WACCM: The High-Top Model

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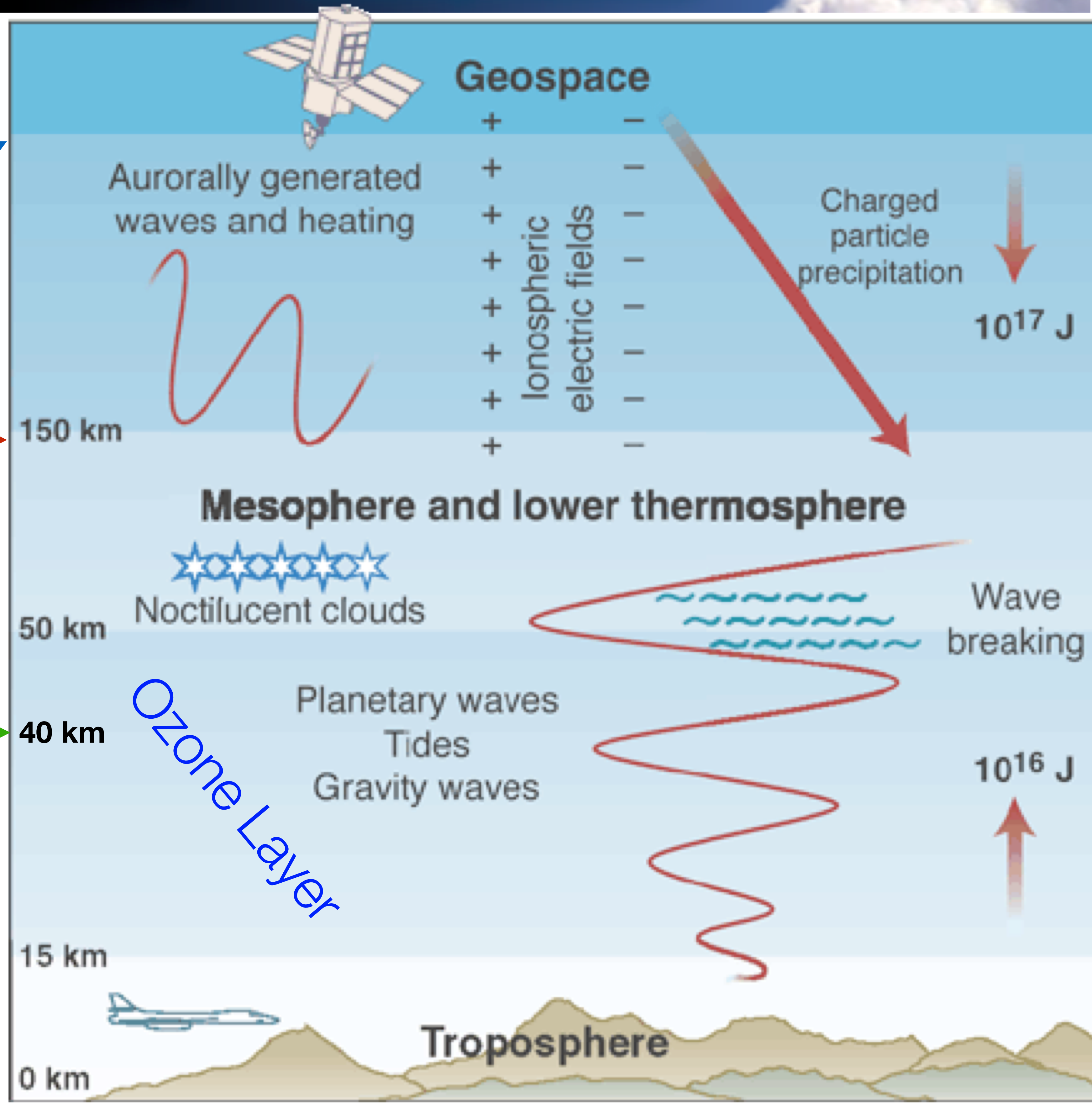
NCAR **WACCM** *Whole Atmosphere Community Climate Model*

