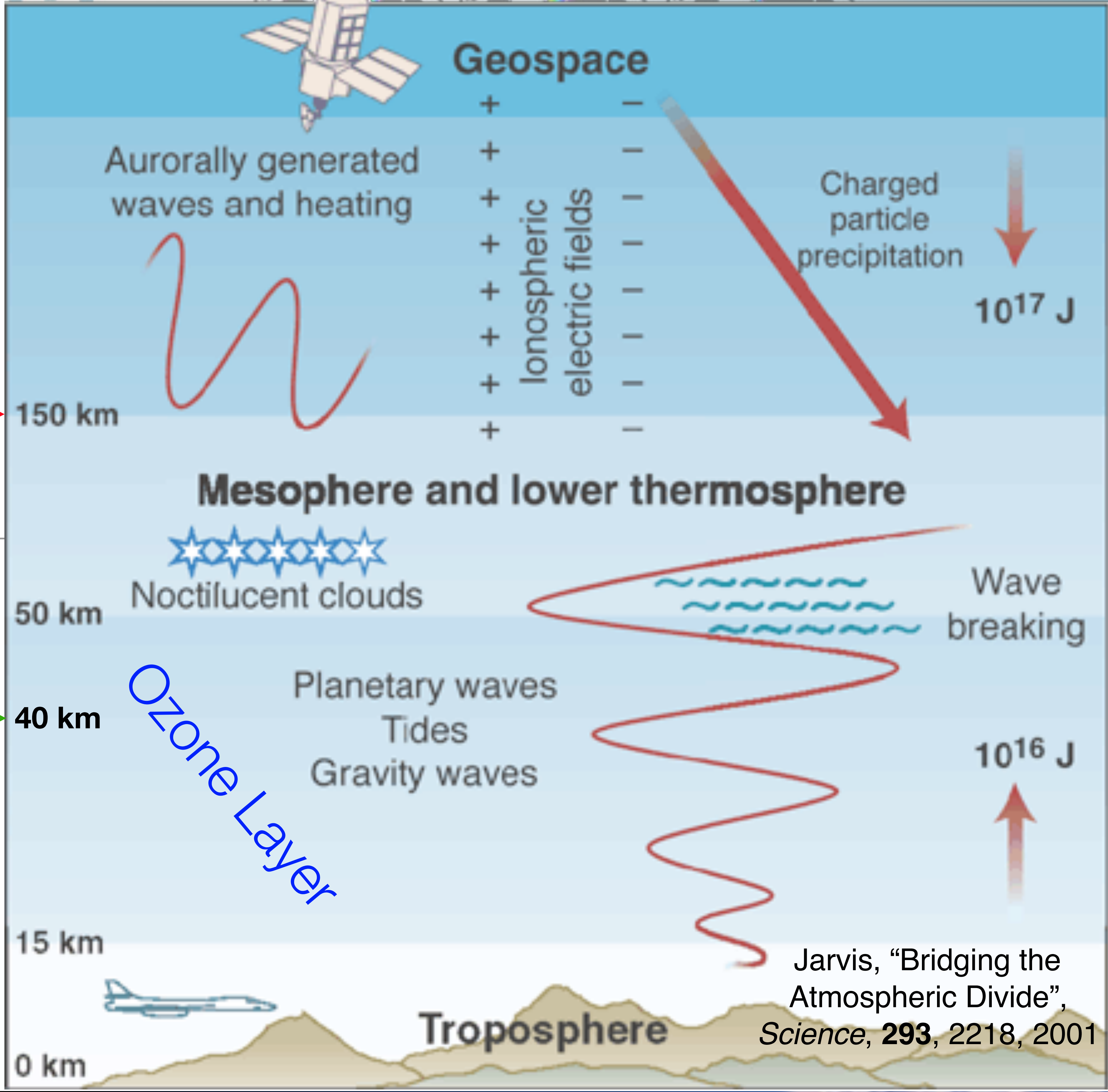
Community Earth System Model CESM

WACCM: The High-Top Model



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

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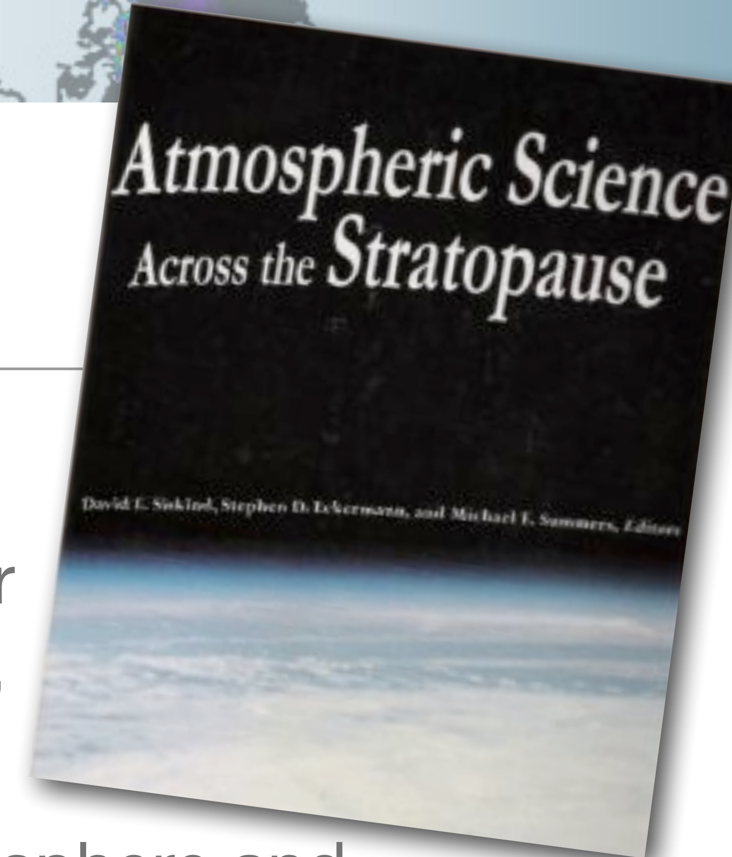
WACCM Whole Atmosphere Community Climate Model

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

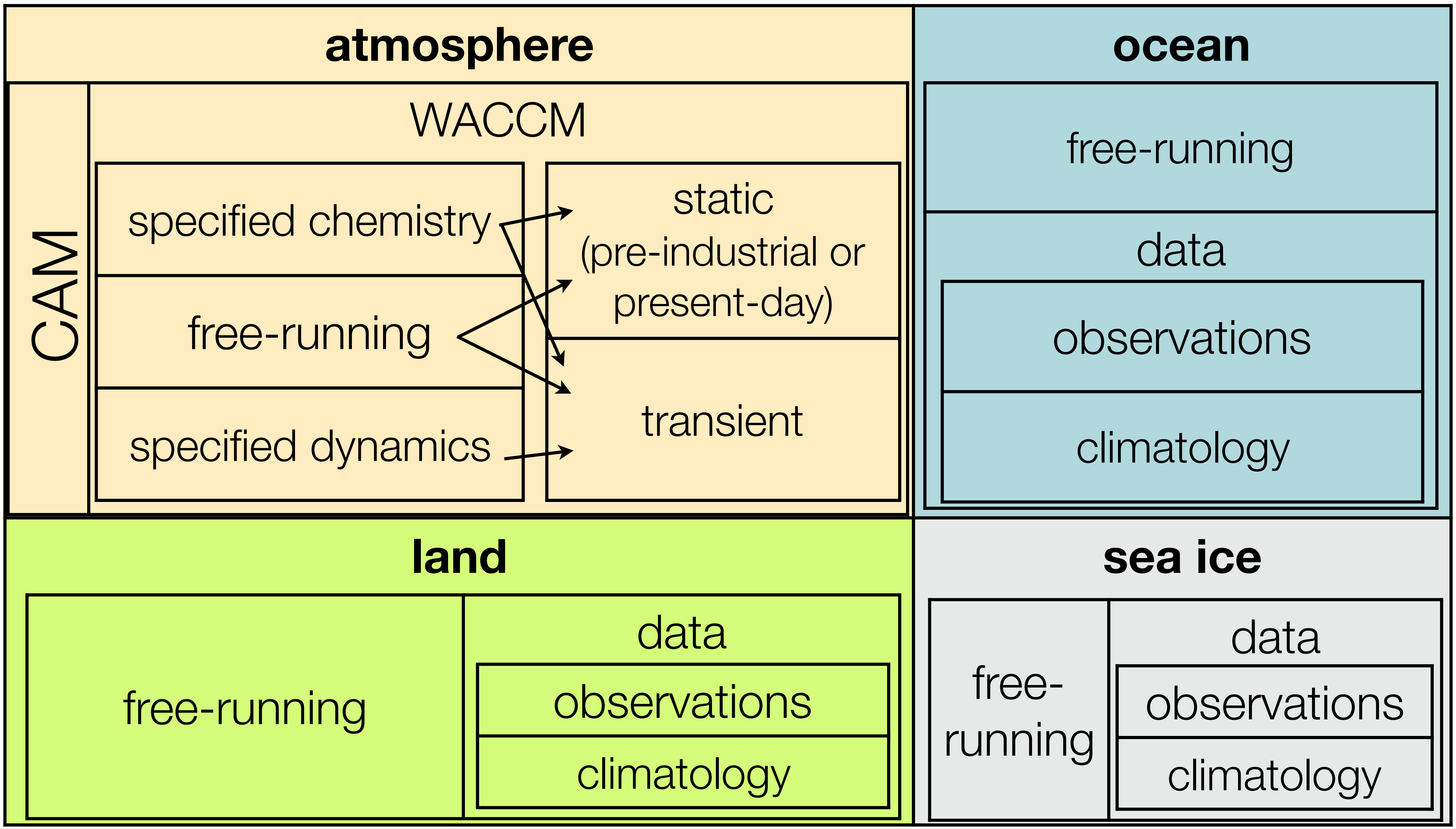
WACCM Motivation

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

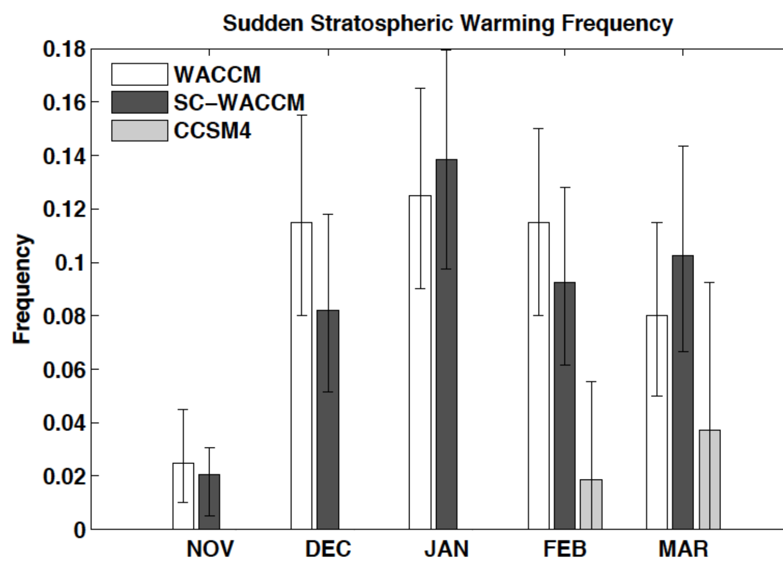
CESM-WACCM component configurations



WACCM Specified Chemistry (WACCM-SC)

