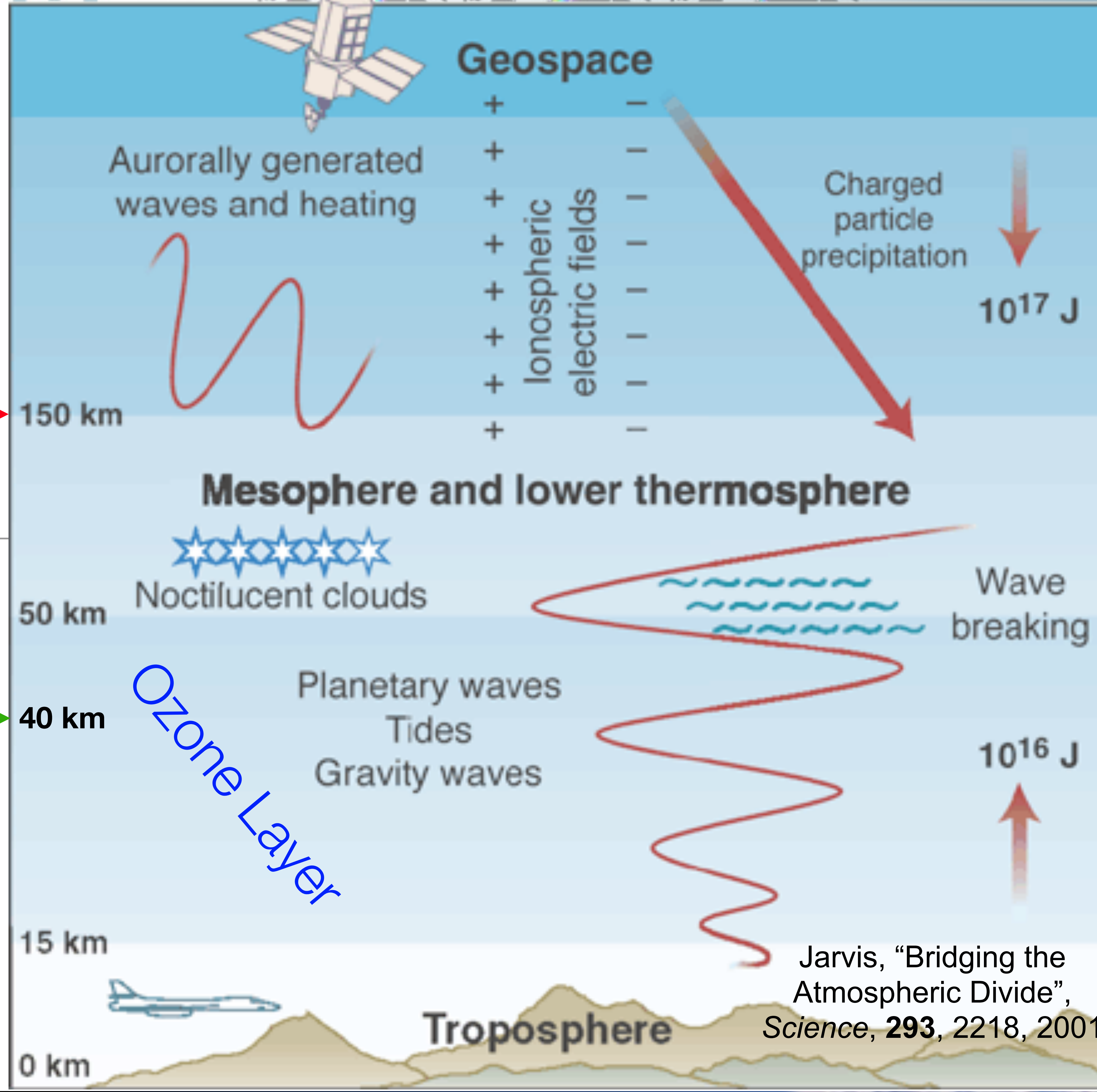
WACCM: The High-Top Model

WACCM top →

CAM top →



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

Michael Mills
WACCM Liaison
mmills@ucar.edu
(303) 497-1425
http://bb.cgd.ucar.edu/

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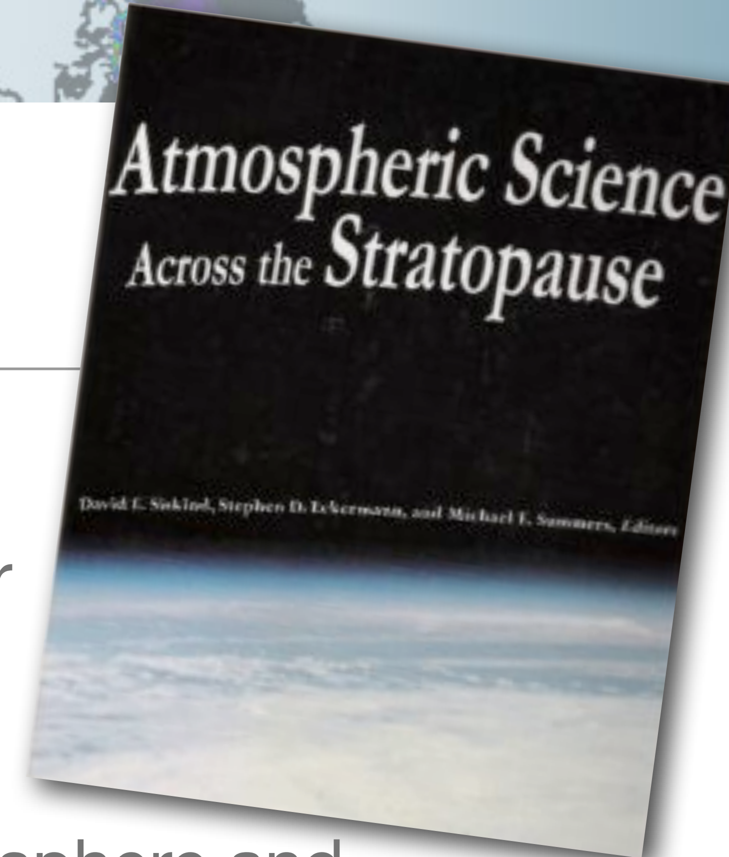
WACCM Additions to CAM

- Extends from surface to 5.1×10^{-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

