

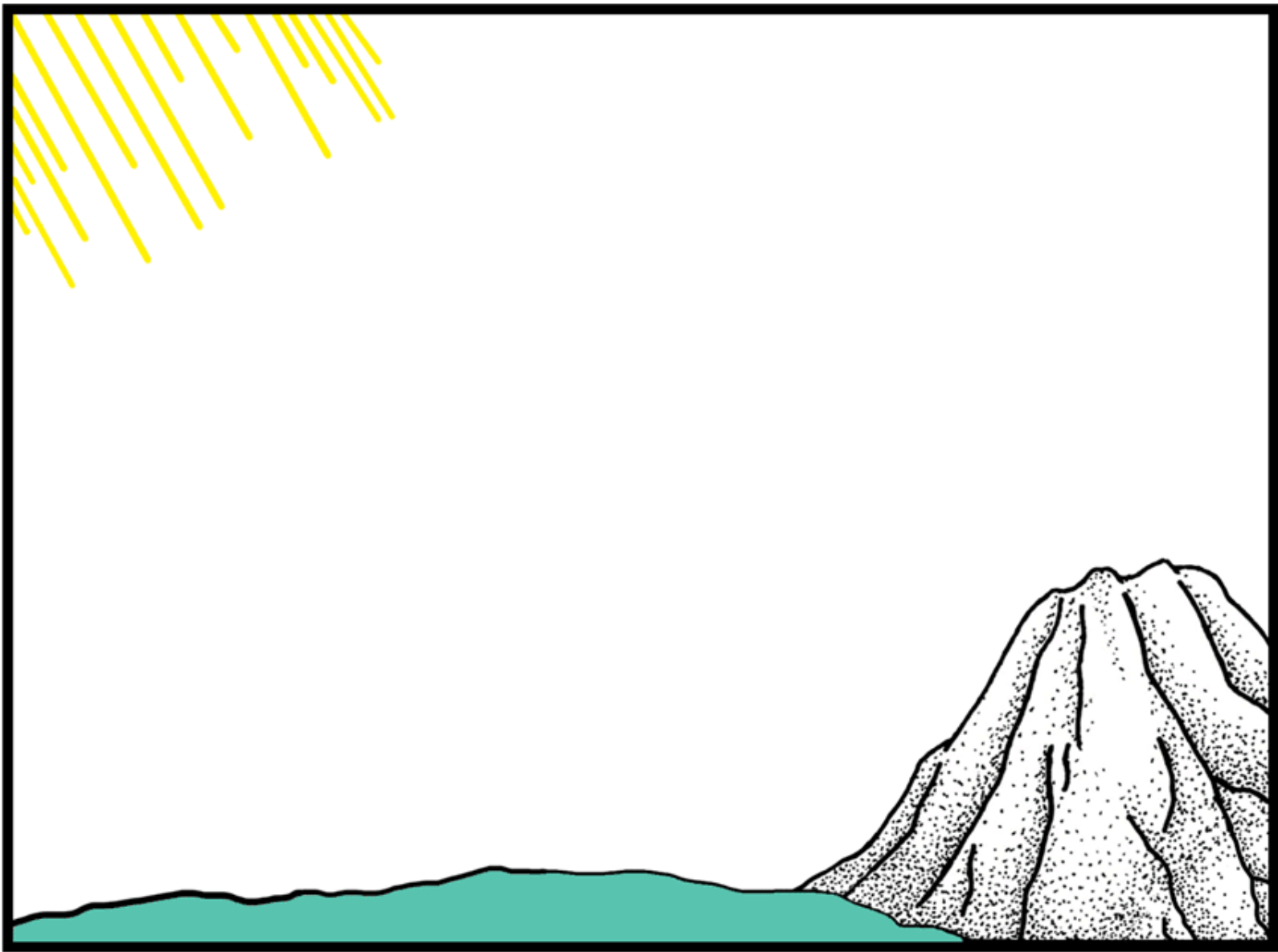


Sarychev Peak,  
Kuril Islands  
June 12, 2009  
viewed from ISS

# Stratospheric aerosols and volcanic eruptions in CESM2

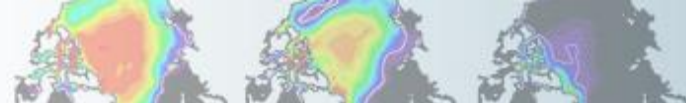
**Mike Mills, WACCM Liaison**

Ryan Neely, Anja Schmidt, Dick Easter,  
Steve Ghan, Andrew Conley  
...and many others!



**Credit: Iris Gottlieb for The New York Times**

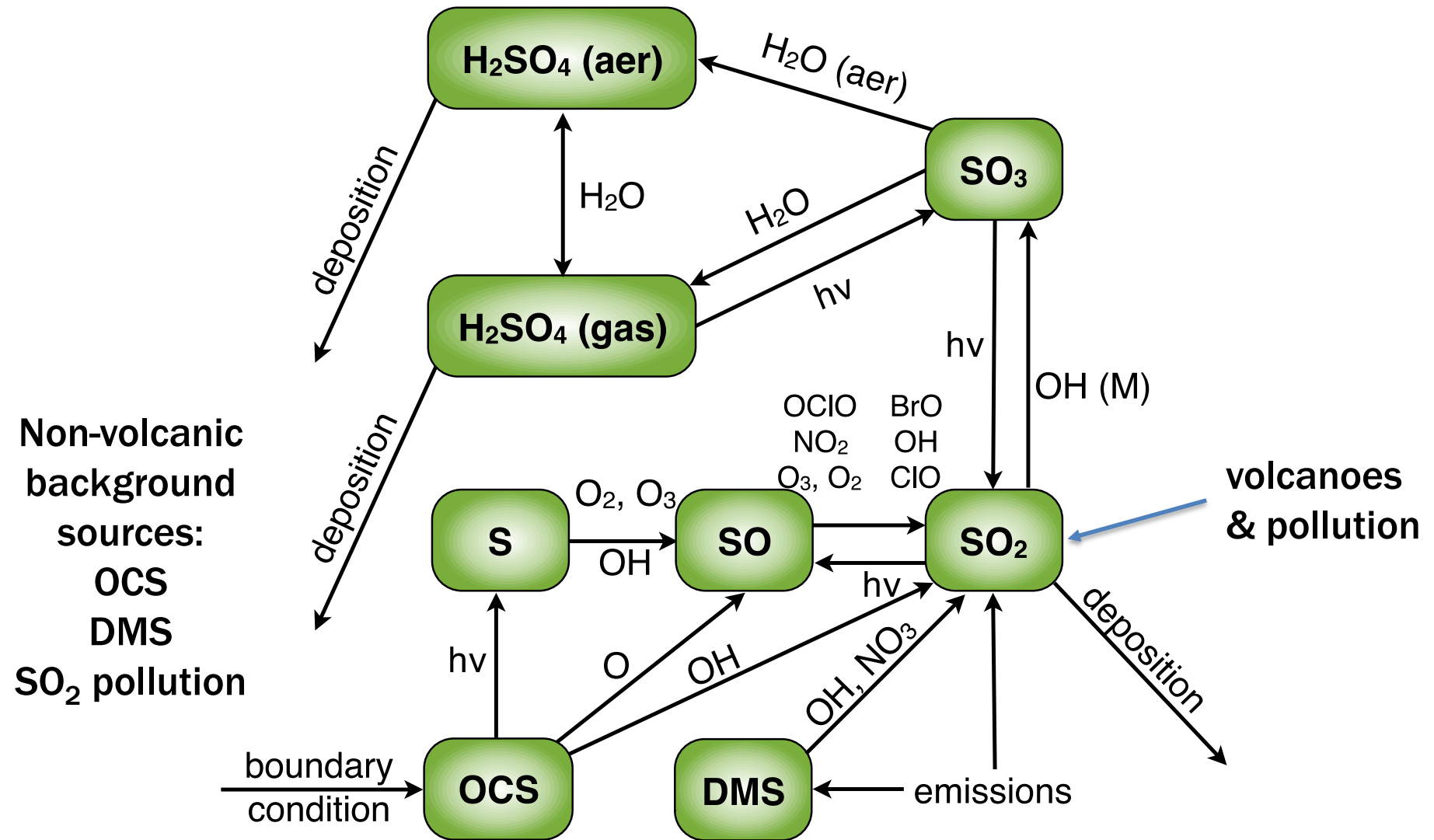
<https://www.nytimes.com/2018/02/01/climate/volcano-geoengineering.html>