Whole Atmosphere Community Climate Model - eXtended (WACCM-X): surface to 750 km

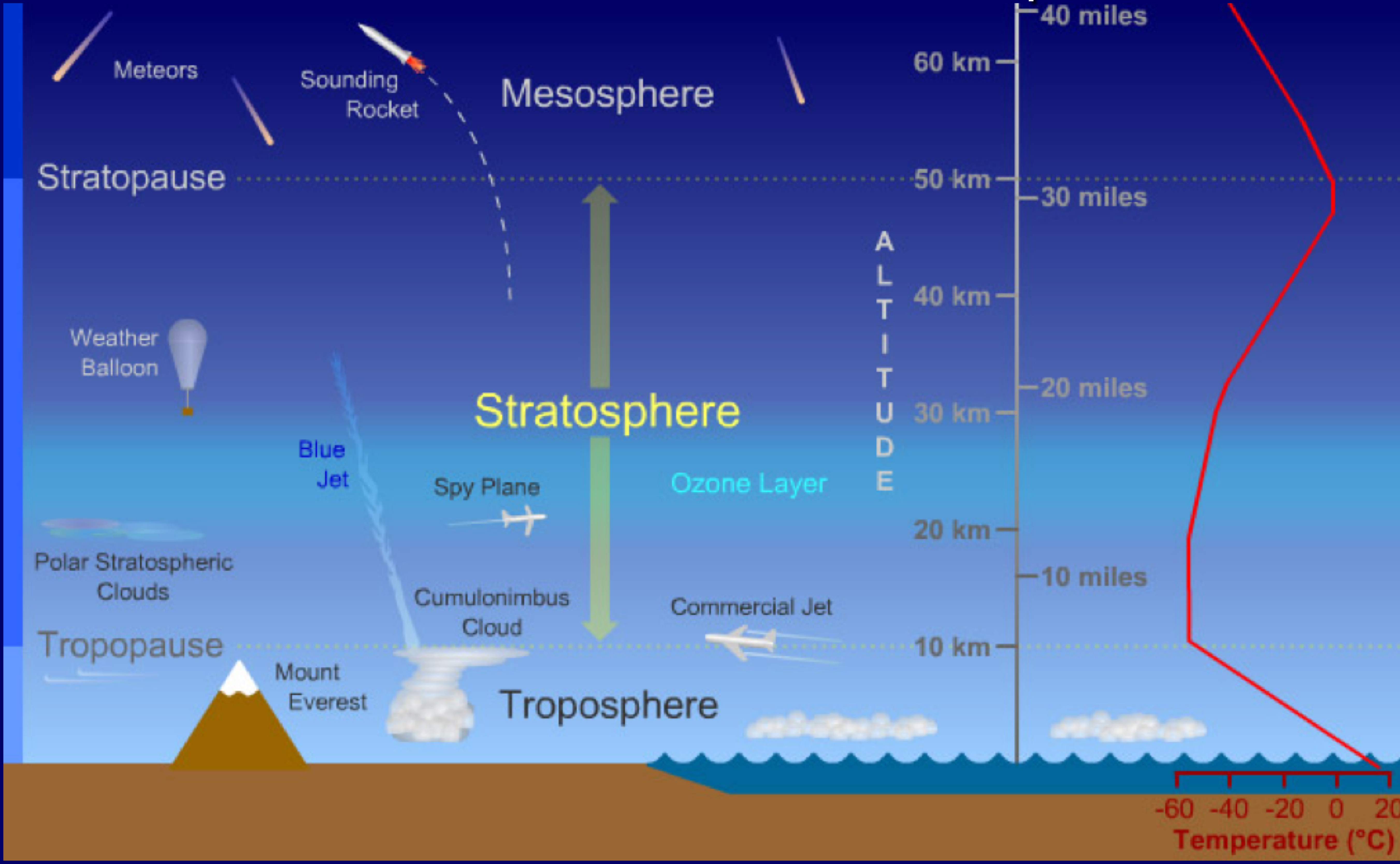
Whole Atmosphere Community Climate Model (WACCM): surface to 145 km

Community Atmosphere Model (CAM): surface to 45 km



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

Ozone defines the stratosphere



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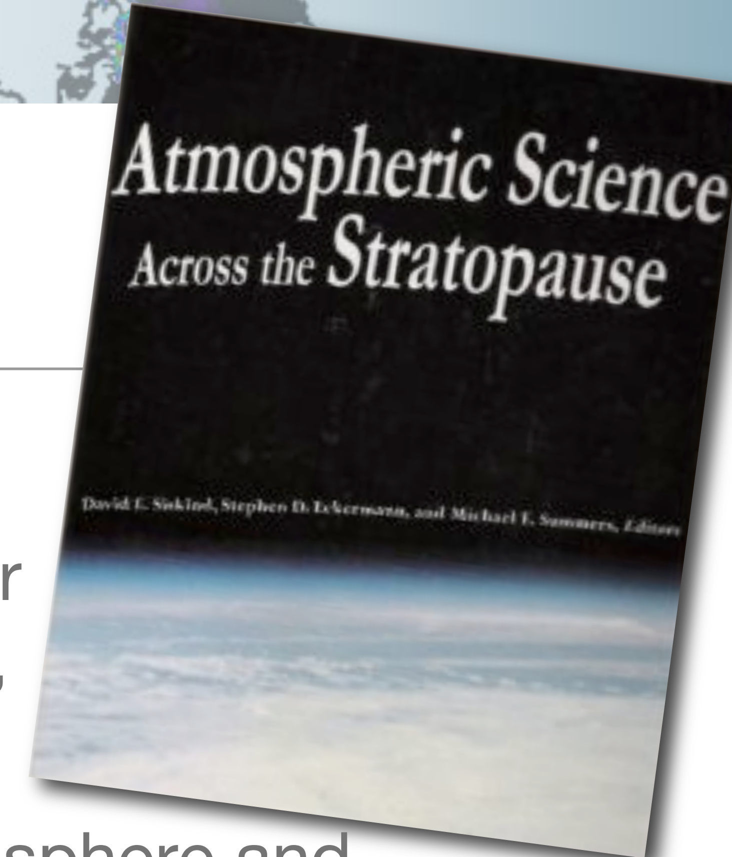
WACCM Additions to CAM

- Extends from surface to 5.1x10^{-6} hPa (~150 km), with 70 vertical levels
- Detailed neutral chemistry models
  - middle atmosphere (MA): catalytic cycles affecting ozone, heterogeneous chemistry on PSCs and sulfate aerosol, heating due to chemical reactions
  - troposphere, stratosphere, mesosphere, and lower thermosphere (TSMLT): adds chemistry affecting tropospheric air quality
- Prognostic stratospheric aerosols derived from sulfur emissions
- 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
- Gravity wave drag deposition from vertically propagating GWs generated by orography, fronts, and convection
- Interactive QBO derived from wave forcing
- Molecular diffusion and constituent separation
- Thermosphere extension (WACCM-X) to ~500 km