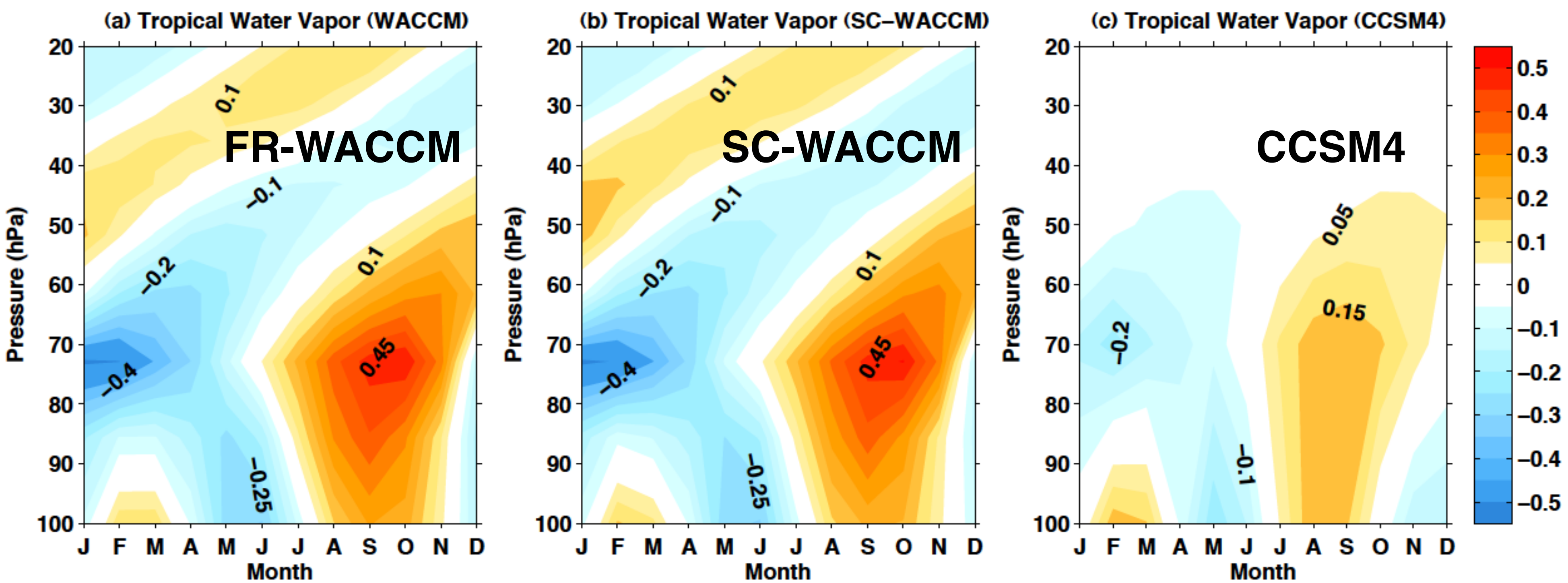
- Specifies Ozone (among other species)
- 2x as fast as WACCM: for stratospheric dynamics studies, with nearly identical results

Model	# cores	simulated years/day	core-hrs/simulated year
WACCM	352	7.5	1130
SC-WACCM	352	14.8	573
CCSM4 1°	352	19.6	432
CCSM4 2°	416	42.0	237



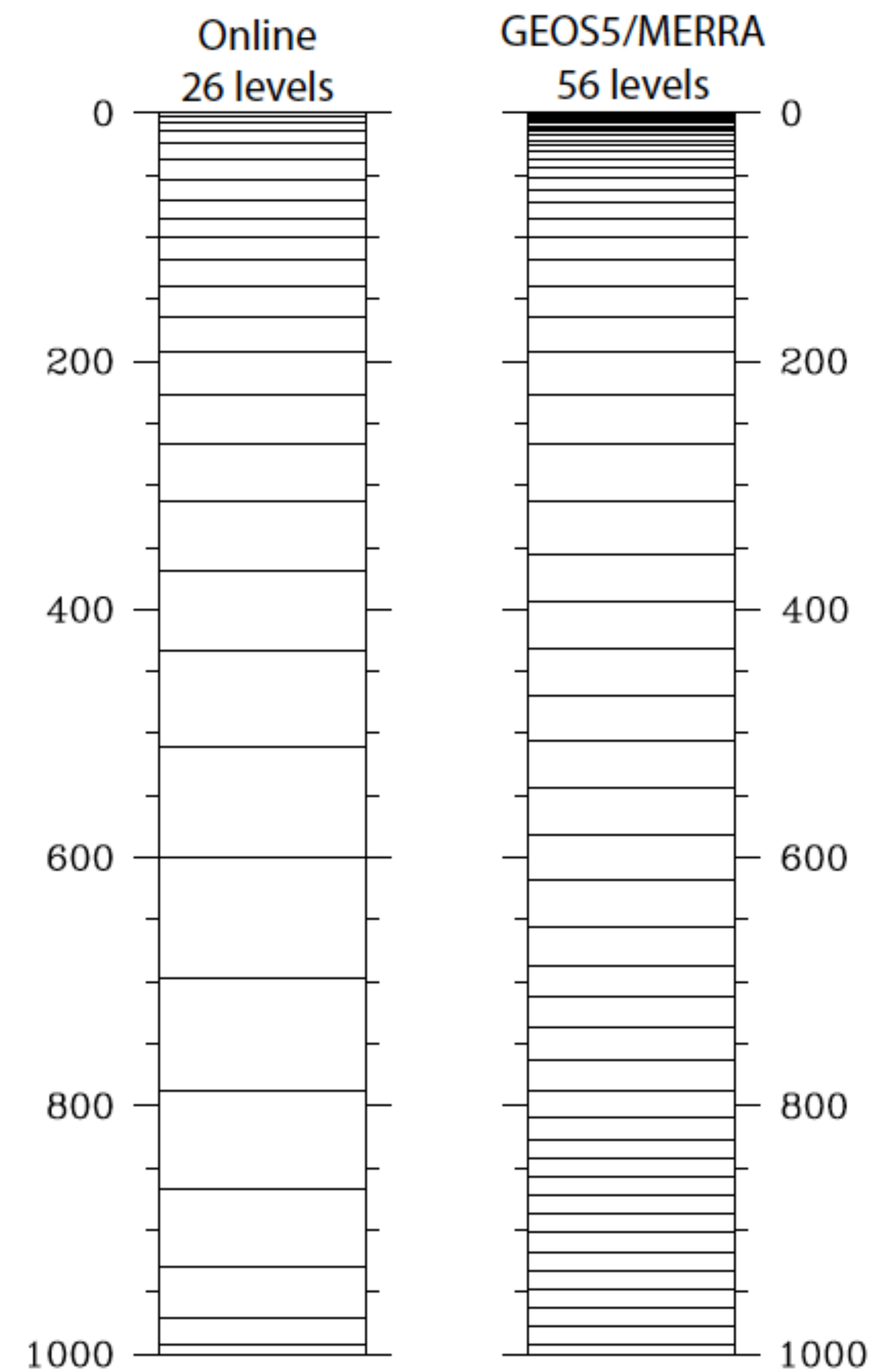
Above: WACCM4-SC also gets sudden stratospheric warming frequency right

Below: Tropical H2O Tape Recorder looks like WACCM (good), not CCSM4 (bad)



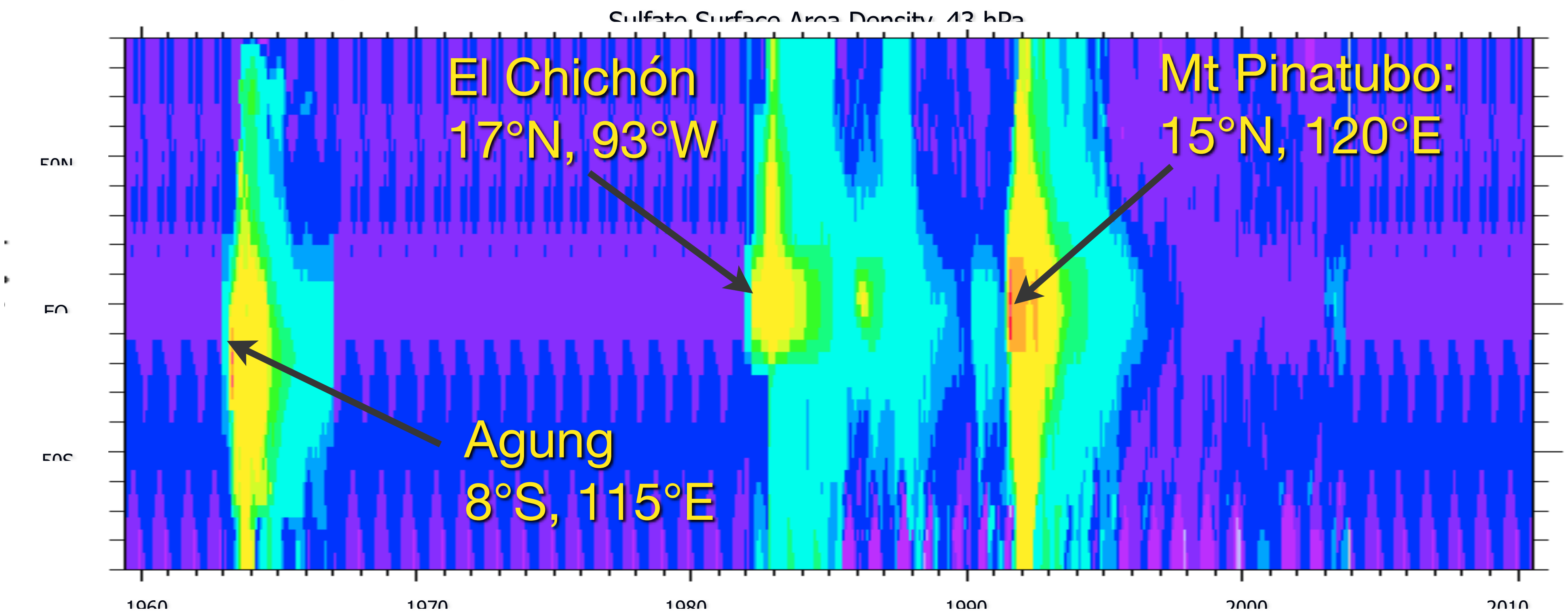
Specified Dynamics: SD-WACCM and SD-CAM-Chem

