New prescribed and prognostic volcanic and stratospheric aerosol options in CESM

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A Consistent Prescription of Stratospheric Aerosol for Both Radiation and Chemistry in the Community Earth System Model (CESM1)

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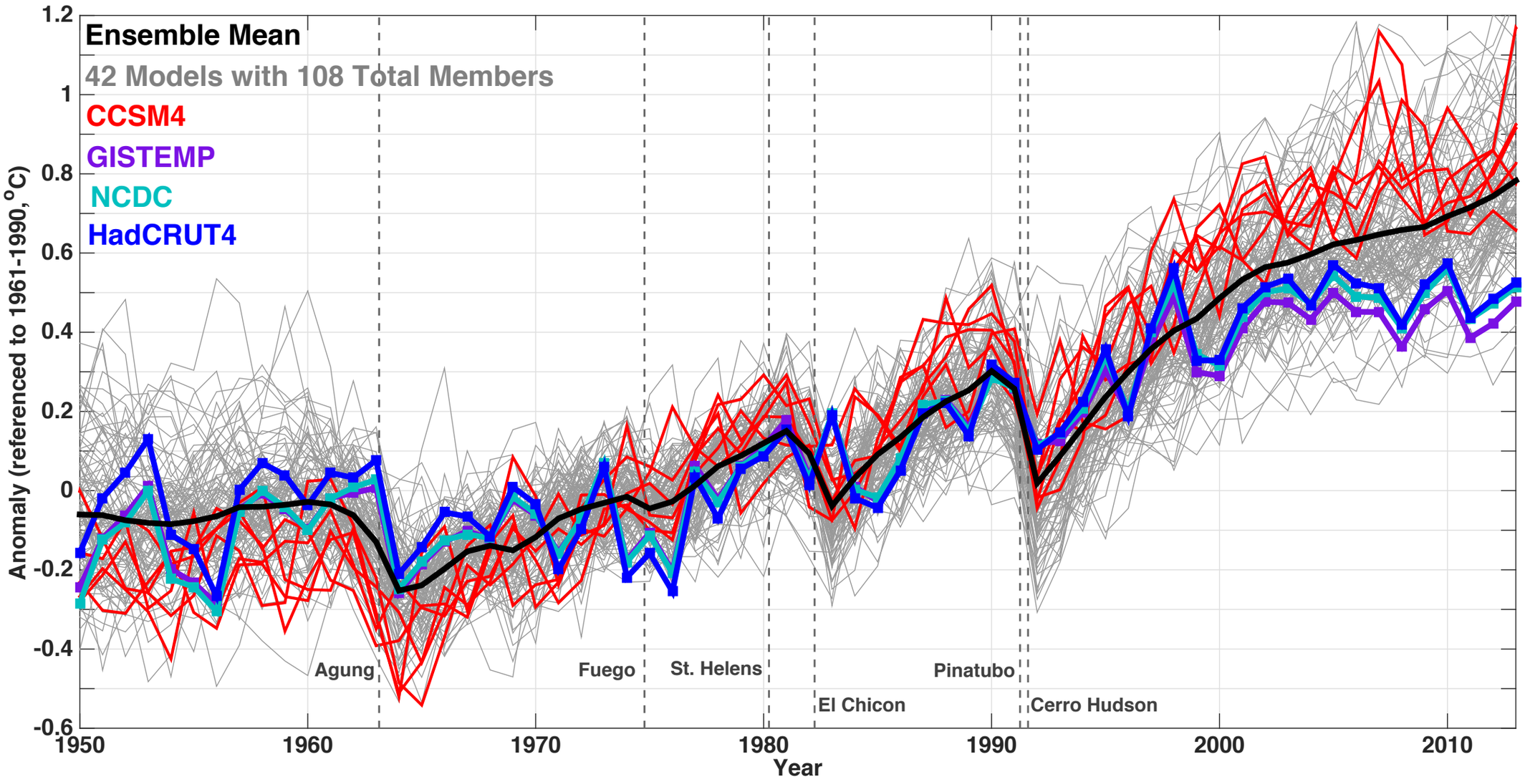
Geoscientific Model Development Discussions

Geosci. Model Dev. Discuss., 8, 10711–10734, 2015
www.geosci-model-dev-discuss.net/8/10711/2015/
doi:10.5194/gmdd-8-10711-2015

Motivation: poor global response of most models in CMIP5 to colossal volcanic perturbations to stratospheric aerosol



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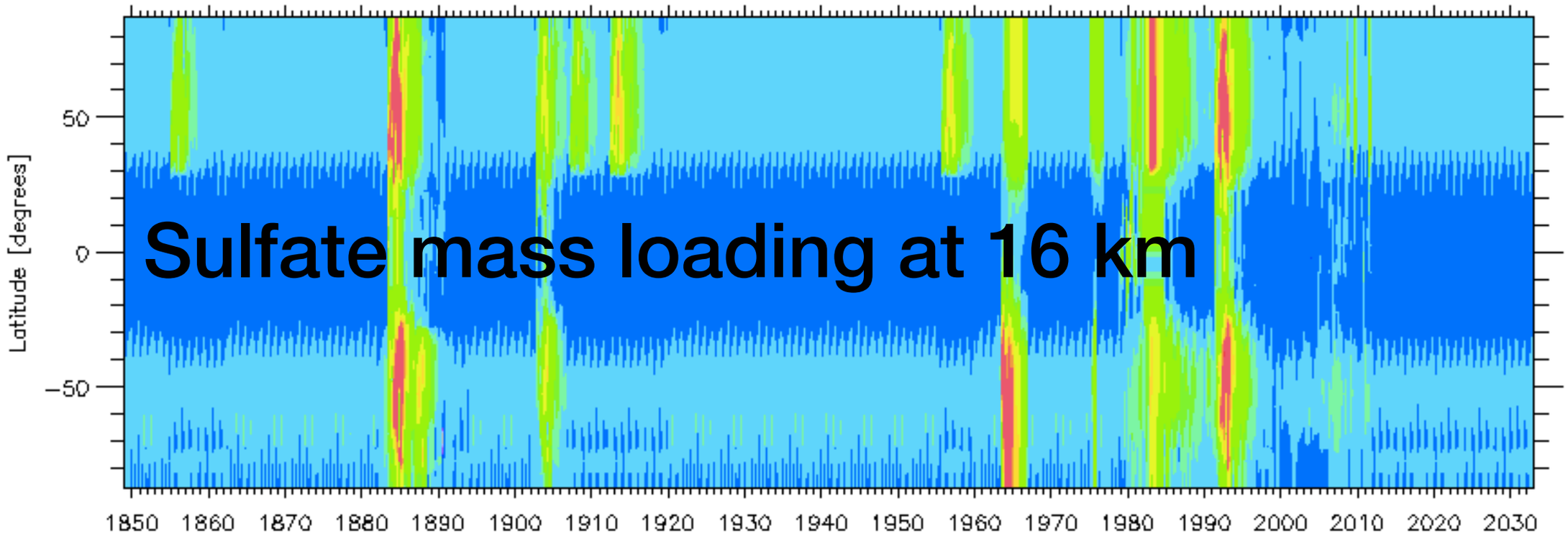
New prognostic stratospheric aerosol scheme