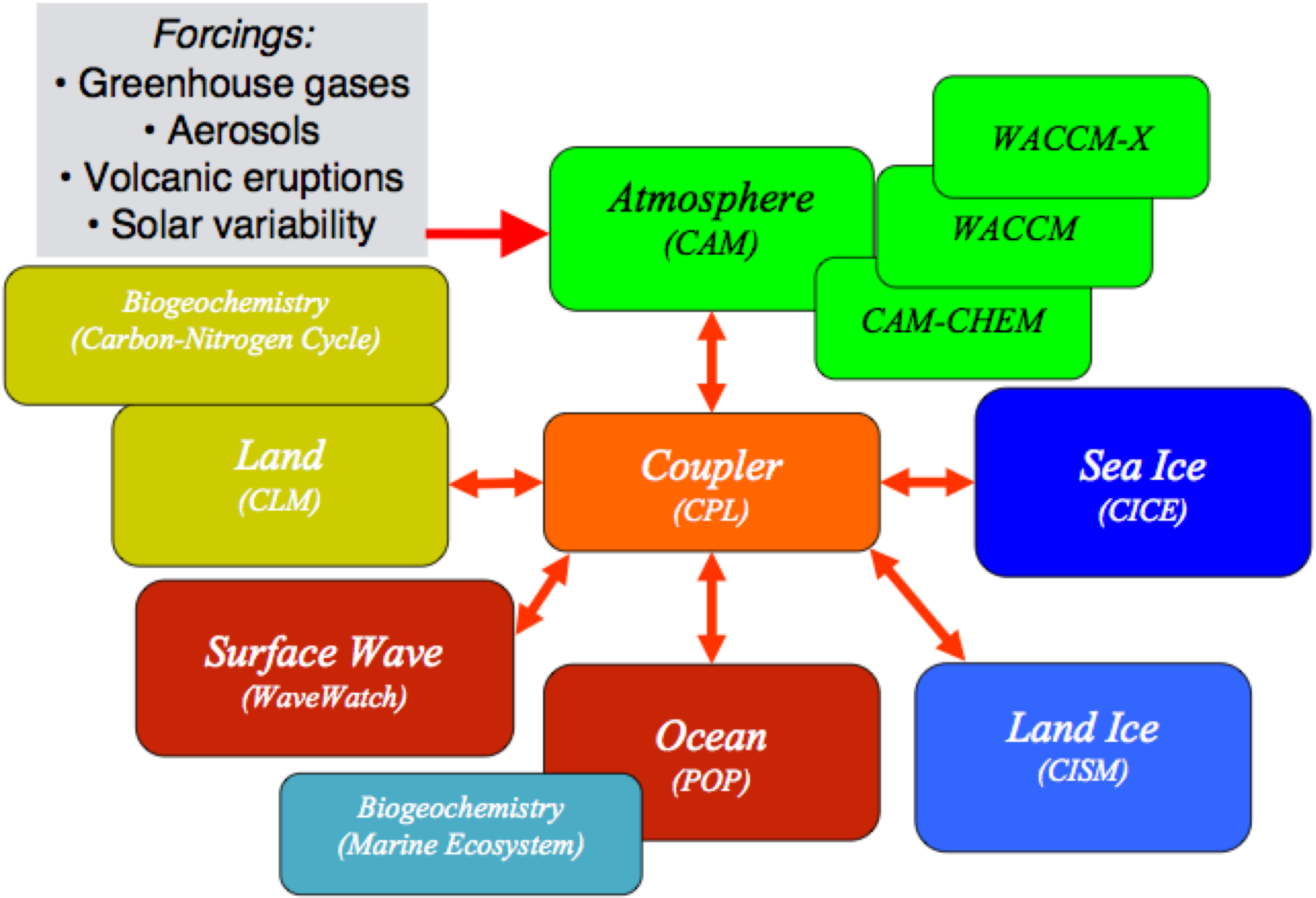
WACCM Motivation

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

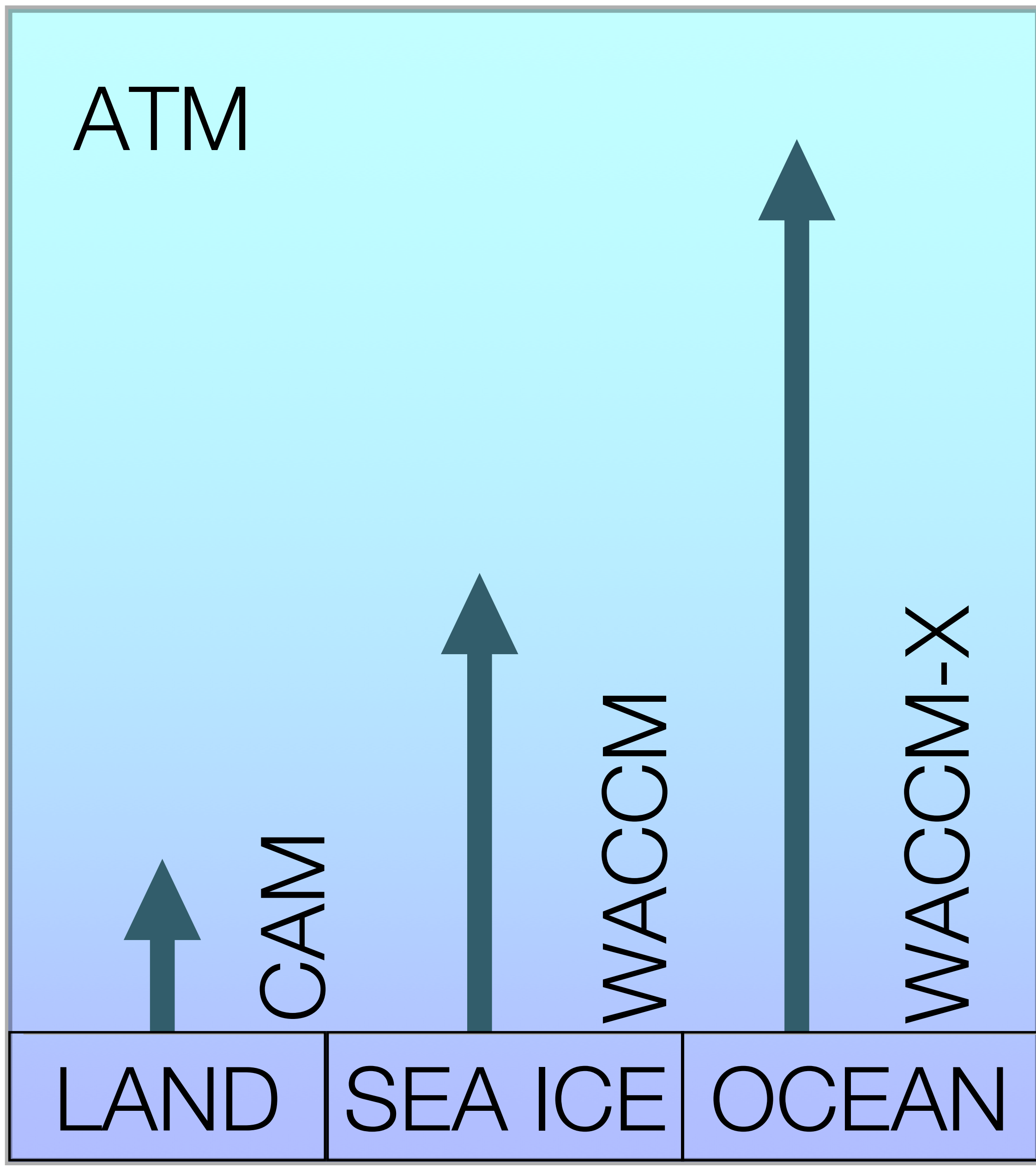


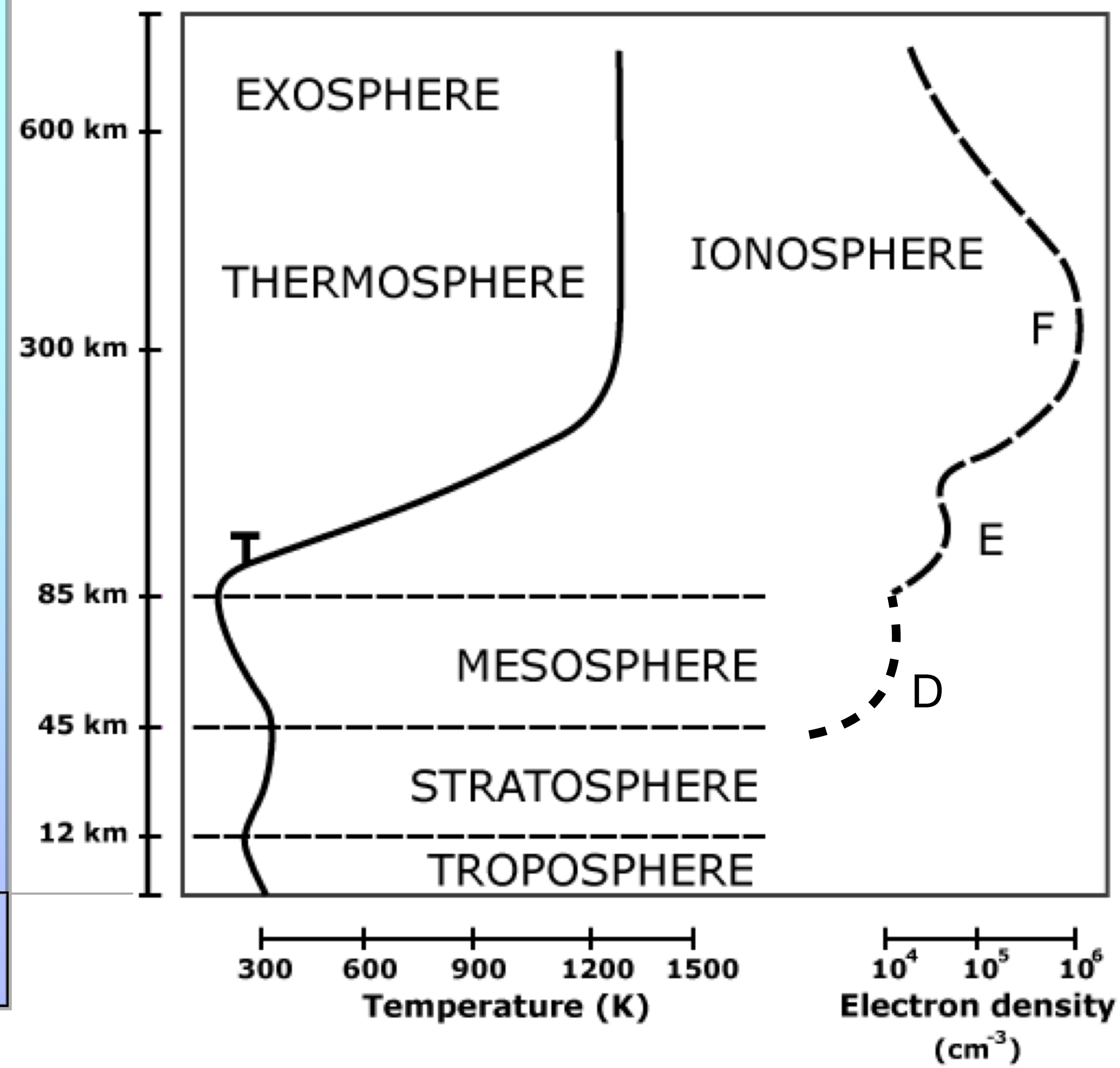
- Coupling between atmospheric layers:
  - Waves transport energy and momentum from the lower atmosphere to drive the QBO, SAO, sudden warmings, mean meridional circulation
  - Solar inputs, e.g. auroral production of NO in the mesosphere and downward transport to the stratosphere
  - Stratosphere-troposphere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

