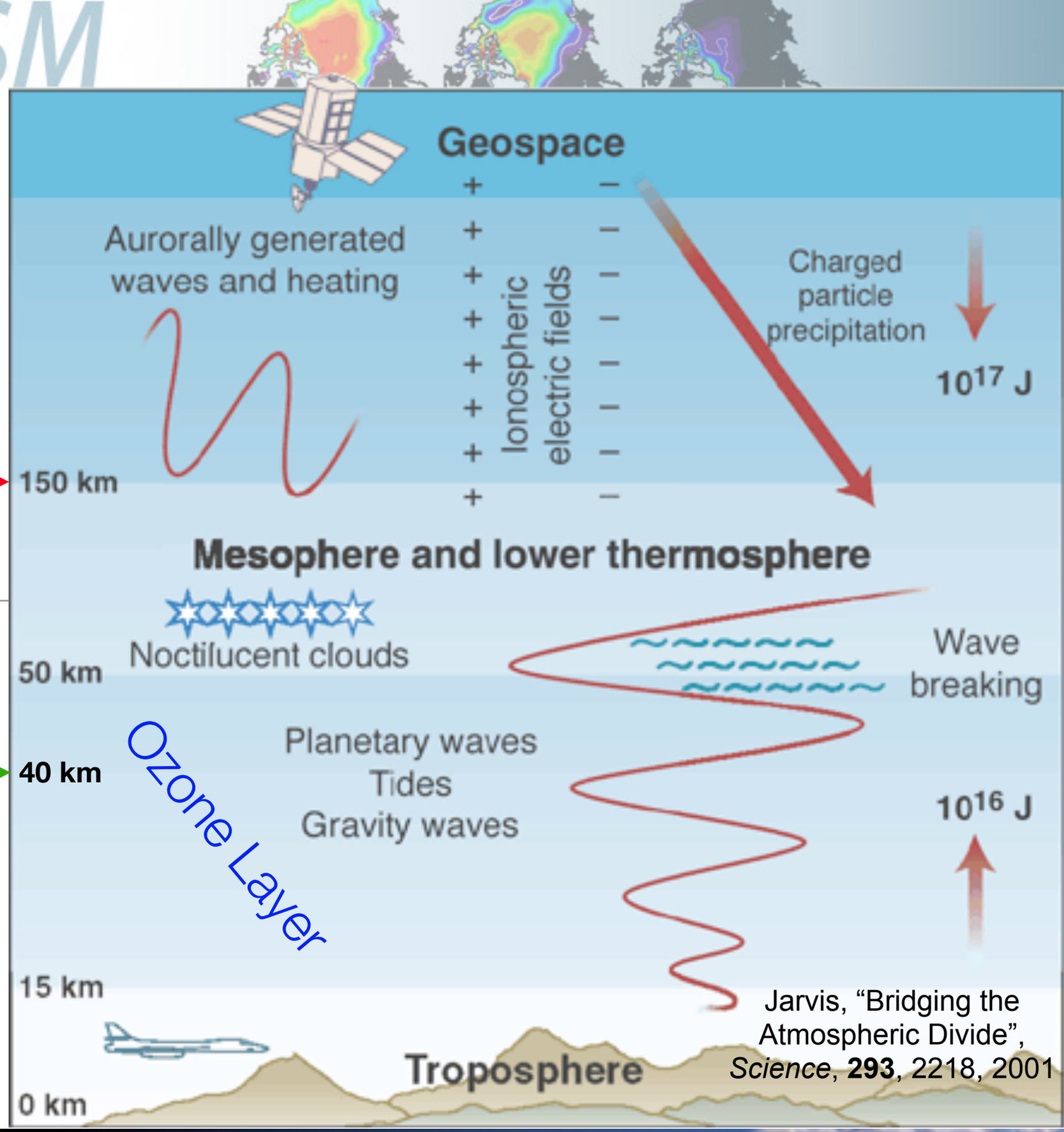
Community Earth System Model

CESM

WACCM: The High-Top Model



Jarvis, "Bridging the Atmospheric Divide", *Science*, **293**, 2218, 2001

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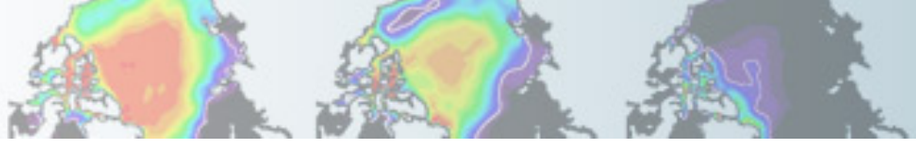
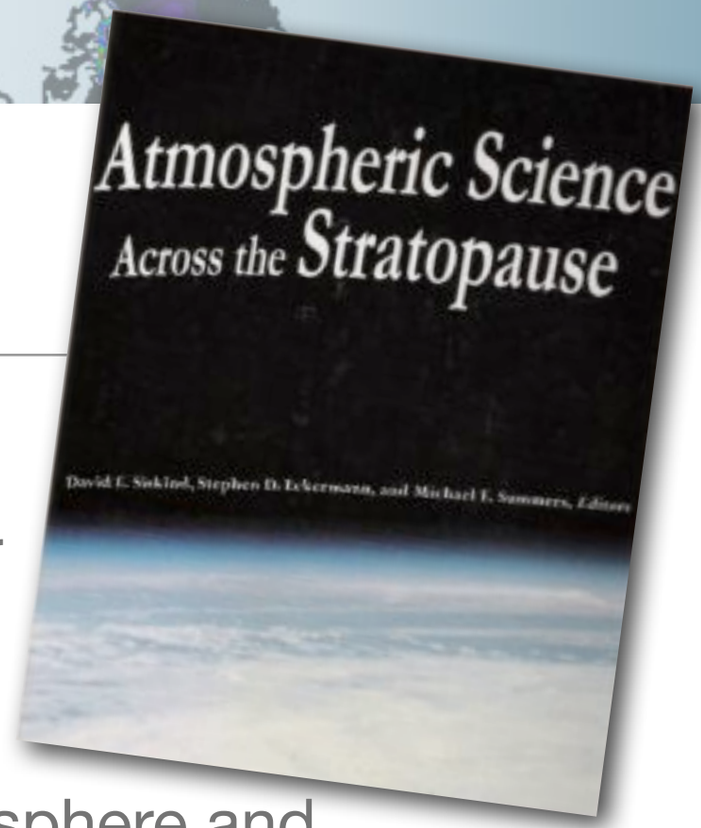


WACCM Additions to CAM

- Extends from surface to 5.1x10^{-6} hPa (~150 km), with 66 vertical levels
- Detailed neutral chemistry model for the middle atmosphere,
  - catalytic cycles affecting ozone
  - heterogeneous chemistry on PSCs and sulfate aerosol
  - heating due to chemical reactions
- Model of ion chemistry in the mesosphere/lower thermosphere (MLT), ion drag, auroral processes, and solar proton events
- EUV and non-LTE longwave radiation parameterizations
- Imposed QBO, based on cyclic, fixed-phase, or observed winds
- Volcanic aerosol heating calculated explicitly
- Gravity wave drag deposition from vertically propagating GWs generated by orography, fronts, and convection
- Molecular diffusion and constituent separation
- Thermosphere extension (WACCM-X) to ~500 km