- accounts for variation in *effective radius* in addition to mass loading
- improved historical volcanic database for 1850-2015 (reduced mass for large eruptions)
- non-volcanic background aerosol included during control simulations and volcanically quiescent periods, including 2016-2100



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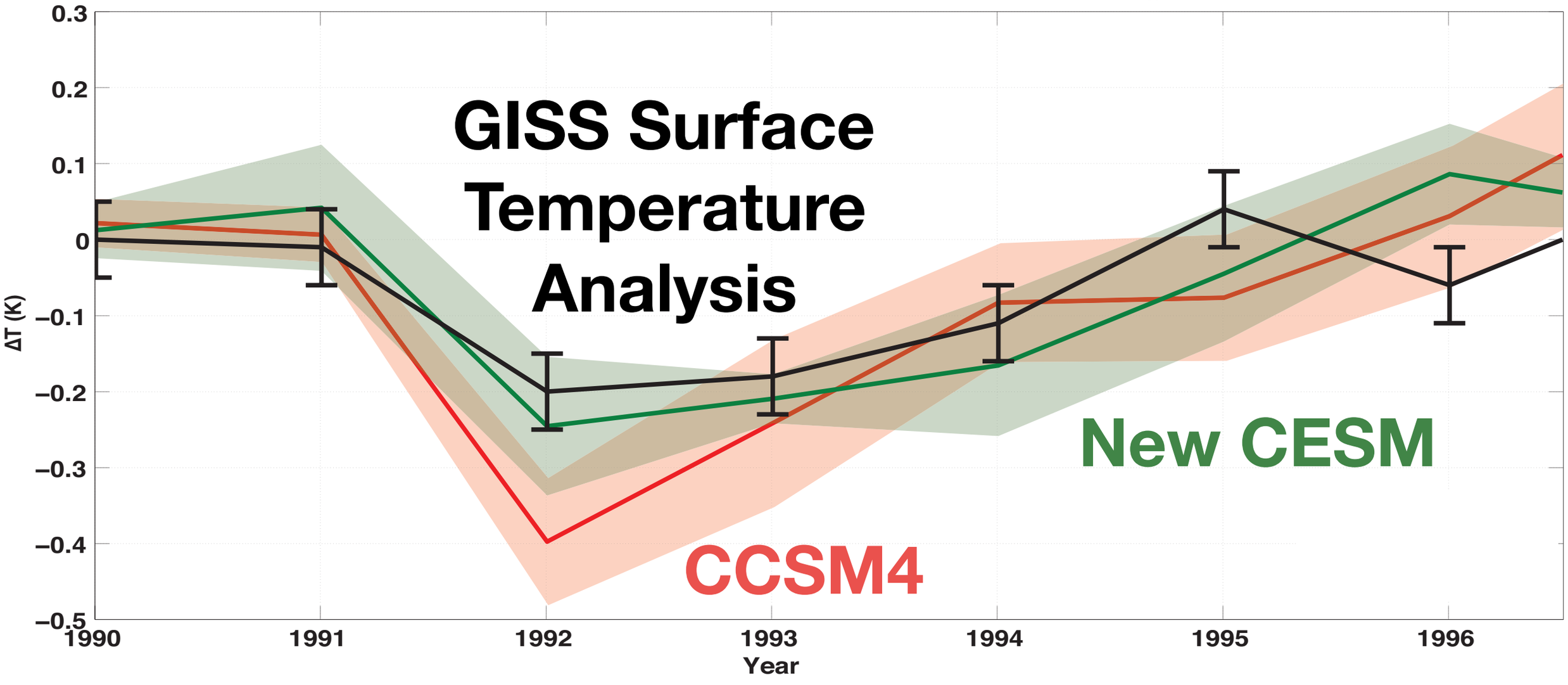
Improved surface cooling