CESM2 components



CESM2 atmosphere components





CESM2: WACCM6 & WACCM-X

	WACCM6	WACCM-X
# levels	70-88	125-145
model top	6×10^{-6} hPa (~140 km)	4×10^{-10} hPa (500~600 km)
Horizontal resolution	$0.95^{\circ} \times 1.25^{\circ}$	$1.9^{\circ} \times 2.5^{\circ}$
Time step	30 min.	5 min.
Specified Dynamics	X	X
Chemistry	TSMLT, MA	MA
Non-orographic GW	X	X
Molecular diffusion	minor	minor and major
Auroral physics	X	X
Ions	E-region or E&D-region	E-region
Ion transport		X
E Dynamo		X

Why WACCM-X?

Because the thermosphere- ionosphere system responds to variability from the Earth's lower atmosphere as well as solar-driven "space weather"

Including:

- Waves and tides
- Tropospheric weather
- Middle-atmosphere events
- Seasonal variations
- Anthropogenic trace gases

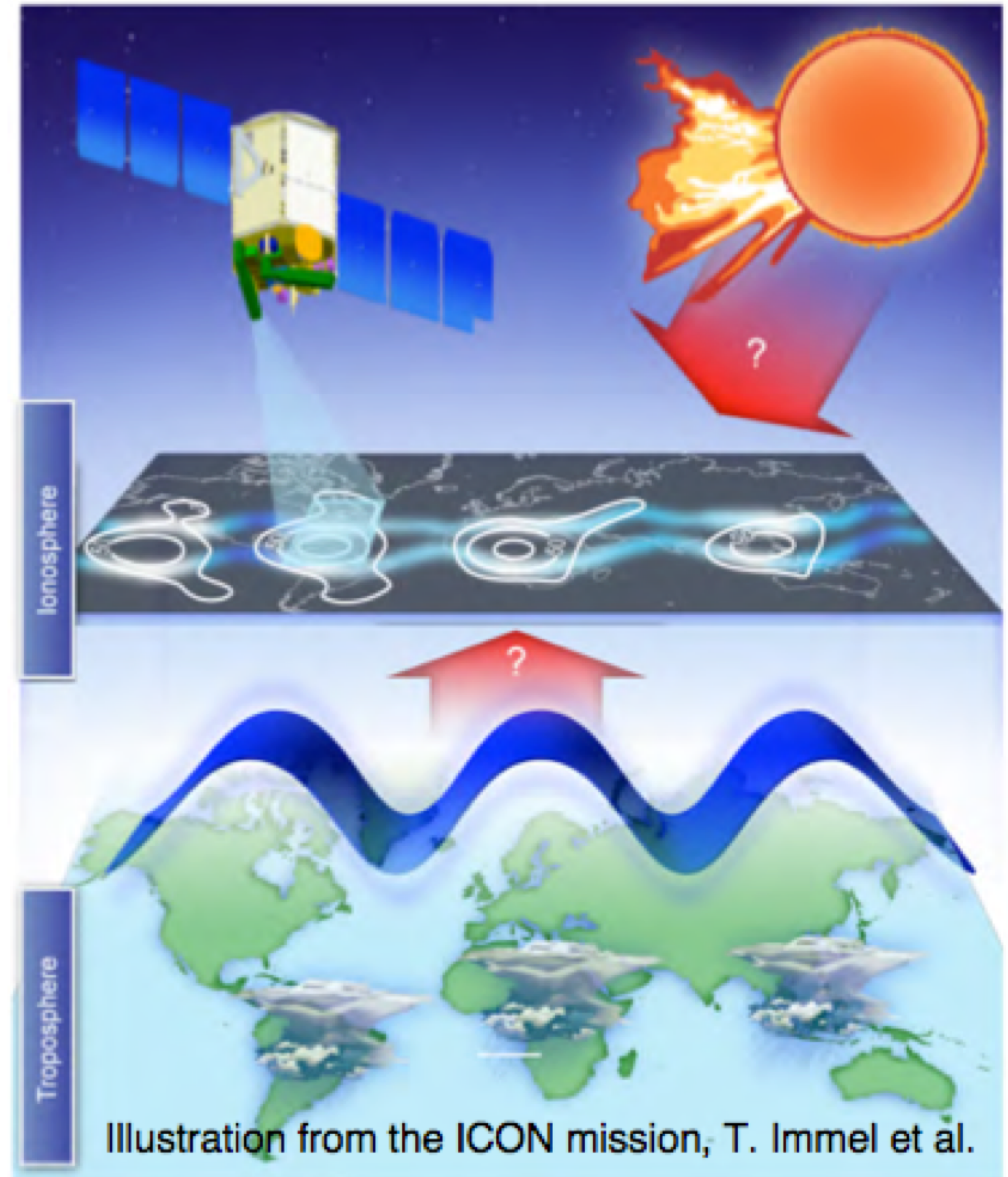
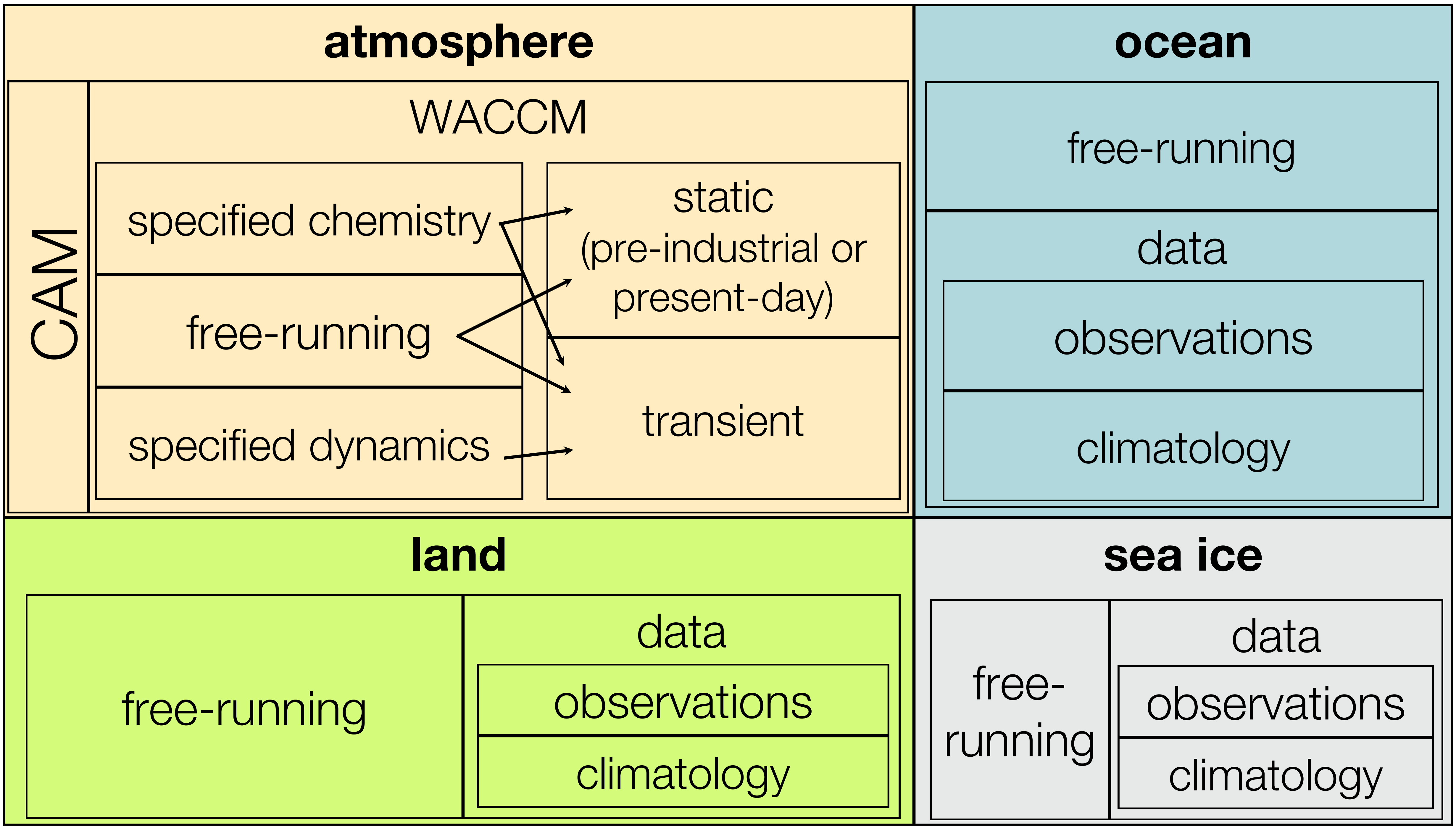
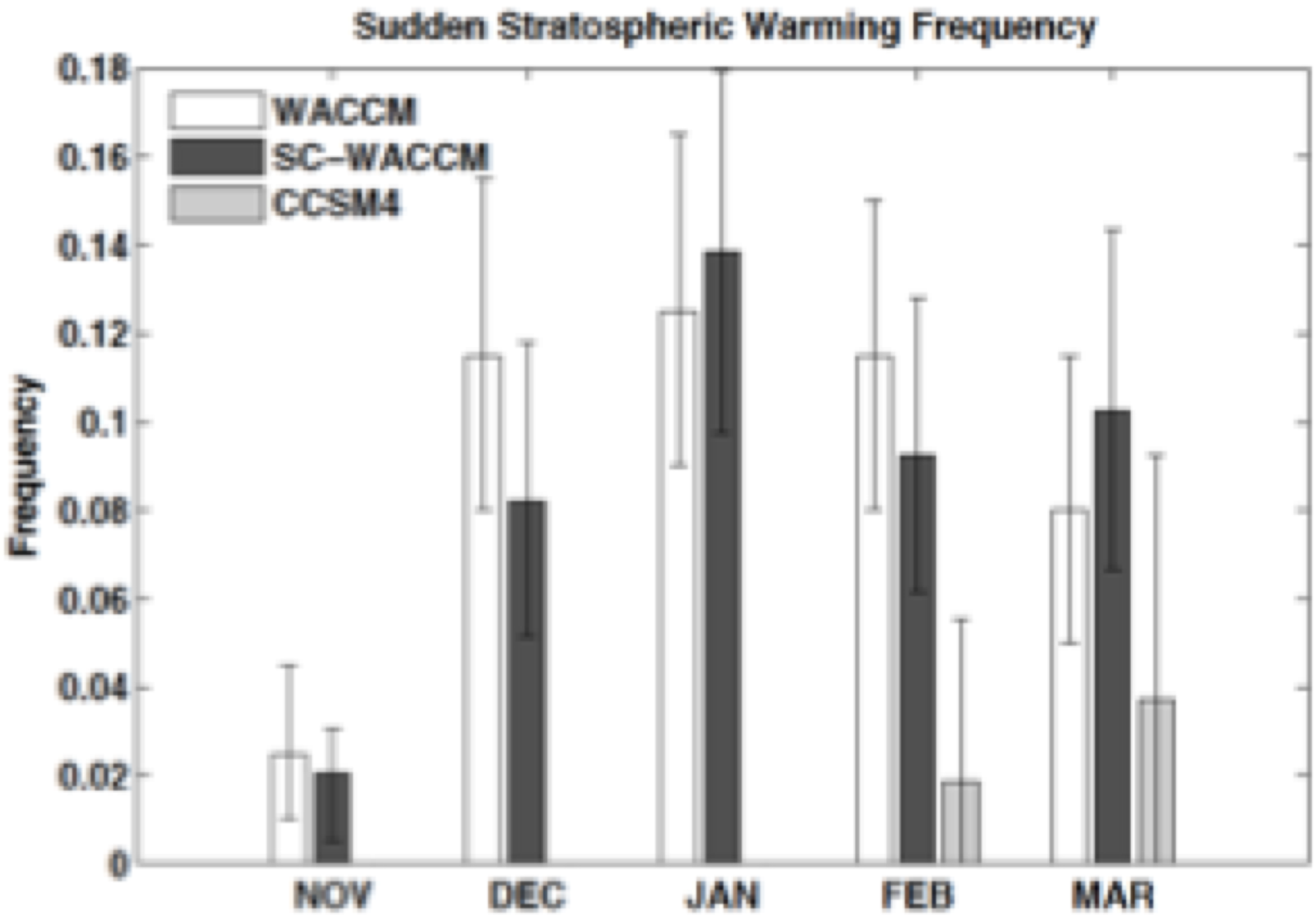