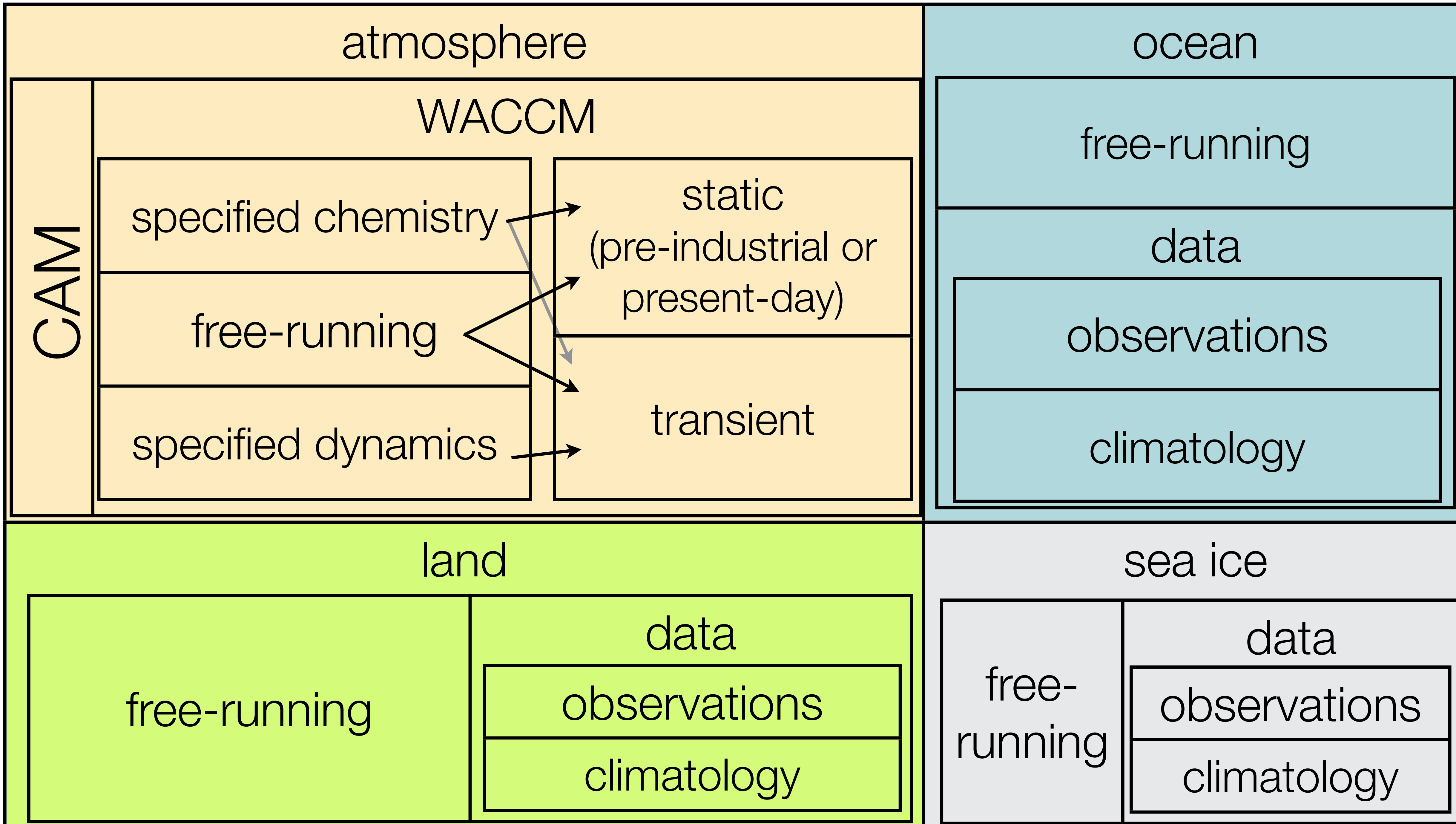
WACCM Motivation

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

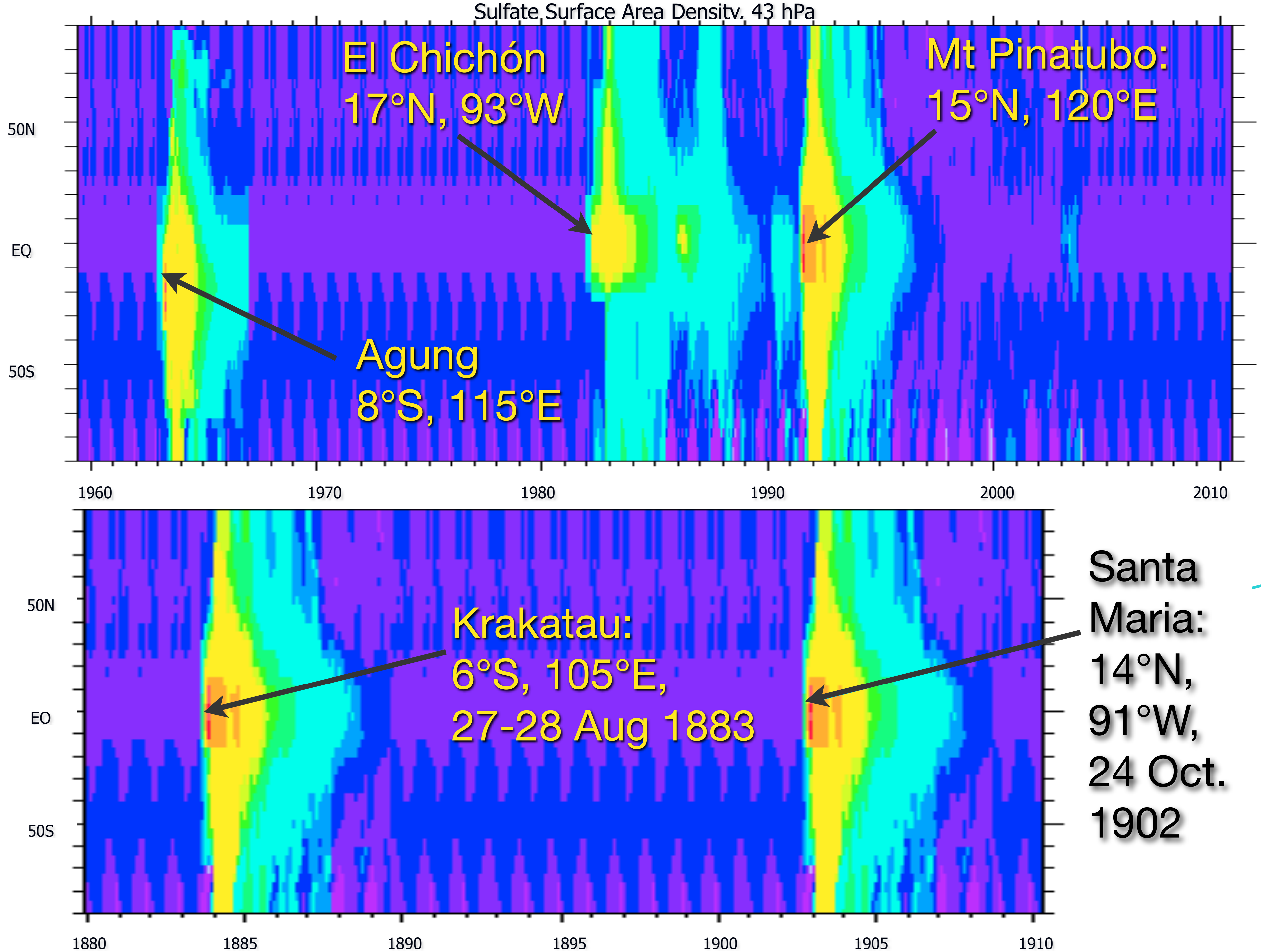


- Coupling between atmospheric layers:
  - Waves transport energy and momentum from the lower atmosphere to drive the QBO, SAO, sudden warmings, mean meridional circulation
  - Solar inputs, e.g. auroral production of NO in the mesosphere and downward transport to the stratosphere
  - Stratosphere-troposphere 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

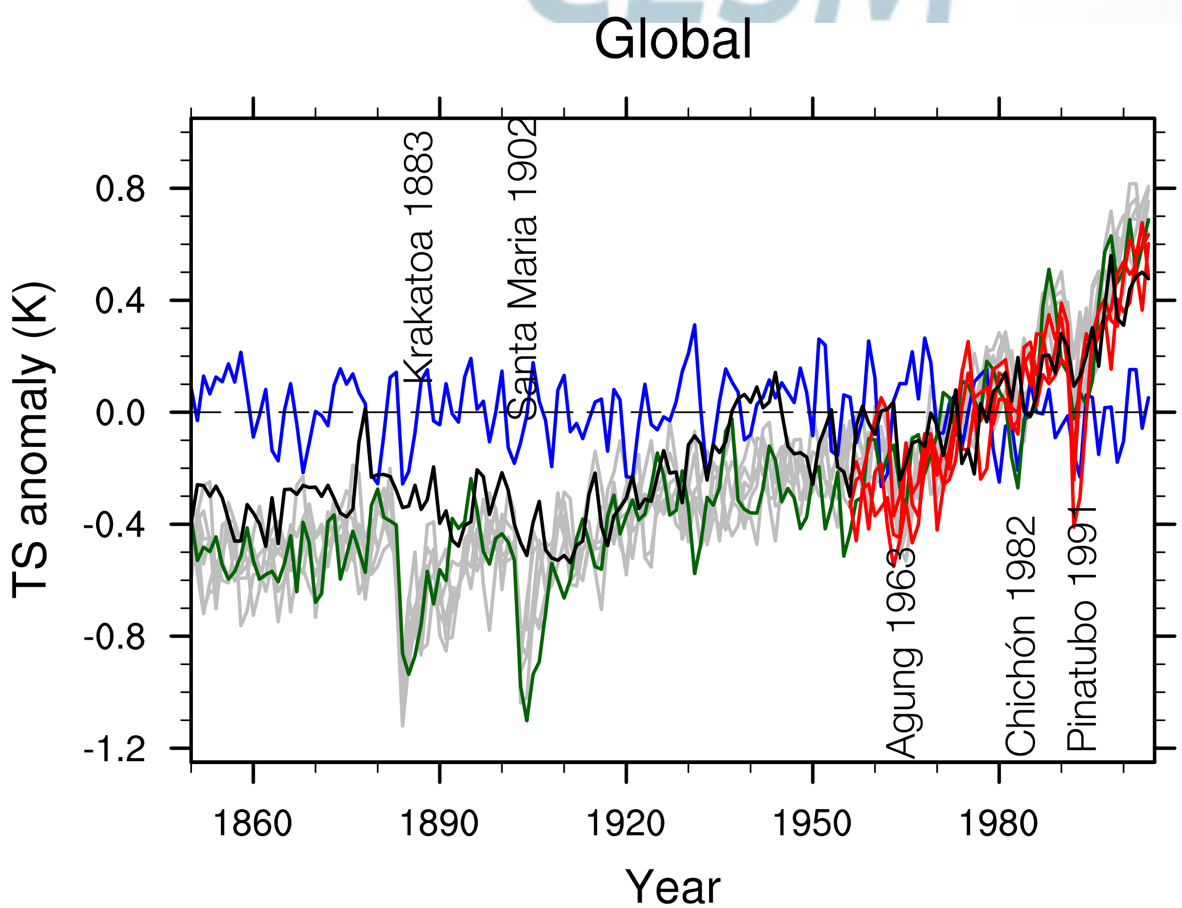


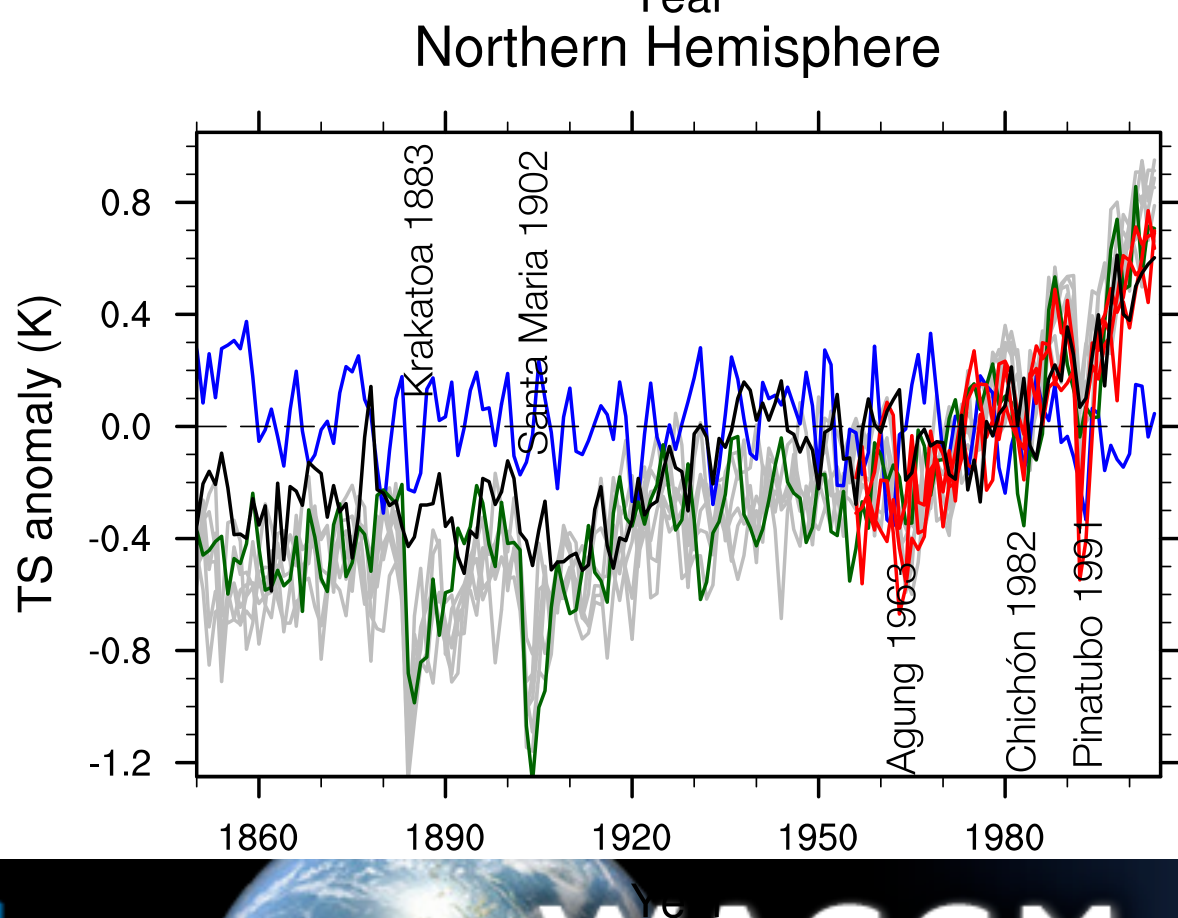
- Observations used: SAGE I, SAGE II, SAM II, and SME instruments.
- Non-volcanic periods filled with monthly mean of 1998-2002 values.
- Used Pinatubo aerosol for Krakatau and Santa Maria.