Global annual average surface temperature anomaly

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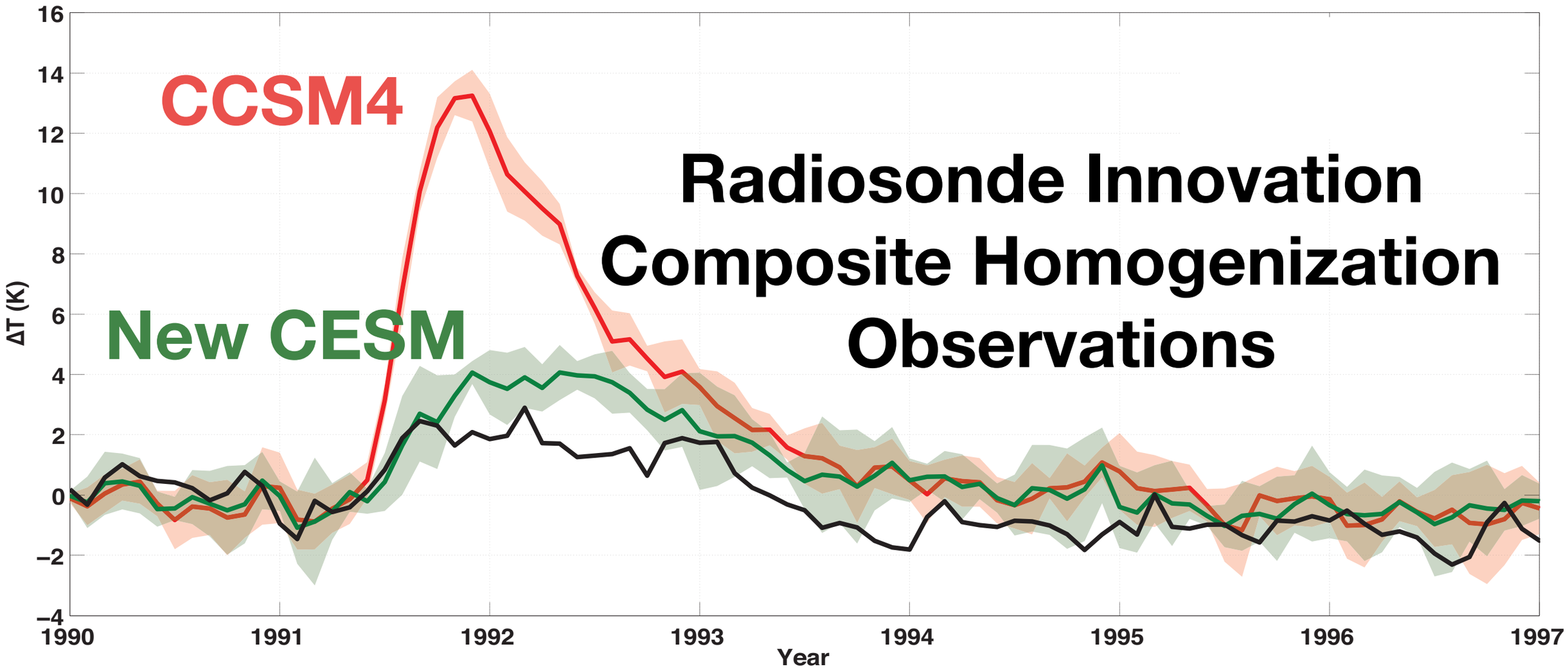
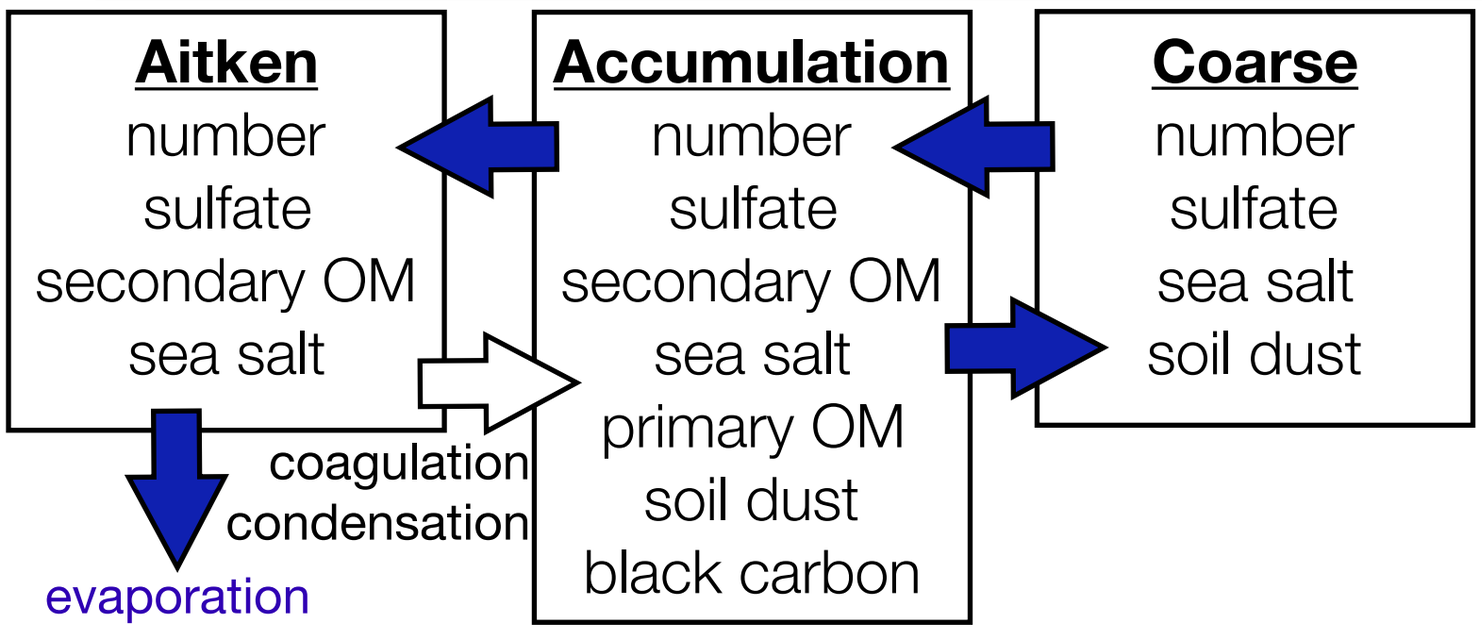
Improved stratospheric heating



Tropical monthly mean temperature anomaly at 50 hPa

Prognostic stratospheric aerosol option:
Extend modal aerosol model (MAM3) for stratospheric aerosols