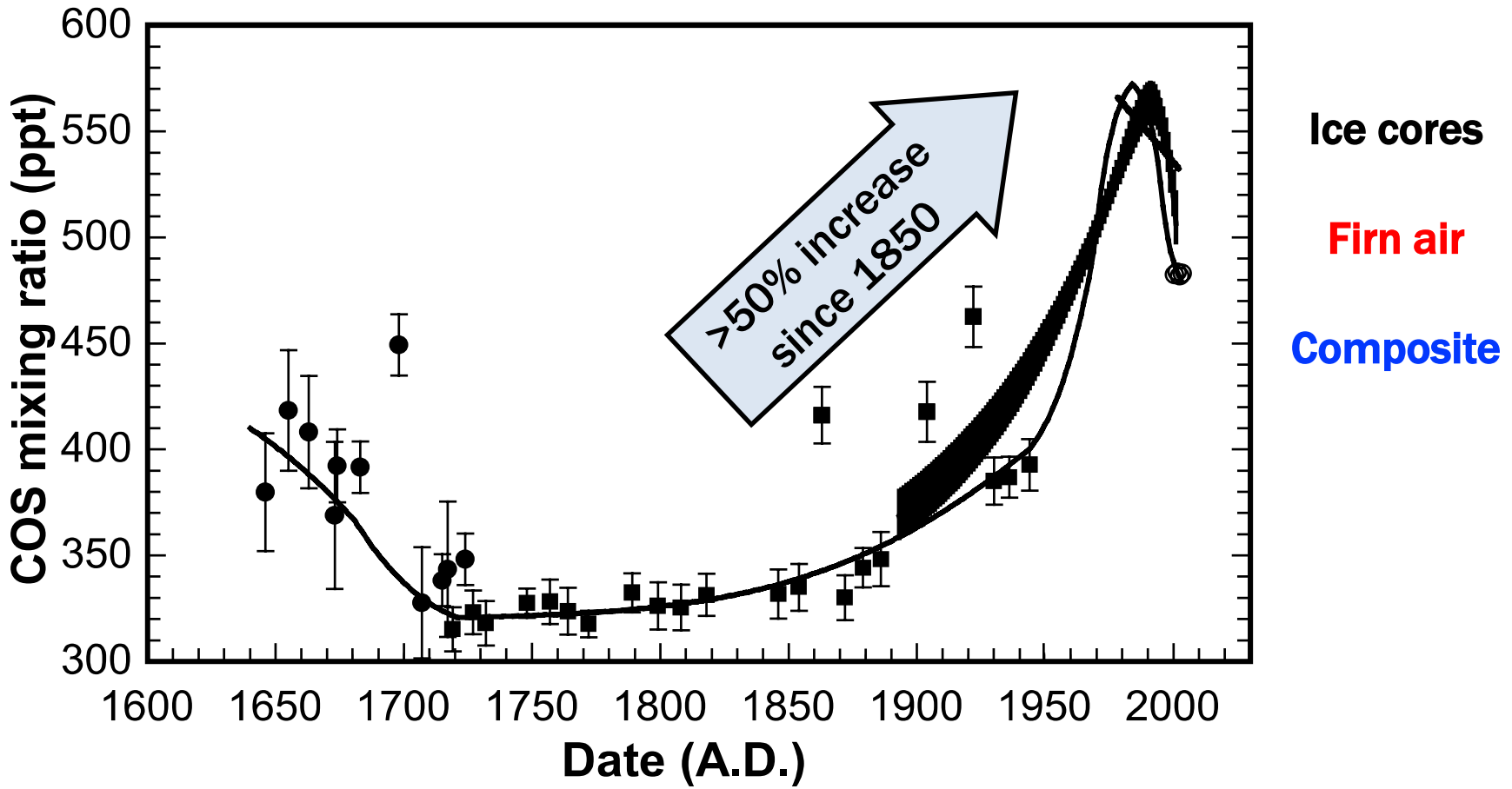
# Volcanic forcing in CESM: a history

- **CESM1 (CMIP5, LENS):** prescribed single mode
  - **CAM5:** prescribed volcanic aerosol mass file (Ammann et al., 2003). Assumes 75%  $\text{H}_2\text{SO}_4$ /25%  $\text{H}_2\text{O}$ , wet effective radius =  $0.426\mu\text{m}$ ,  $\sigma(\ln(r)) = 1.8$
  - **WACCM4:** prescribed volcanic surface area density file (Kinnison et al., 2007). Composition varies with T &  $\text{H}_2\text{O}$ ,  $r_{\text{eff wet}} = 0.5\mu\text{m}$ ,  $\sigma(\ln(r)) = 1.25$
- **CESM2**
  - **WACCM6:** prognostic volcanic aerosol derived from  $\text{SO}_2$  emissions (Mills et al., 2016; 2017)
  - **CAM6 CMIP6:** 3 modes prescribed from WACCM6 output (Neely et al., in preparation)

## Gas-phase and aerosol sulfur chemistry



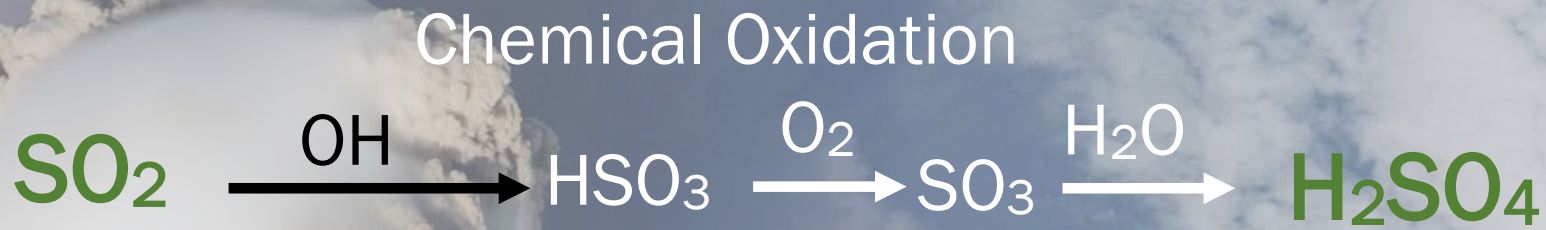
# Carbonyl sulfide (OCS) lower boundary condition



Montzka et al. (2004), A 350-year atmospheric history for carbonyl sulfide inferred from Antarctic firn air and air trapped in ice, *JGR-A*, doi:10.1029/2004JD004686