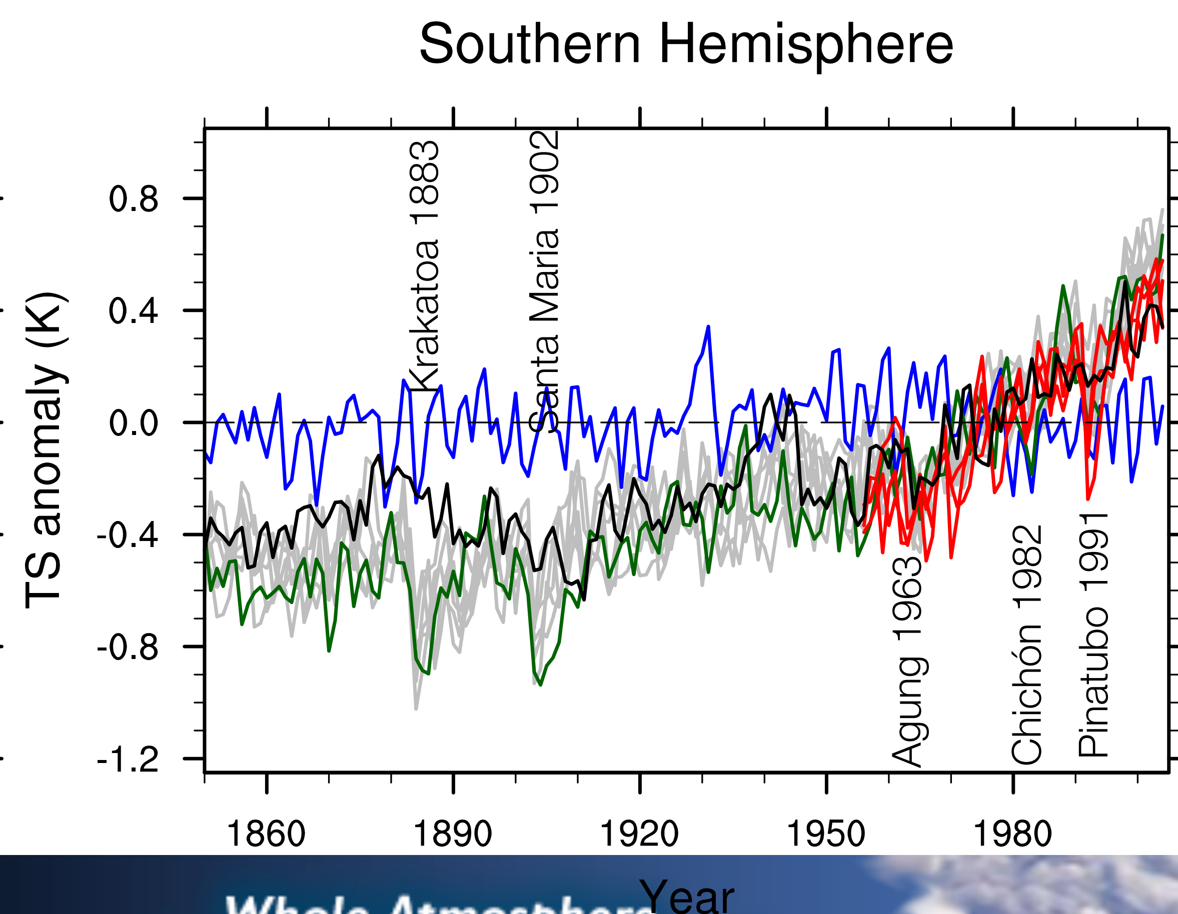
Surface Temperature Anomalies

normalized to 1961-90

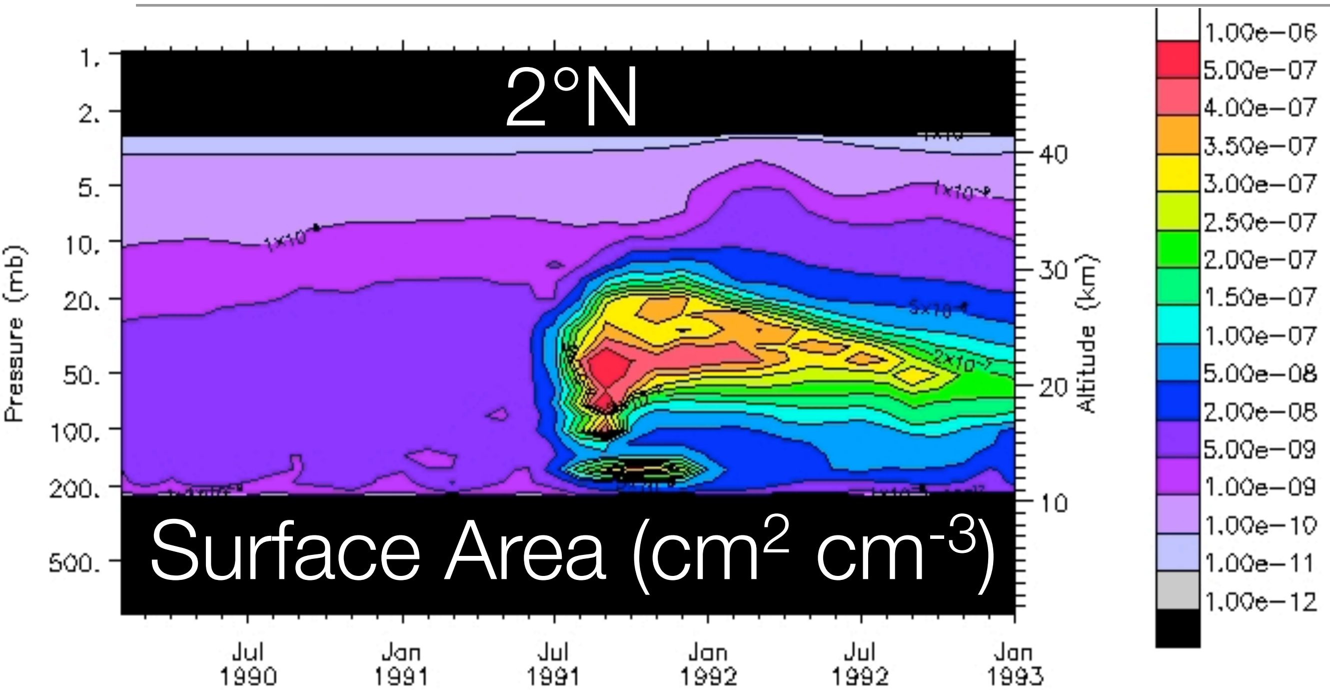
- CCSM-CAM4 1deg
- WACCM4 Pre-Indusrtrial
- WACCM4 20th Century
- WACCM4 1955-2005
- Observations (HadCRUT3)