Gas-phase species: H_2SO_4, SO_2, DMS, SOA (gas)

Added sulfate evaporation above tropopause

Added growth between modes

Adjusted diameter ranges, mode widths

Mode	Aitken	Accumulation	Coarse
Standard MAM3 radius (μm) geom. std. dev	0.00435 - 0.026 1.6	0.02675 - 0.22 1.8	0.5 - 2.0
Modified MAM3 radius (μm) geom. std. dev.	0.00435 - 0.026 1.6	0.02675 - 0.22 1.6	>0.22 1.2

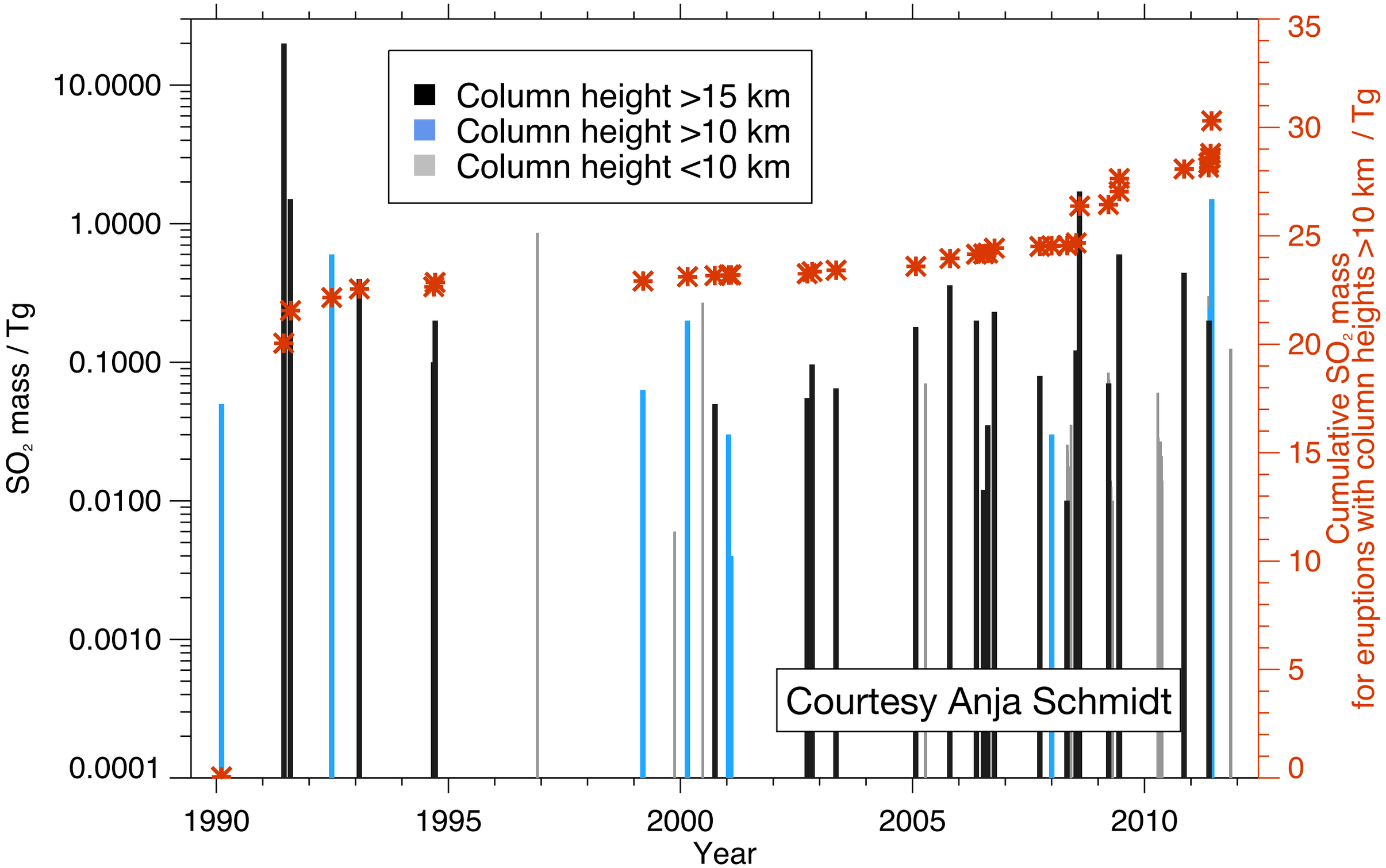
With chemistry: added OCS, S, SO, SO_3

Without chemistry:

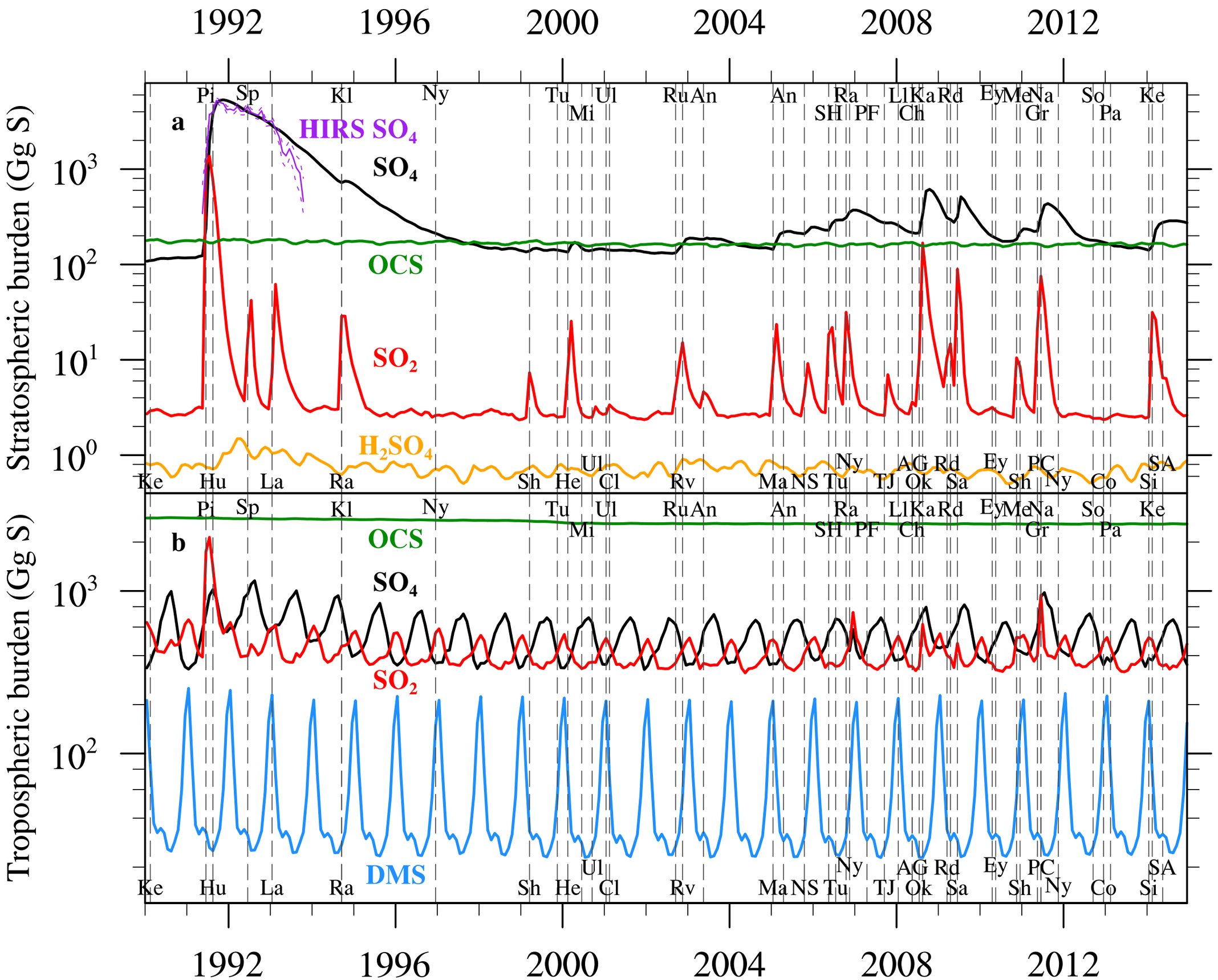
- **added SO_2 external forcing from OCS oxidation**
- **added H_2O external forcing from CH_4 oxidation**

VolcanEESM 3D volcanic strat/trop SO_2 input file for 1850-2015 (Schmidt, Neely)

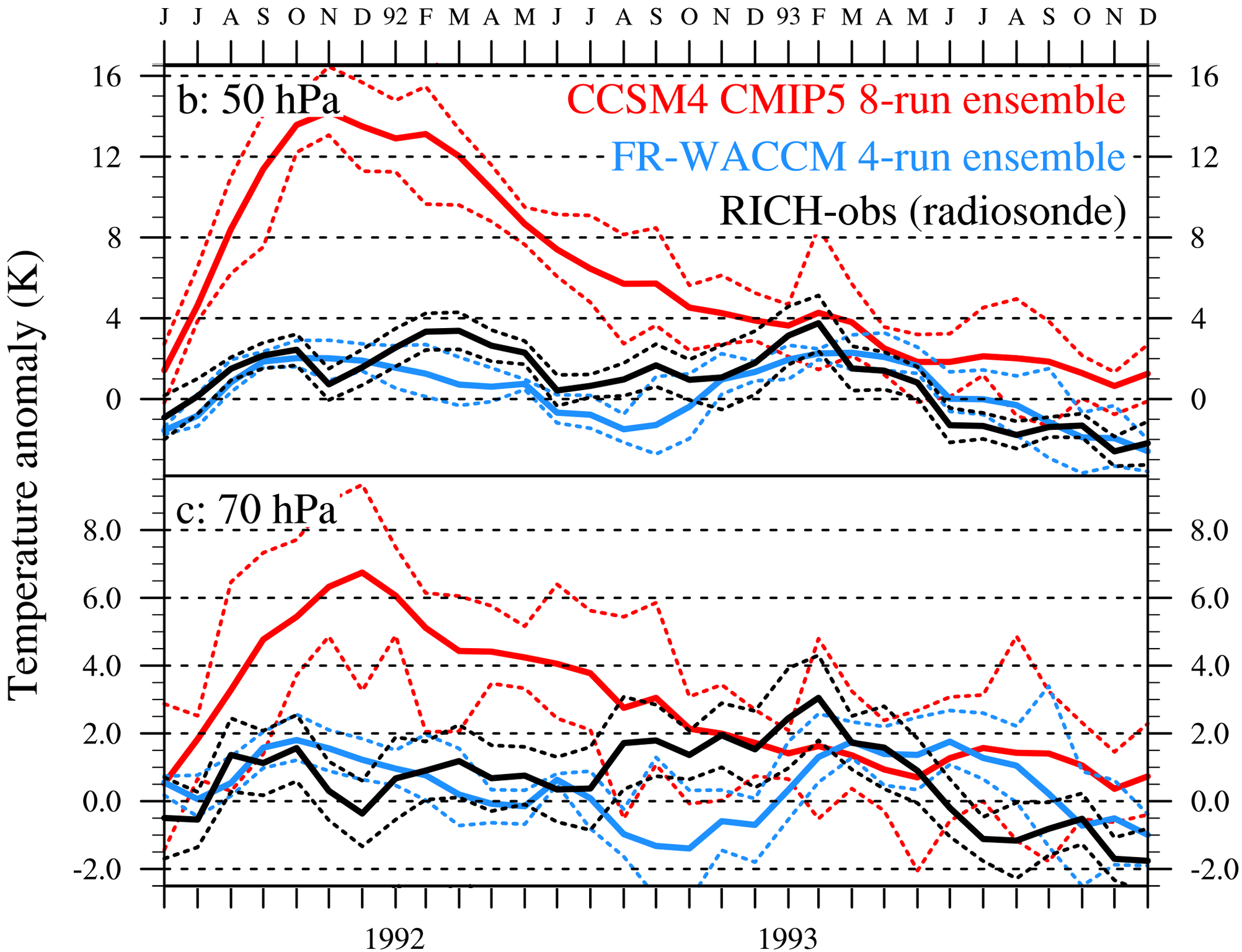
VEI > 2 eruptions since 1990 (with SO_2 reported)