# Sulfate aerosol formation and evolution

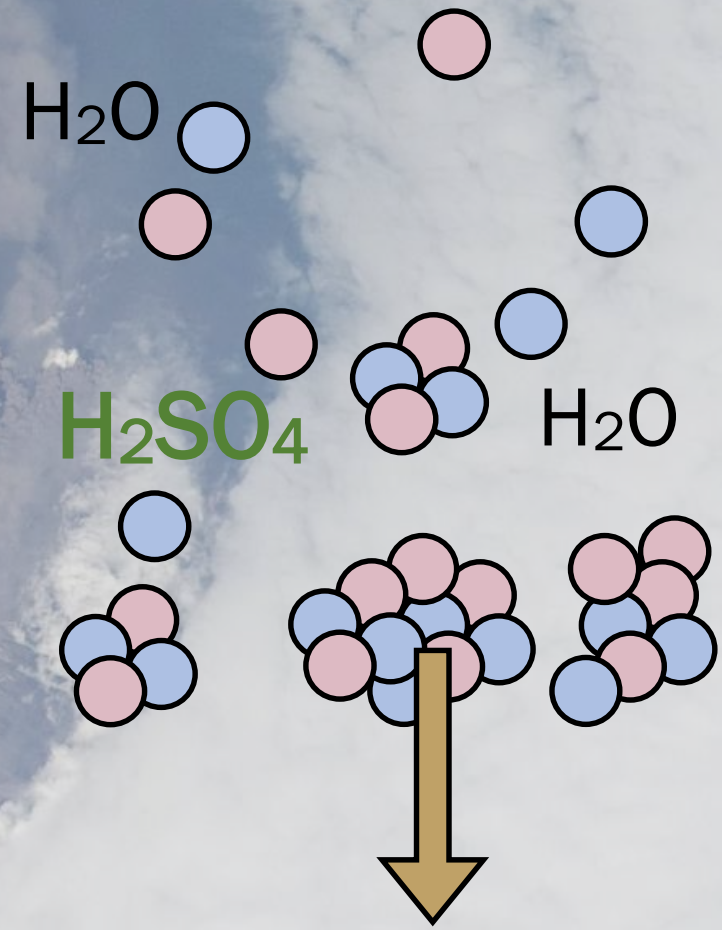


Gas-to-particle nucleation

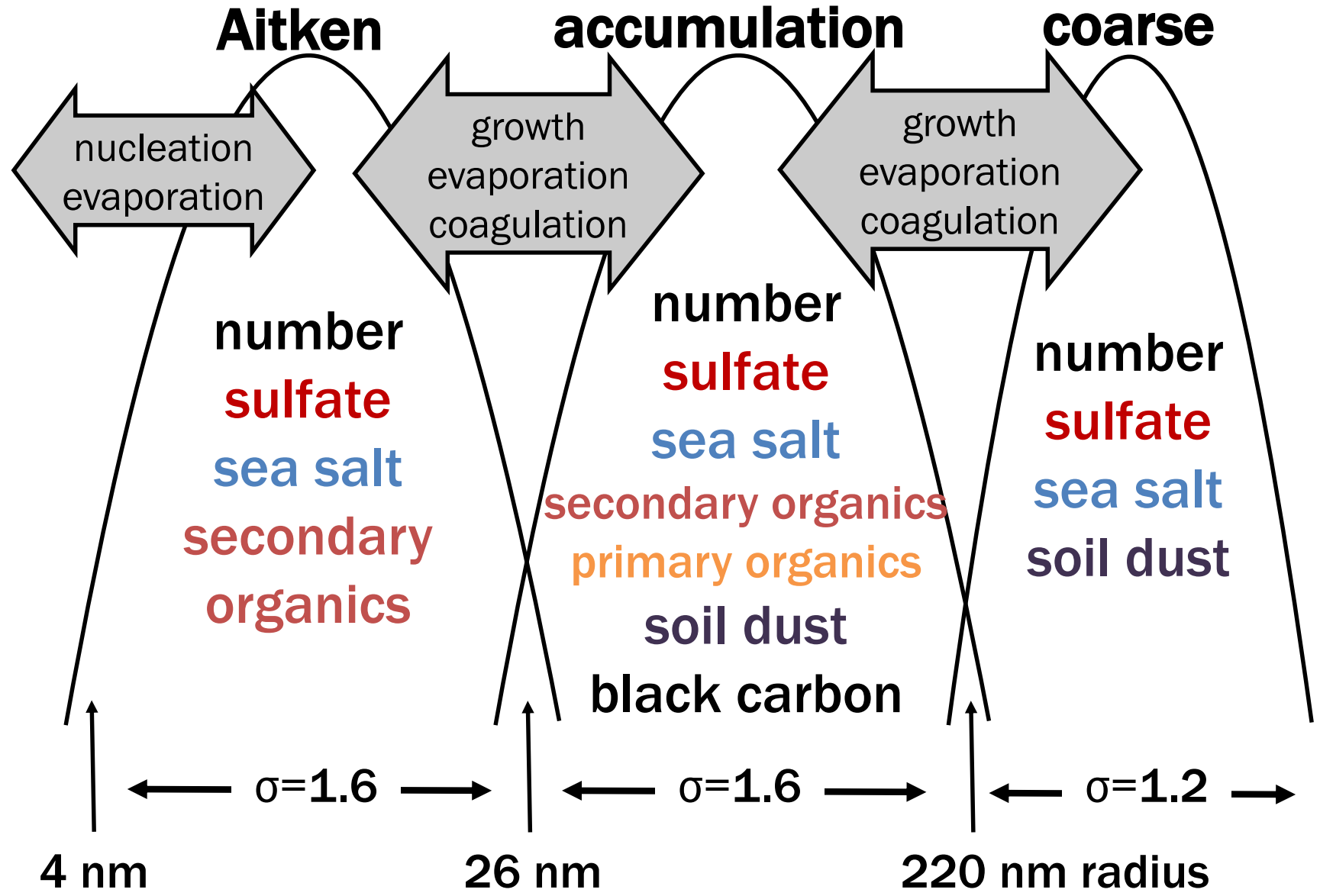
Condensation growth

Coagulation growth

Sedimentation removal

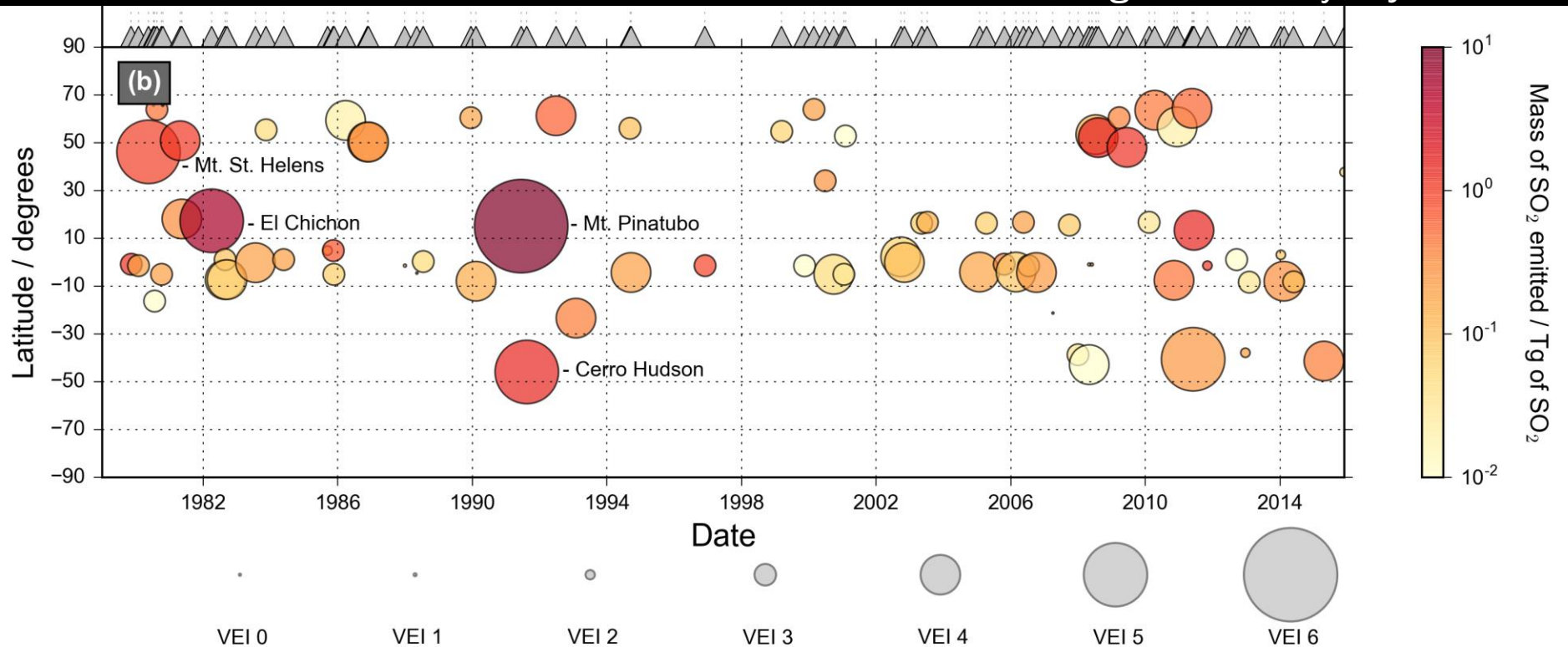


## Prognostic modal aerosols in WACCM



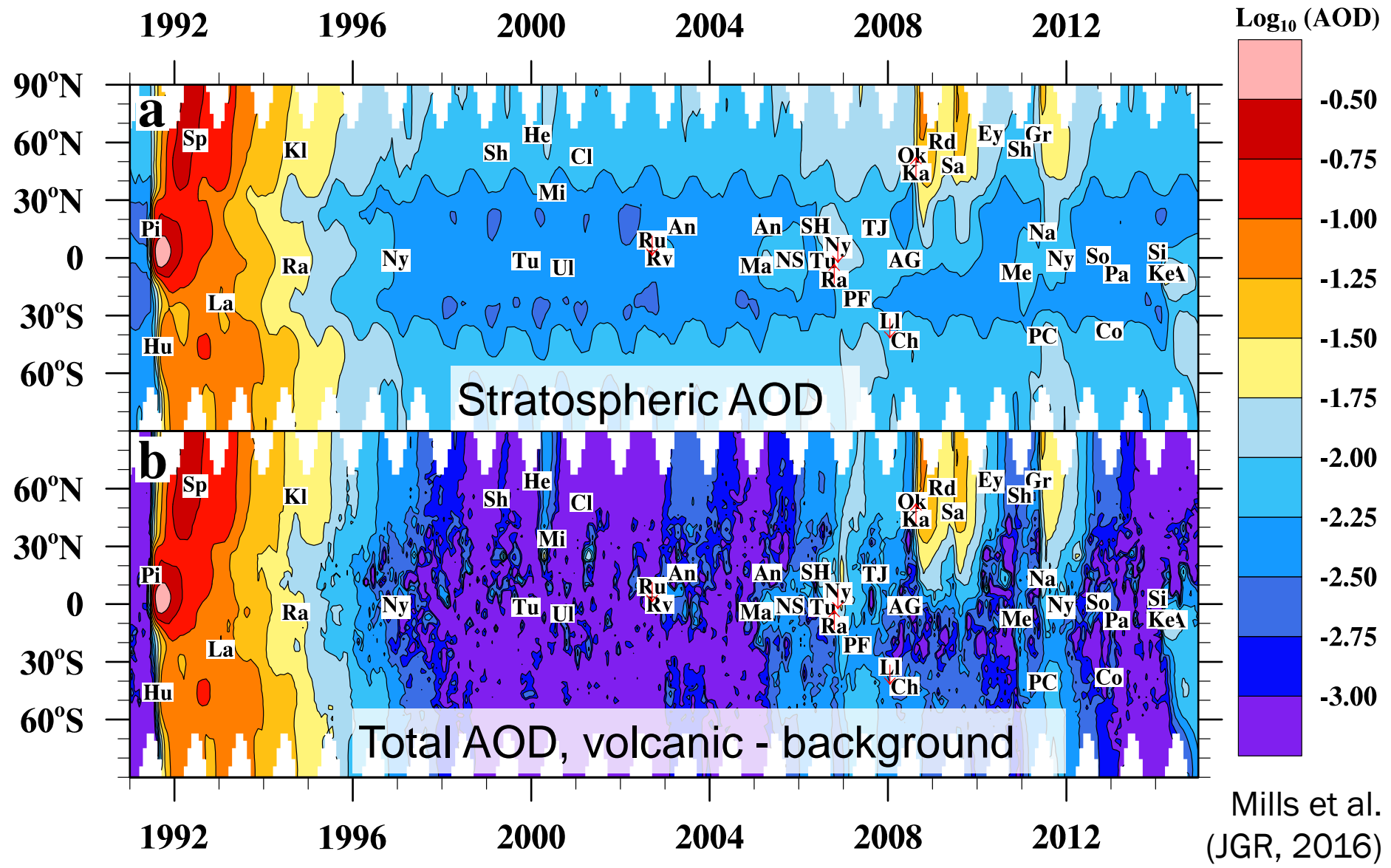
# Volcanic eruptions, 1979-2015

Figure courtesy Anja Schmidt

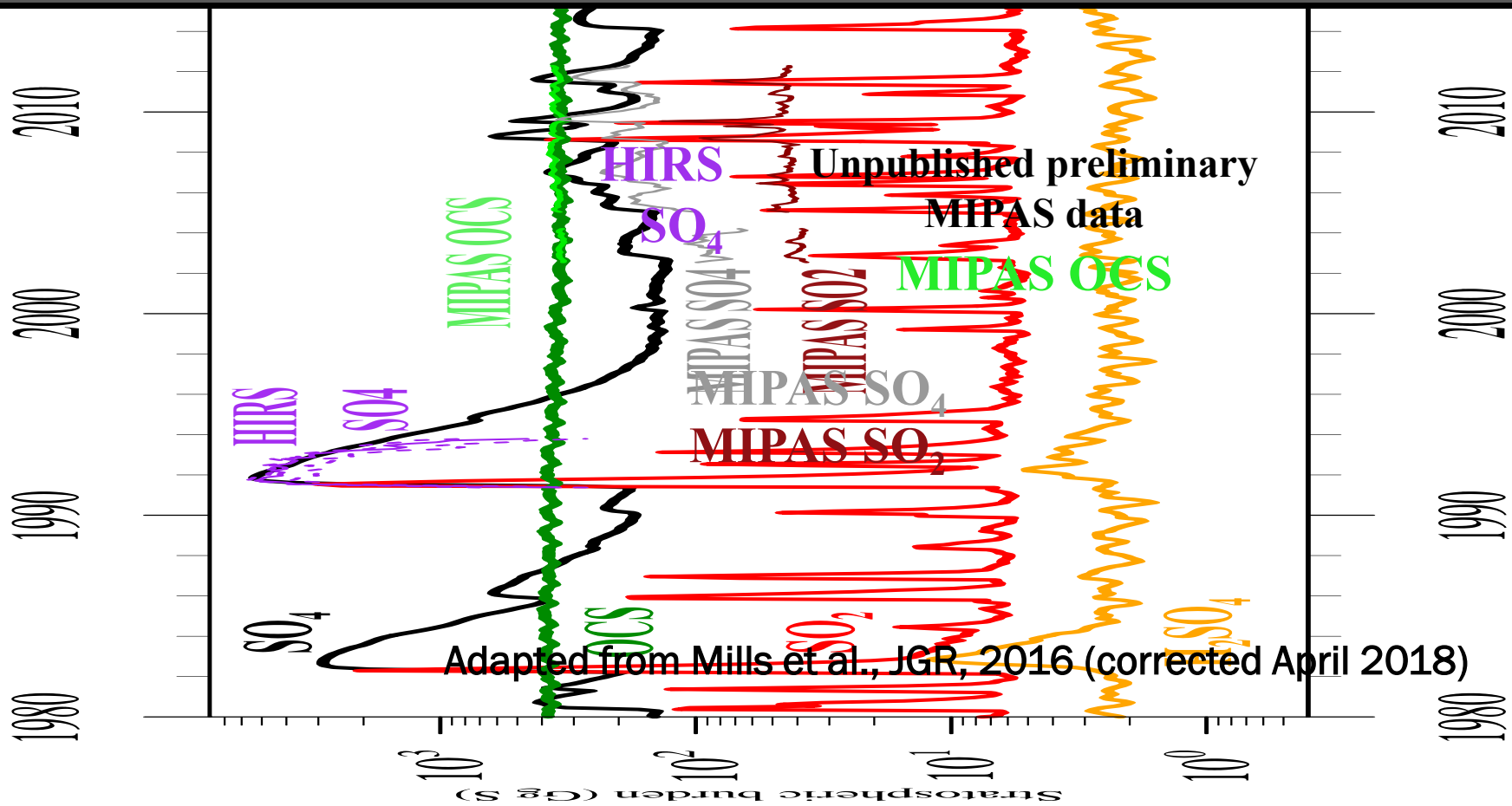


- Volcanic eruptions increasingly well characterized
  - Satellite retrievals, in-situ measurements, geochemical & geophysical monitoring
- 1979: first satellite retrieval of volcanic  $\text{SO}_2$ , from TOMS
- VolcanEESM  $\text{SO}_2$  database (Neely and Schmidt, 2016): 1850-2016
- **VEI** = volcanic explosivity index, a logarithmic measure of the energy released by an eruption