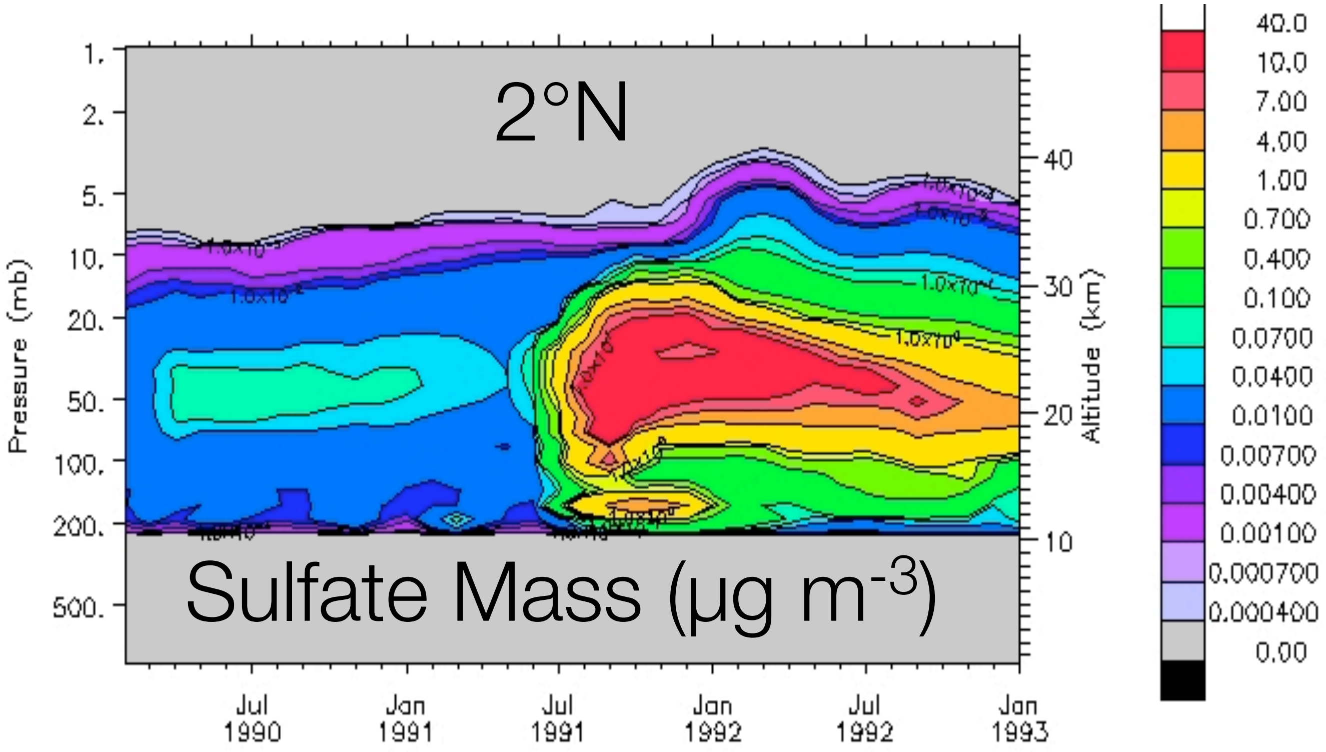


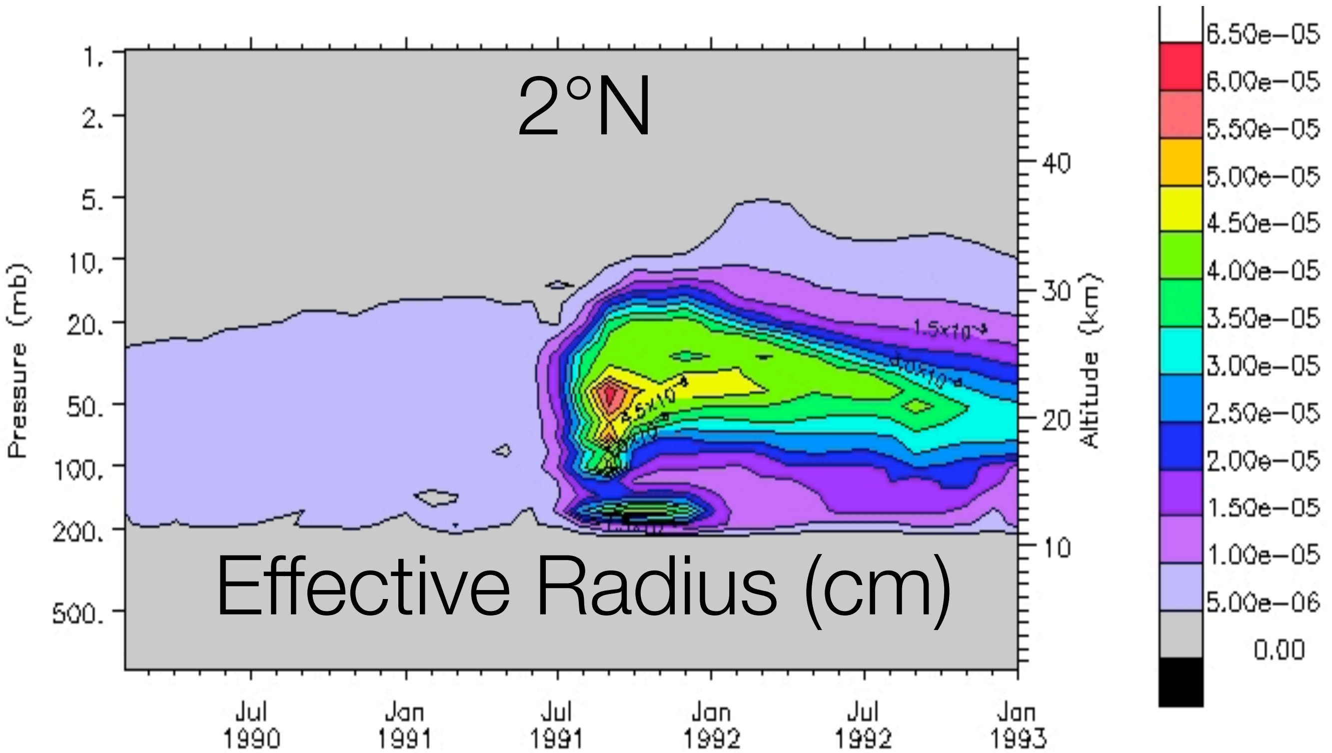


Volcanic heating in WACCM

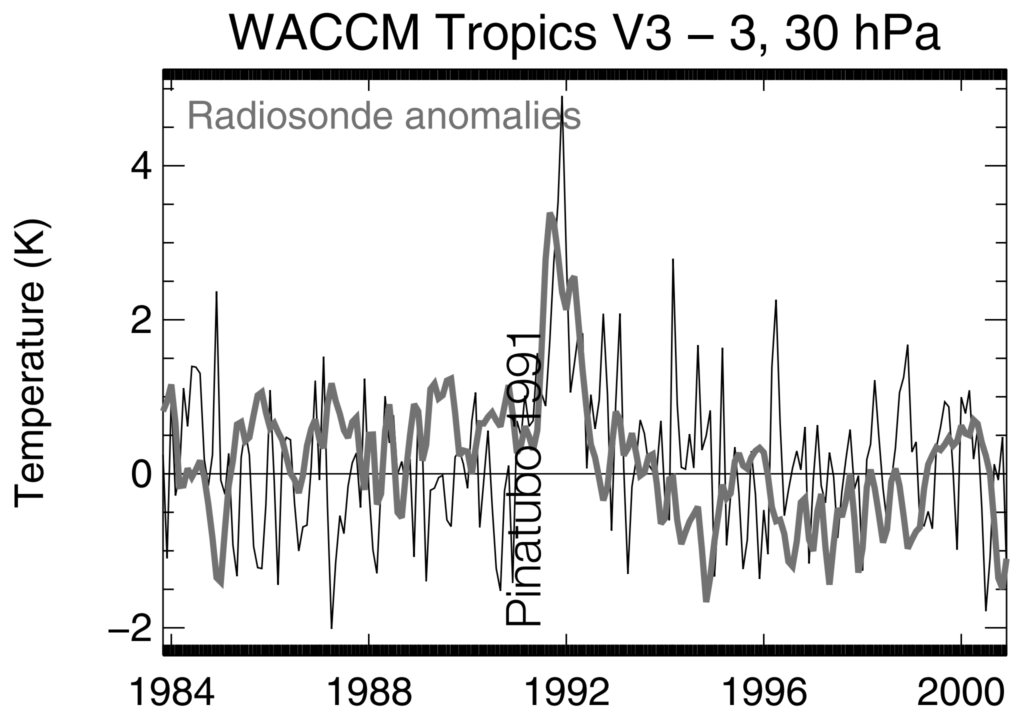


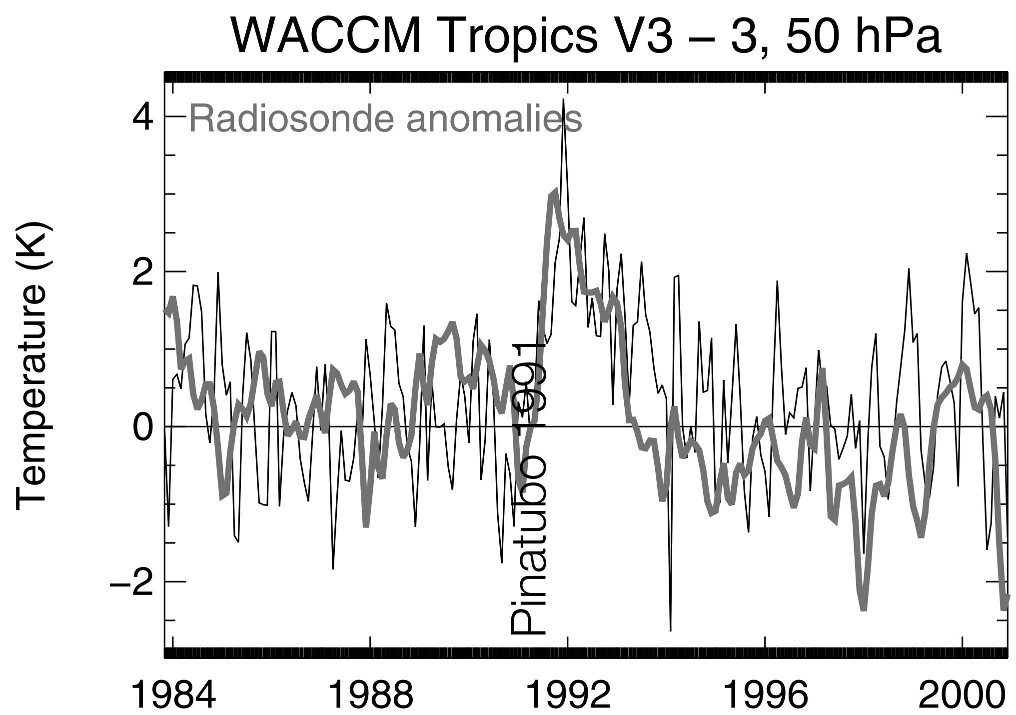
Multiple aerosol independent parameters derived from observations used as inputs.



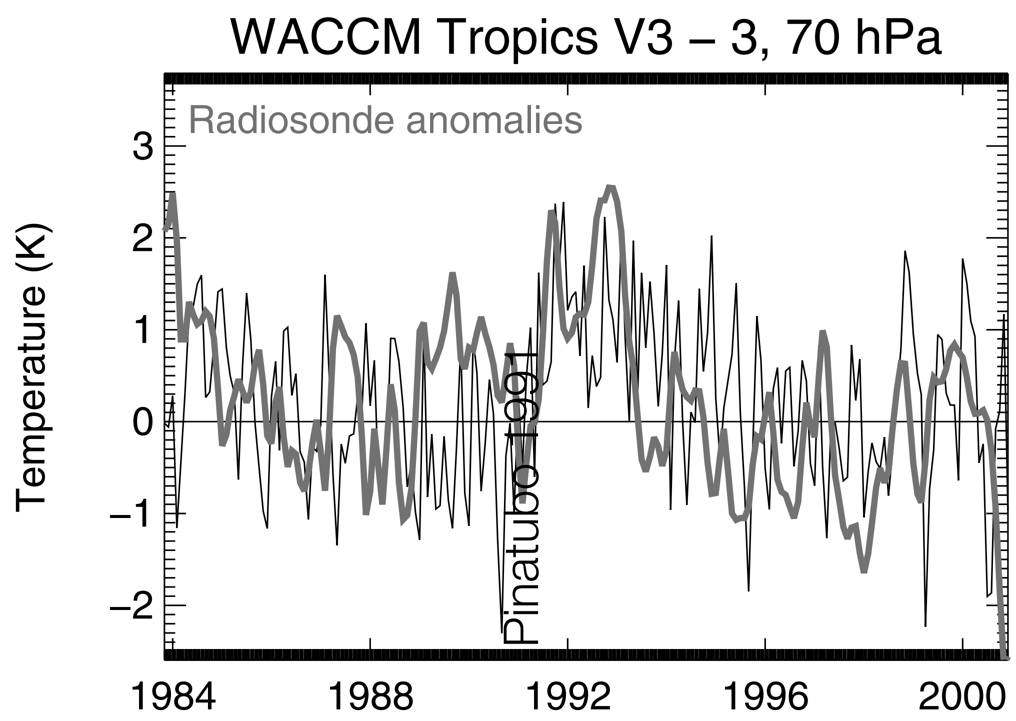


Volcanic heating in WACCM

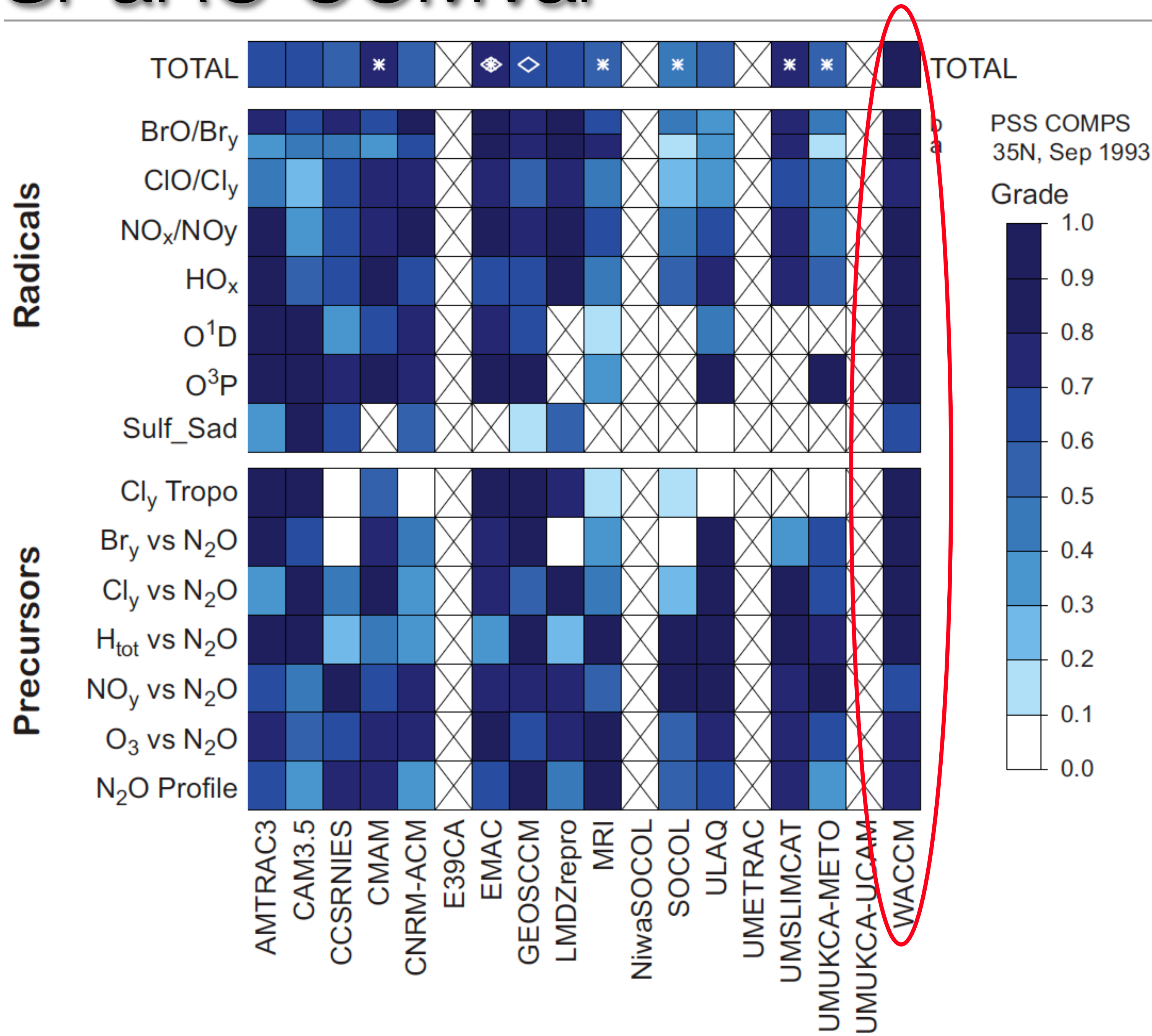




Temperature anomalies calculated with WACCM (black lines) and observed (grey lines) at pressures in the lower stratosphere (Tilmes *et al.*, 2009)