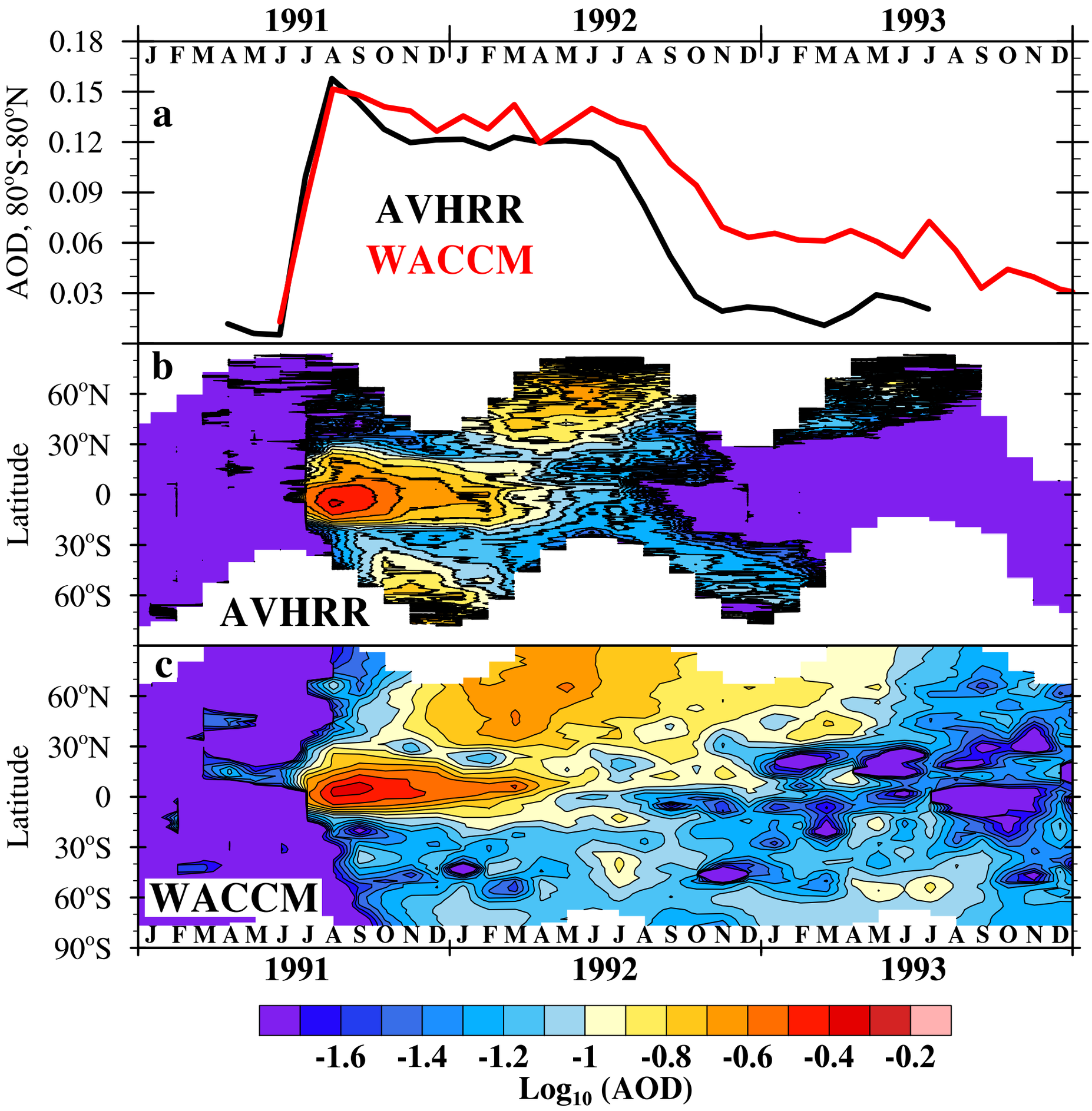
SD-WACCM simulations from “Global volcanic aerosol properties derived from emissions, 1990-2014, using CESM1(WACCM)," Mills et al., submitted to JGR.



Prognostic aerosols: *Improved stratospheric heating*



Tropical temperature anomalies from Mills et al., submitted to JGR.