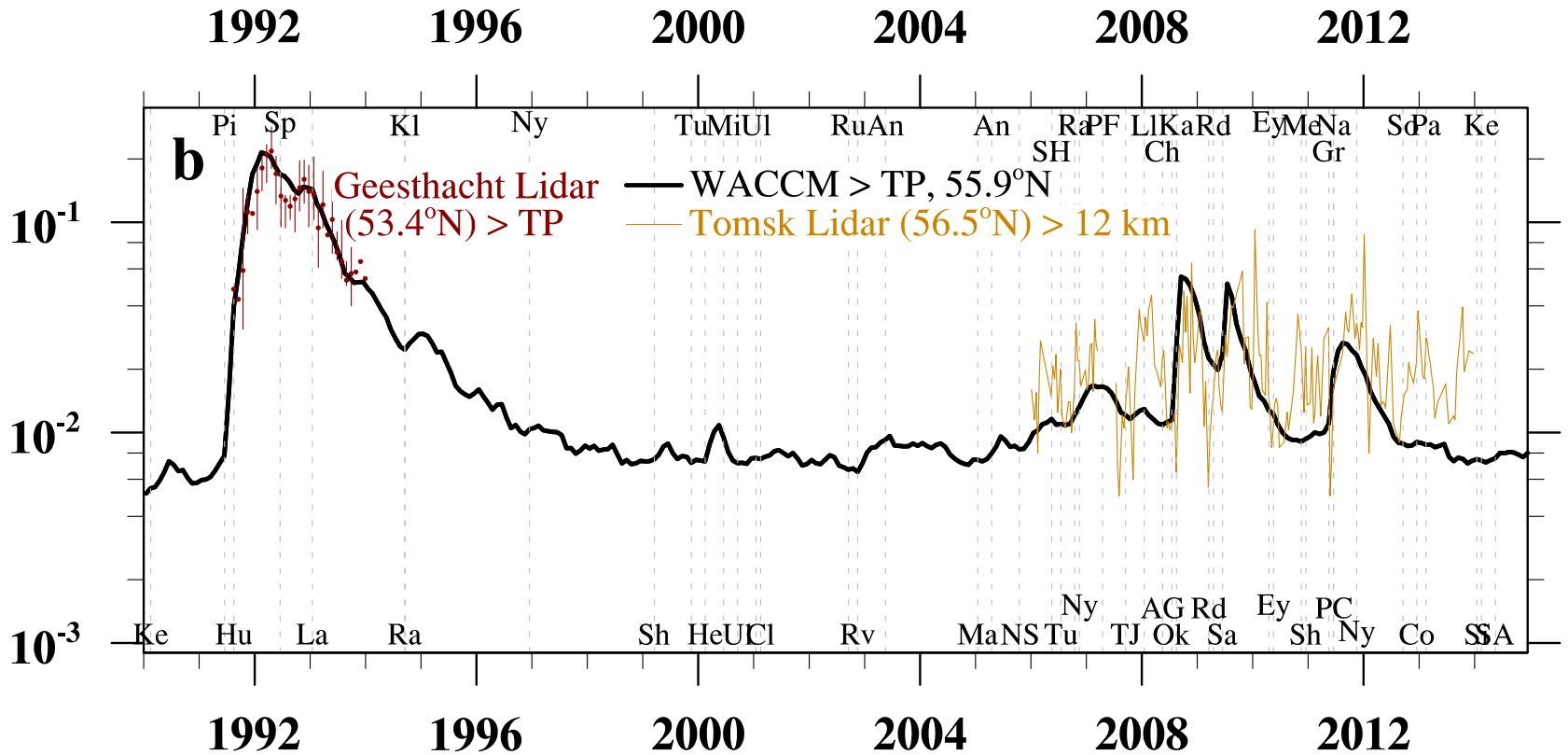


# WACCM 1980-2015: stratospheric sulfur burdens



**OCS: 360 Gg S, close to MIPAS (M. Höpfner)**  
**Volcanic SO<sub>4</sub> peaks at 5.3 Tg S in 1991,**  
**matching HIRS peak  $5.6 \pm 0.34$  Tg S**  
**What's going on with MIPAS SO<sub>2</sub>?**

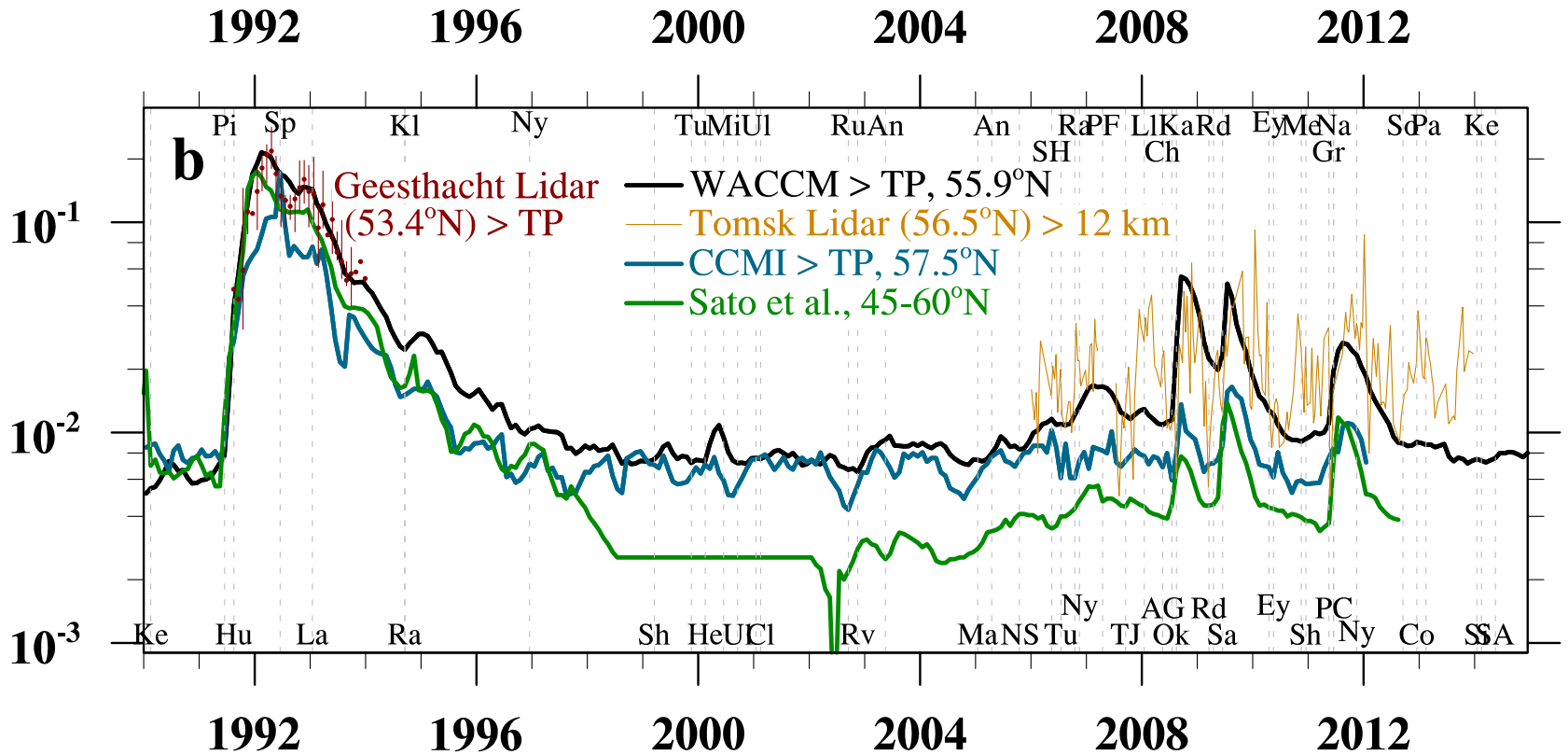
Aerosol Optical Depth, visible



## 2° SD-WACCM5 at Northern Mid-latitudes compared to lidars

Mills et al. (JGR, 2016)