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} = ƒ {Log Normal Size; # particles cc; width distribution; condensed phase HNO_3}

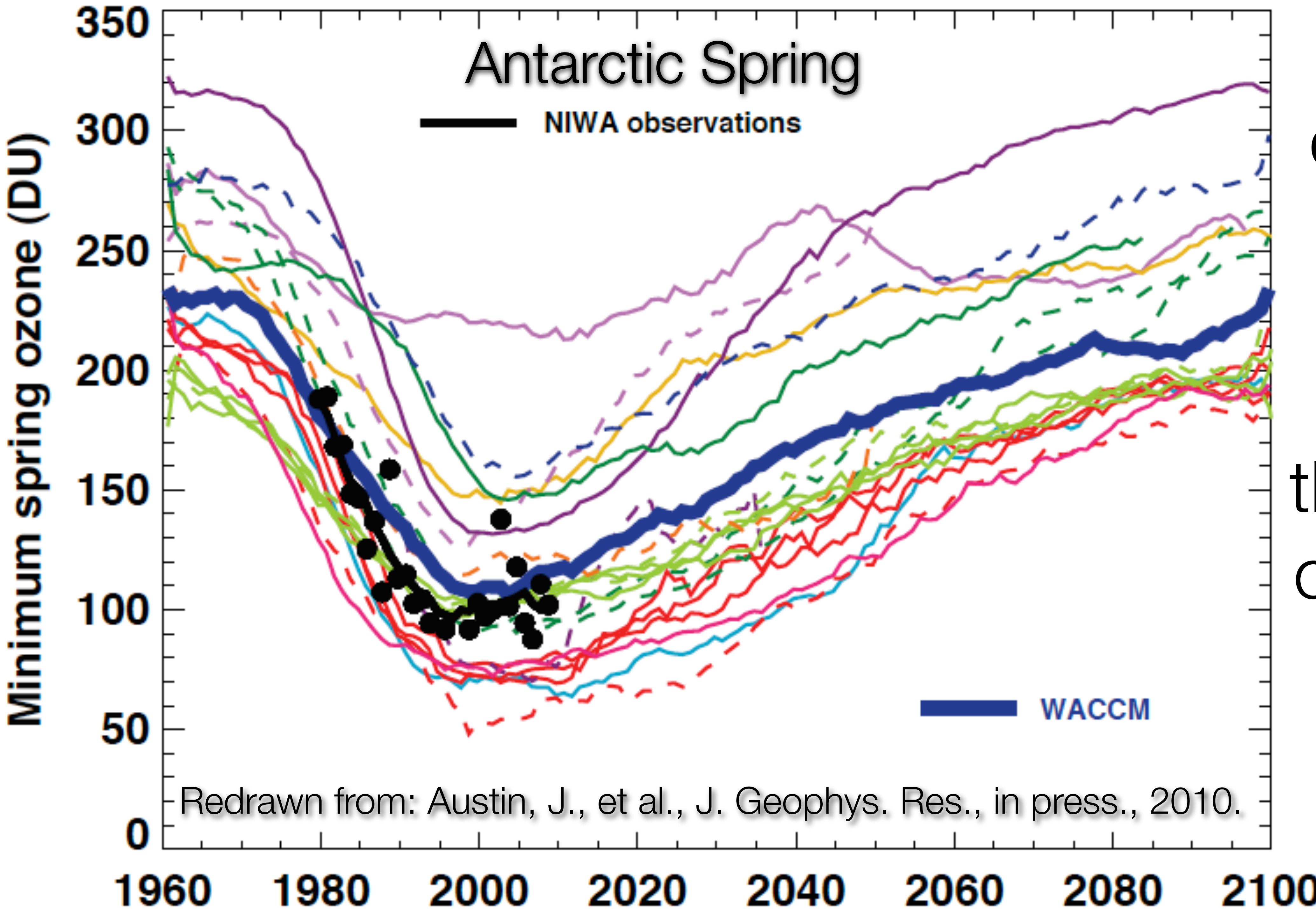
188 K (T_{sat})

ICE (H_2O, with NAT Coating)

R_{ice}= 10-30 μm

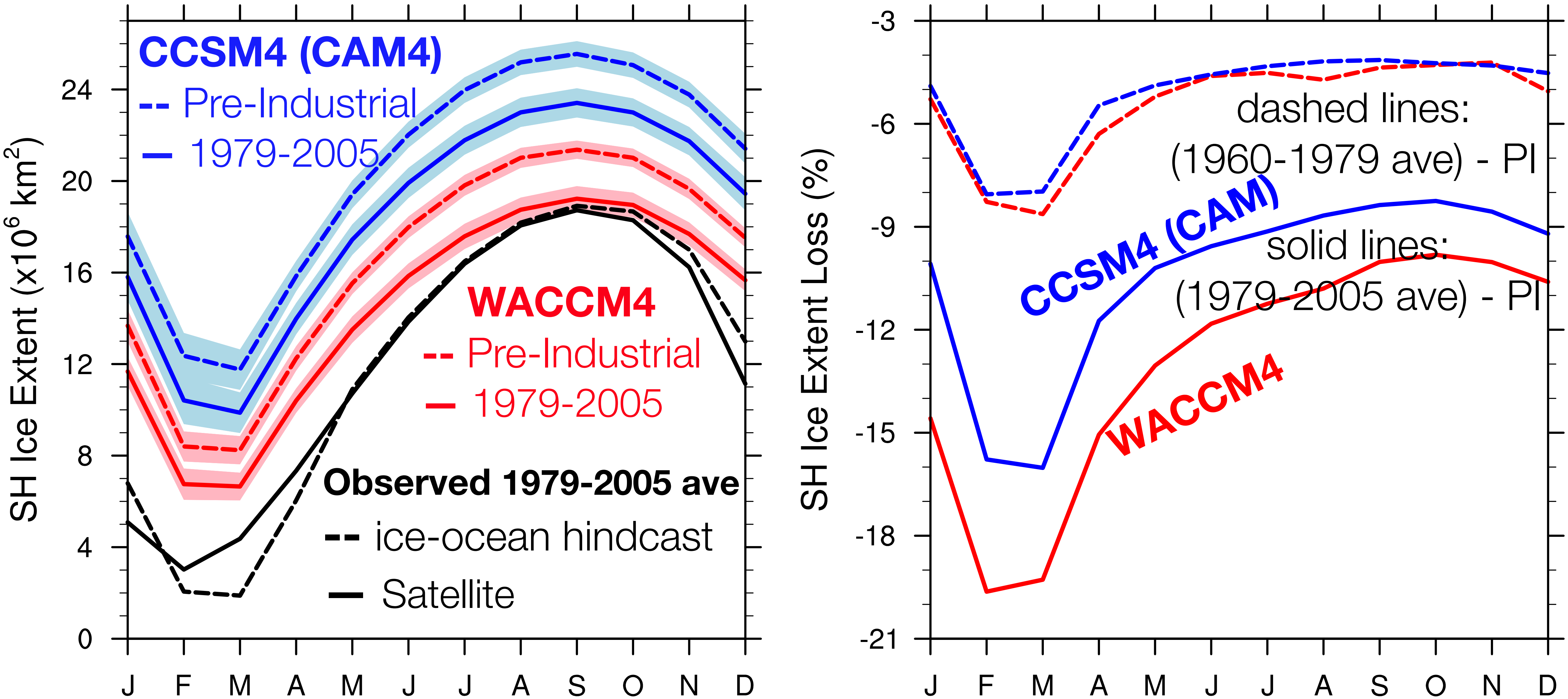
185 K (T_{nuc})