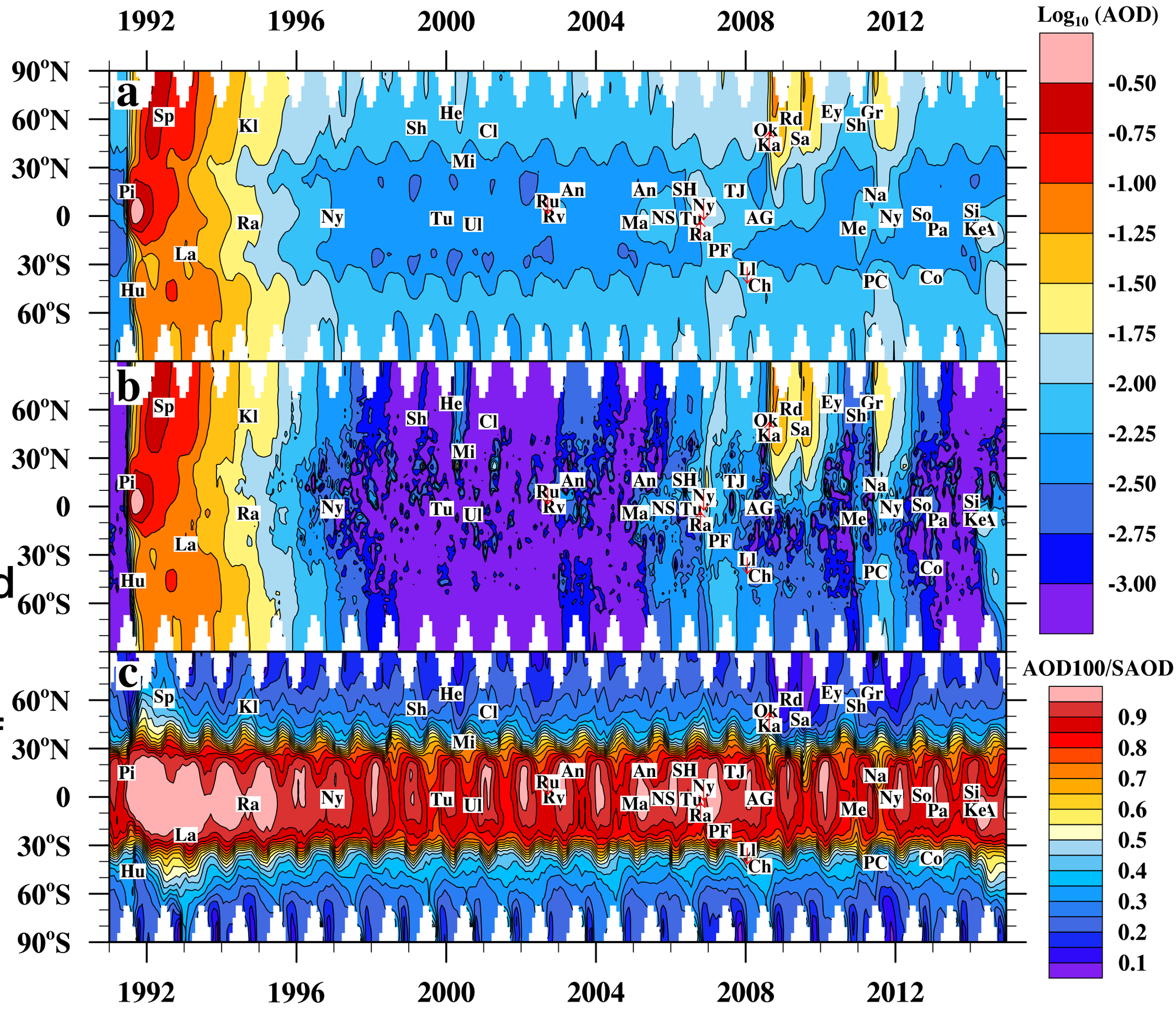
Total AOD over ocean minus background

from Mills et al., submitted to JGR.

Strat AOD

Total AOD, volcanic - background

Fraction of strat AOD above 100 hPa



1992 1996 2000 2004 2008 2012

Aerosol Optical Depth, Visible

a

WACCM > TP, 60-90°N
Ny Alesund Lidar (78.9°N) > 10 km
CCMI > TP, 60-90°N
WACCM > 100 hPa, 60-90°N
Sato et al., 60-90°N

10^{-1} 10^{-2} 10^{-3}

Pi Sp Kl Ny TuMiUl RuAn An SH RaPF LlKaRd Ch EyMeNa Gr ScPa Ke

Ke Hu La Ra Sh HeUCl Rv Ma NS Tu Ny TJ AG Ok Rd Sa Ey Sh PC Ny Co SSA

b

Geesthacht Lidar (53.4°N) > TP
WACCM > TP, 55.9°N
Tomsk Lidar (56.5°N) > 12 km
CCMI > TP, 57.5°N
WACCM > 100 hPa, 55.9°N
Sato et al., 45-60°N
Vernier et al., 45-60°N

10^{-1} 10^{-2} 10^{-3}

Pi Sp Kl Ny TuMiUl RuAn An SH RaPF LlKaRd Ch EyMeNa Gr ScPa Ke

Ke Hu La Ra Sh HeUCl Rv Ma NS Tu Ny TJ AG Ok Rd Sa Ey Sh PC Ny Co SSA

1992 1996 2000 2004 2008 2012

Aerosol Optical Depth, Visible

1992 1996 2000 2004 2008 2012

c

10^{-1} 10^{-2} 10^{-3}

WACCM > TP, 36.9°N
Tsukuba Lidar (36.1°N) > TP
CCMI > TP, 37.5°N
WACCM > 100 hPa, 36.9°N
Sato et al., 30-45°N
Vernier et al., 30-45°N

Pi Sp Kl Ny TuMiUl RuAn An SH RaPF LlKaRd Ch EyMeNa Gr ScPa Ke

Ke Hu La Ra Sh HeUCl Rv Ma NS Tu Ny TJ AG Ok Rd Sa Ey Sh PC Ny Co SSA

d

10^{-1} 10^{-2} 10^{-3}

WACCM > TP, 19.9°N
Mauna Loa Lidar (19.5°N) > TP
CCMI > TP, 17.5°N
WACCM > 100 hPa, 19.9°N
Sato et al., 0-30°N
Vernier et al., 0-30°N

Pi Sp Kl Ny TuMiUl RuAn An SH RaPF LlKaRd Ch EyMeNa Gr ScPa Ke

Ke Hu La Ra Sh HeUCl Rv Ma NS Tu Ny TJ AG Ok Rd Sa Ey Sh PC Ny Co SSA

1992 1996 2000 2004 2008 2012

Community Earth System Model

CESM

July 1991-December 1996

1997-2005

SD-WACCM, all aer

SD-WACCM, chem aer

Balloon (SAGE coinc)

Balloon (HALOE coinc)

CCMI

Altitude (km)

32

28

24

20

16

12

10^{-1}

10^{0}

10^{1}

Surface Area Density ($\mu m^2 cm^{-3}$)

Calculated SAD matches obs. CCMI SAD misses >60%.

from Mills et al., submitted to JGR.