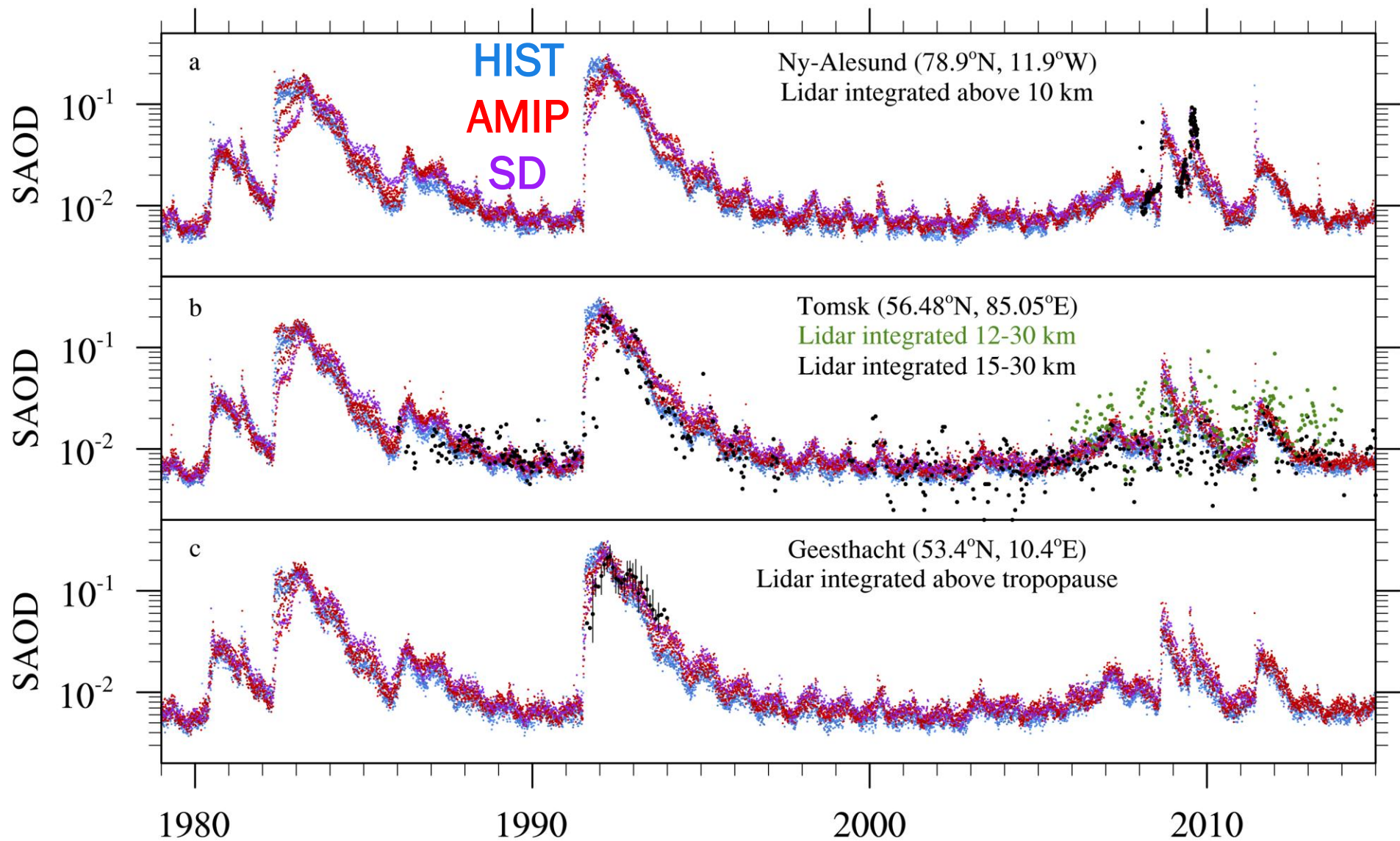
Aerosol Optical Depth, visible



**Previous climatologies were deficient  
in the lowermost stratosphere**

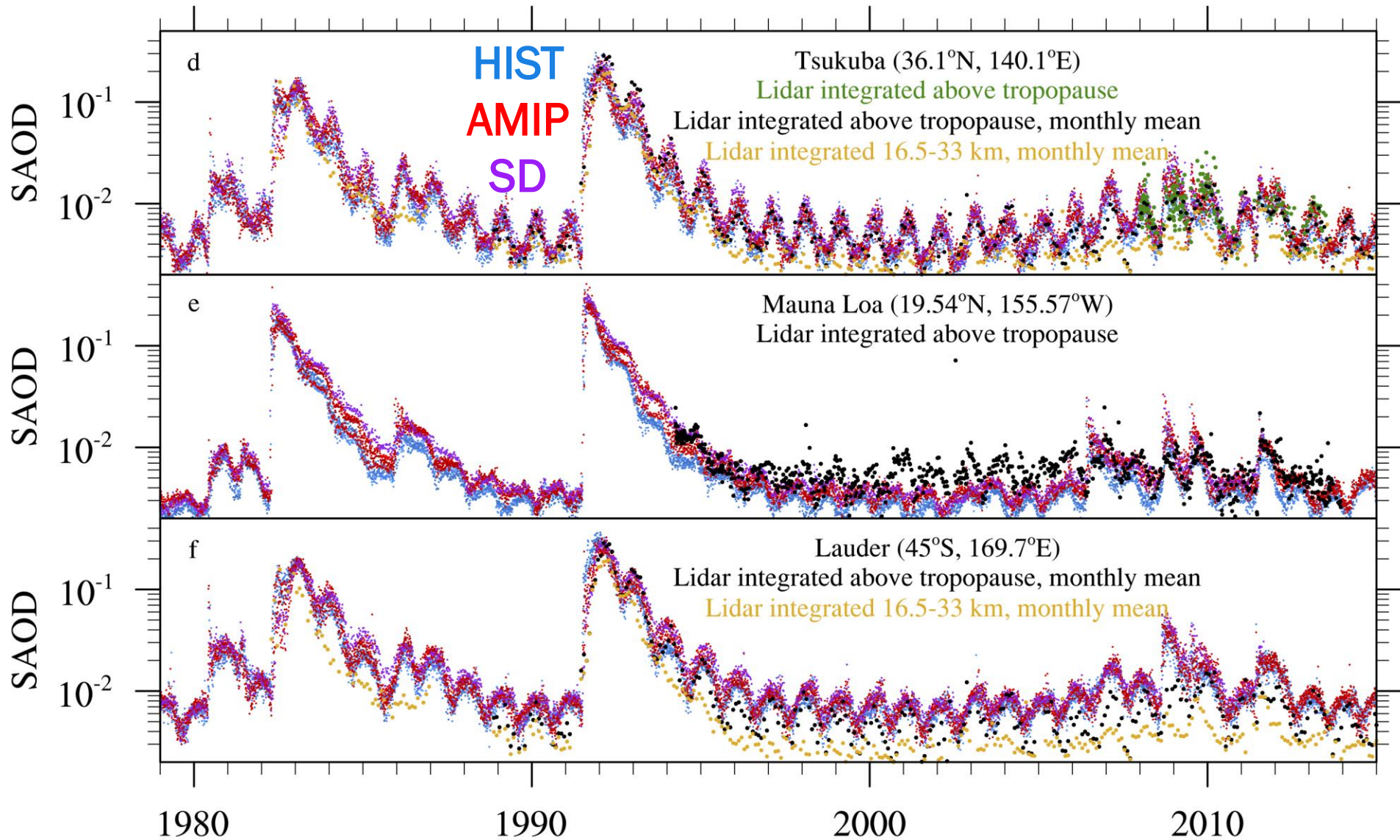
Mills et al. (JGR, 2016)

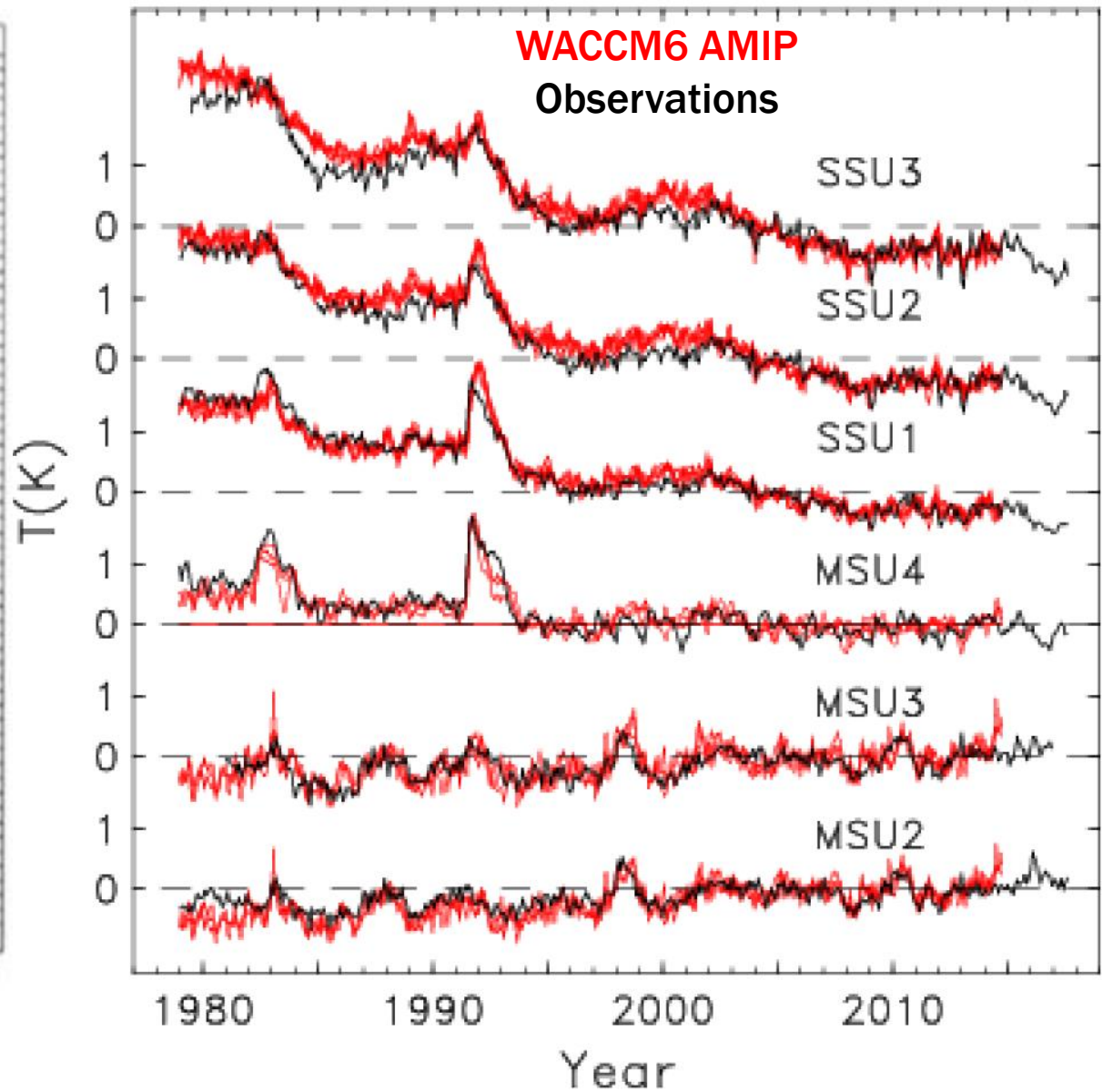
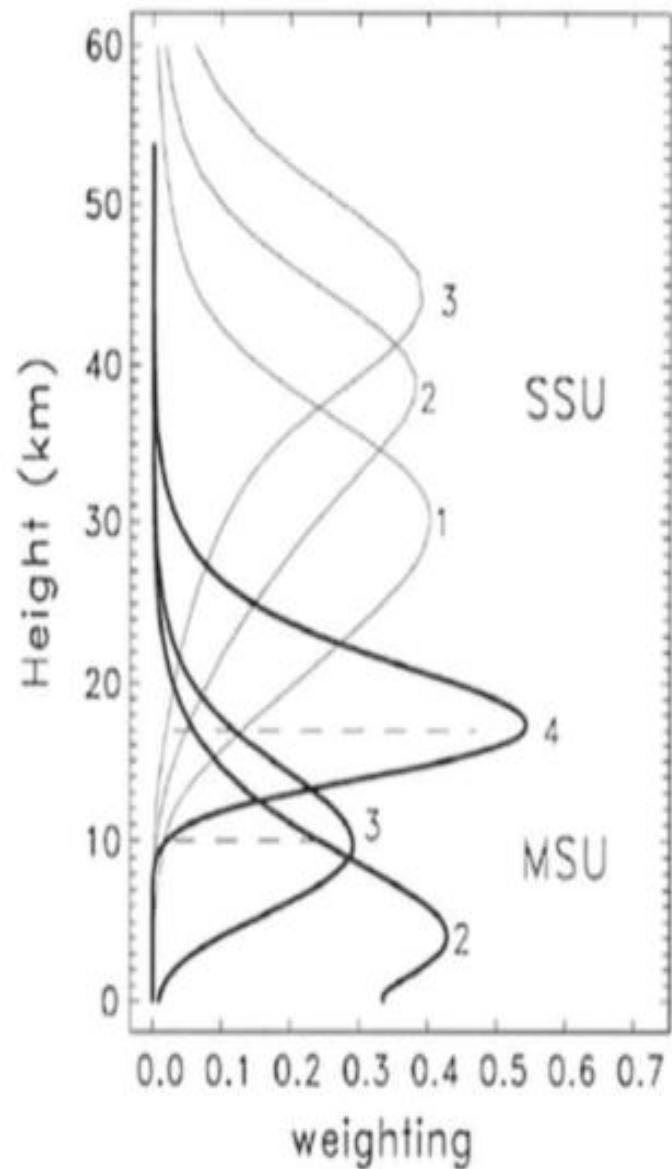
# WACCM6 SAOD compared to lidars