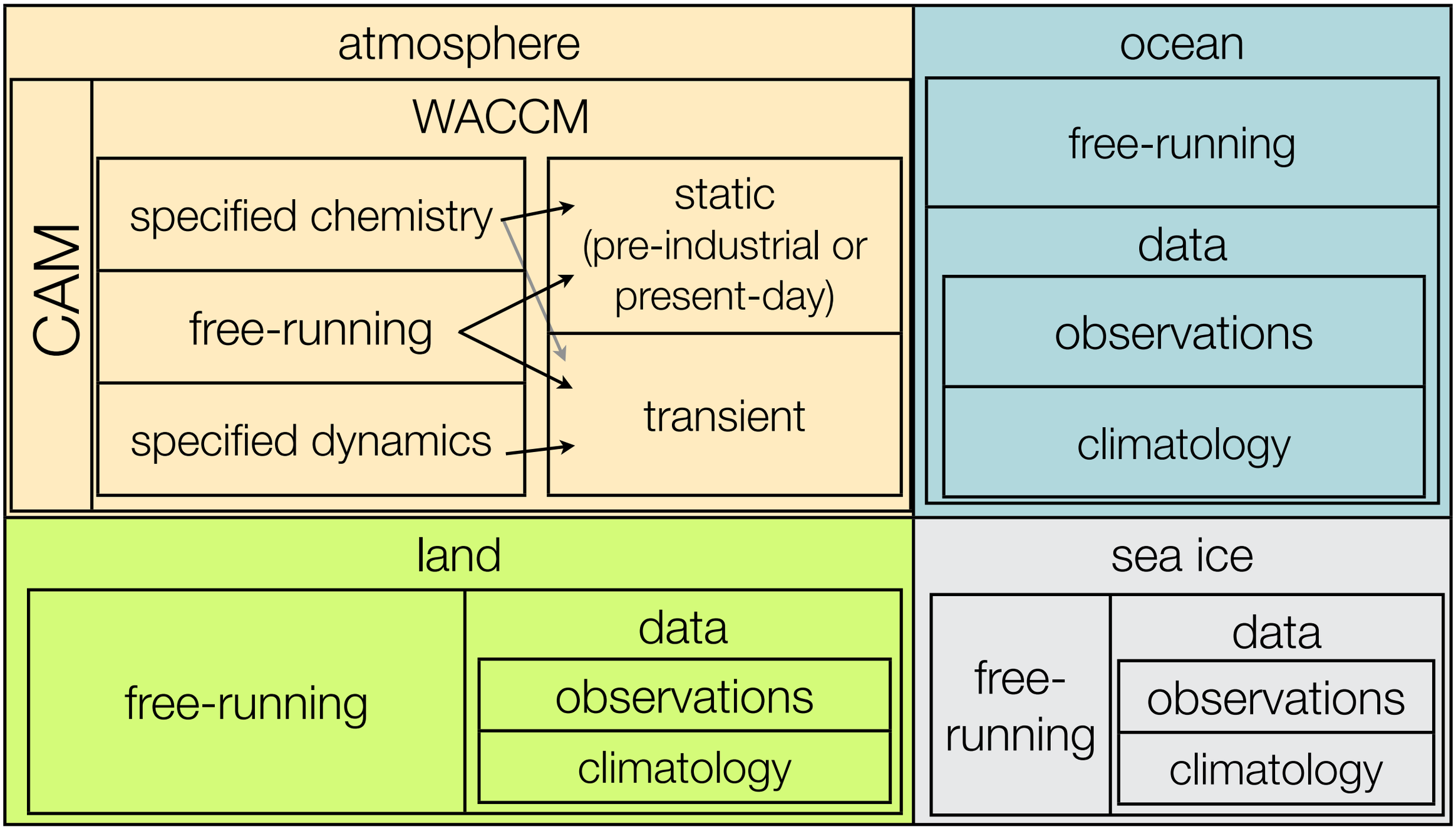
WACCM Motivation

Roble, Geophysical Monograph, **v. 123**, p. 53, 2000

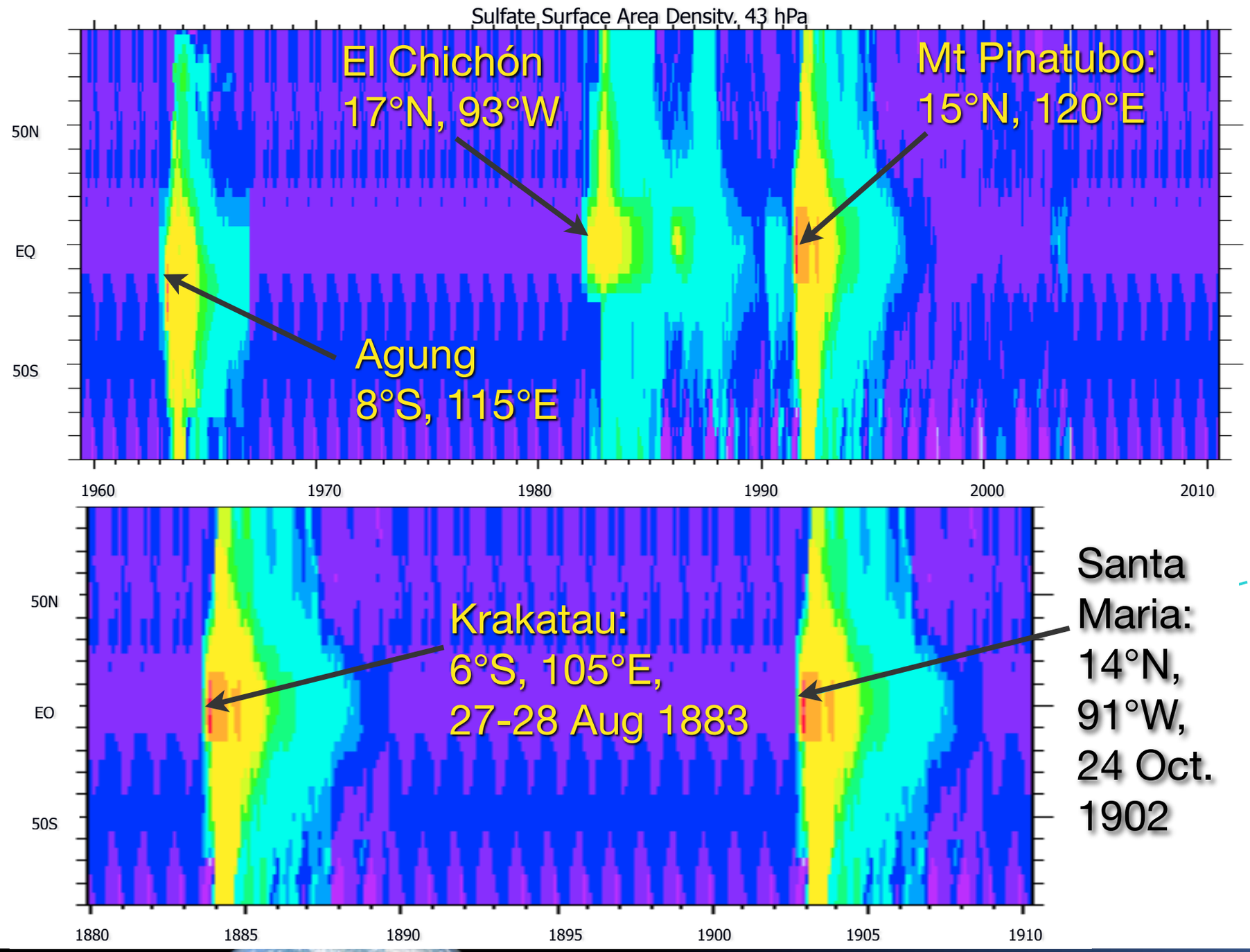


- Coupling between atmospheric layers:
  - Waves transport energy and momentum from the lower atmosphere to drive the QBO, SAO, sudden warmings, mean meridional circulation
  - Solar inputs, e.g. auroral production of NO in the mesosphere and downward transport to the stratosphere
  - Stratosphere-troposphere exchange
- Climate Variability and Climate Change:
  - What is the impact of the stratosphere on tropospheric variability?
  - How important is coupling among radiation, chemistry, and circulation? (e.g., in the response to O_3 depletion or CO_2 increase)
  - Response to solar variability: impacts mediated by chemistry?
- Interpretation of Satellite Observations

CESM-WACCM component configurations



Stratospheric Sulfate Surface Area Density Climatology

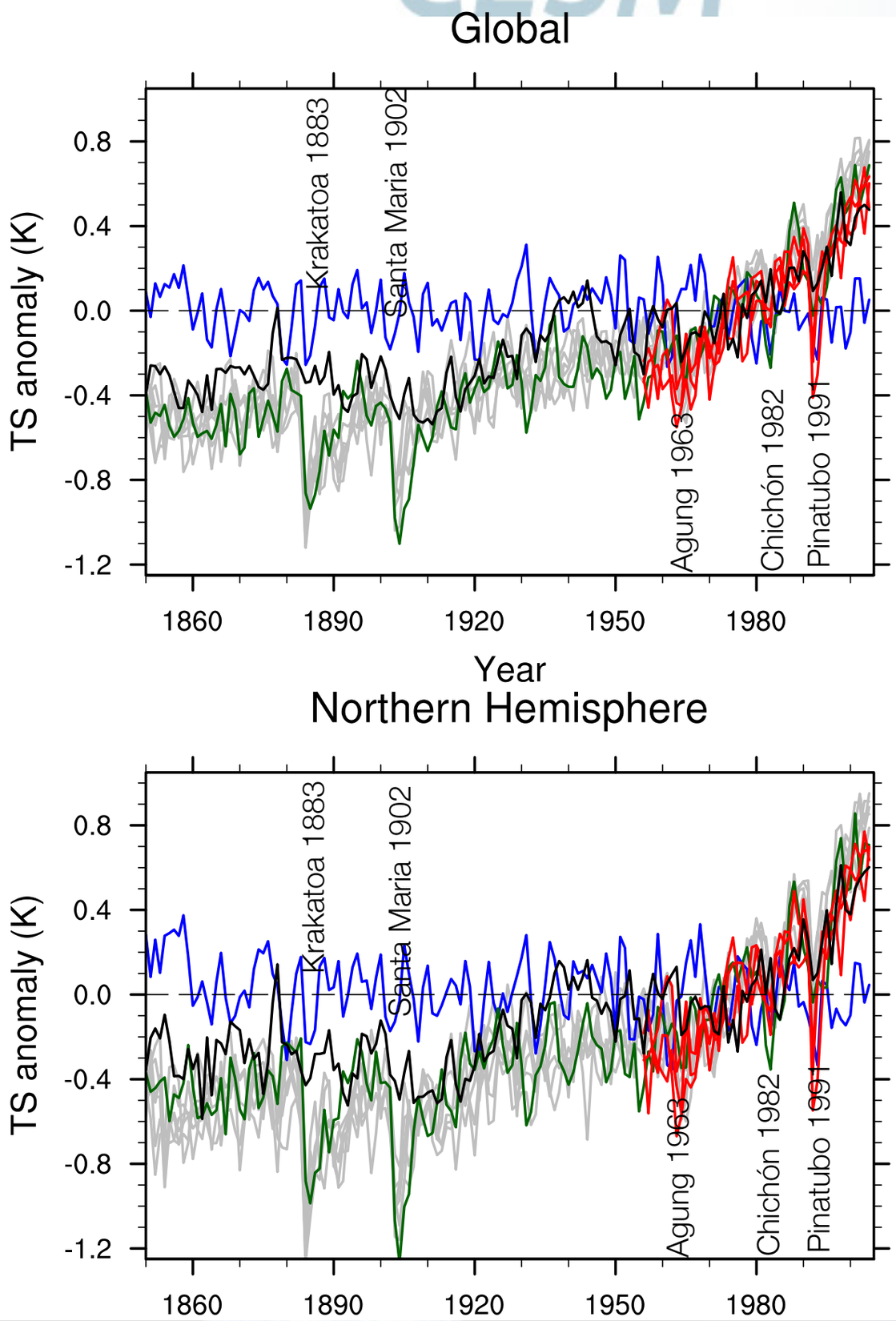


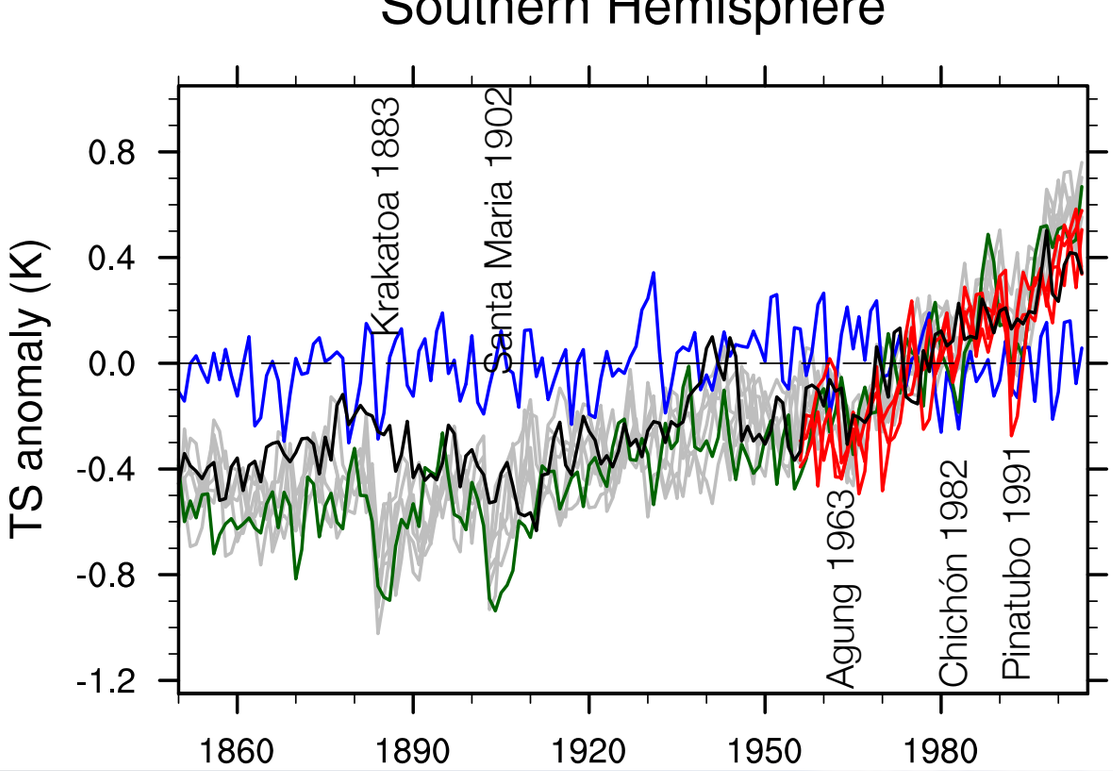
- Observations used: SAGE I, SAGE II, SAM II, and SME instruments.
- Non-volcanic periods filled with monthly mean of 1998-2002 values.
- Used Pinatubo aerosol for Krakatau and Santa Maria.