Community Earth System Model

CESM

SD-WACCM SAD ($\mu m^2 cm^{-3}$), July 2009

CCMI SAD ($\mu m^2 cm^{-3}$), July 2009

Altitude (km)

32
28
24
20
16
12
8

60S 30S 0 30N 60N

0.10 0.18 0.32 0.56 1 1.78 3.16 5.62 10 17.8 31.6 56.2

Post-Sarychev eruption: calculated SAD = 10x CCMI

from Mills et al., submitted to JGR.

New prescribed and prognostic volcanic and stratospheric aerosol options in CESM

- Prescribed stratospheric aerosol based on effective radius, improved mass loading.
- Prognostic modal volcanic aerosol is now available for use in CESM.
- VolcanEESM SO_2 emissions available for 1850-2015.
- Completed 1990-2014 runs with and without volcanoes. Comparison to lidar shows excellent agreement, reveals limitations of satellite data in the lower stratosphere.
- Surface area densities from prognostic aerosols in excellent agreement with Laramie OPC data. In contrast, CCMI-recommended SAD misses 60% of observed SAD in both volcanic and quiescent periods.
- New prescribed and prognostic options greatly improve stratospheric heating after Pinatubo compared to CCSM4.
- CAM may be run with prognostic stratospheric aerosol, or prescribed based on WACCM prognostic run.

Extra slides

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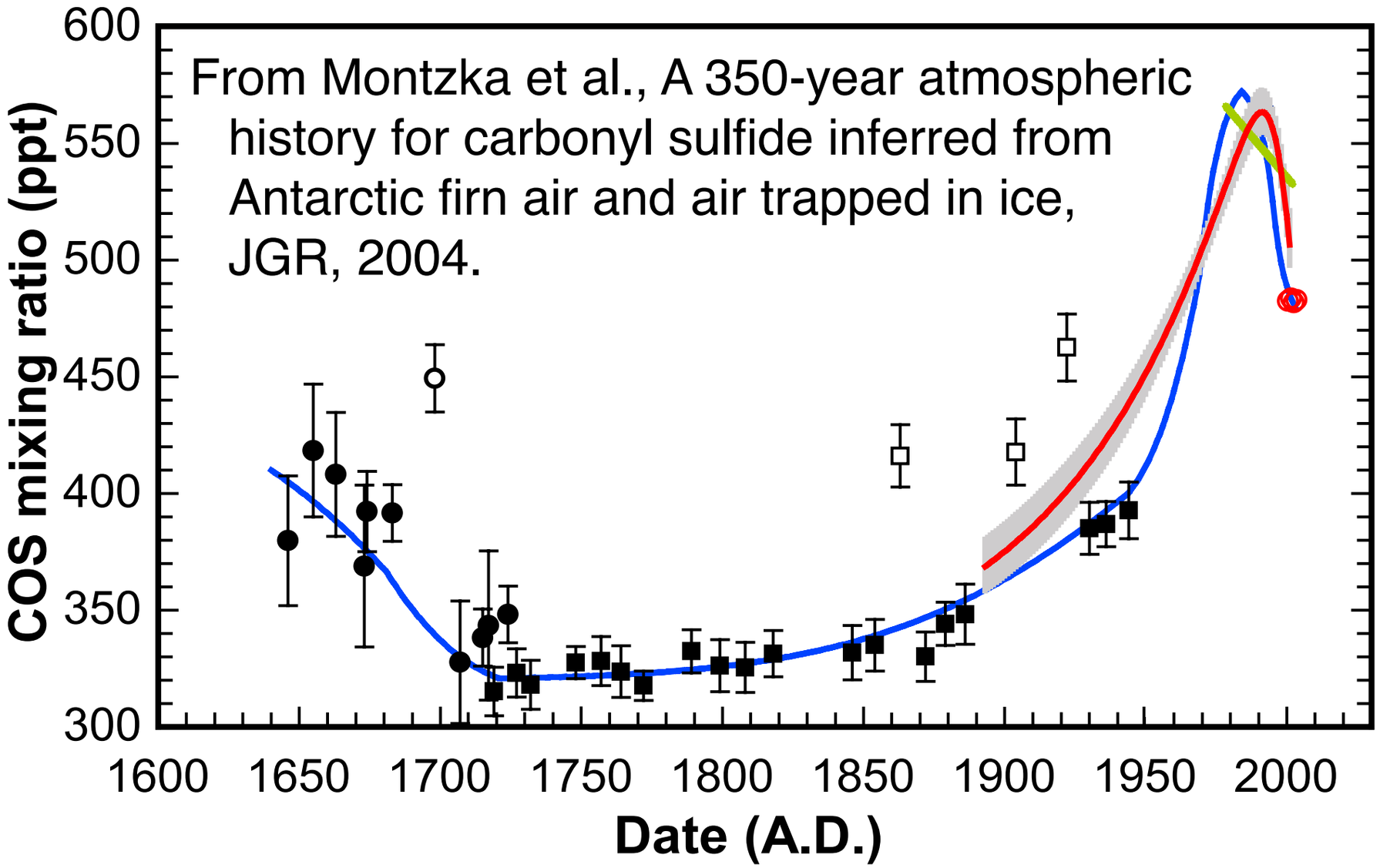
Time-varying lower boundary condition for OCS



- New LBC file for runs with chemistry (WACCM, CAM-chem)
- External forcing files developed for SO_2 produced from OCS oxidation in CAM without chemistry: 1850, 20th Century

3D volcanic strat/trop SO_2 input file for 1990-2011