WACCM Ozone Trend: CCMVal and WMO



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

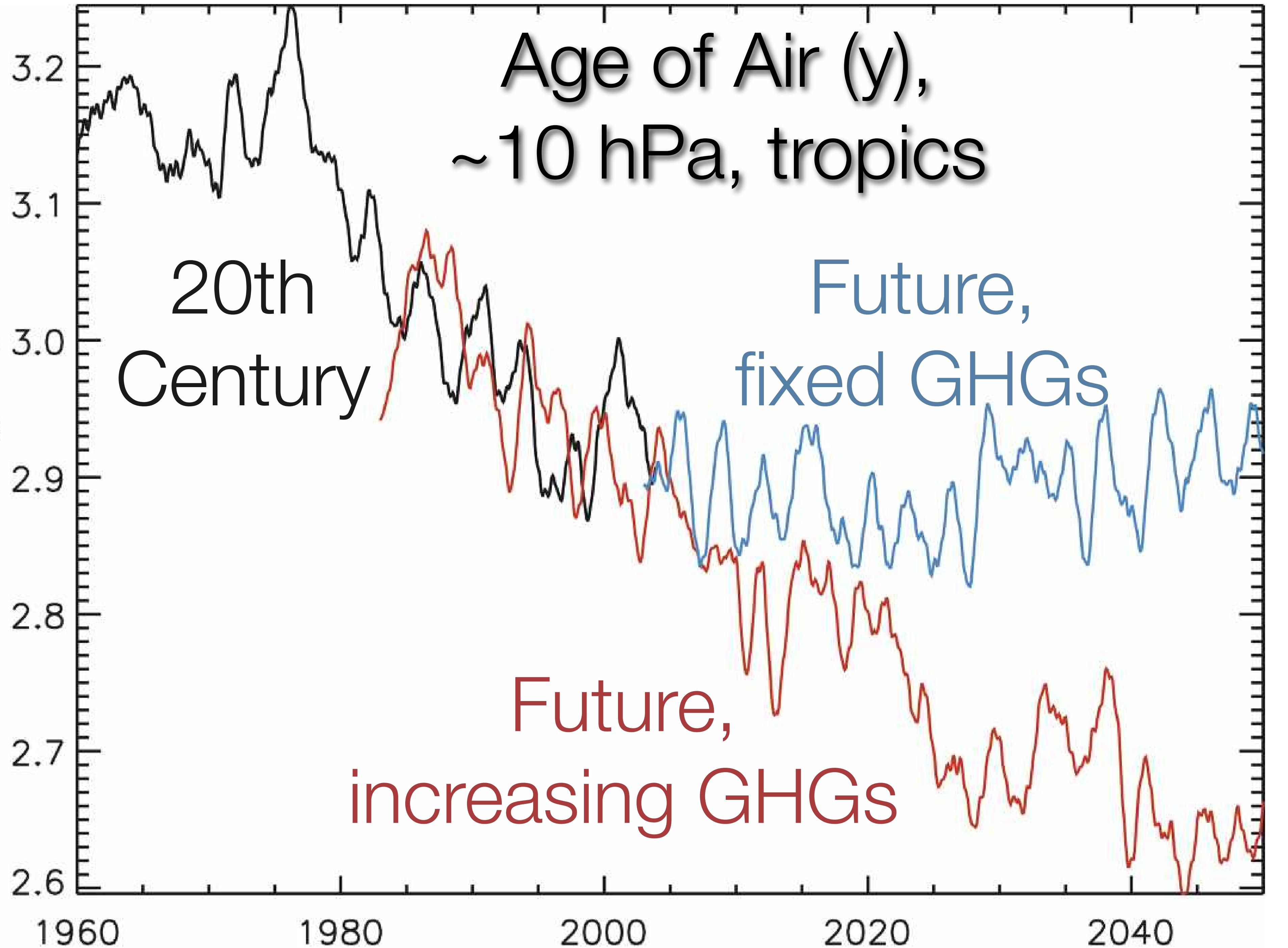
Antarctic sea-ice extent



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

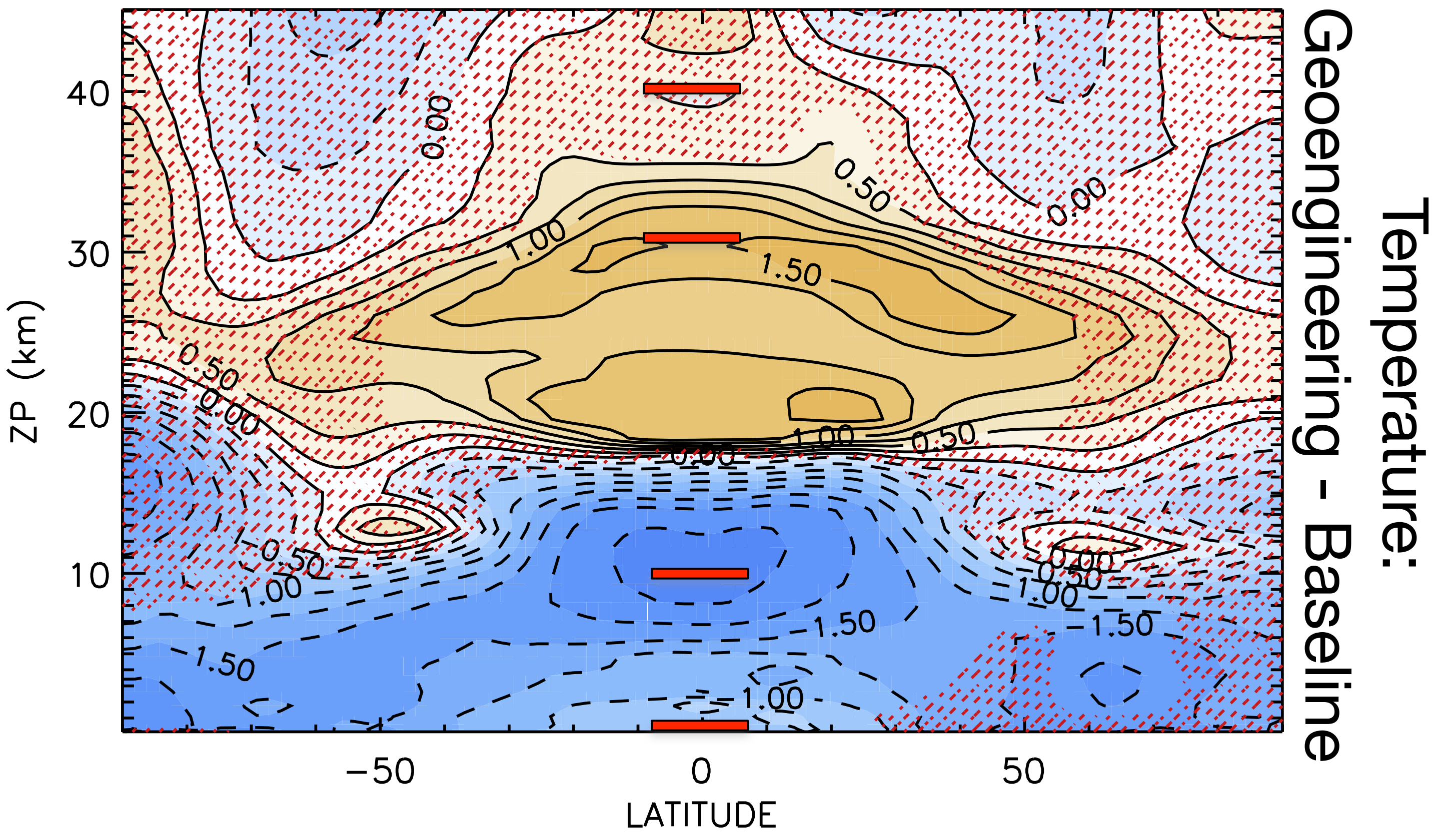
Acceleration of the Brewer–Dobson Circulation due to Increases in Greenhouse Gases
Garcia and Randel, *J. Atmos. Sci.*, vol. 65 (8), pp. 2731-2739, 2008.

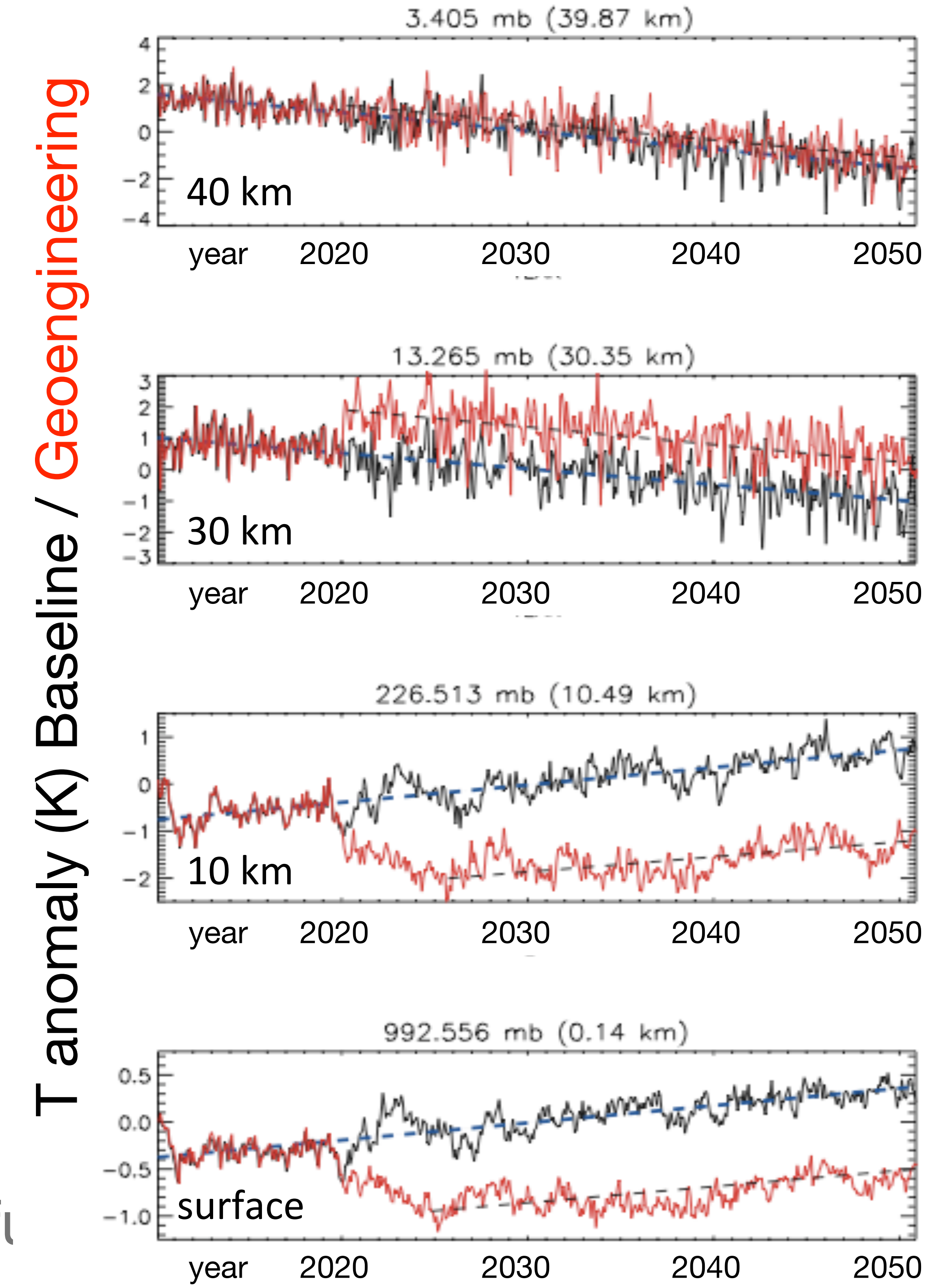
- faster circulation in greenhouse world due to enhanced propagation of wave activity into the lower stratosphere and its dissipation in the subtropics
- changes in meridional temperature gradient affect zonal winds, which change the regions where waves dissipate, increasing momentum deposition