Surface Temperature Anomalies

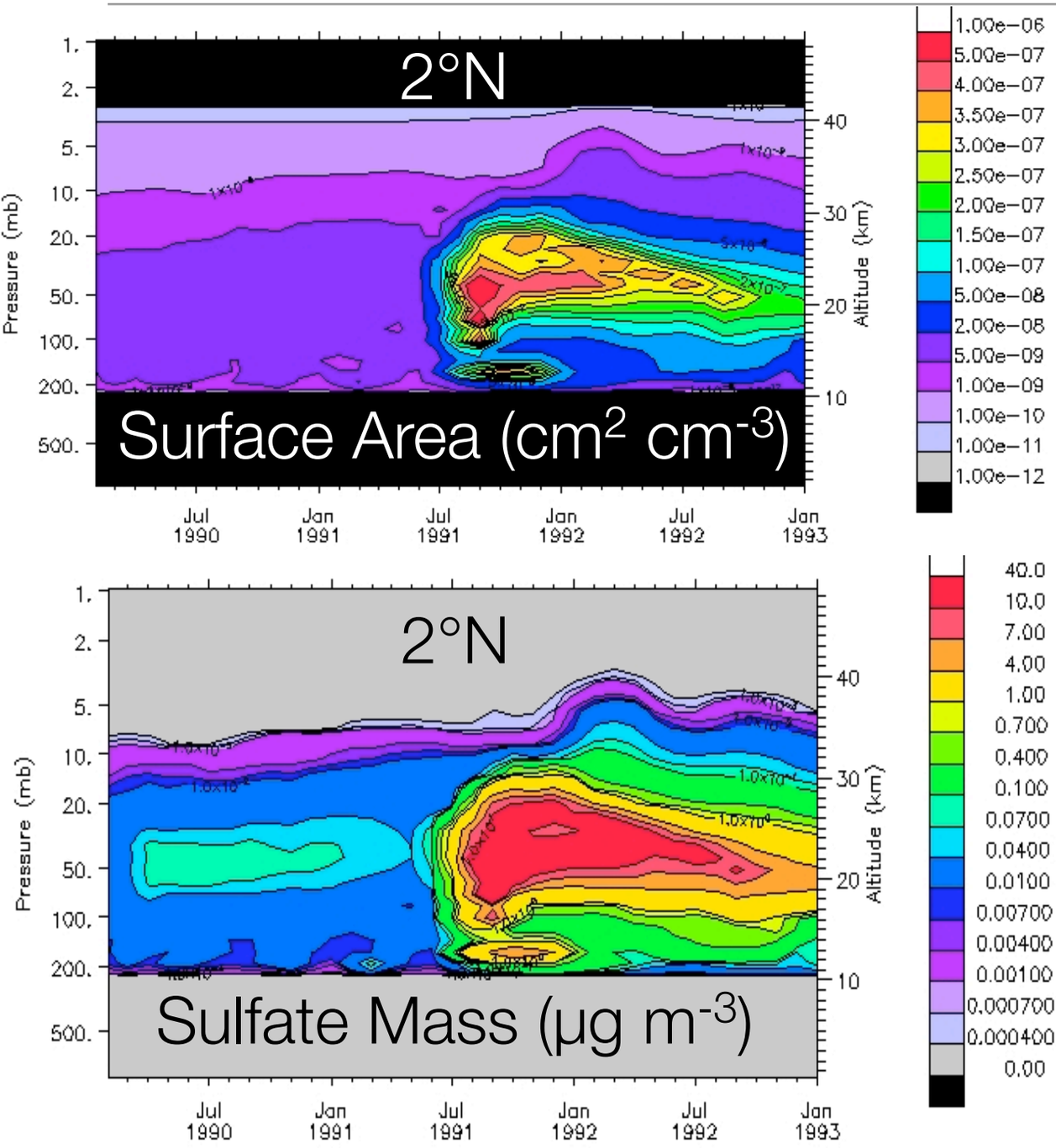
normalized to 1961-90

- CCSM-CAM4 1deg
- WACCM4 Pre-Indusrtrial
- WACCM4 20th Century
- WACCM4 1955-2005
- Observations (HadCRUT3)

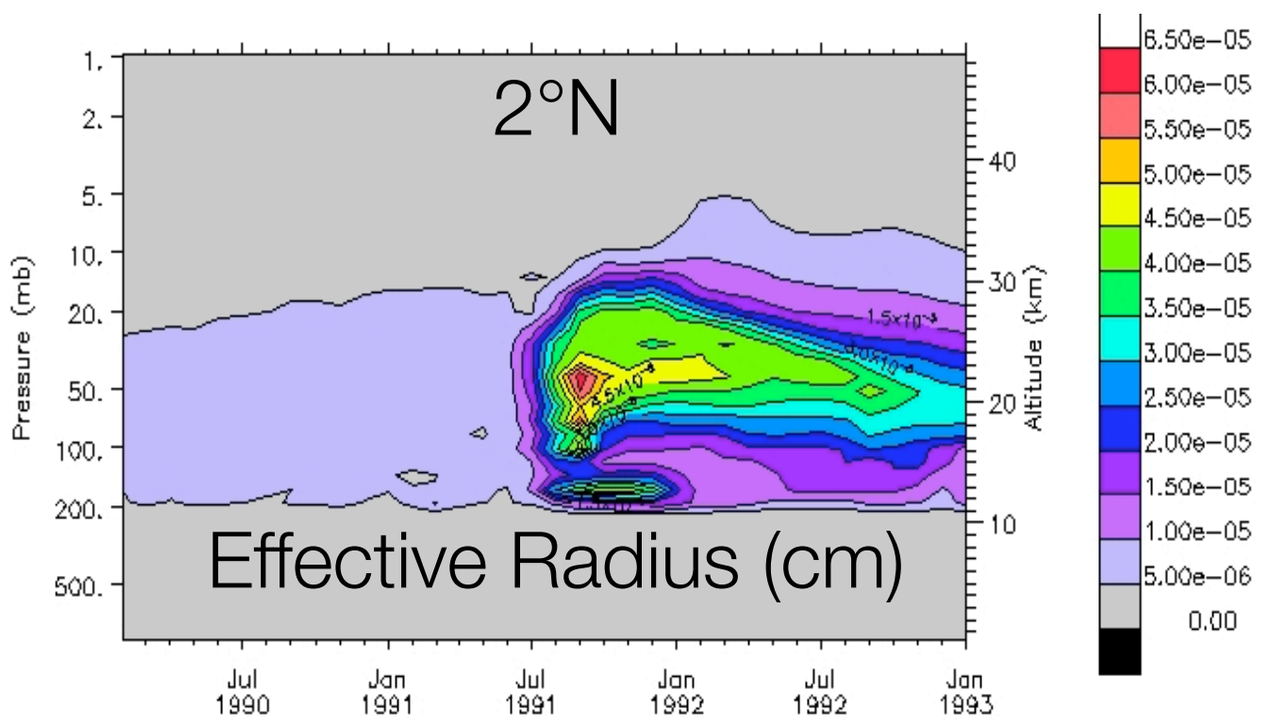




Volcanic heating in WACCM



Multiple aerosol independent parameters derived from observations used as inputs.