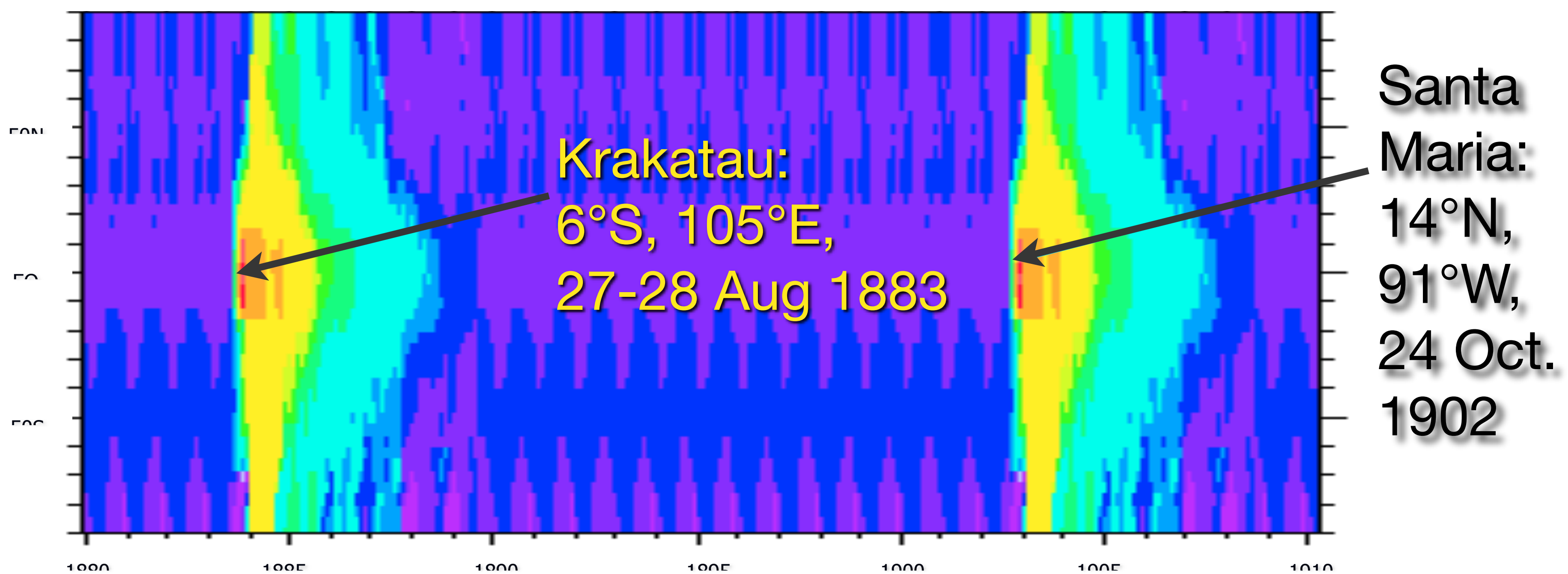
- Reproduce winds and temperatures from specific periods in analyses from GEOS5 (2004-present) or MERRA (1979-present).
- **FSDW** compset starts on 1 Jan 2005, uses GEOS5, out of the box.
- Increased vertical resolution
  - CAM-Chem: 26 levels → SD-CAM-Chem: 56 levels
  - WACCM: 66 levels → SD-WACCM: 88 levels
- Nudge T, U, V, PS towards analyses at every dynamics timestep. Nudging strength (i.e. 1%, 10% each timestep) and top altitude (50 km default for WACCM) can be adjusted.
- Chemistry interacts with radiation, atmosphere, land, ocean
- Data ocean and sea ice components



Community Earth System Model

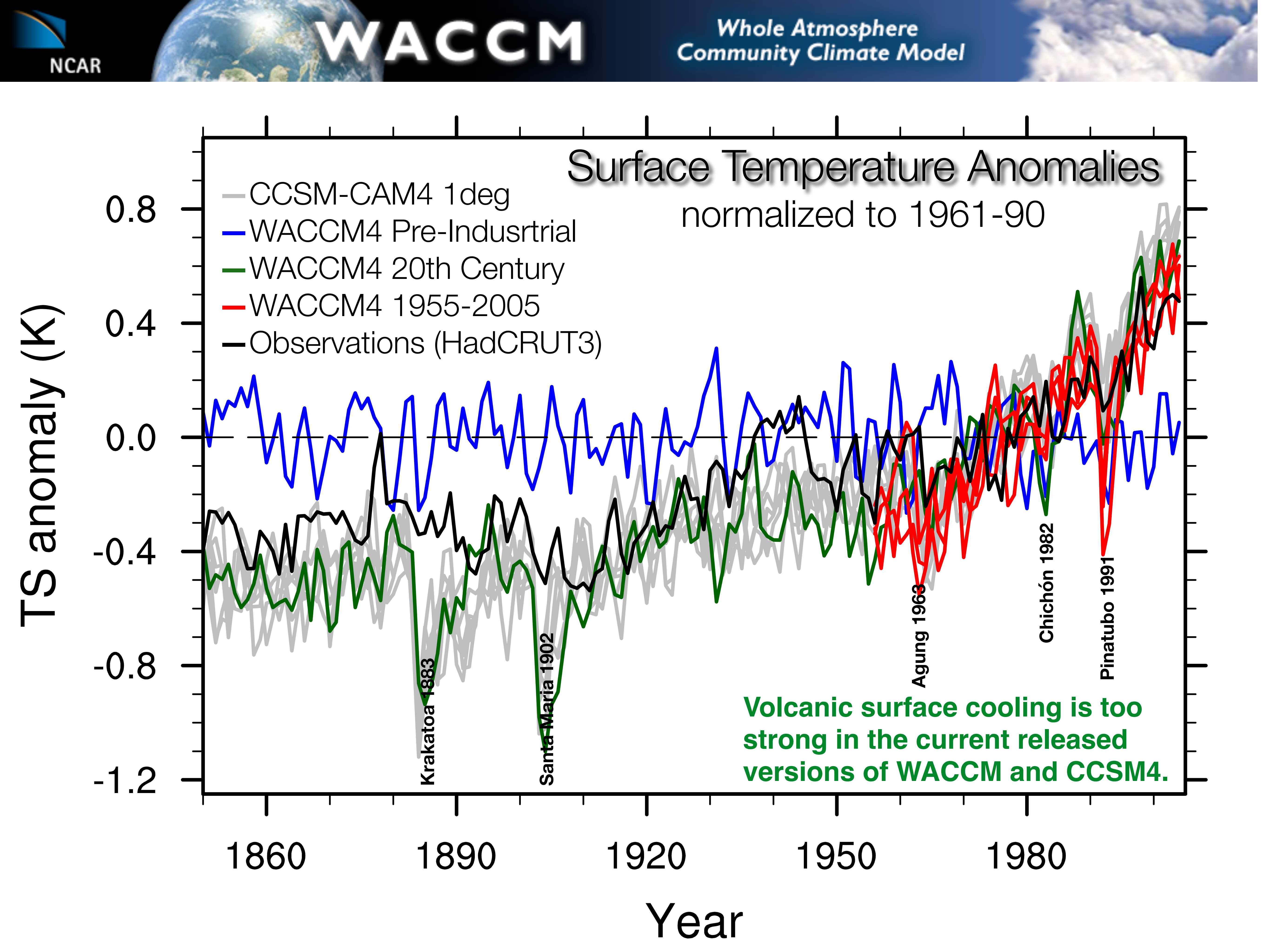
Stratospheric Sulfate Surface Area Density Climatology





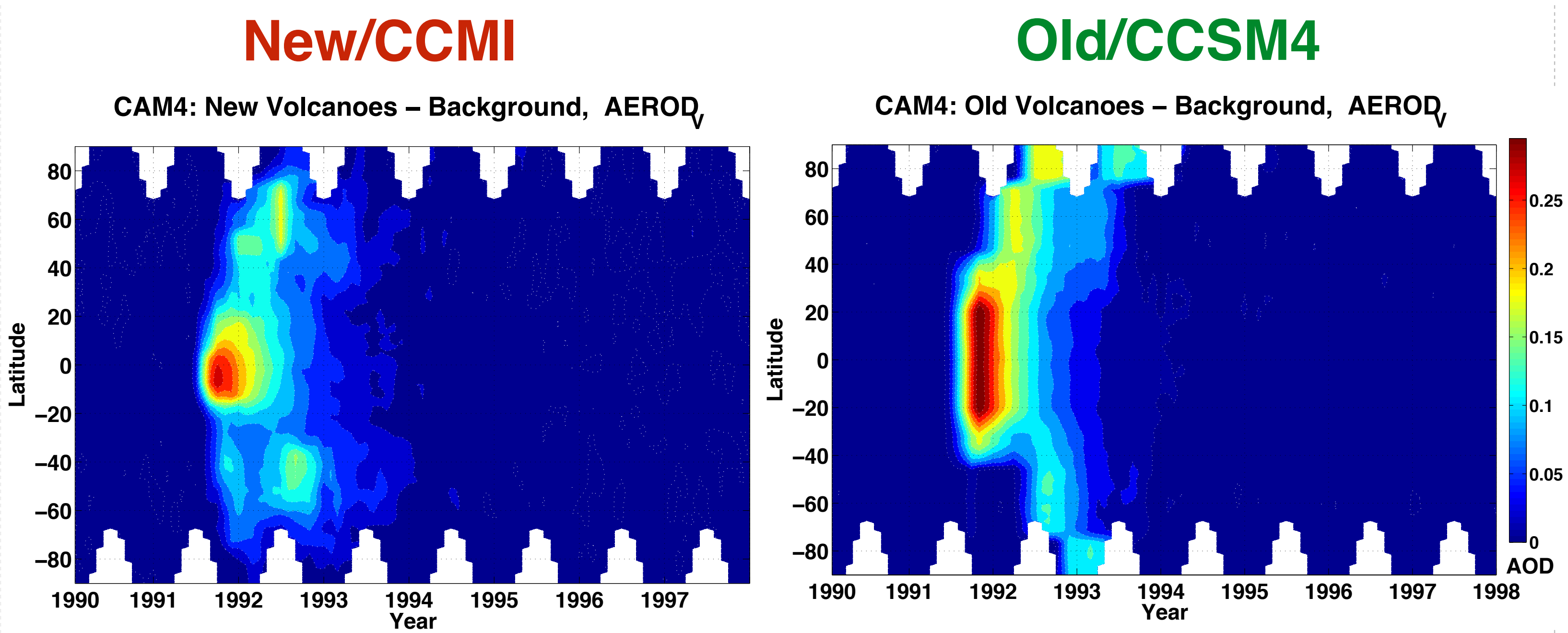
- Observations used: SAGE I, SAGE II, SAM II, and SME instruments.
- Non-volcanic periods filled with monthly mean of 1998-2002 values.
- Used Pinatubo aerosol for Krakatau and Santa Maria.

