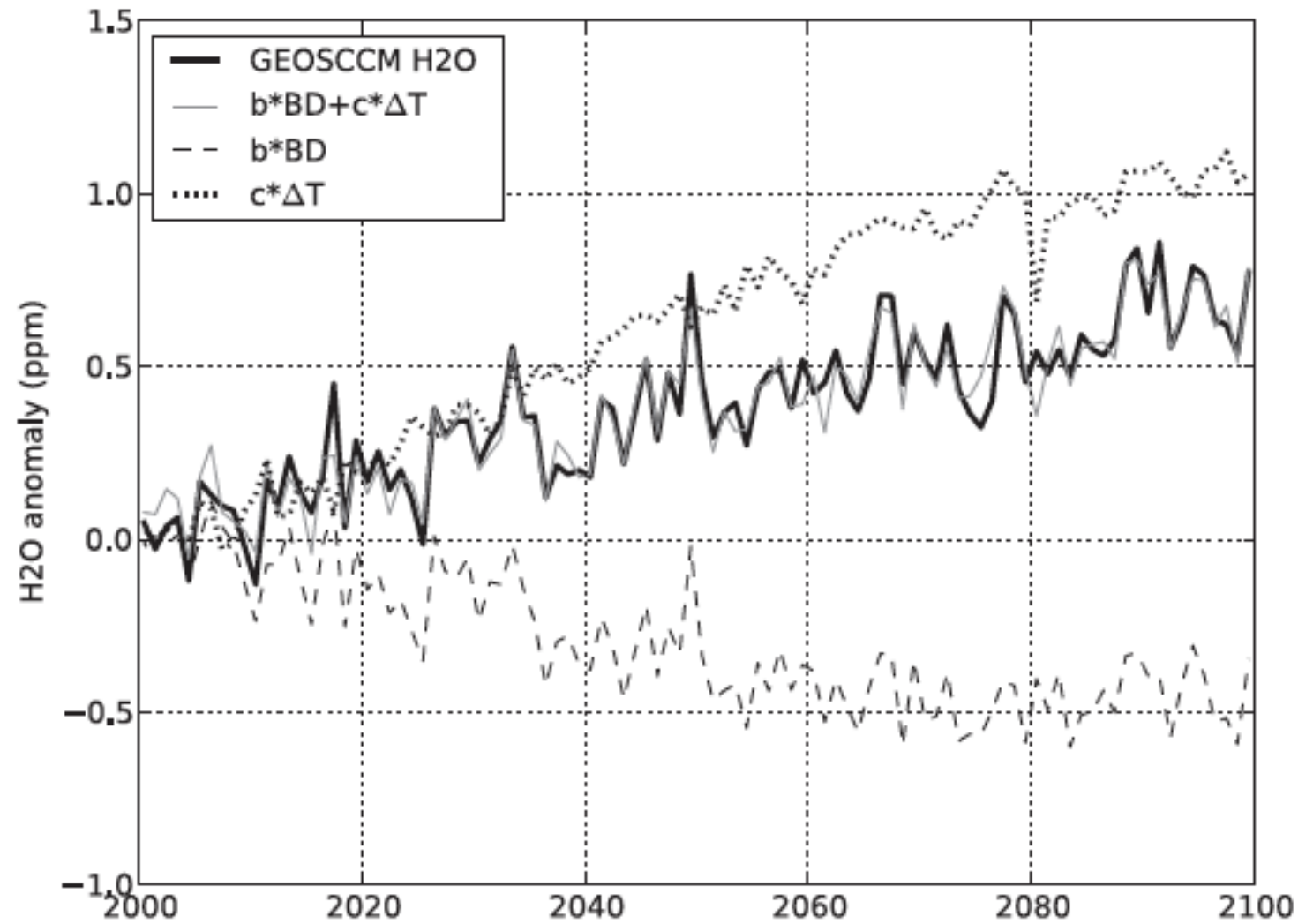
Socially relevant implications:

- Volcanoes and the Paris Agreement
- Geoengineering

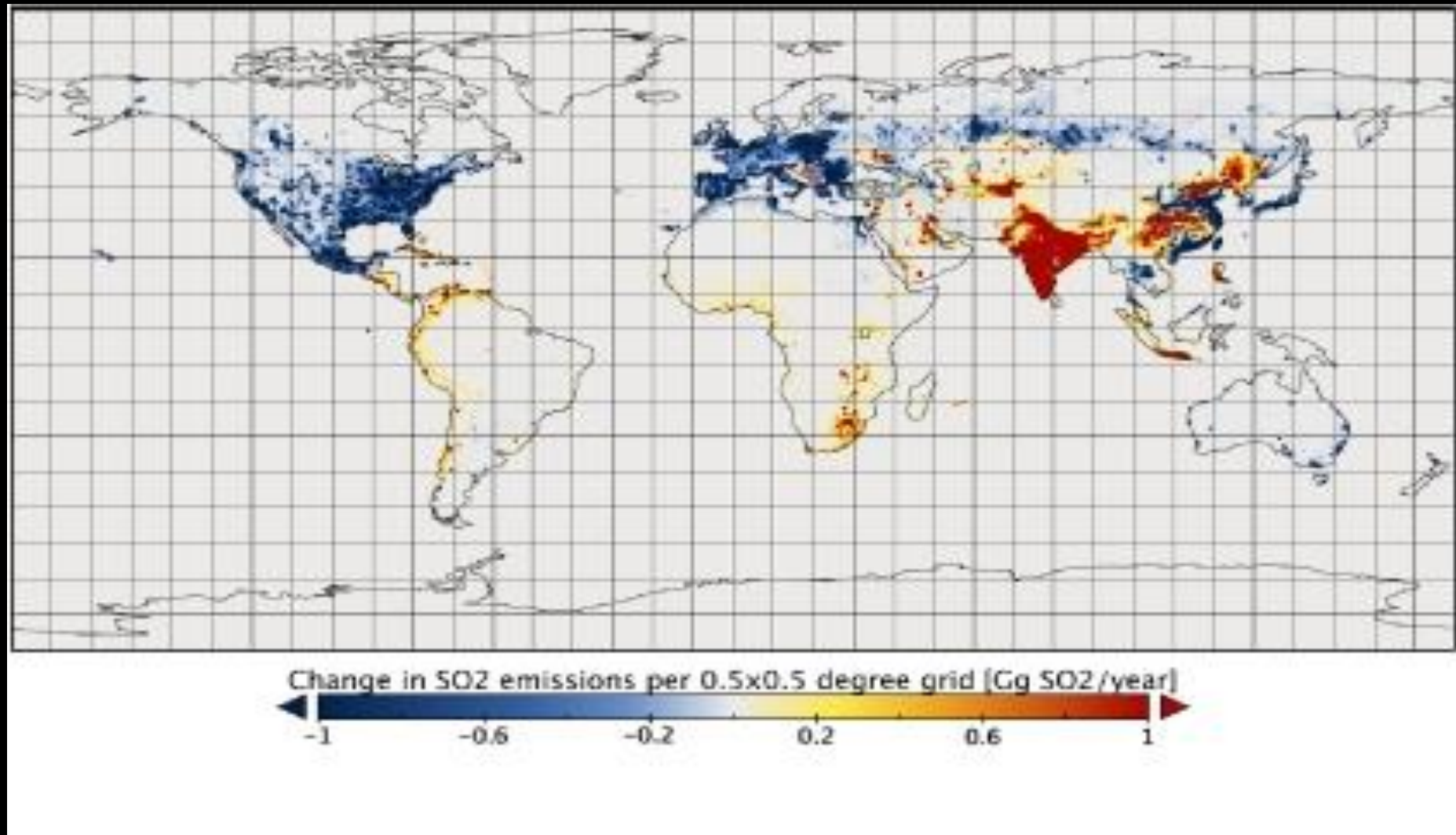
: Ingo Bethke, et al Nature Climate Change (2017)



Changes in climate variables-H₂O



Sulfur emissions are not changing uniformly



Klimont et al 2013 Environ. Res. Lett. 8 014003
doi:10.1088/1748-9326/8/1/014003

“There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of fact” Mark Twain, Life on the Mississippi