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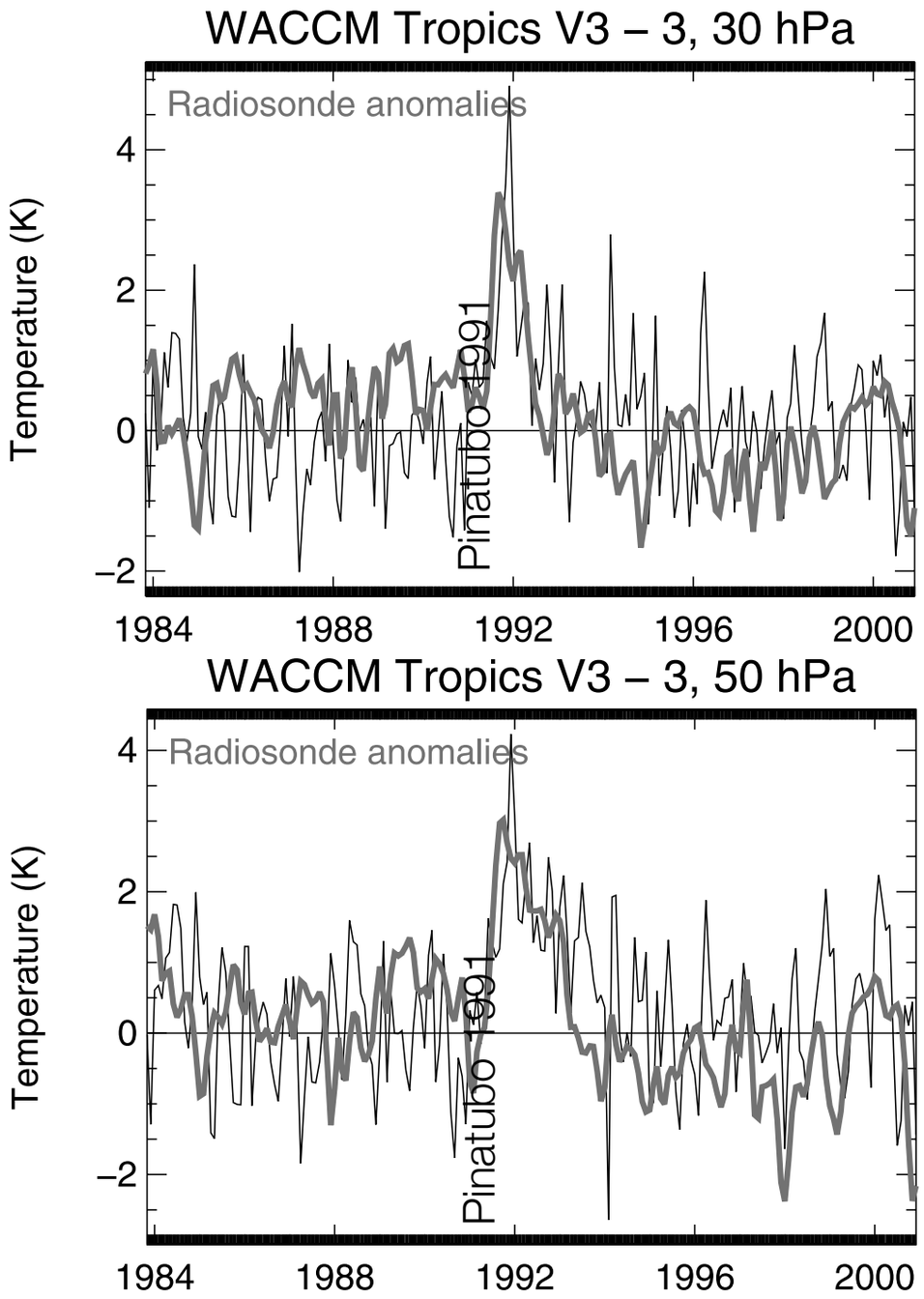
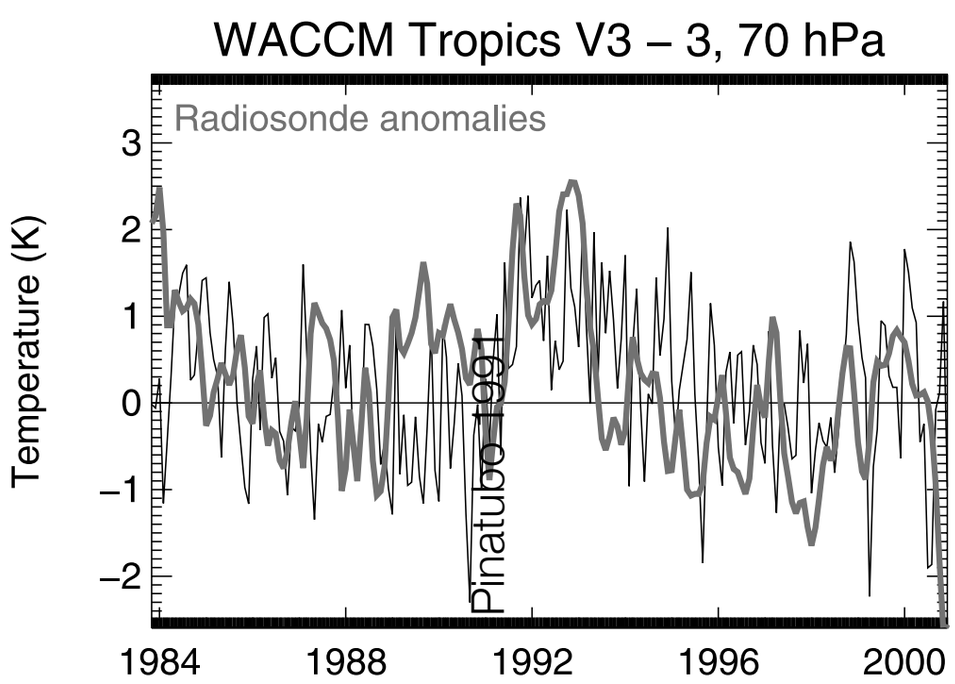
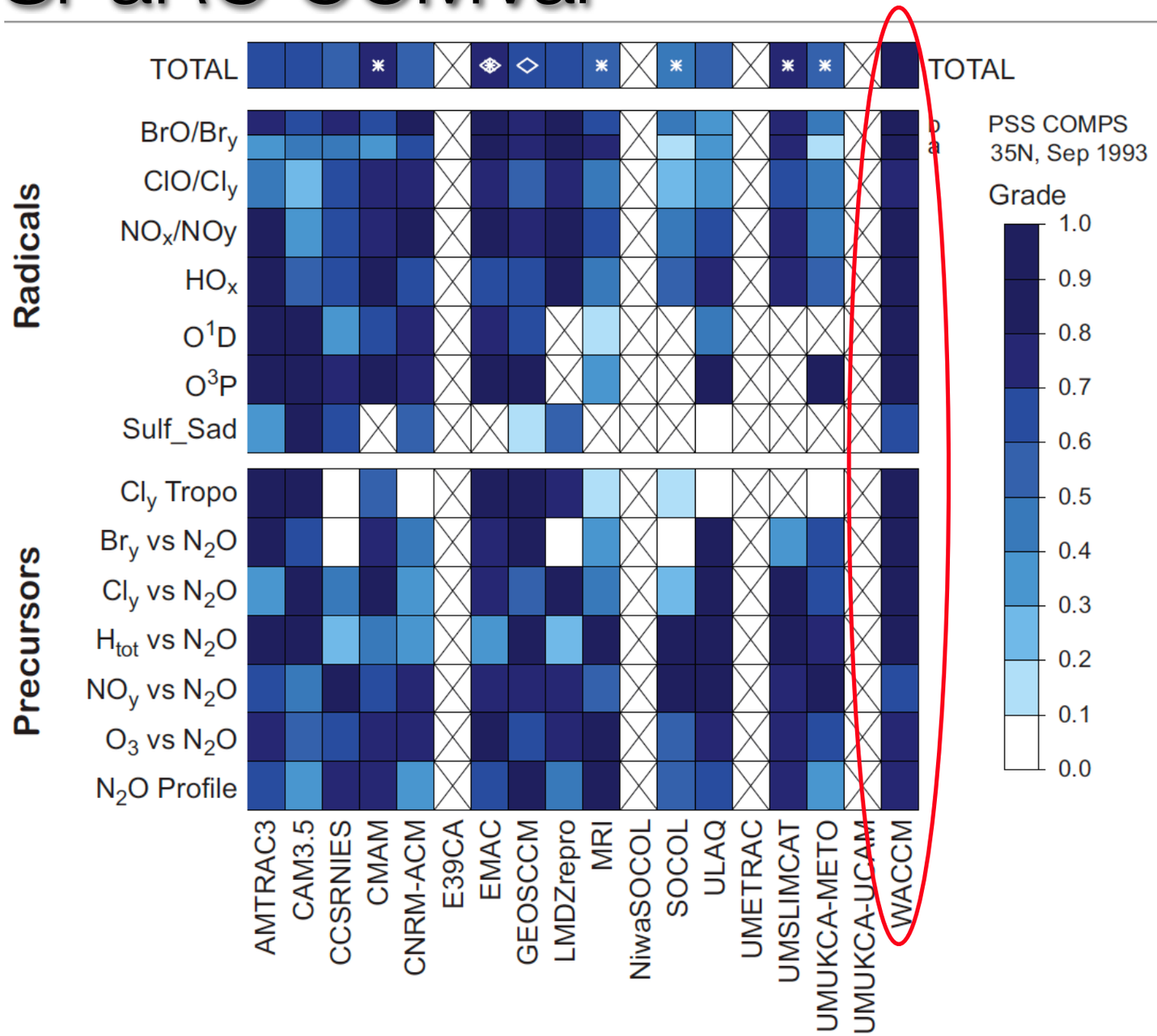




Temperature anomalies calculated with WACCM (black lines) and observed (grey lines) at pressures in the lower stratosphere (Tilmes *et al.*, 2009)

Grading of Chemistry in CCMs: Chapter 6 of the SPaRC CCMVal



- CCMs were evaluated on their ability to represent long-lived constituents (precursors) and short-lived substances (radicals).
- WACCM graded out high in all categories (i.e., grade of 1 is the highest possible).
- This is a reflection of the:
  1) completeness of the chemical processes included
  2) accuracy of photolysis rates (J's)
  3) and accuracy of the numerical solution approach.

SPARC CCMVal, Report on the Evaluation of Chemistry-Climate Models, V.Eyring, T. G. Shepherd, D. W. Waugh (EDs.), SPARC Reprot No.4, WCRP-X, WMO/TD-No. X, http://www.atmosp.physics.utoronto.ca/SPARC, 2010.

WACCM Heterogeneous Chemistry Module

Temperature

Sulfate Aerosols (H_2O, H_2SO_4) - LBS

R_{lbs} = 0.1 μm

>200 K

Sulfate Aerosols (H_2O, HNO_3, H_2SO_4) - STS

R_{sts} = 0.5 μm

Thermo. Model (Tabazadeh)

?

Nitric Acid Hydrate (H_2O, HNO_3) – NAT

$R_{NAT} = f$ {Log Normal Size; # particles cc; width distribution; condensed phase HNO_3}