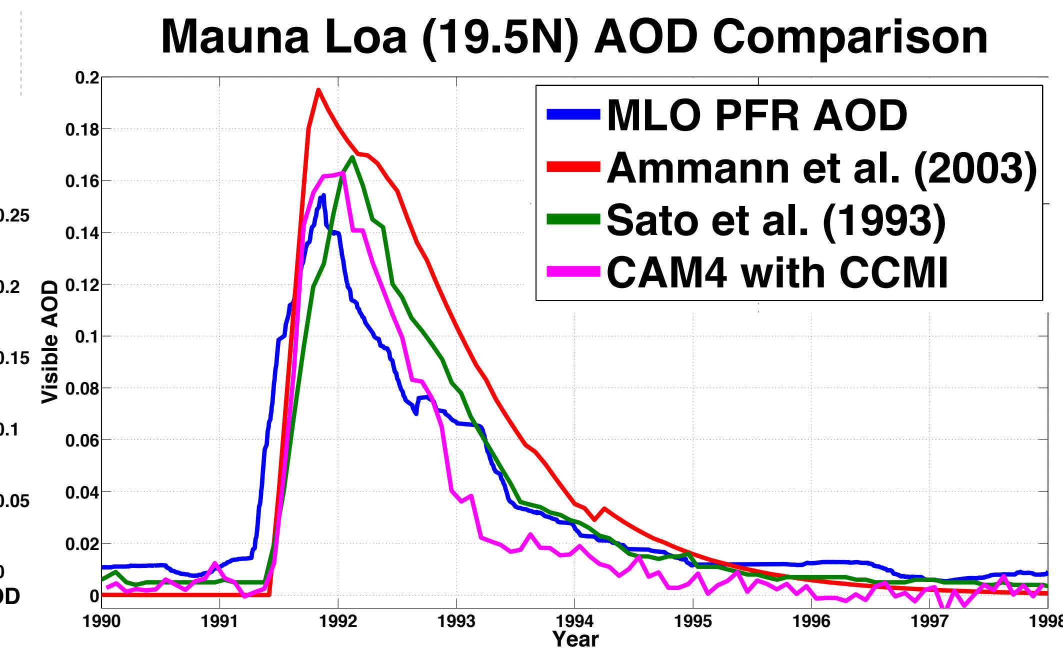
WACCM
Whole Atmosphere Community Climate Model



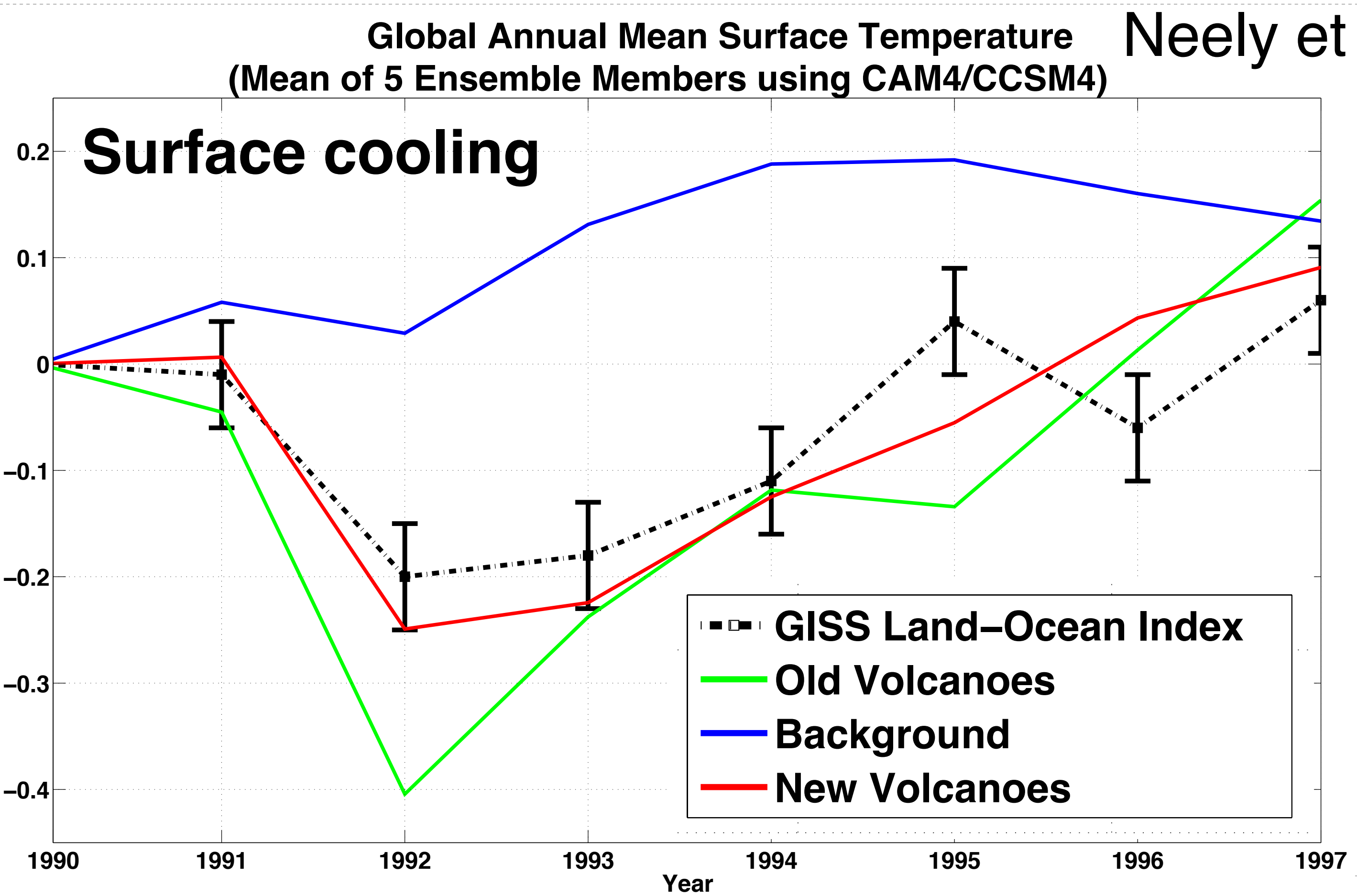
NCAR
WACCM
Whole Atmosphere
Community Climate Model
Surface Temperature Anomalies
normalized to 1961-90
CCSM-CAM4 1deg
WACCM4 Pre-Indusrtrial
WACCM4 20th Century
WACCM4 1955-2005
Observations (HadCRUT3)
0.8
0.4
0.0
-0.4
-0.8
-1.2
TS anomaly (K)
1860
1890
1920
1950
1980
Year
Krakatoa 1883
Santa Maria 1902
Agung 1963
Chichón 1982
Pinatubo 1991
Volcanic surface cooling is too strong in the current released versions of WACCM and CCSM4.

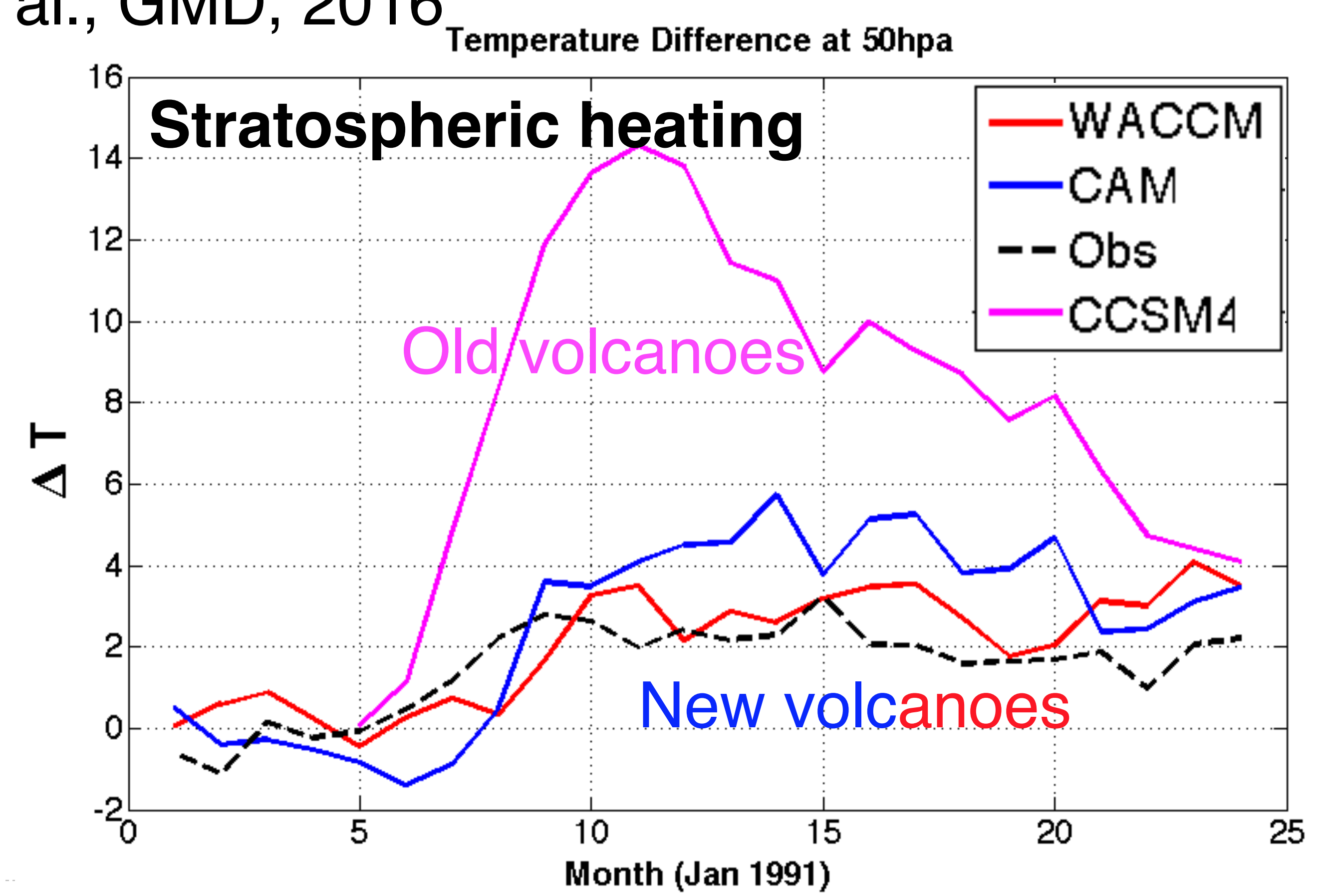
New stratospheric sulfate dataset for CCMI: significant improvements (Contact Doug Kinnison: dkin@ucar.edu)



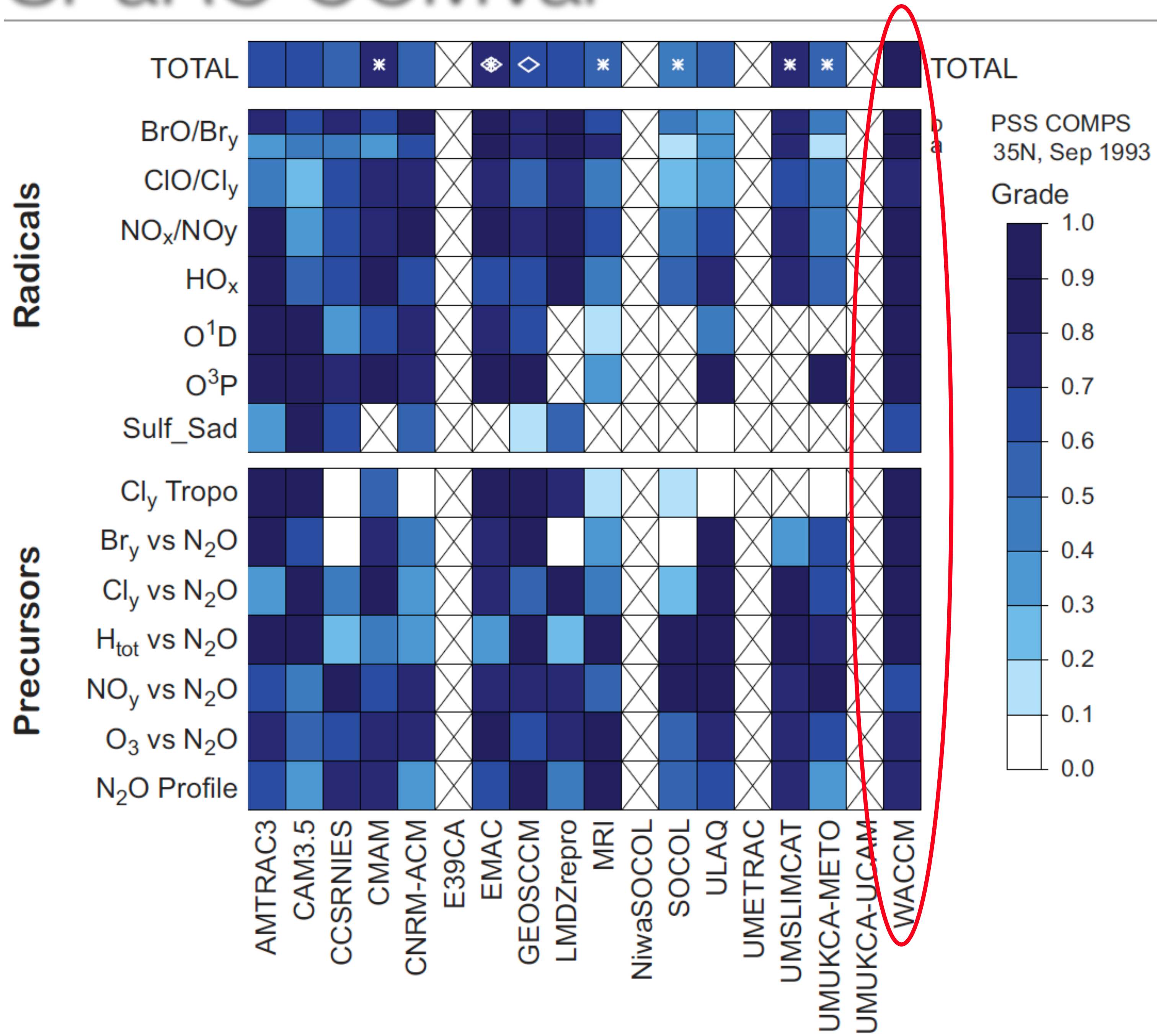


Neely et al., GMD, 2016





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

?