Illustration from the ICON mission, T. Immel et al.

WACCM component configurations



WACCM Specified Chemistry (WACCM-SC)



WACCM-SC gets sudden stratospheric warming (SSW) frequency right.

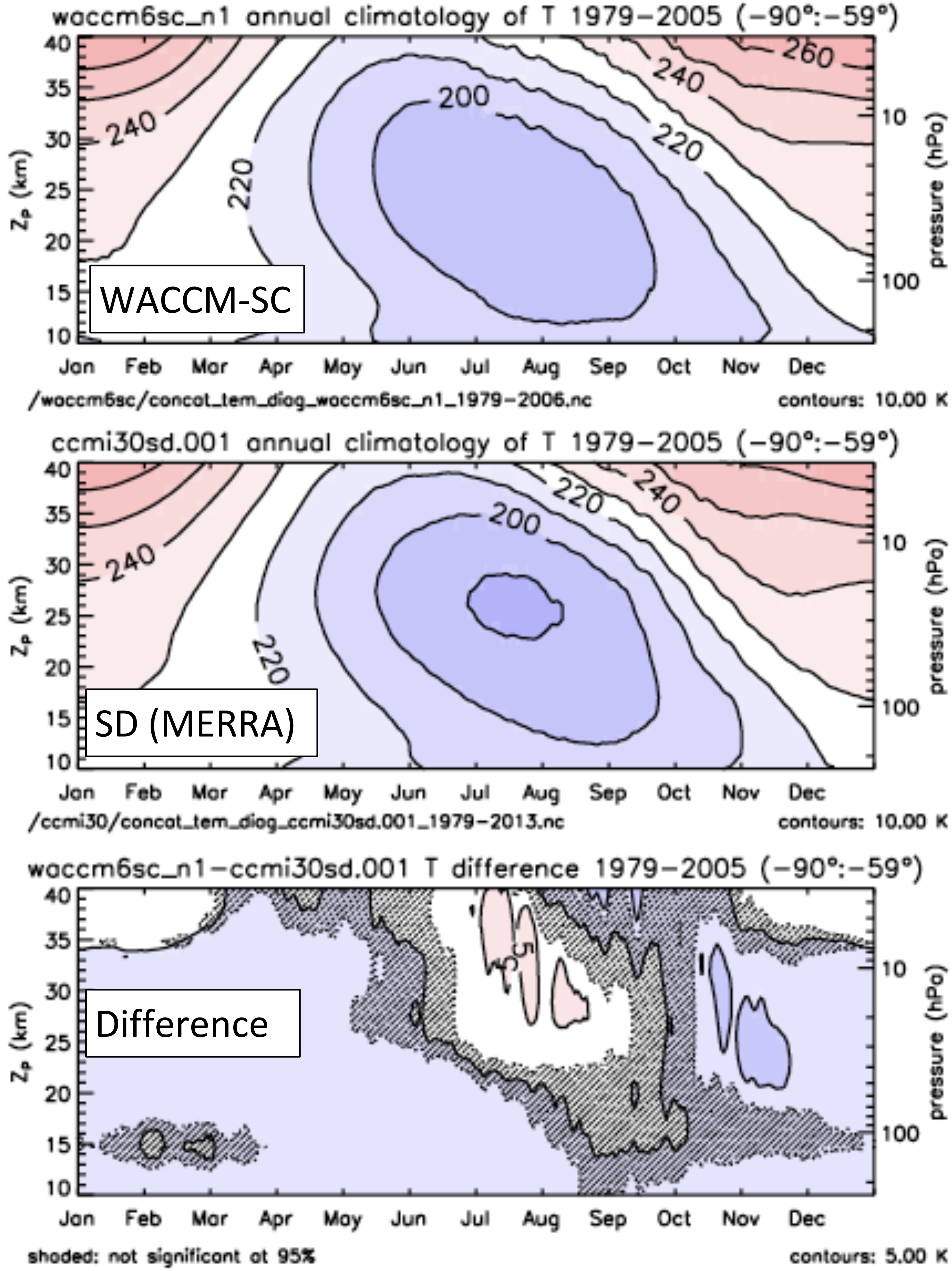
SSWs trigger the negative mode of the North Atlantic Oscillation, which affects weather over Europe and the eastern US.