# WACCM6 SAOD compared to lidars

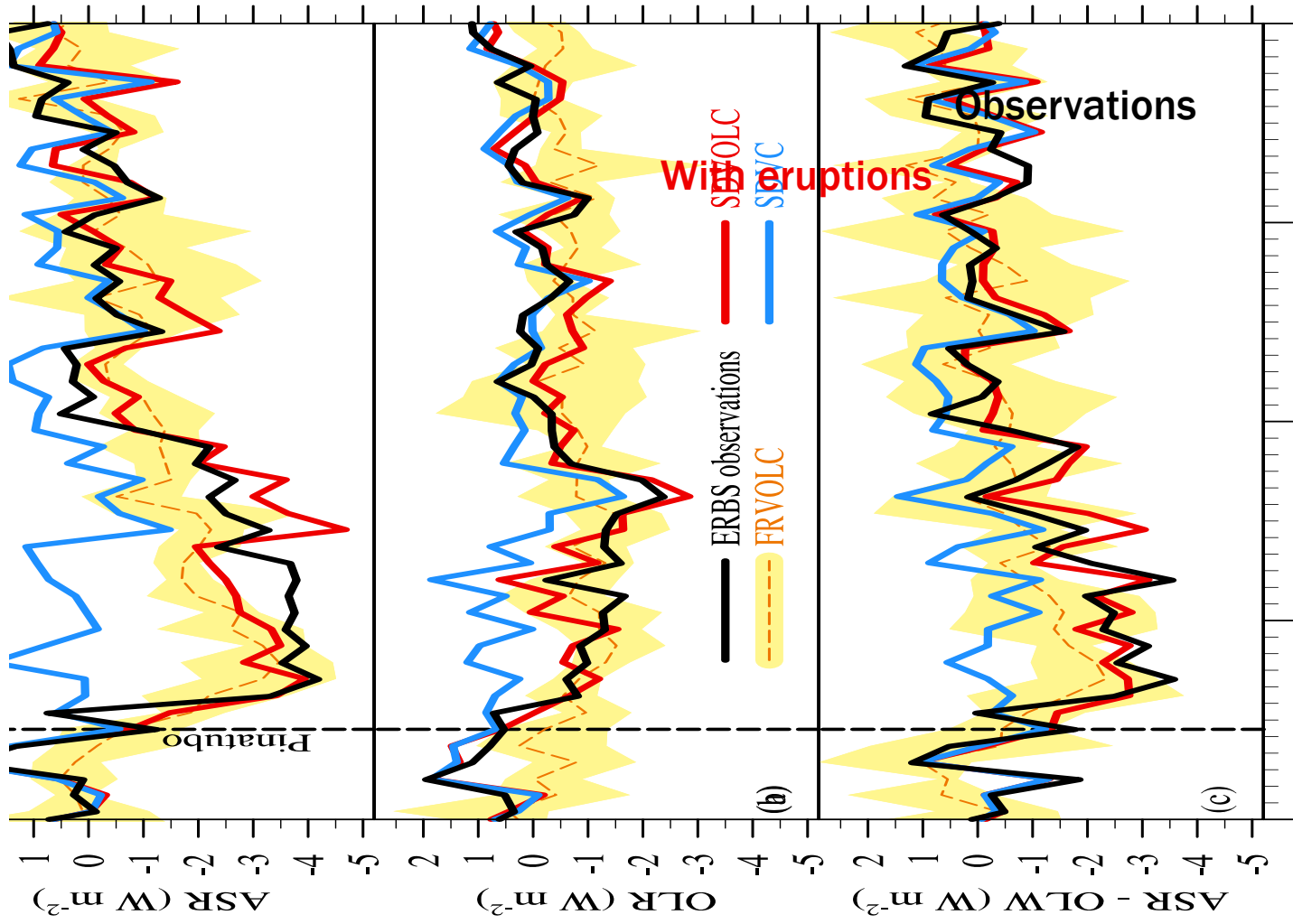




**WACCM6 AMIP** ensemble (3 realizations) global stratospheric temperatures compare very well to observations, including volcanic heating.  
 Figure courtesy of Fei Wu and Bill Randel, NCAR.



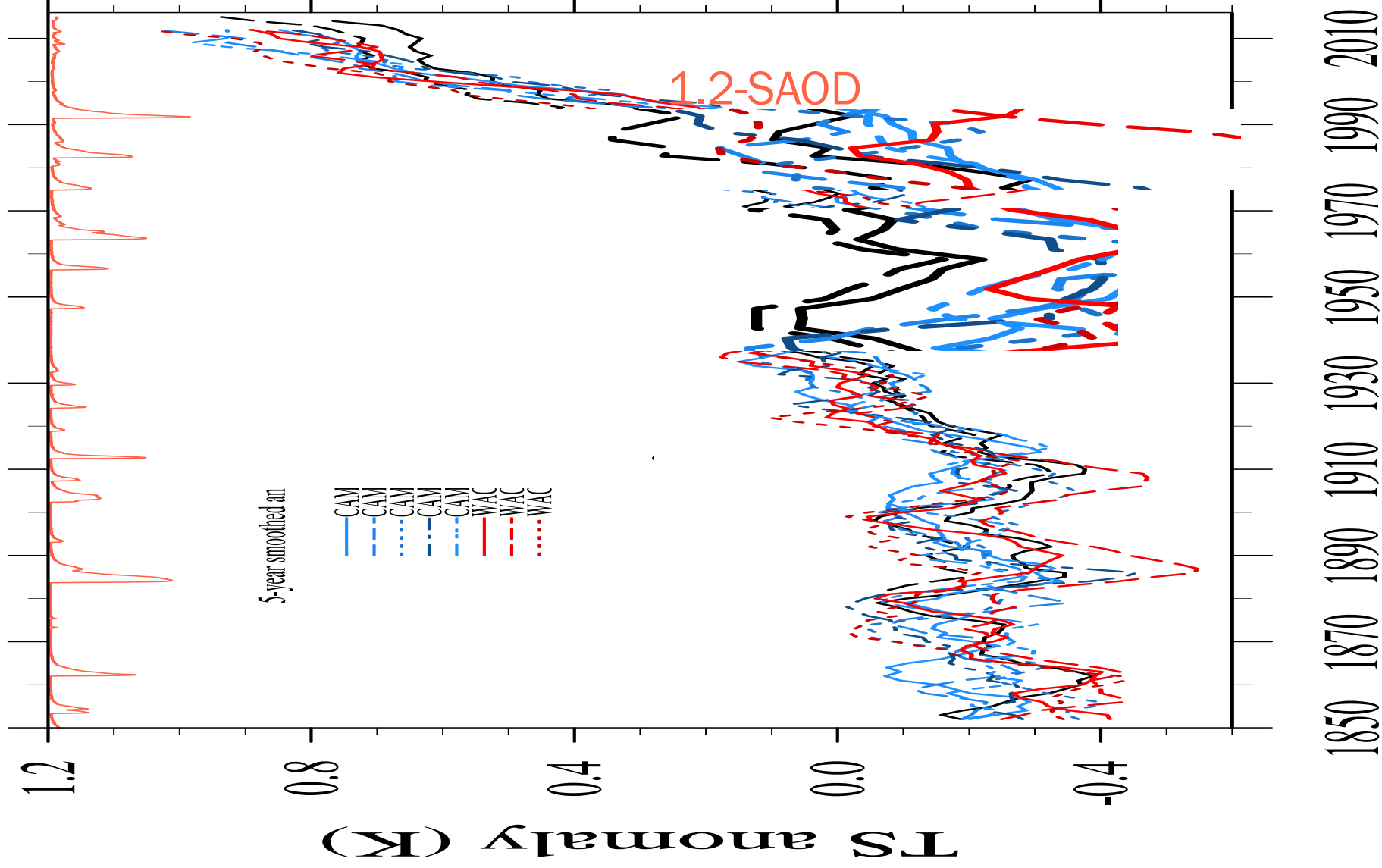
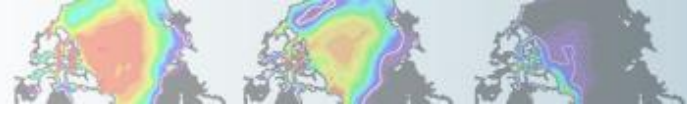
Without eruptions



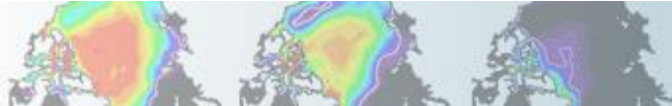
Absorbed  
shortwave  
(ASR)

Outgoing  
longwave  
(OLR)