Nitric Acid Hydrate (H_2O, HNO_3) – NAT

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

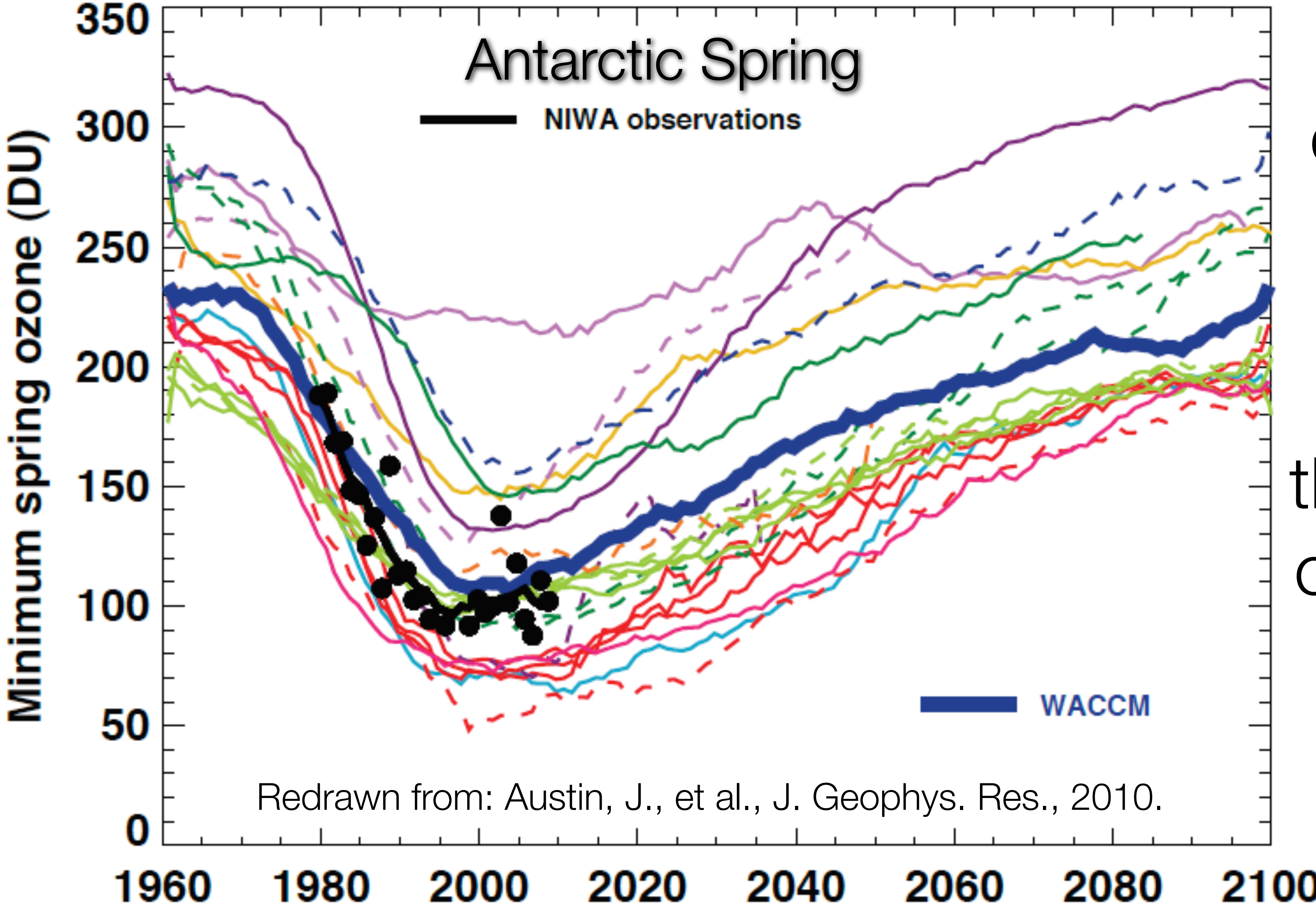
188 K (T_{sat})

ICE (H_2O, with NAT Coating)

R_{ice}= 10-30 μm

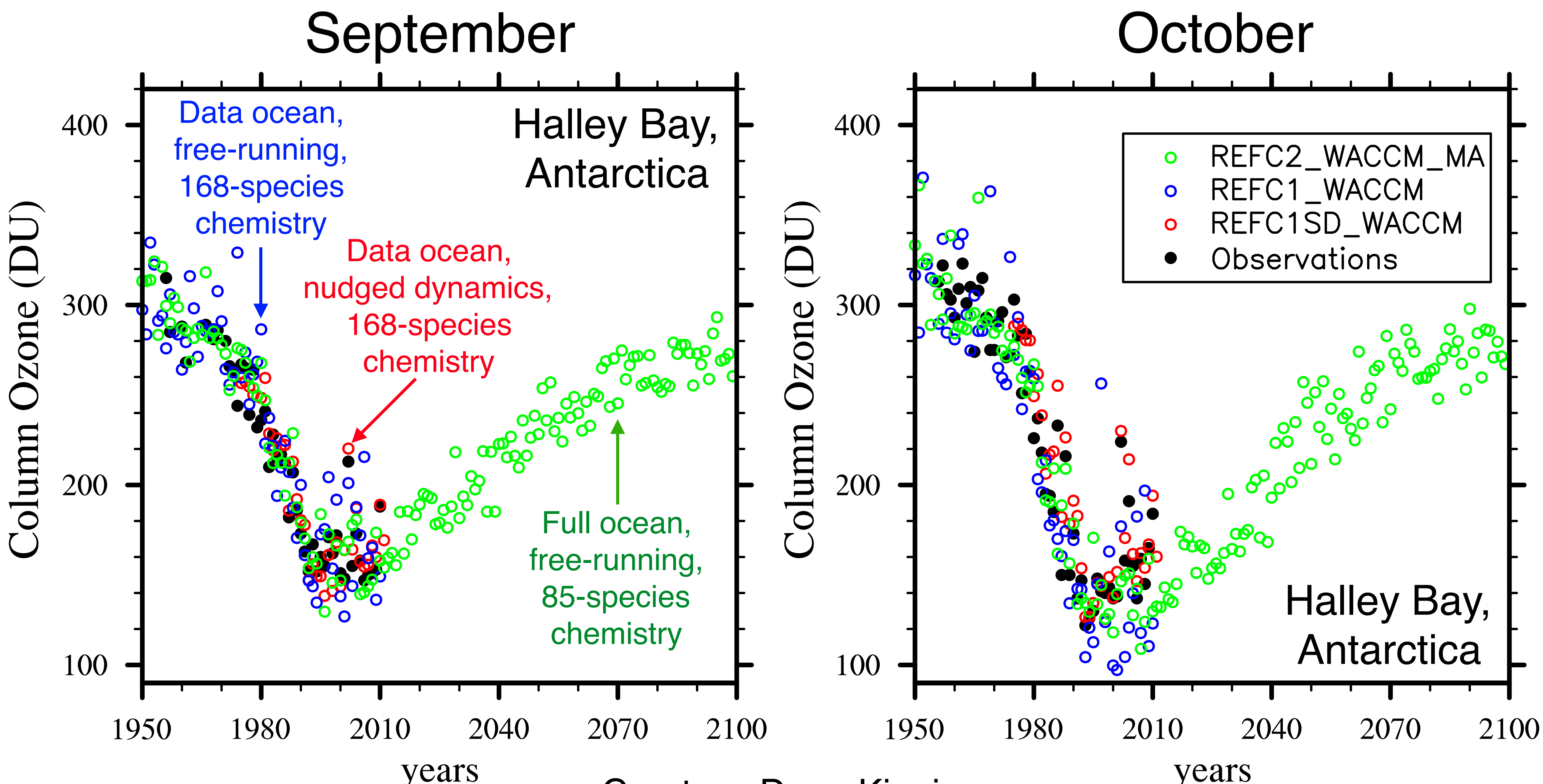
185 K (T_{nuc})

WACCM Ozone Trend: CCMVal and WMO (2010)



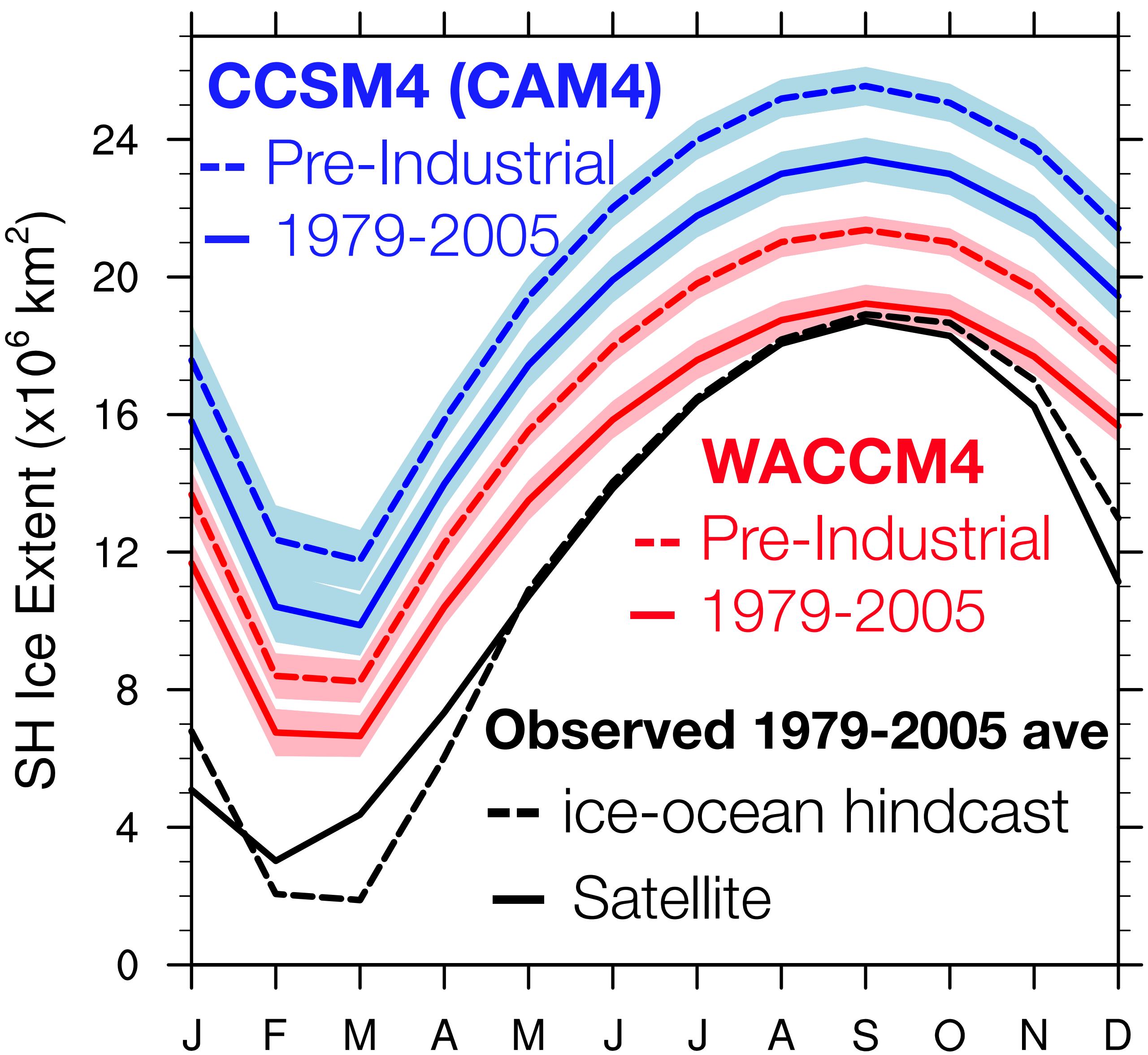
WACCM does better than most models at calculating the evolution of the ozone hole.