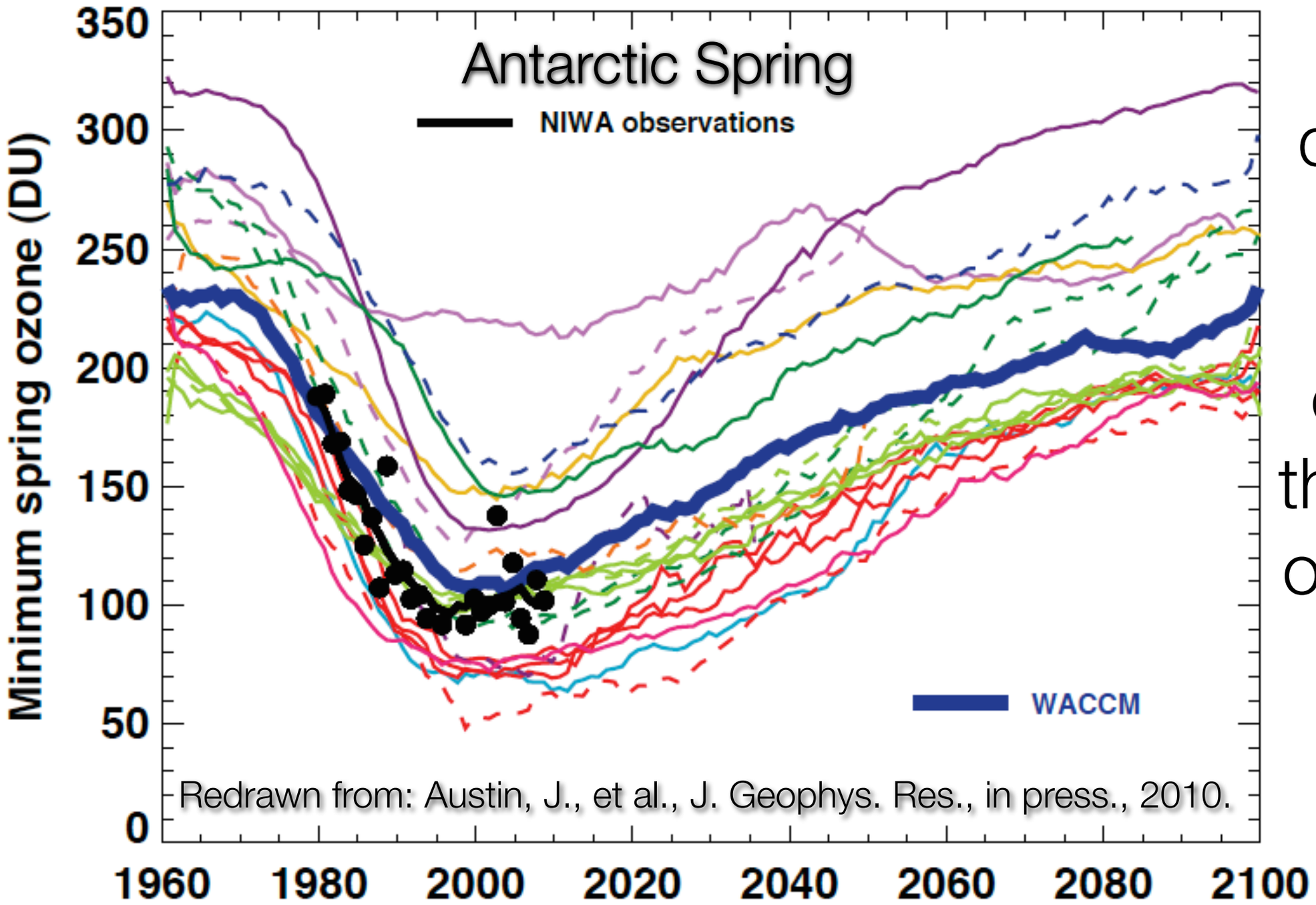
188 K (T_{sat})

ICE (H_2O, with NAT Coating)

R_{ice}= 10-30 μm

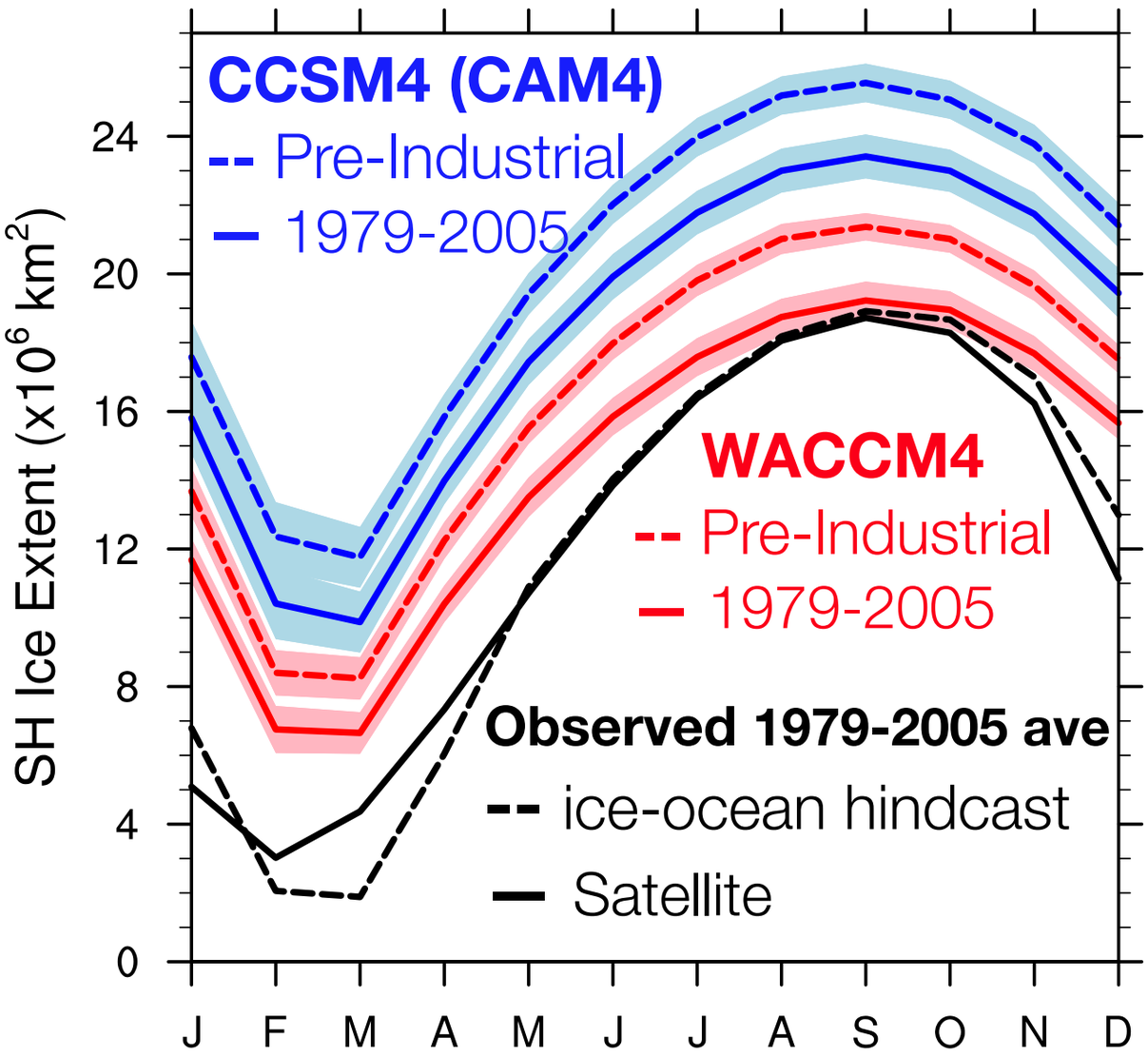
185 K (T_{nuc})

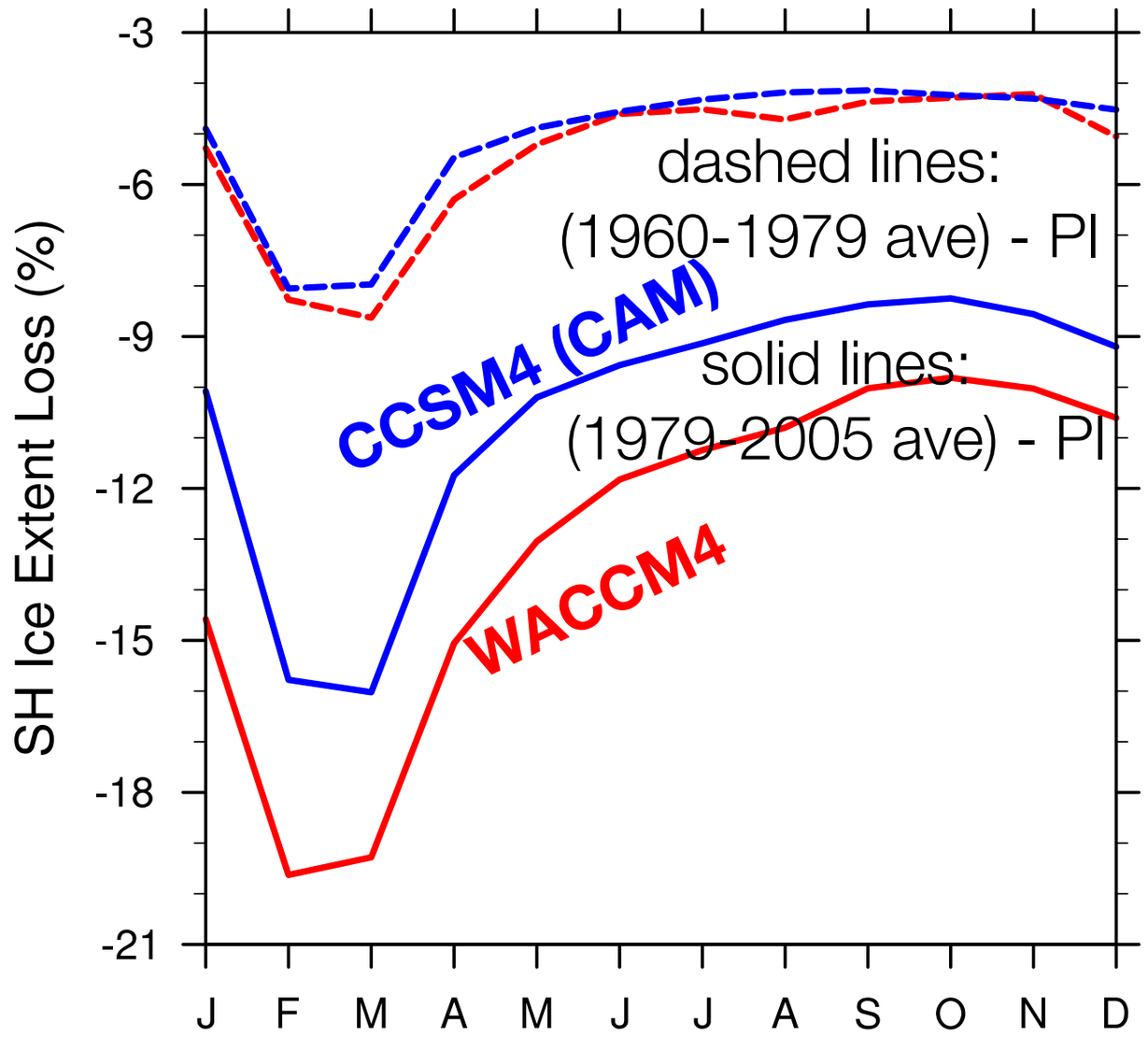
WACCM Ozone Trend: CCMVal and WMO



WACCM does better than most models at calculating the evolution of the ozone hole.