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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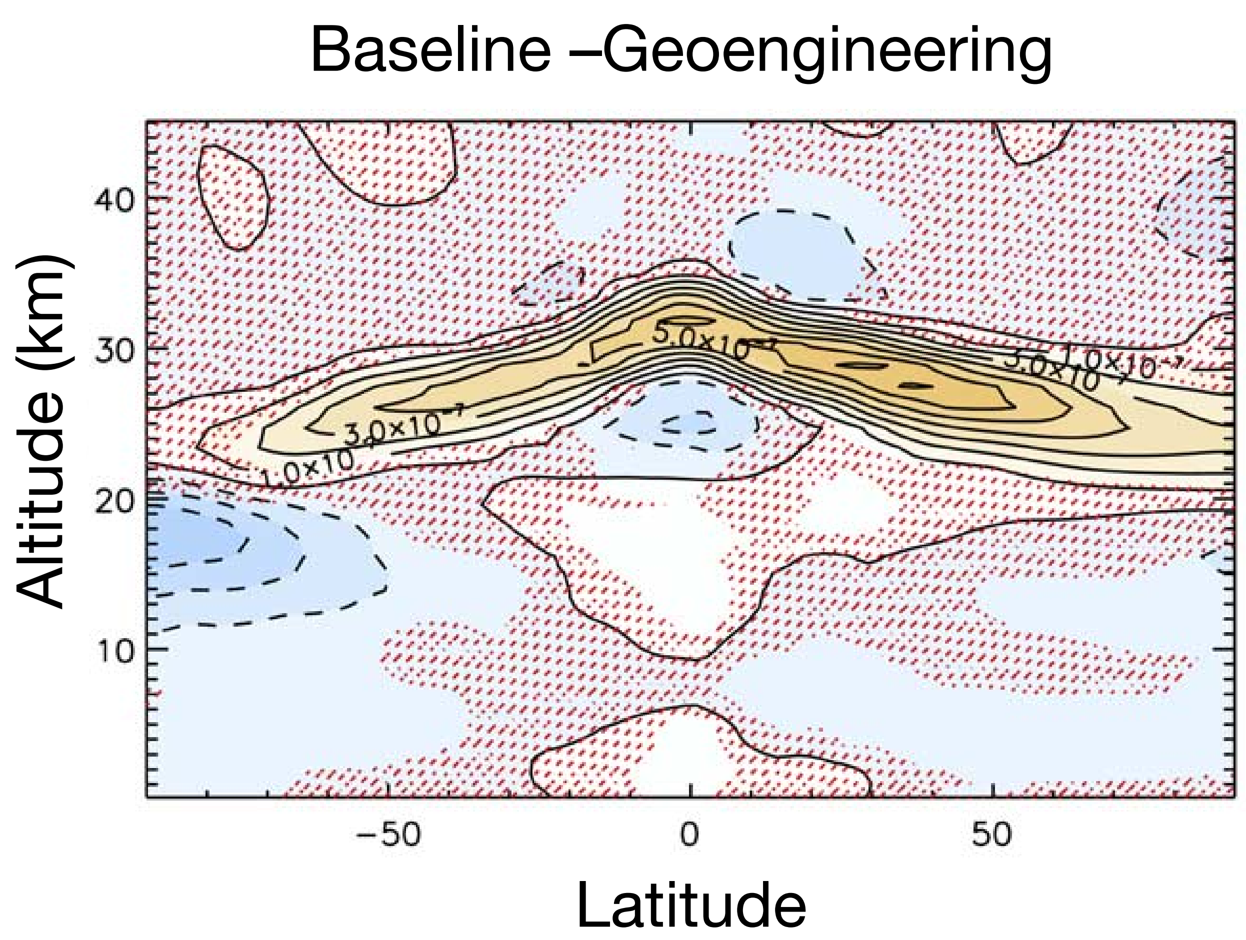
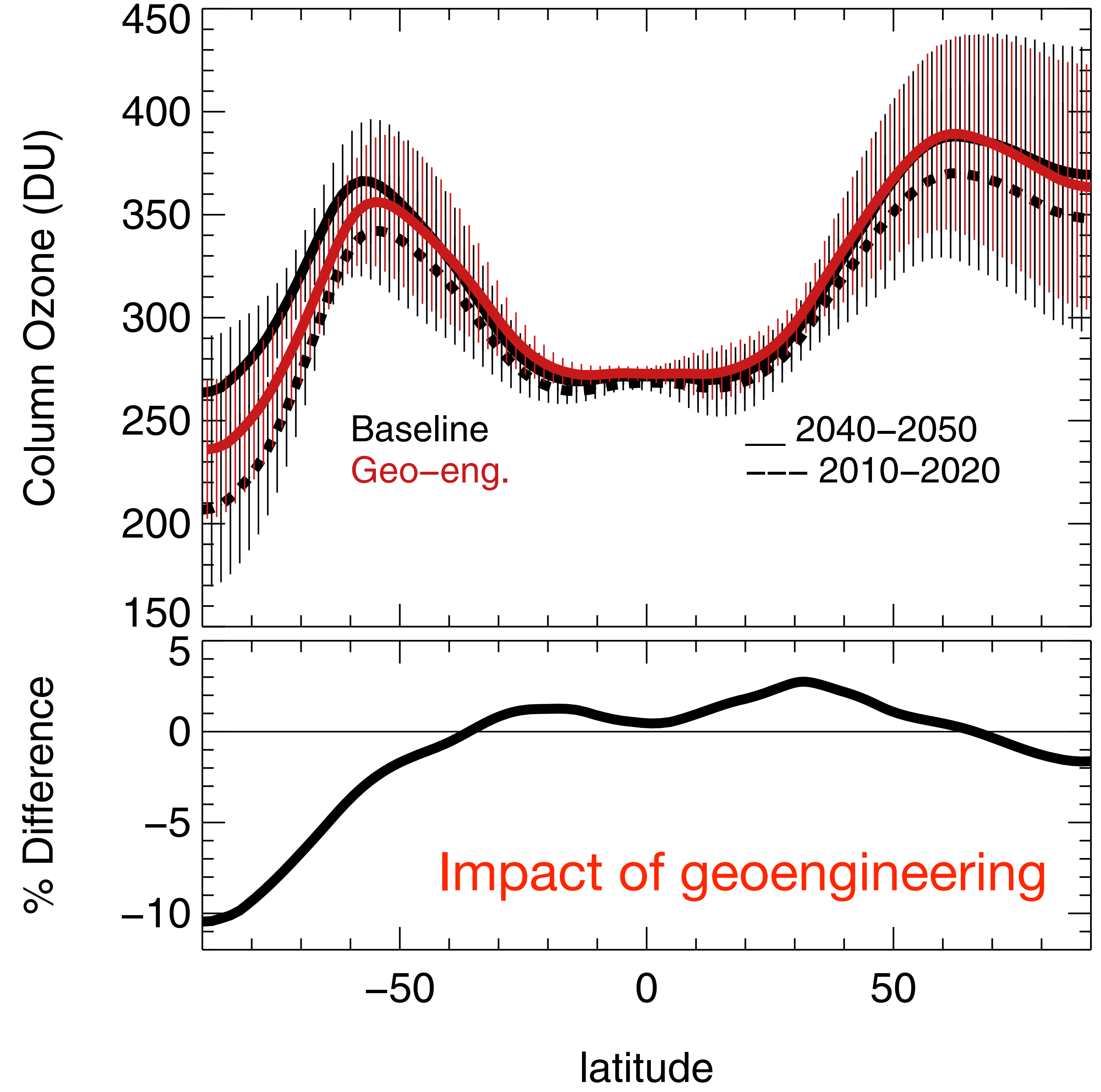
Impacts of geoengineering on ozone