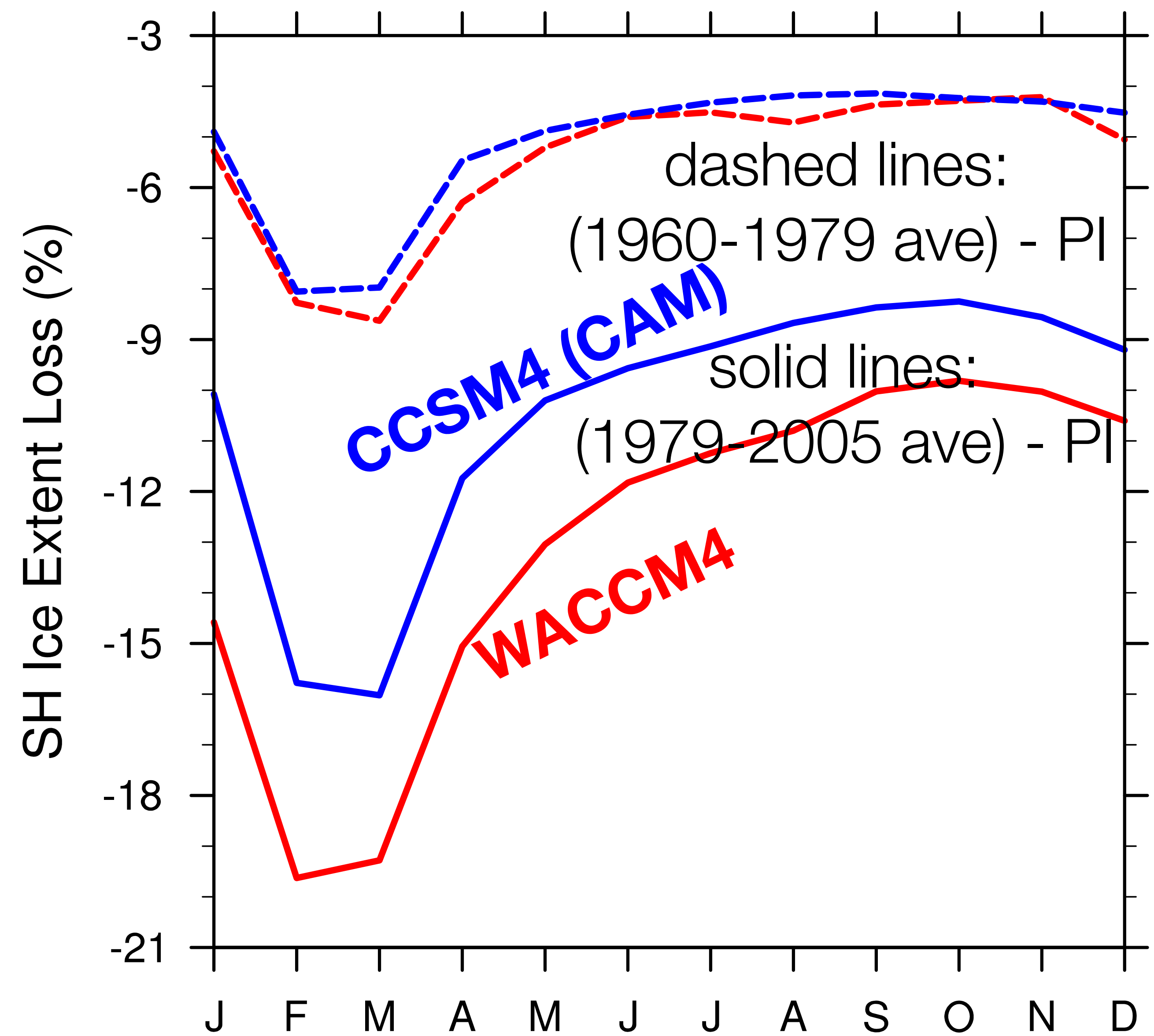
CCMI runs (2013/14): updated chemistry and dynamics (not yet released)



Courtesy Doug Kinnison

Antarctic sea-ice extent

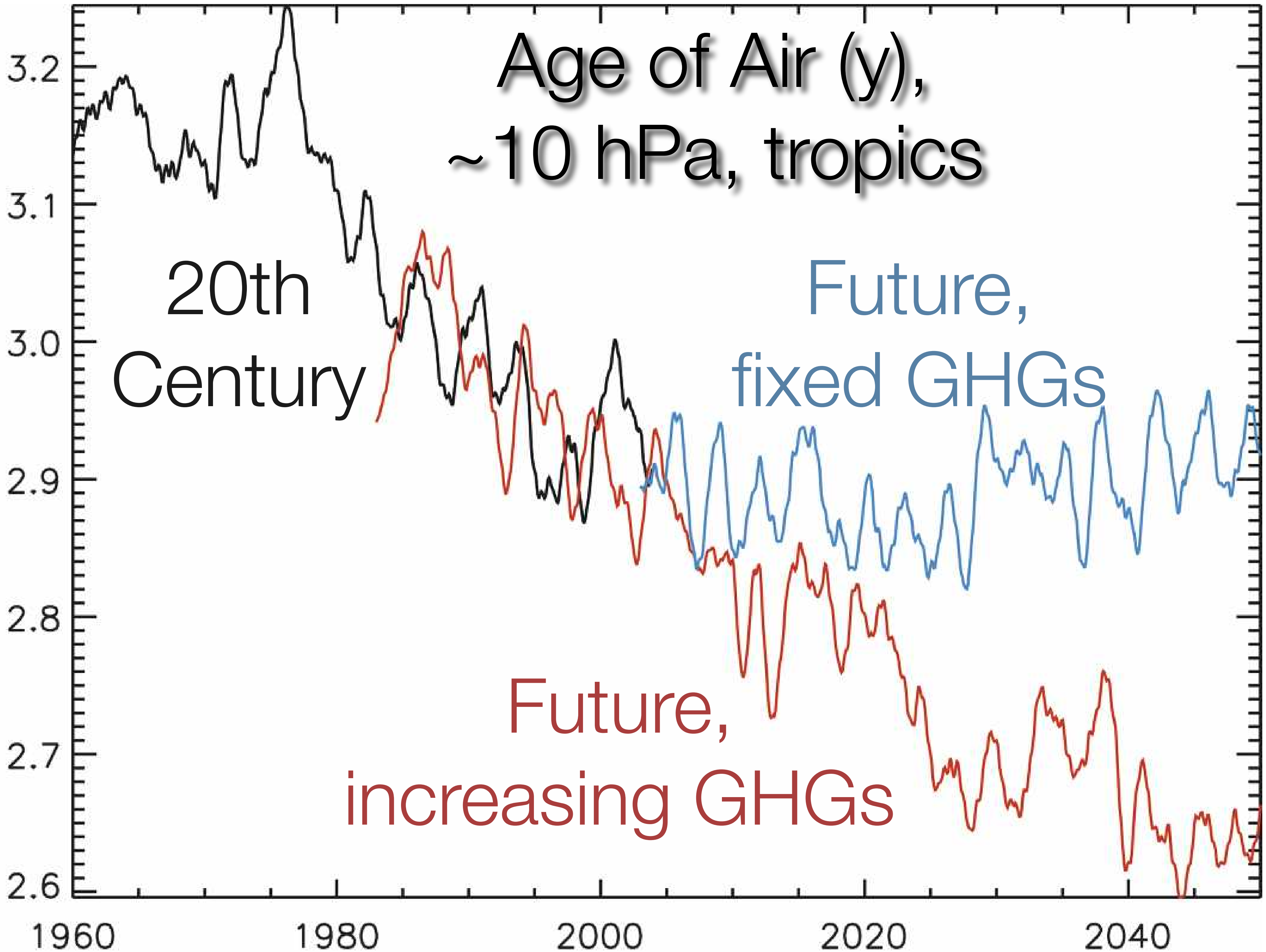




The more realistic ozone loss in WACCM drives changes in winds that enhance sea-ice loss, producing sea-ice extent closer to modern observations.