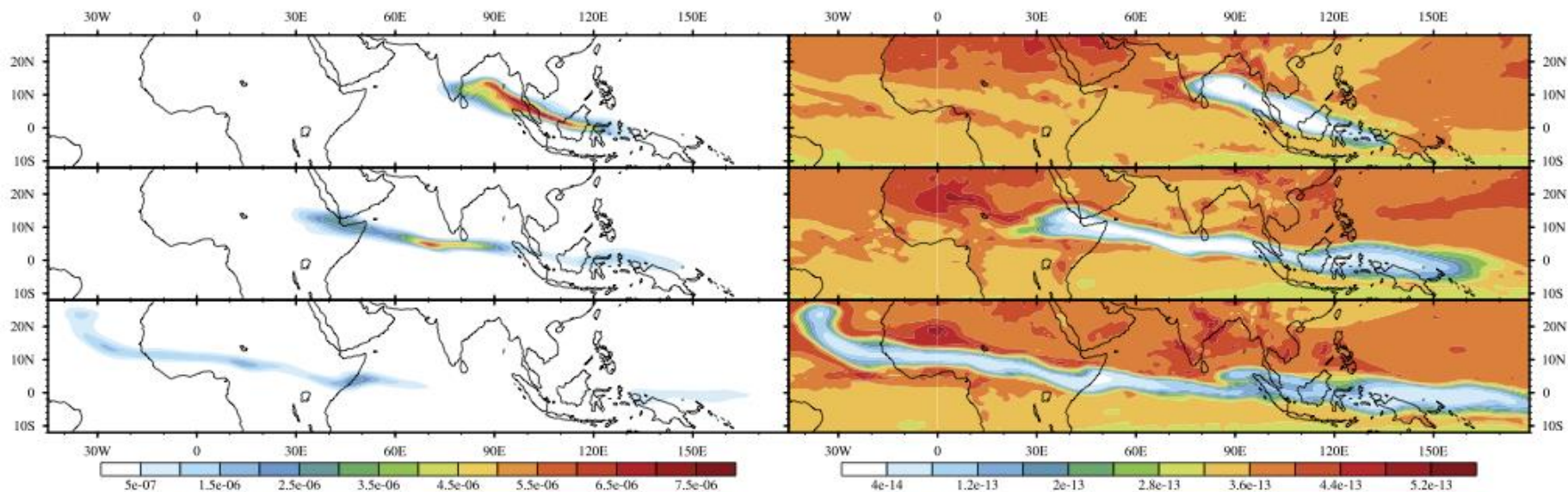
ASR-OLW







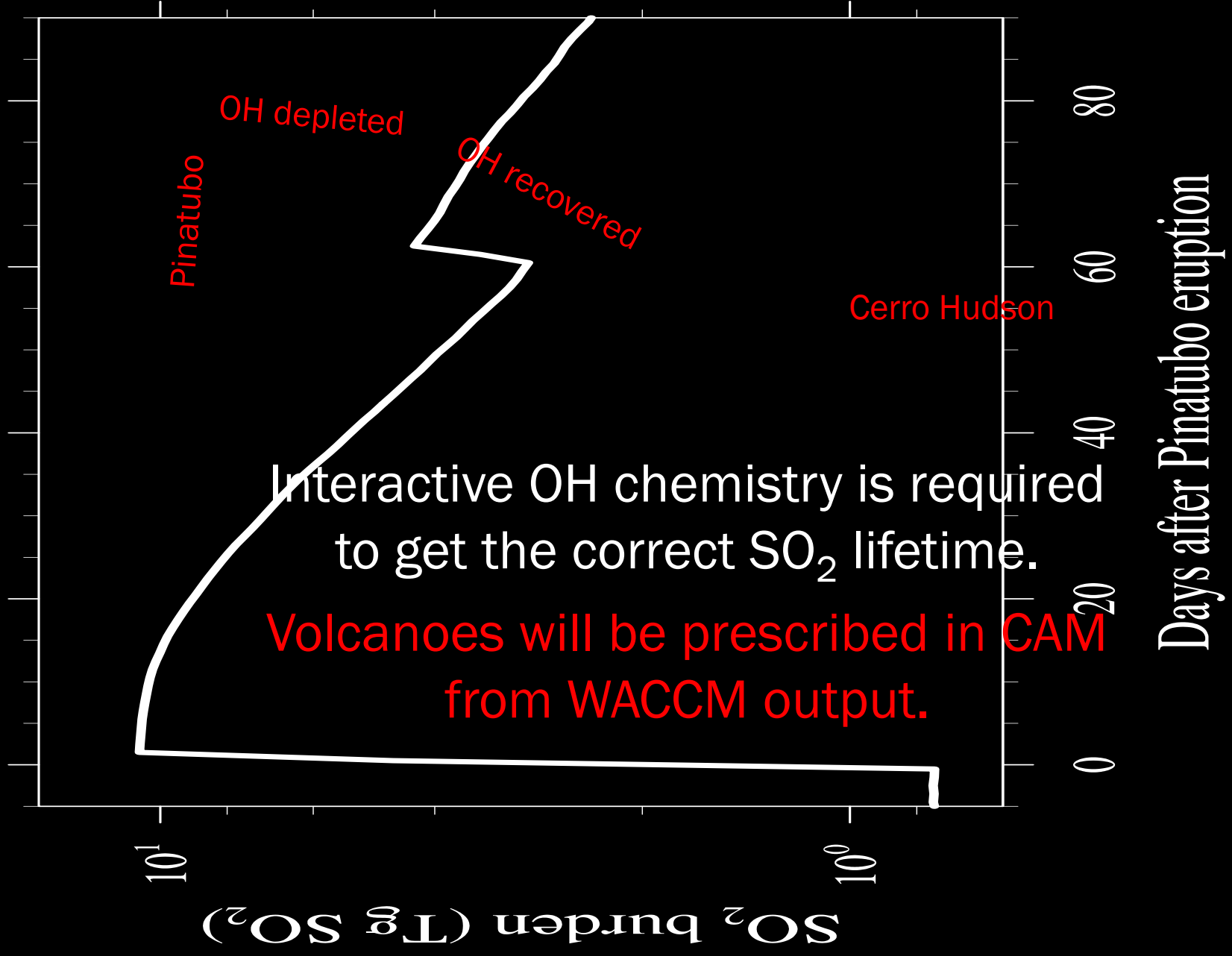
# Volcanic SO<sub>2</sub> cloud depletes OH



*Mills et al., JGR, 2017*

OH oxidizes SO<sub>2</sub> to sulfate aerosols



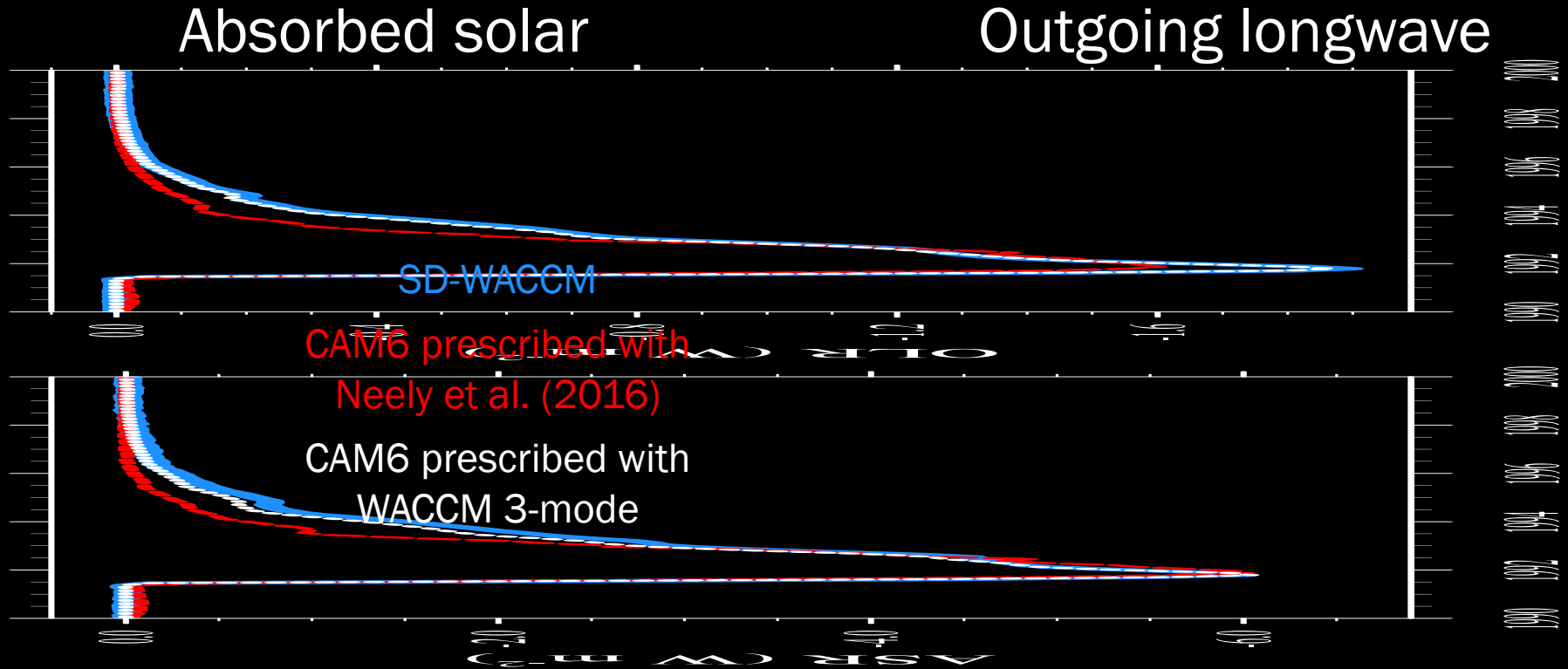


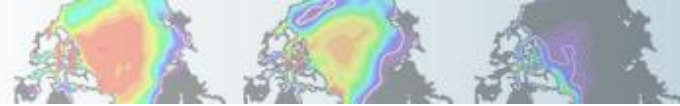


# CAM volcanoes prescribed from WACCM output

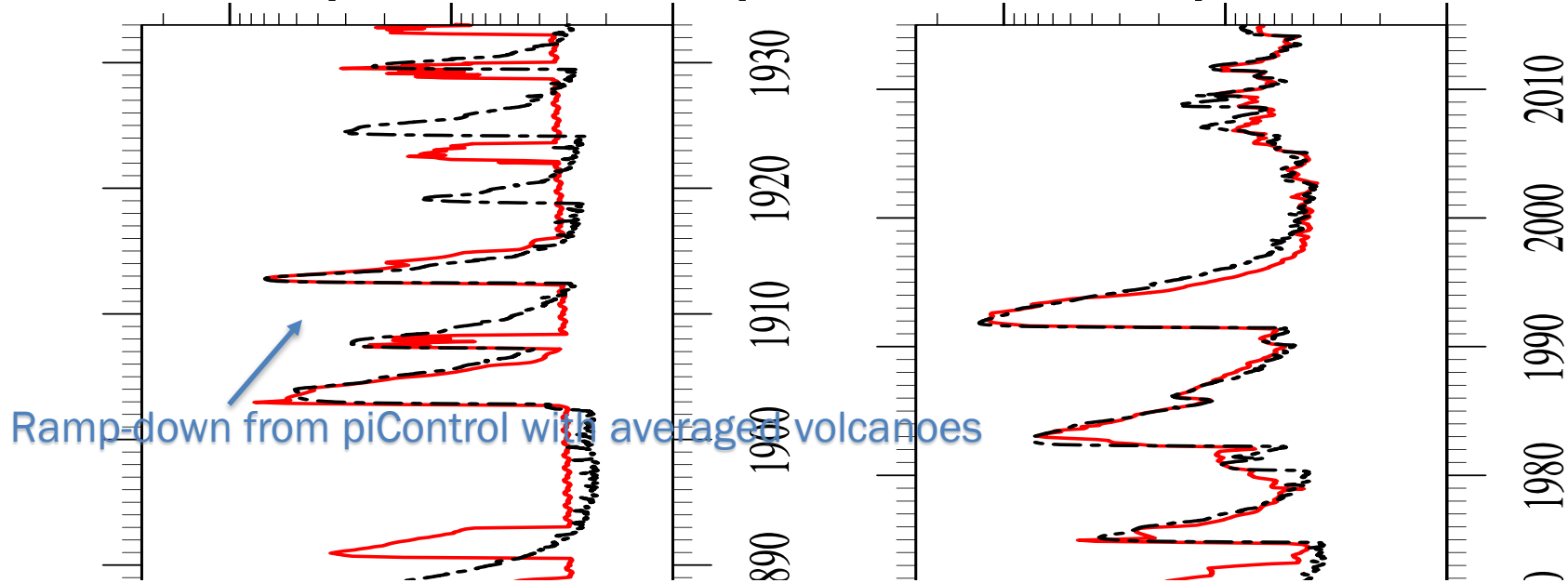
Information from all 3 sulfate aerosol modes used.