Antarctic sea-ice extent

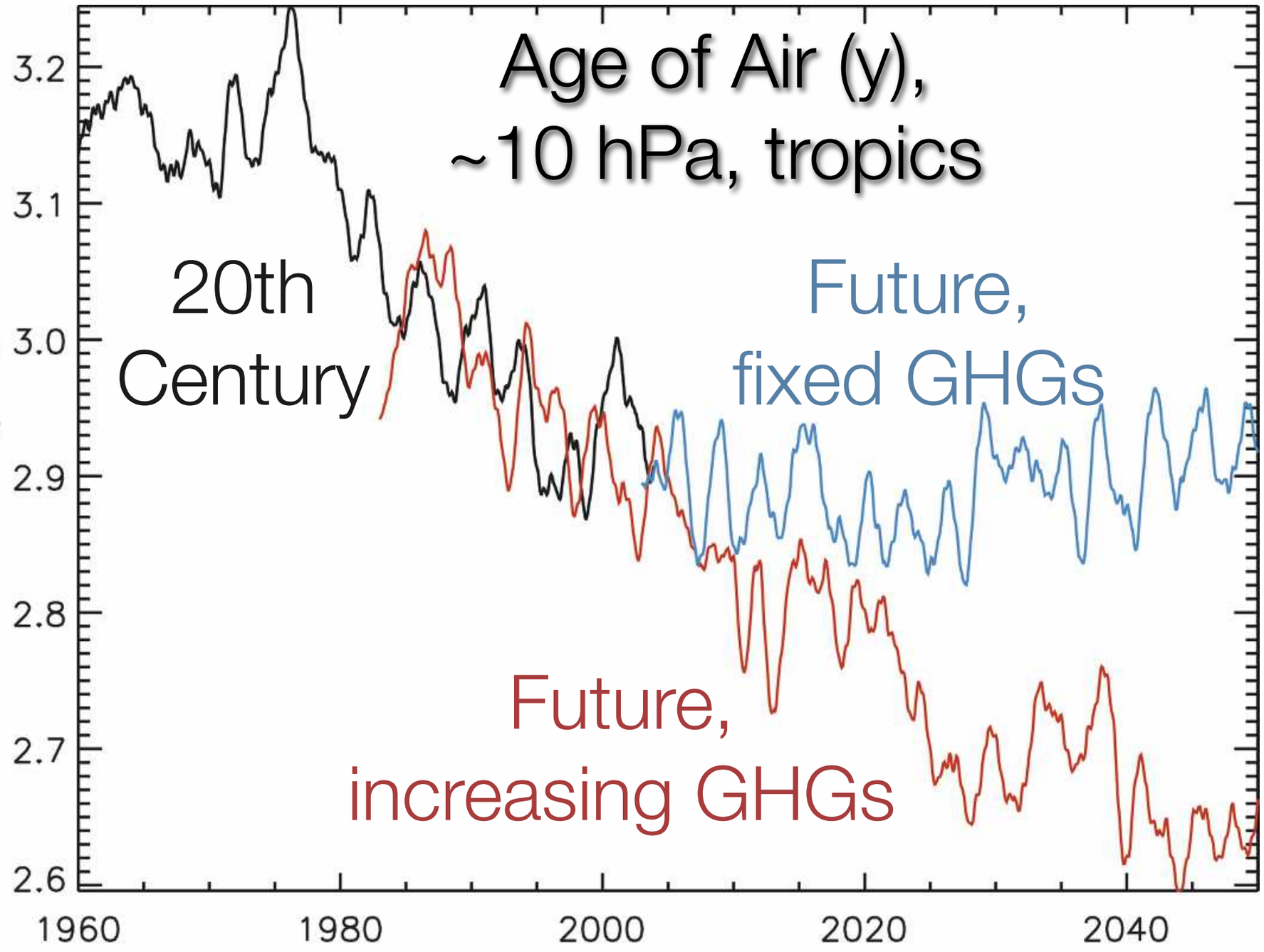




The more realistic ozone loss in WACCM drives changes in winds that enhance sea-ice loss, producing sea-ice extent closer to modern observations.

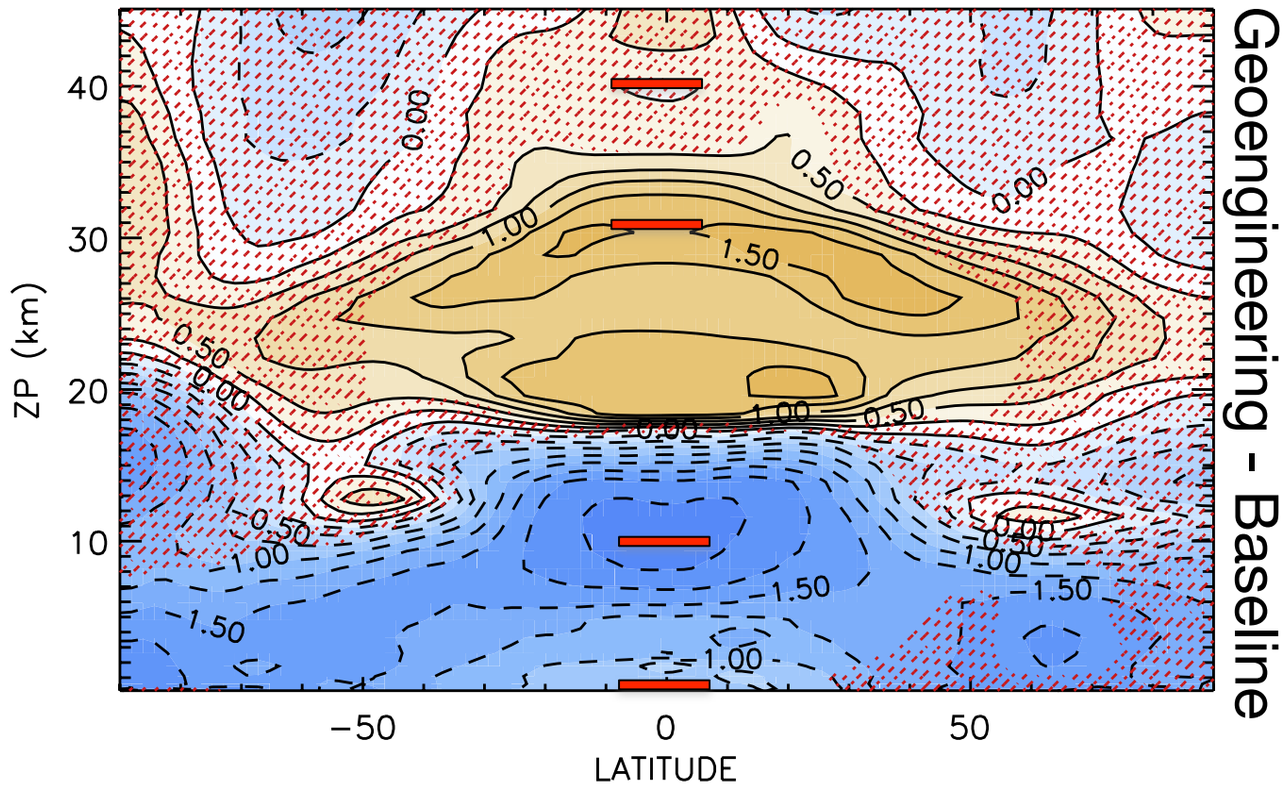
Acceleration of the Brewer–Dobson Circulation due to Increases in Greenhouse Gases
Garcia and Randel, *J. Atmos. Sci.*, vol. 65 (8), pp. 2731-2739, 2008.

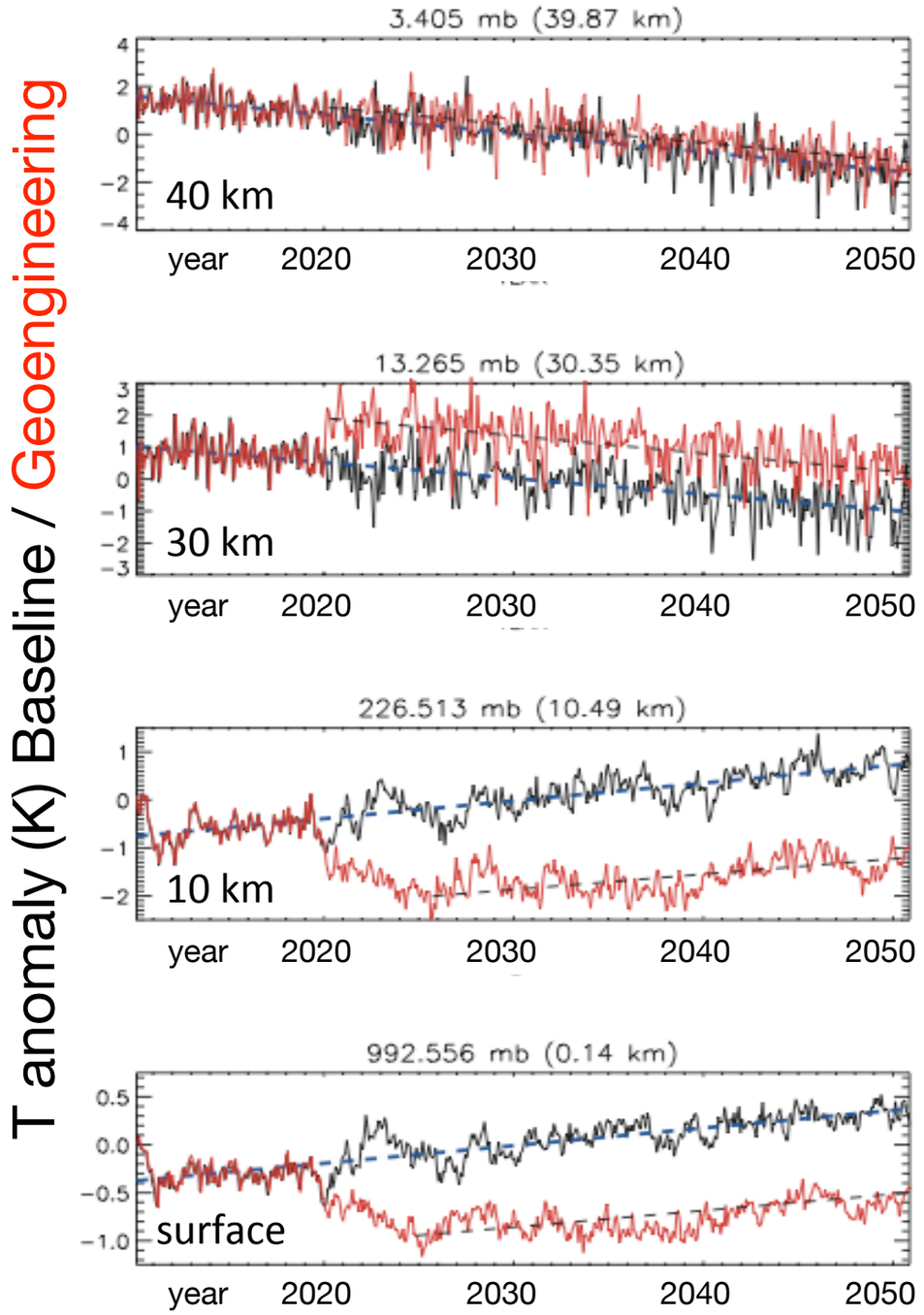
- faster circulation in greenhouse world due to enhanced propagation of wave activity into the lower stratosphere and its dissipation in the subtropics
- changes in meridional temperature gradient affect zonal winds, which change the regions where waves dissipate, increasing momentum deposition



Impact of geoengineered aerosols on the troposphere and stratosphere

Tilmes *et al.*, J. Geophys. Res., vol. 114, pp. 12305, 2009.