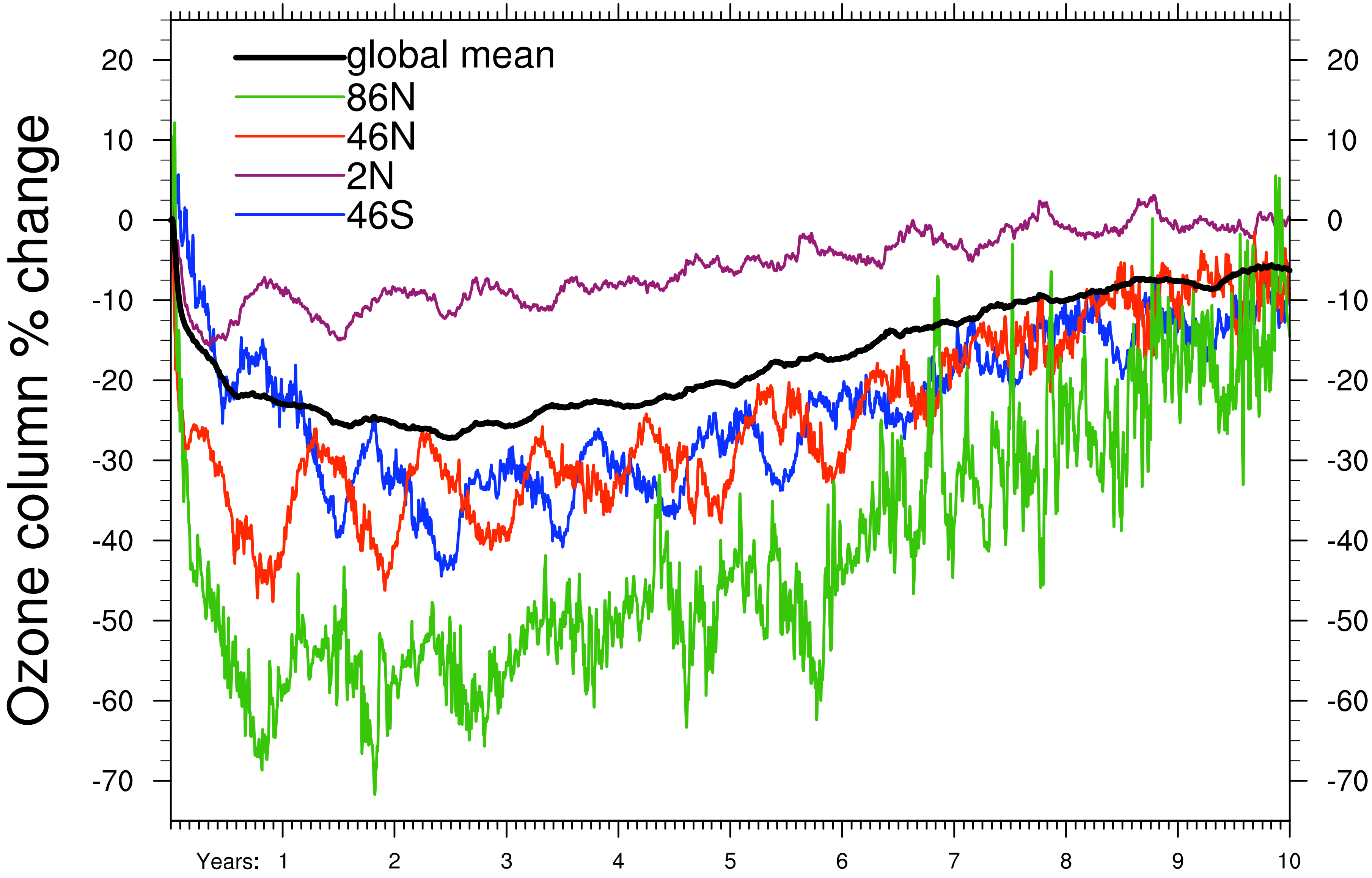




Massive global ozone loss predicted following regional nuclear conflict

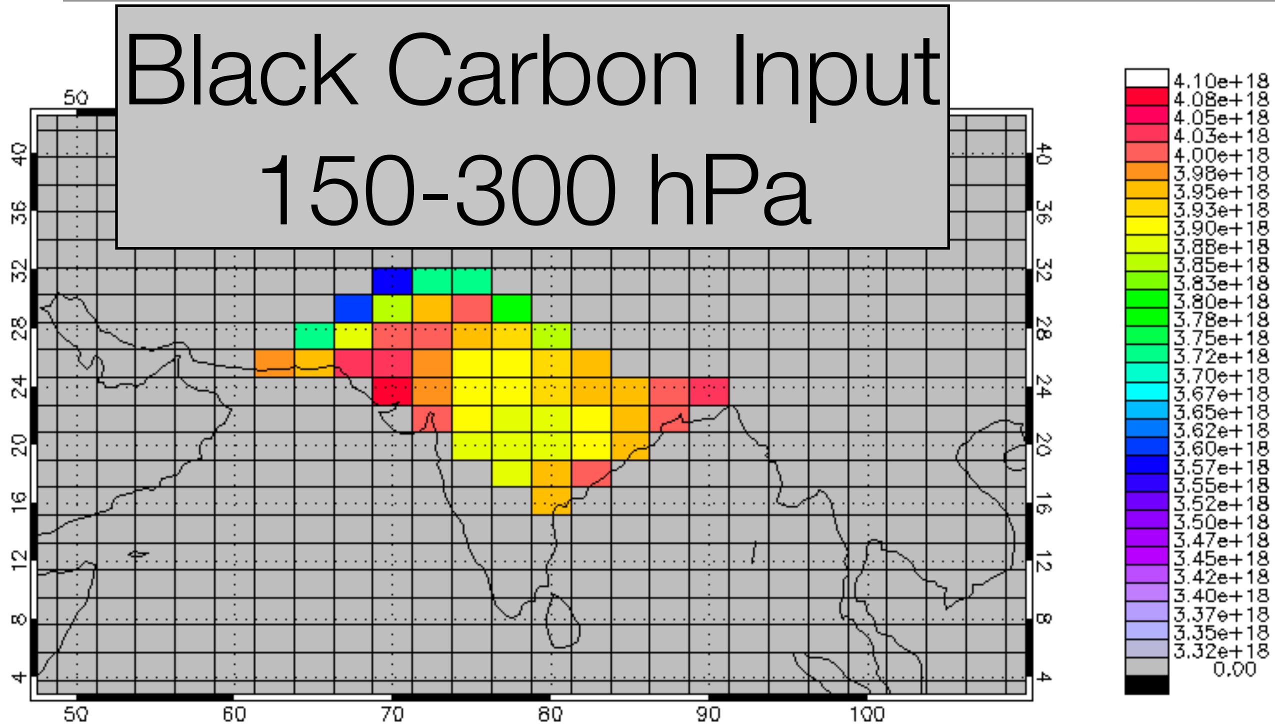
Mills *et al.*, PNAS, vol. 105, pp. 5307, 2008

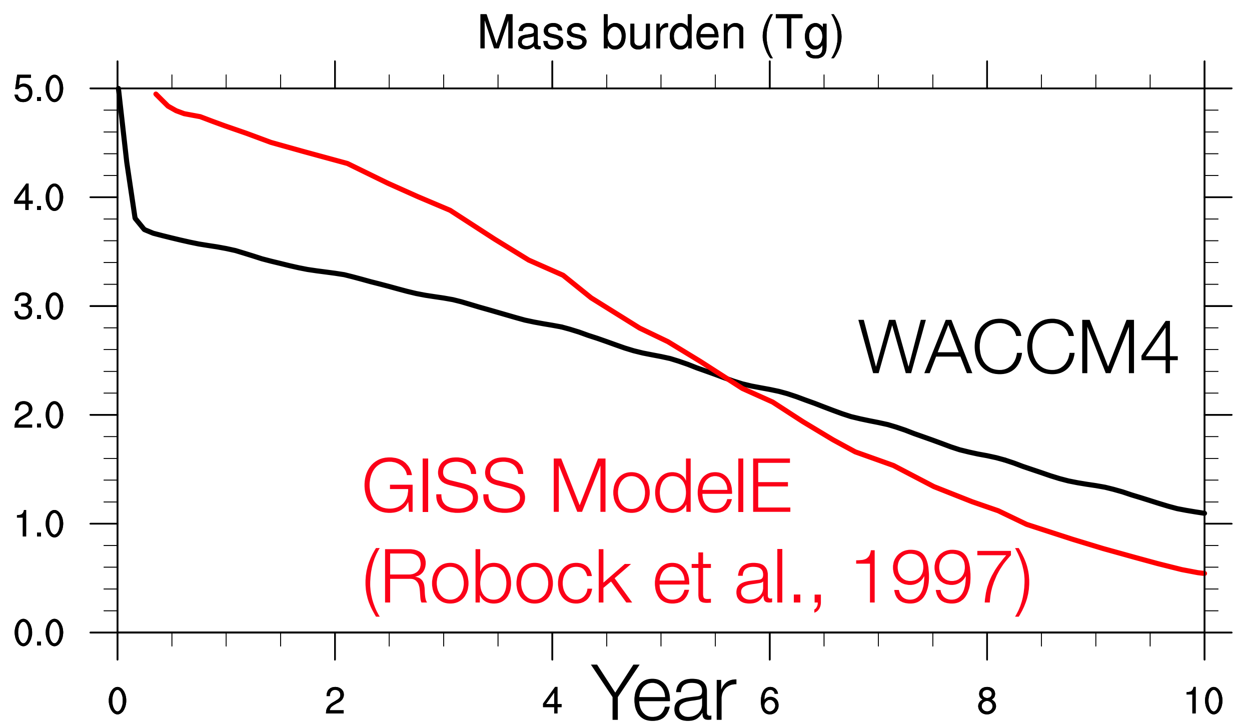
- WACCM input: new estimates of smoke produced by fires in contemporary cities following a regional nuclear war between India and Pakistan
- Solar radiation heats the soot, lofting it to the stratopause, heating the the entire stratosphere for 10 years, altering reaction rates affecting ozone.

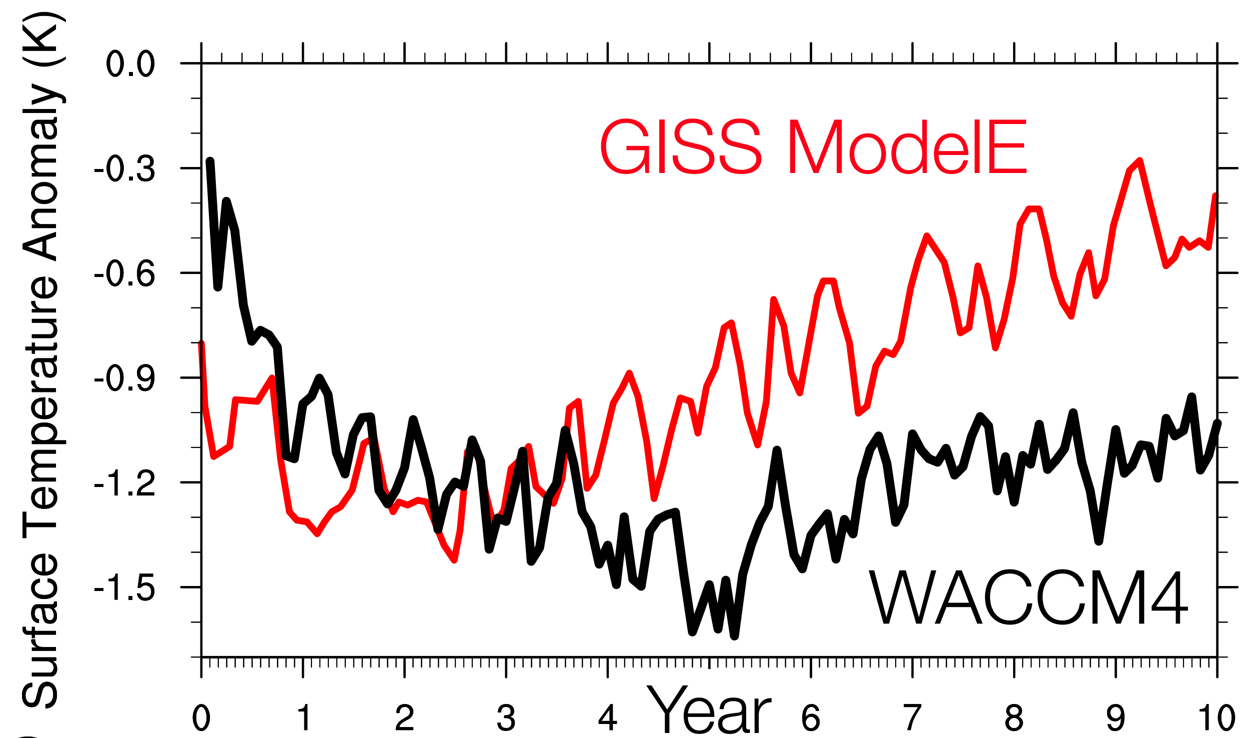


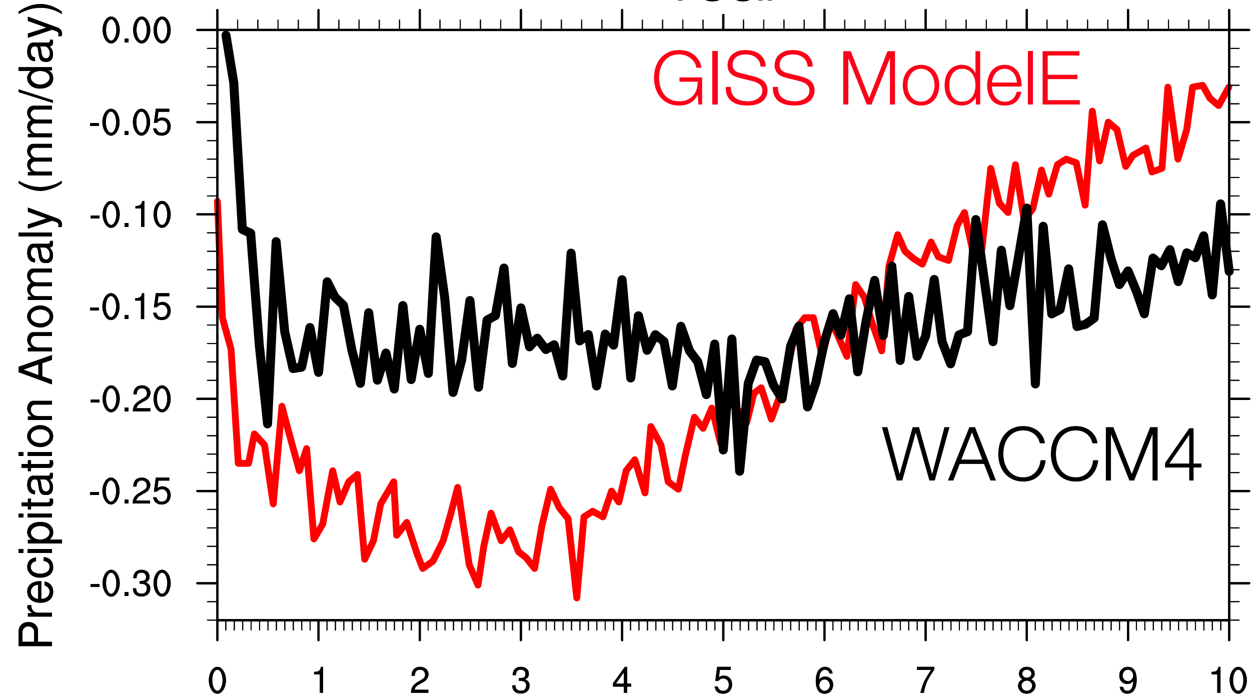
- Calculated ozone losses exceed 20% globally, 25-45% at midlatitudes, and 50-70% at northern high latitudes persisting for 5 years, with substantial losses continuing for 5 additional years. Column ozone amounts remain below that which defines the Antarctic ozone hole everywhere outside of the tropics.

Nuclear winter in WACCM4









WACCM and CAM-Chem Customer Support

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

Mike Mills
WACCM Liaison
mmills@ucar.edu
(303) 497-1425

Simone Tilmes
CAM-Chem Liaison
tilmes@ucar.edu
(303) 497-1425