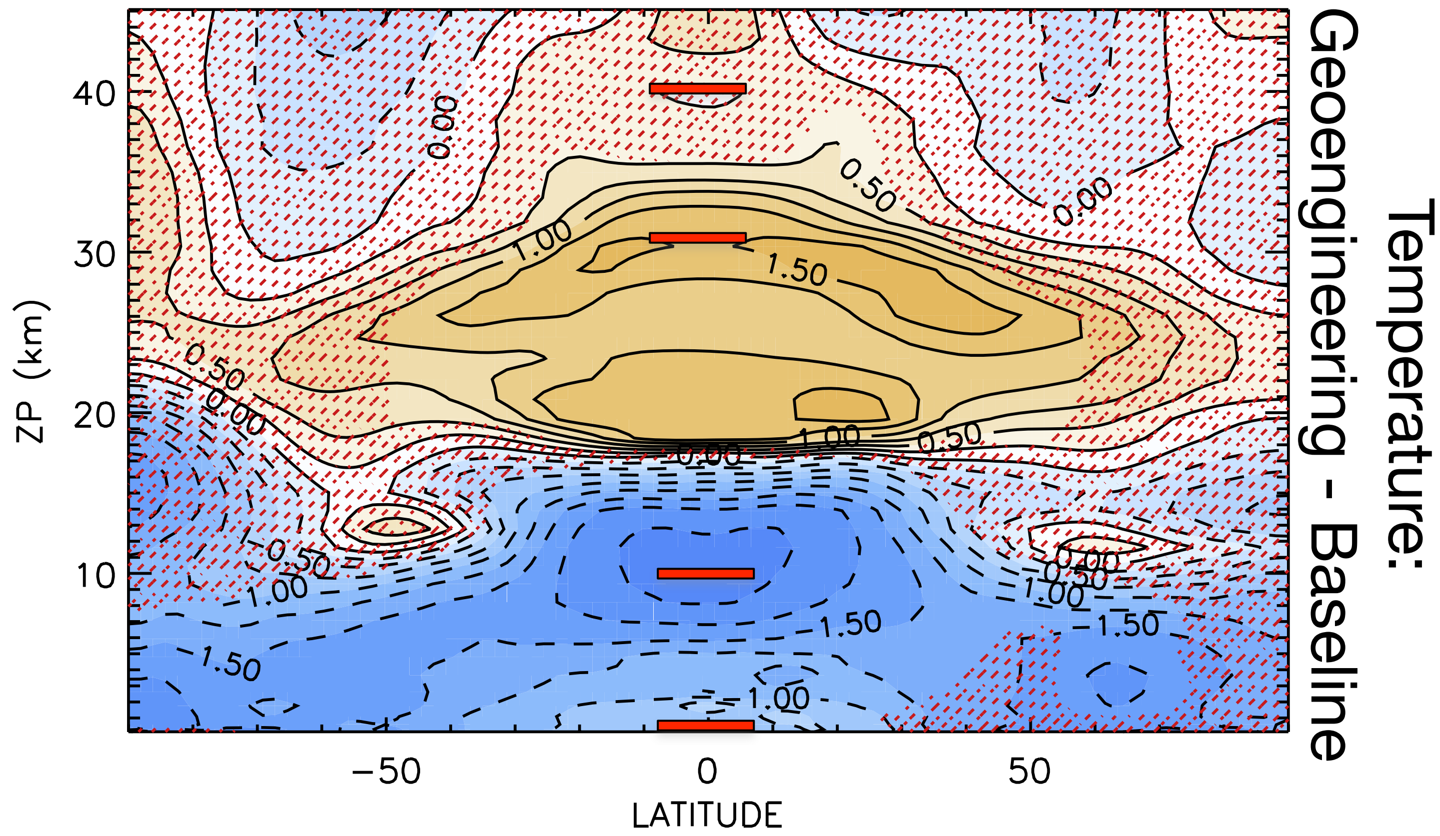
Acceleration of the Brewer–Dobson Circulation due to Increases in Greenhouse Gases
Garcia and Randel, *J. Atmos. Sci.*, vol. 65 (8), pp. 2731-2739, 2008.

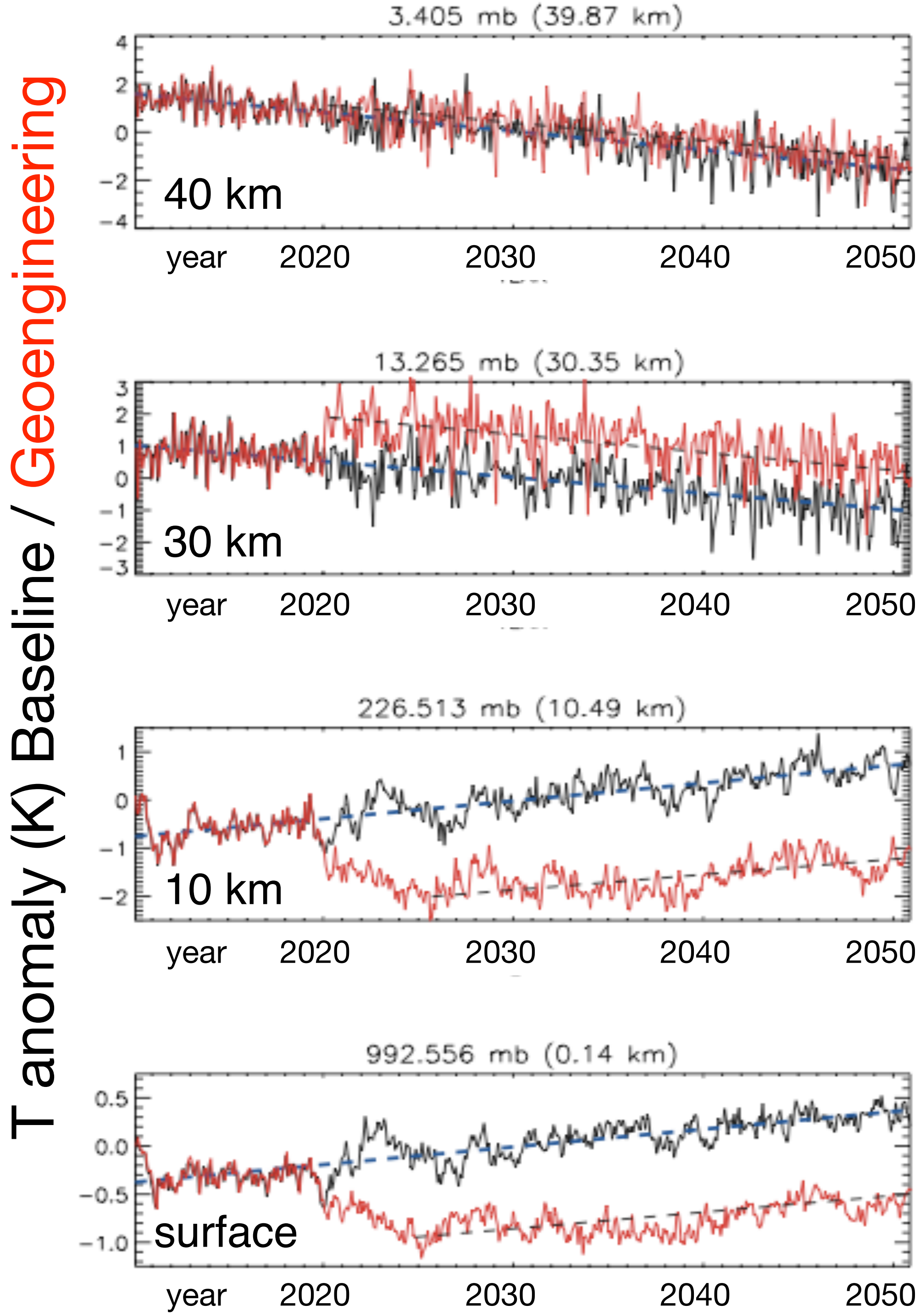
- faster circulation in greenhouse world due to enhanced propagation of wave activity into the lower stratosphere and its dissipation in the subtropics
- changes in meridional temperature gradient affect zonal winds, which change the regions where waves dissipate, increasing momentum deposition