## Monthly global mean clearsky volcanic flux anomalies





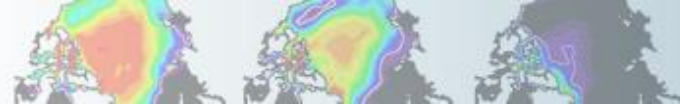
## CESM compared to CMIP6 prescribed stratospheric aerosols v3.0



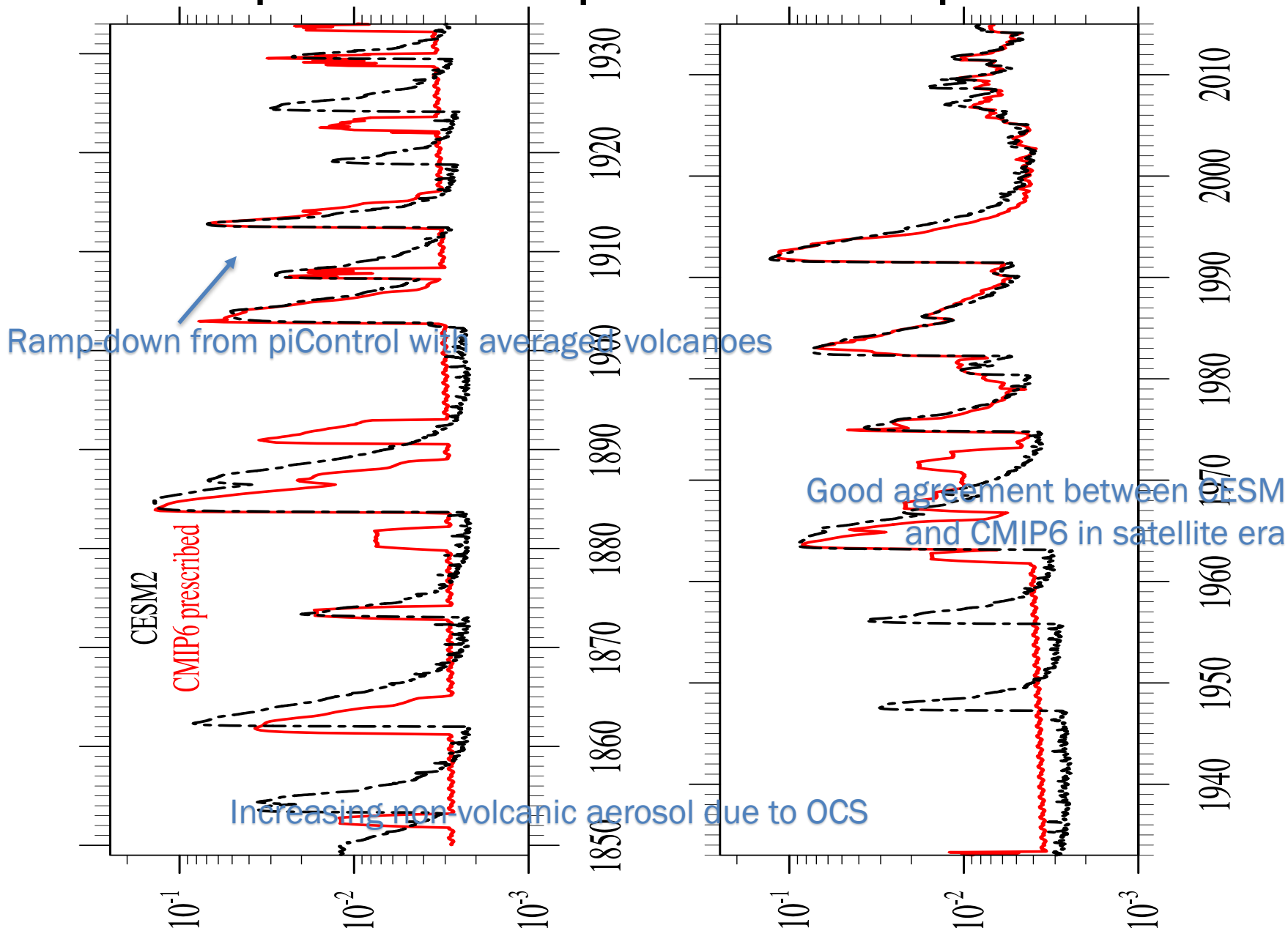
CMIP6 piControl: “Background volcanic aerosol that results in radiative forcing matching, as closely as possible, that was experienced, on average, during the historical simulation (i.e. 1850–2014 mean)” (Eyring et al., 2016)

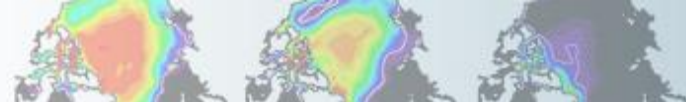
WACCM uses averaged 1850-2014 volcanic emissions in piControl. Historical simulations ramp down stratospheric aerosols from 1850 as the stratosphere naturally cleans out, until first eruption adds more aerosol in 1853.

CMIP6 prescribed stratospheric aerosols have an abrupt jump from piControl (not shown) to historical forcing.



## CESM compared to CMIP6 prescribed stratospheric aerosols v3.0



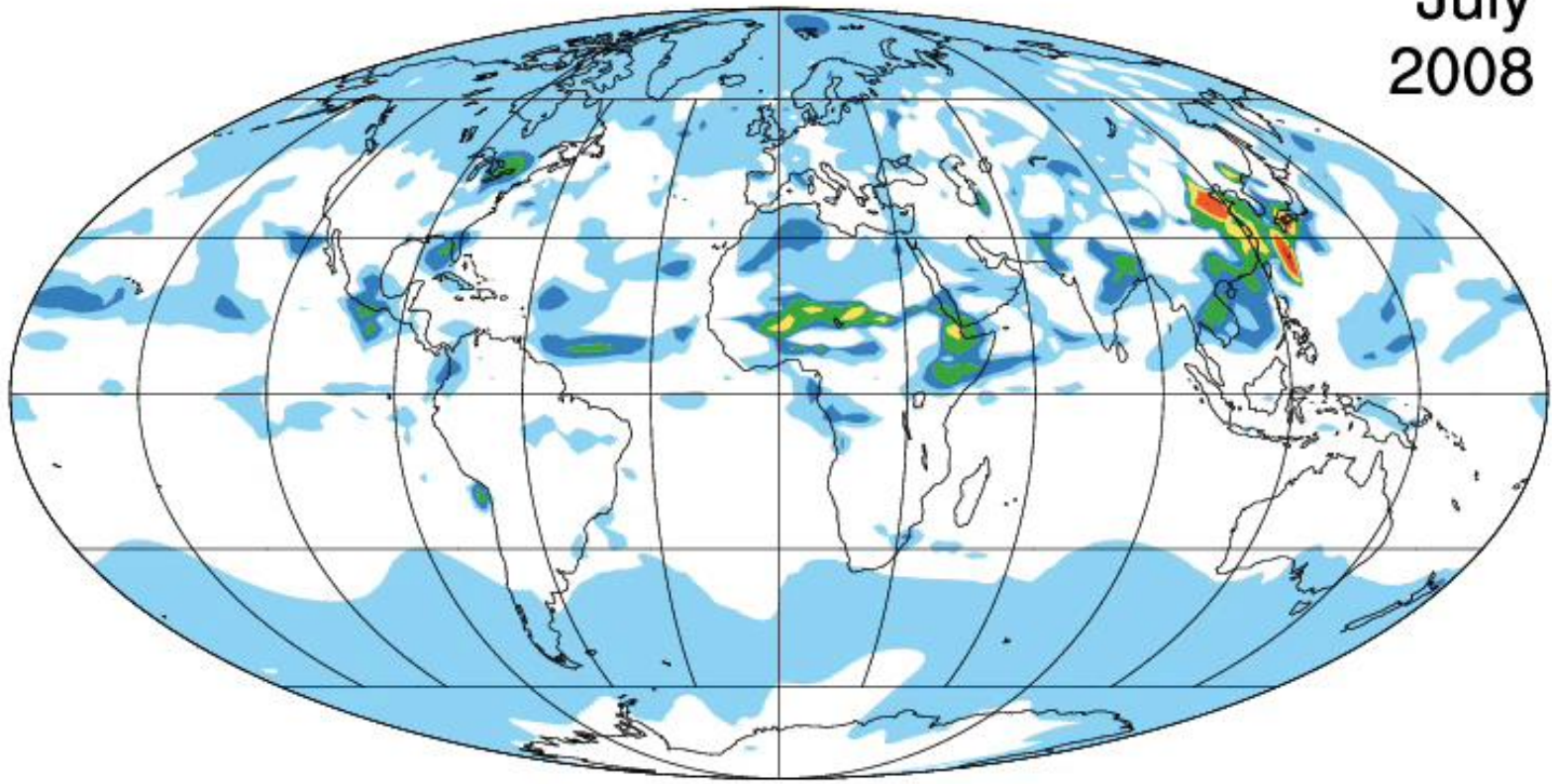


# Summary

- Prognostic volcanic aerosol from SO<sub>2</sub> emissions has been validated in WACCM, with significant improvements over volcanoes prescribed from observations.
- Due to lack of interactive OH chemistry, volcanoes will be prescribed in CAM from WACCM output. Information from all aerosol modes is used, forcing with excellent agreement to WACCM.
- CESM2 volcanoes derived from emissions differ from CMIP6 prescribed volcanoes used by other models, but agreement post-1979 is excellent.



July  
2008



Volcanic Aerosol Column Burden ( $\text{kg S m}^{-2}$ )