- ~5 years for adjustment of temperatures
- Constant temperature offset
- The fixed amount of sulfur cools the Earth's surface by ~0.9 K (Tropics), ~1.2 K (Global)
  - Delay of global warming by ~ 40 years
  - Dependence on continuous injection of sulfu

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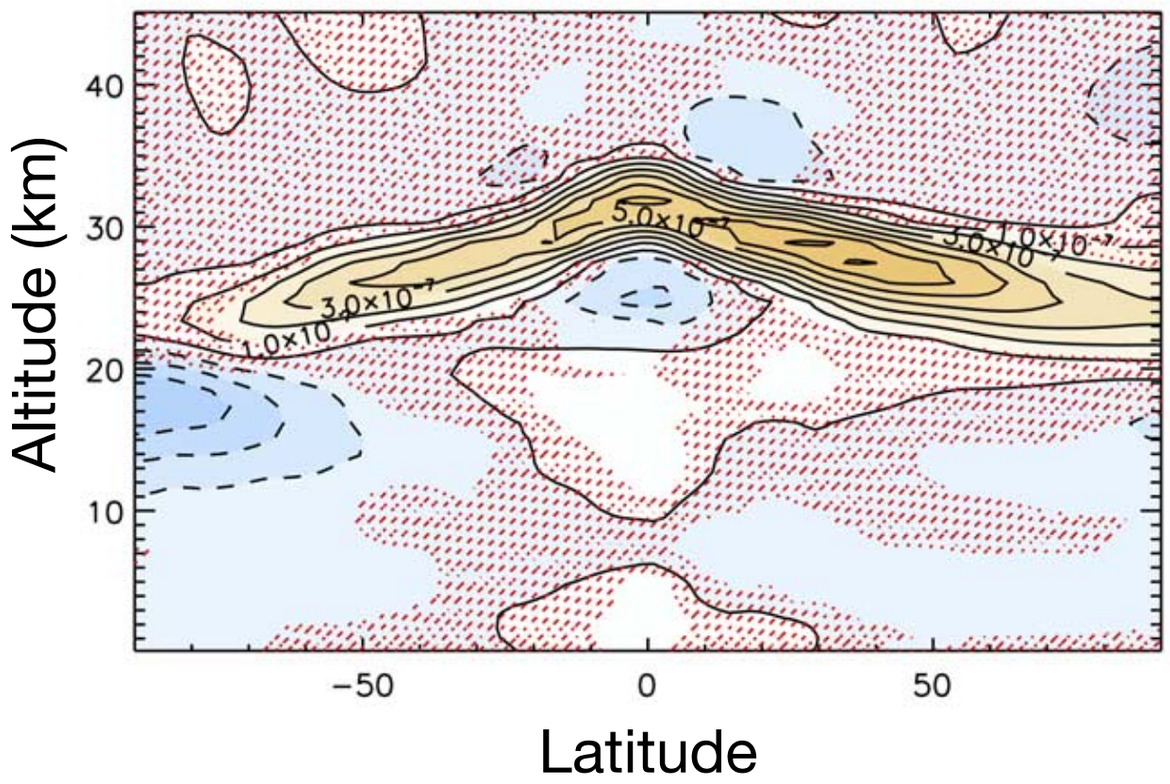
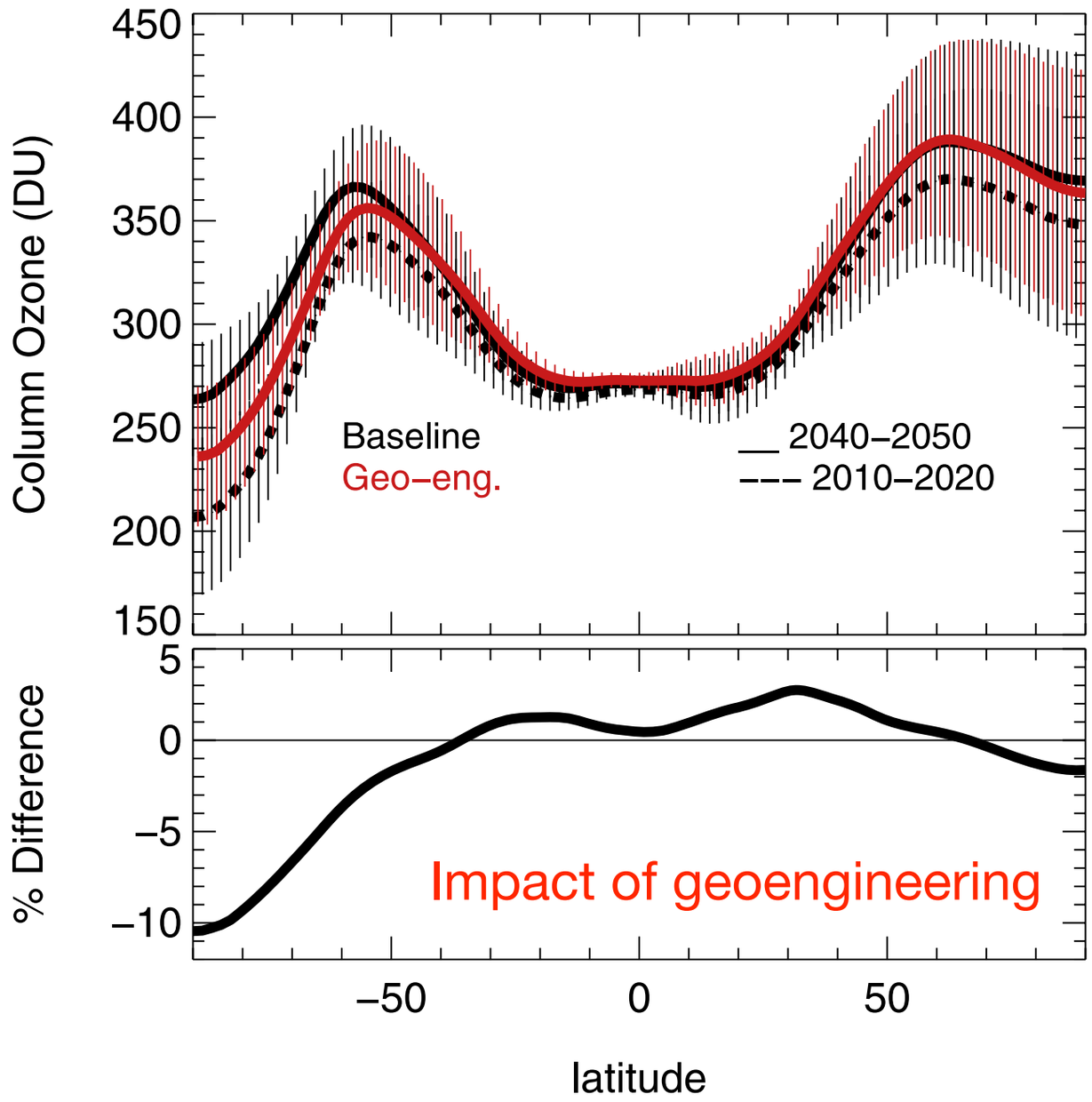
Impacts of geoengineering on ozone