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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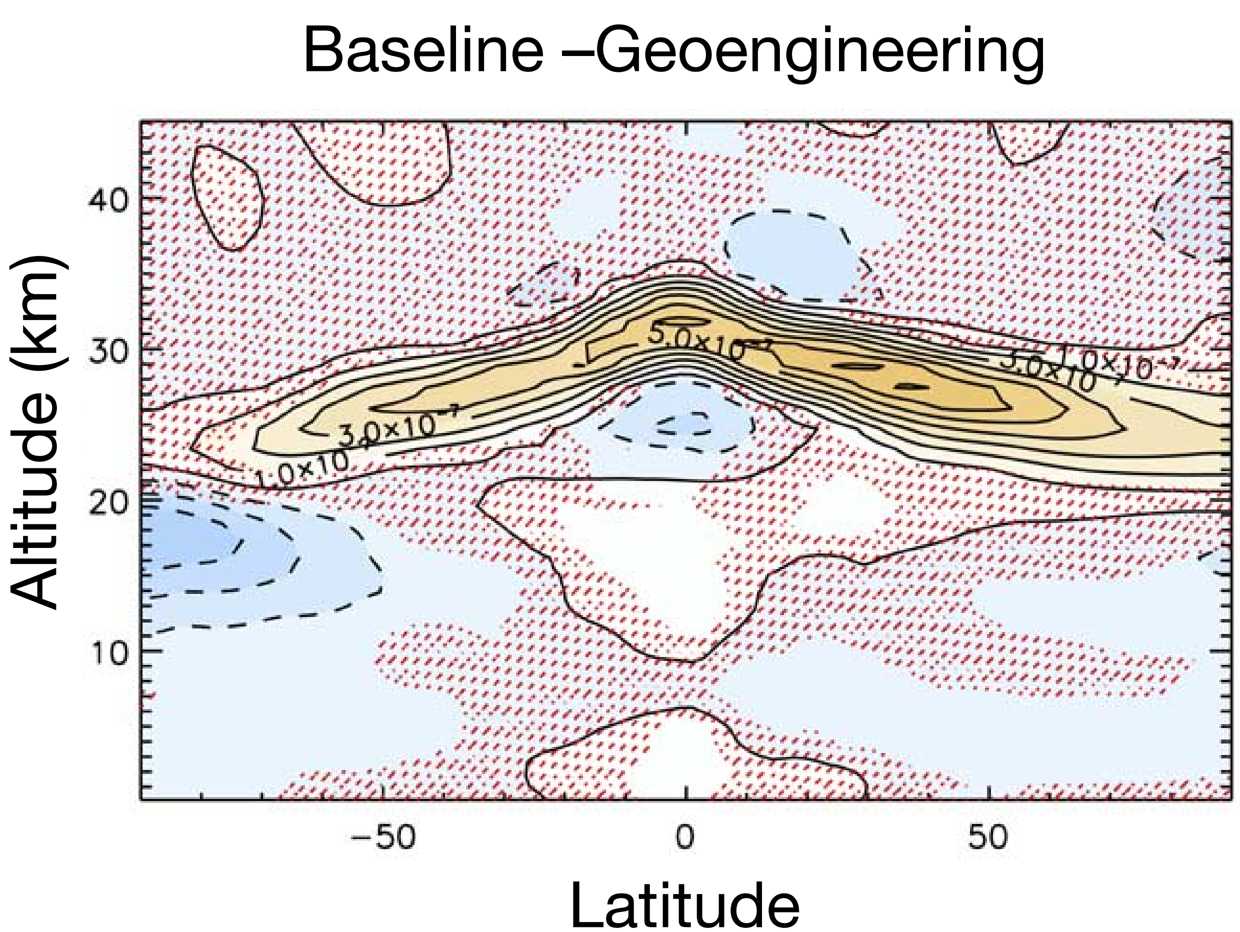
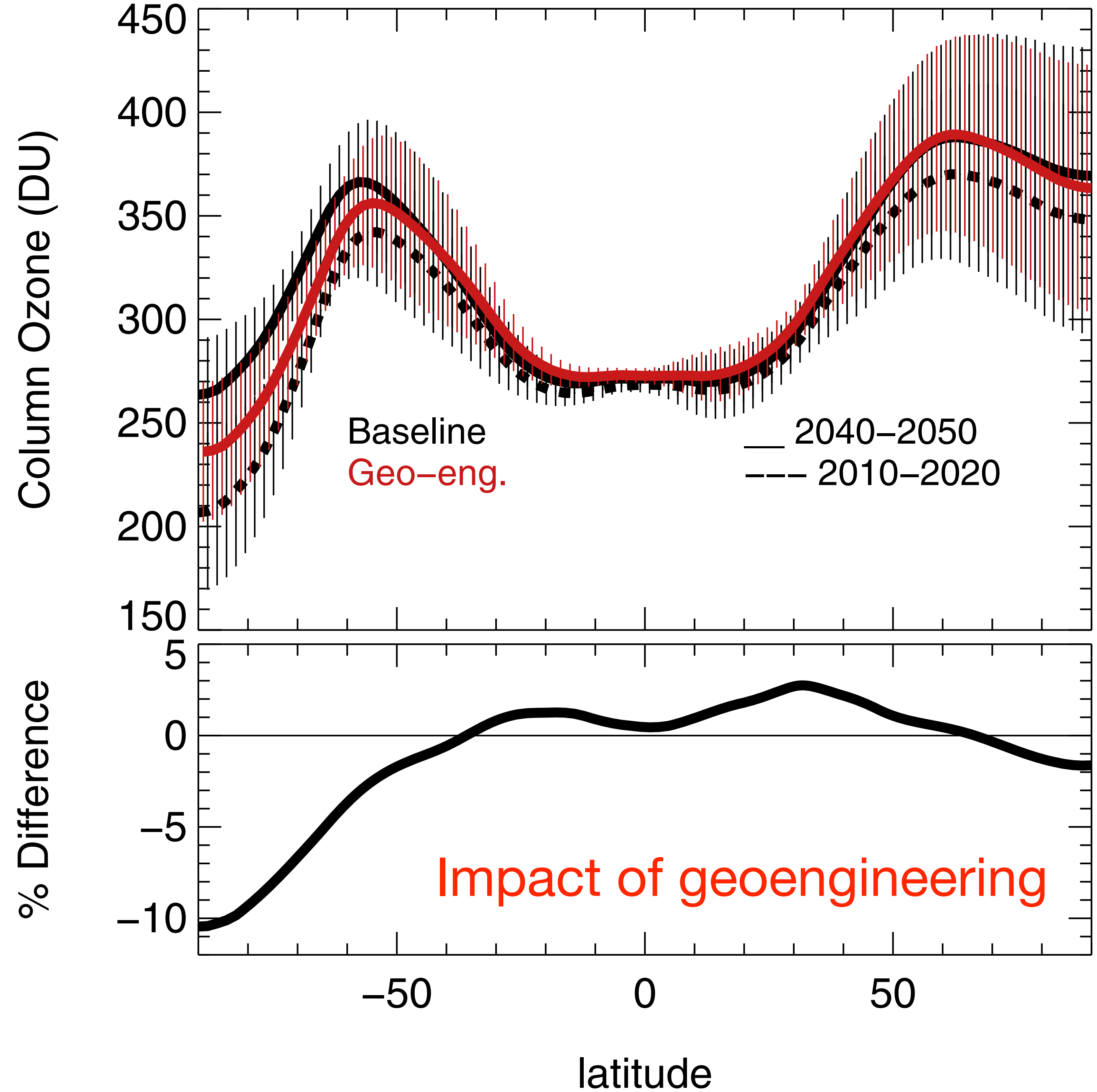
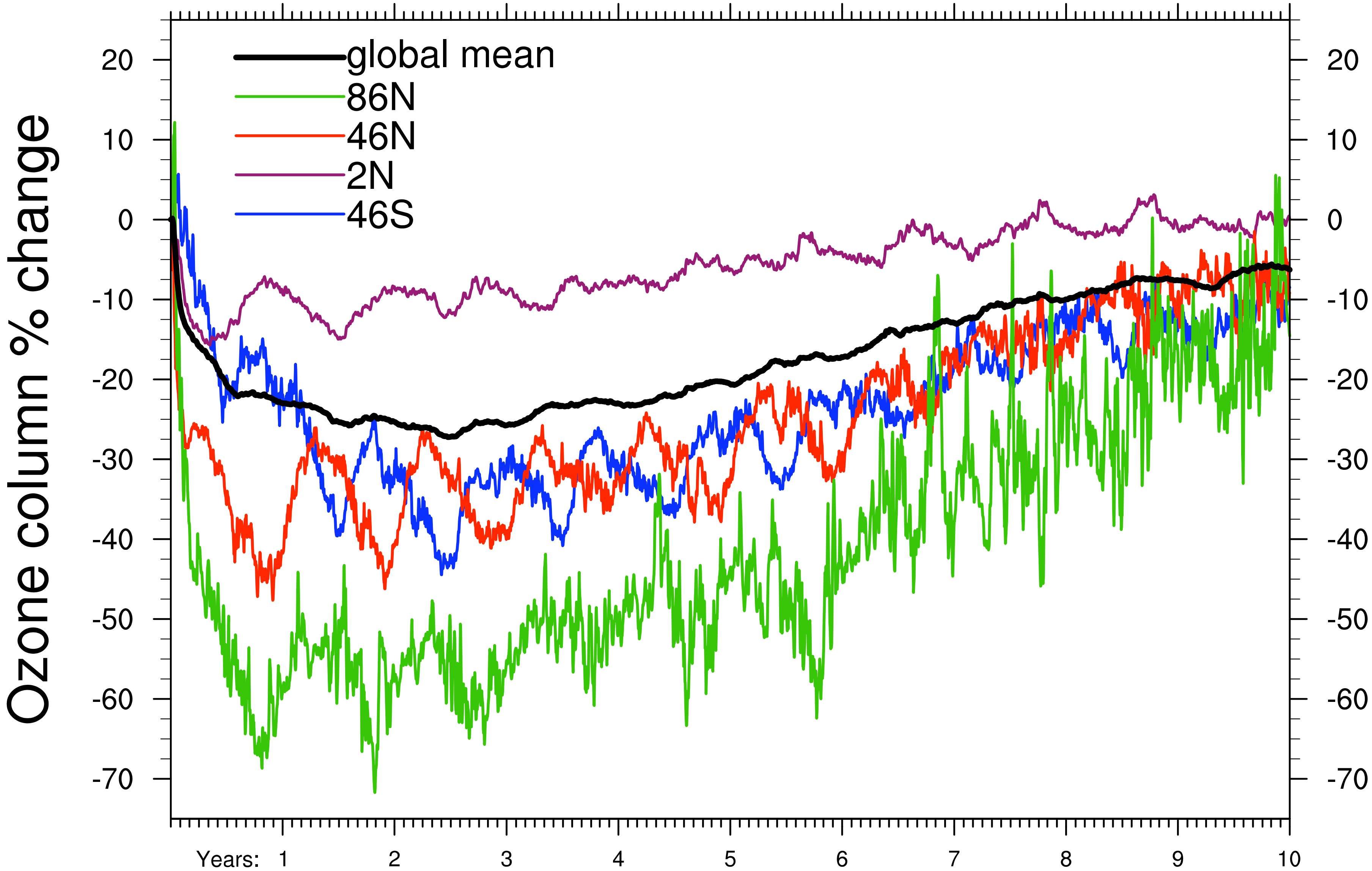
Impacts of geoengineering on ozone





Massive global ozone loss predicted following regional nuclear conflict
Mills *et al.*, PNAS, vol. 105, pp. 5307, 2008

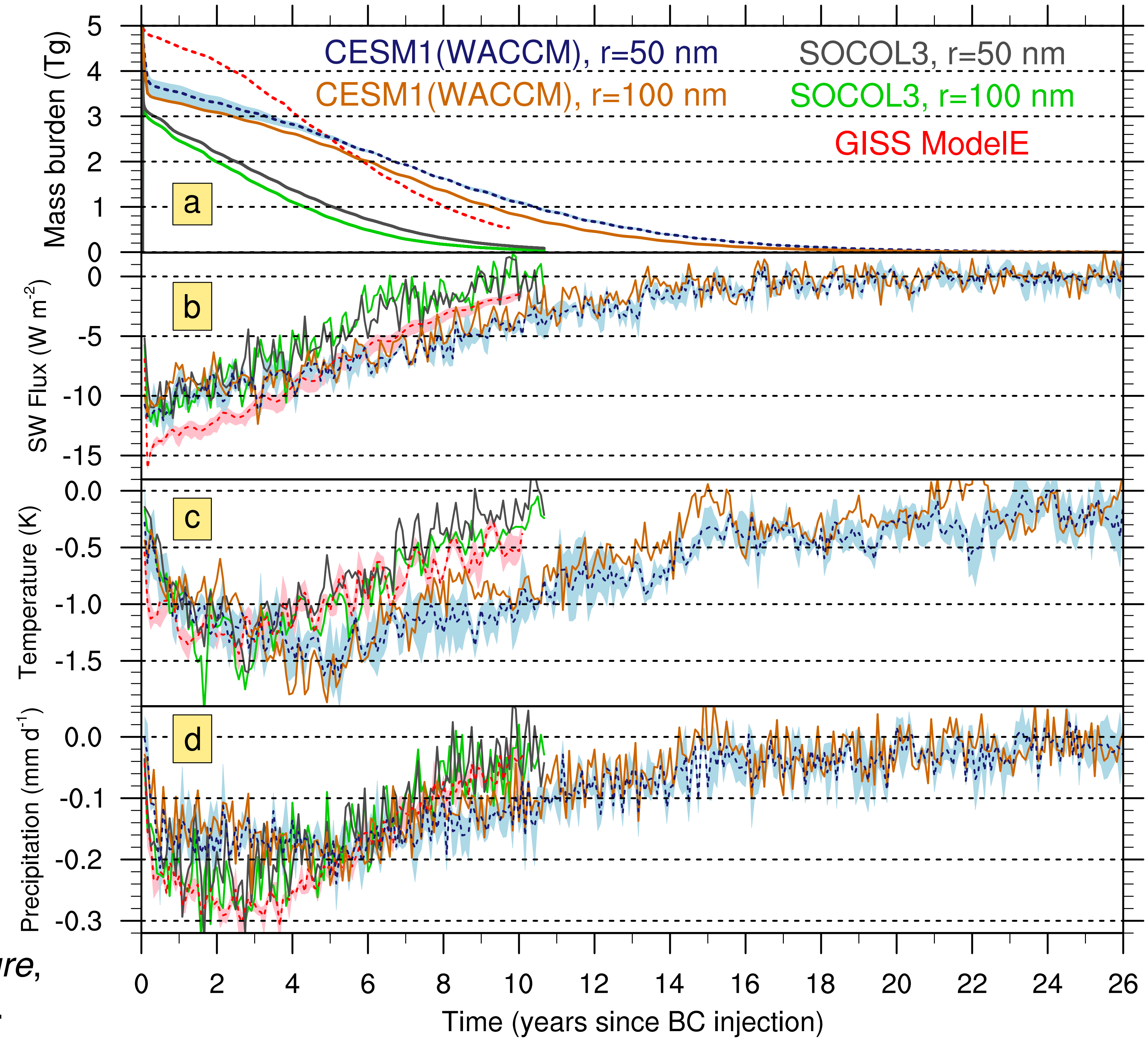
- WACCM input: new estimates of smoke produced by fires in contemporary cities following a regional nuclear war between India and Pakistan
- Solar radiation heats the soot, lofting it to the stratopause, heating the the entire stratosphere for 10 years, altering reaction rates affecting ozone.



- 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.

Multidecadal global cooling and unprecedented ozone loss following a regional nuclear conflict

- CESM1(WACCM) with interactive chemistry, sea ice, full ocean, and land components
- Deep ocean cooling, sea ice expansion result in slower initial cooling, thermal inertia, increased albedo, more prolonged recovery: extended from 10 years in previous studies to more than 25 years
- Killing frosts would reduce growing seasons by 10 – 40 days per year for 5 years
- Summer enhancements in UV indices of 30% – 80% over midlatitudes
- Global nuclear famine?



Mills et al. (2014), *Earth's Future*, doi:10.1002/2013EF000205.

WACCM and CAM-Chem Customer Support

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

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