Baseline –Geoengineering



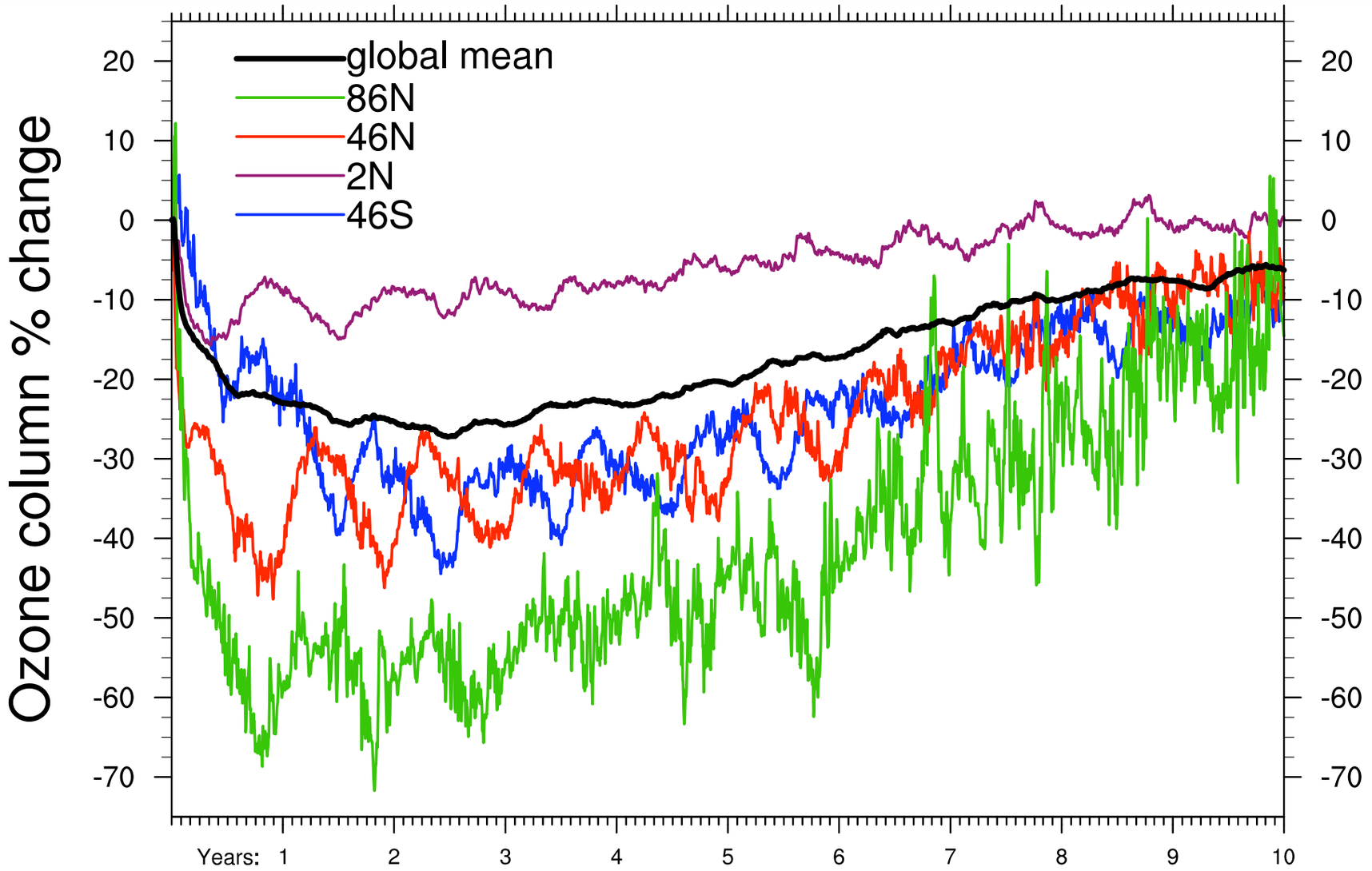


Massive global ozone loss predicted following regional nuclear conflict

Mills *et al.*, PNAS, vol. 105, pp. 5307, 2008

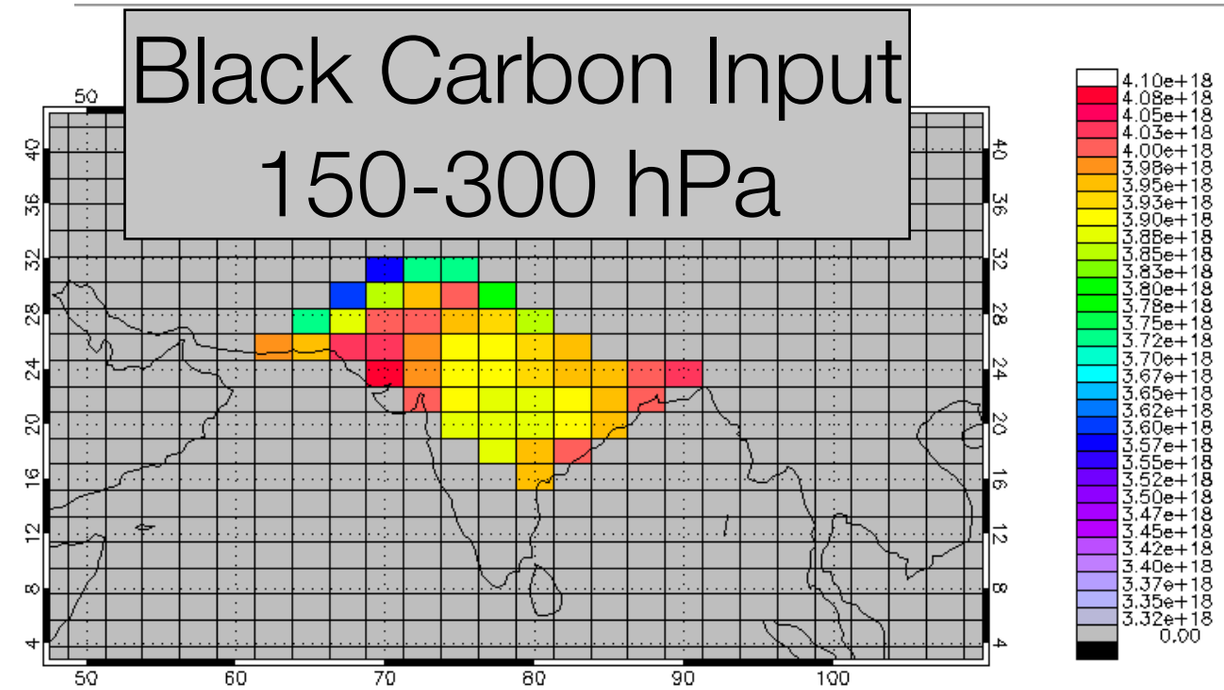
- WACCM input: new estimates of smoke produced by fires in contemporary cities following a regional nuclear war between India and Pakistan

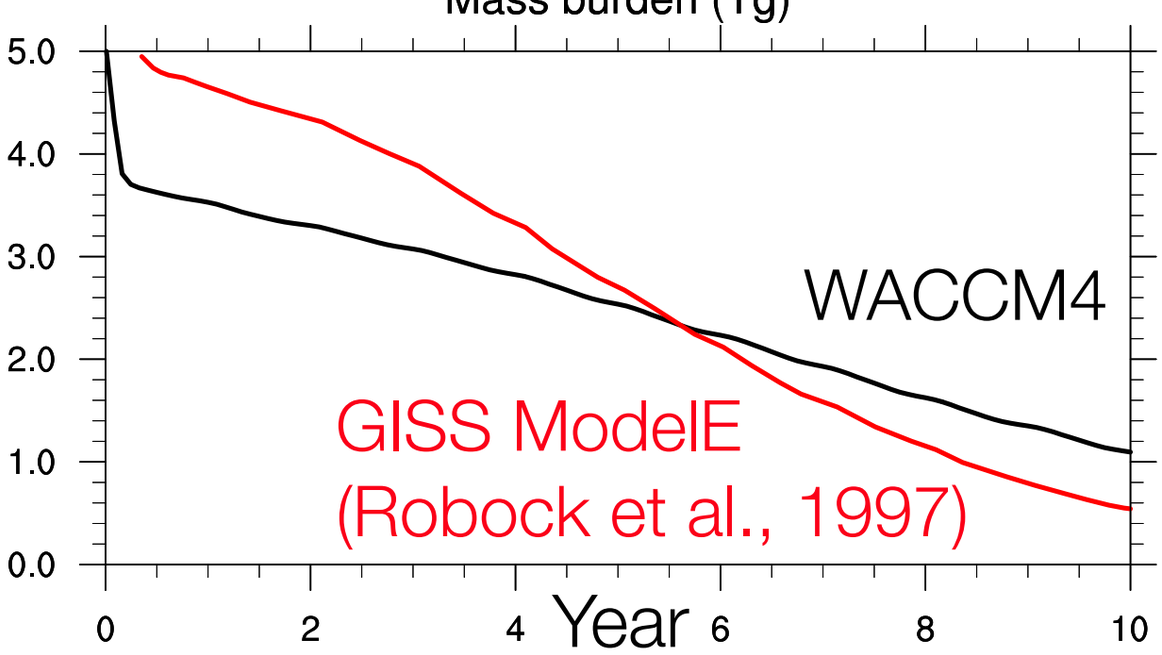
- Solar radiation heats the soot, lofting it to the stratopause, heating the the entire stratosphere for 10 years, altering reaction rates affecting ozone.

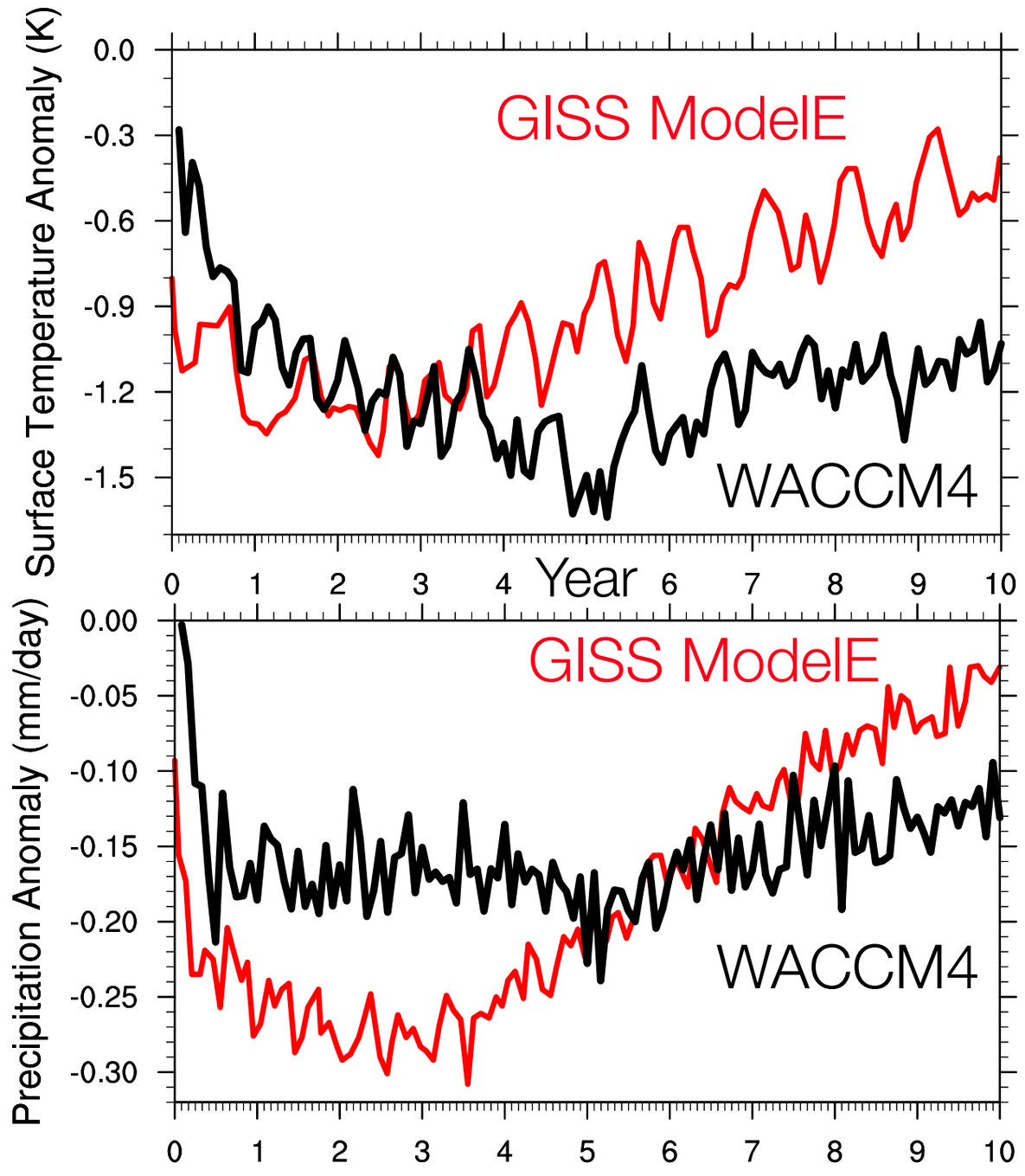


- Calculated ozone losses exceed 20% globally, 25-45% at midlatitudes, and 50-70% at northern high latitudes persisting for 5 years, with substantial losses continuing for 5 additional years. Column ozone amounts remain below that which defines the Antarctic ozone hole everywhere outside of the tropics.

Nuclear winter in WACCM4







WACCM and CAM-Chem Customer Support

CGD Forum: http://bb.cgd.ucar.edu/

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