WACCM6-SC

SH 60˚S-90˚S Temperatures

Temperatures are reasonable in Southern Hemisphere

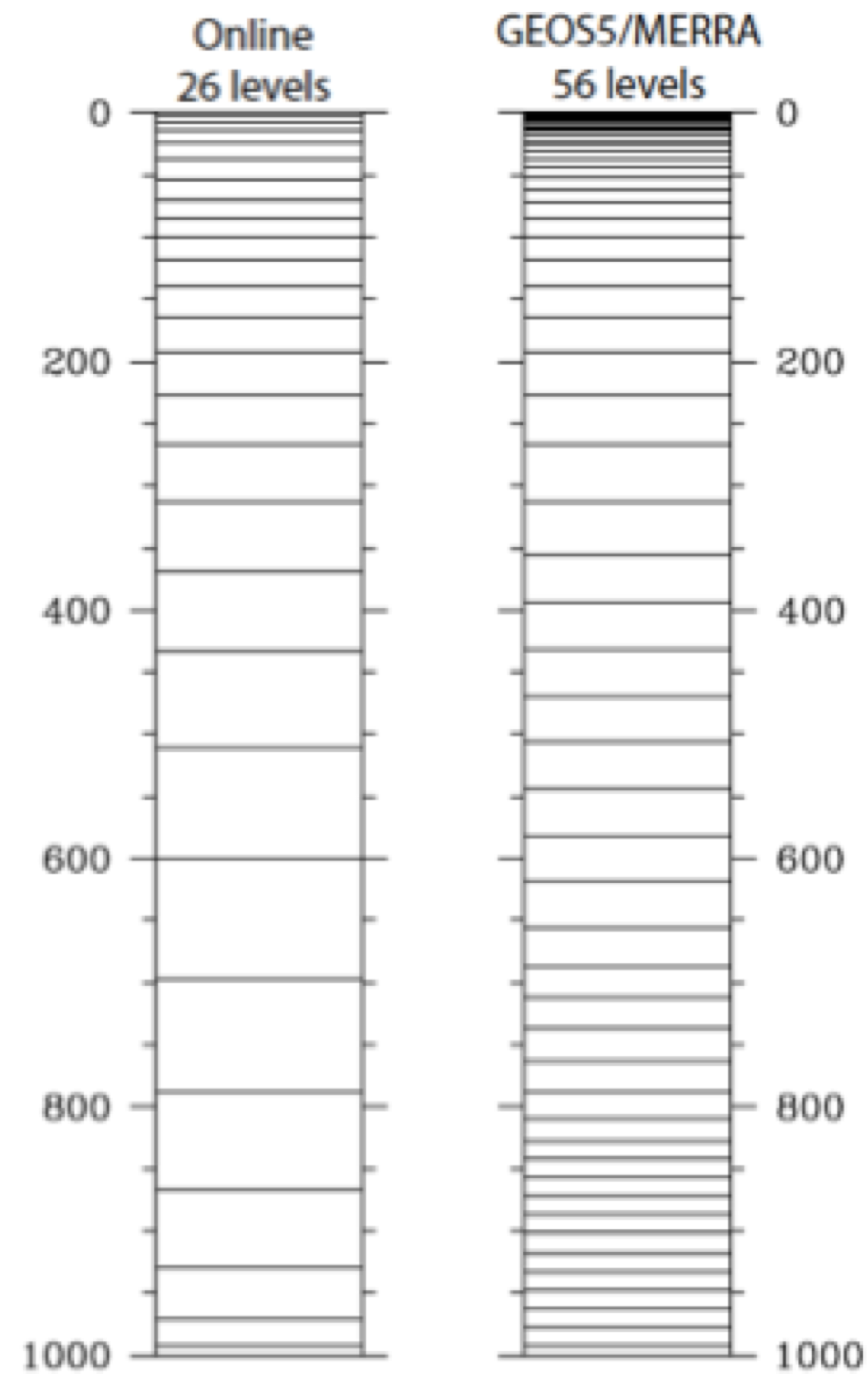
Note: Lower stratosphere difference not significant



Courtesy Rolando Garcia

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: 32 levels → SD-CAM-Chem: 56 levels
  - WACCM: 70 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



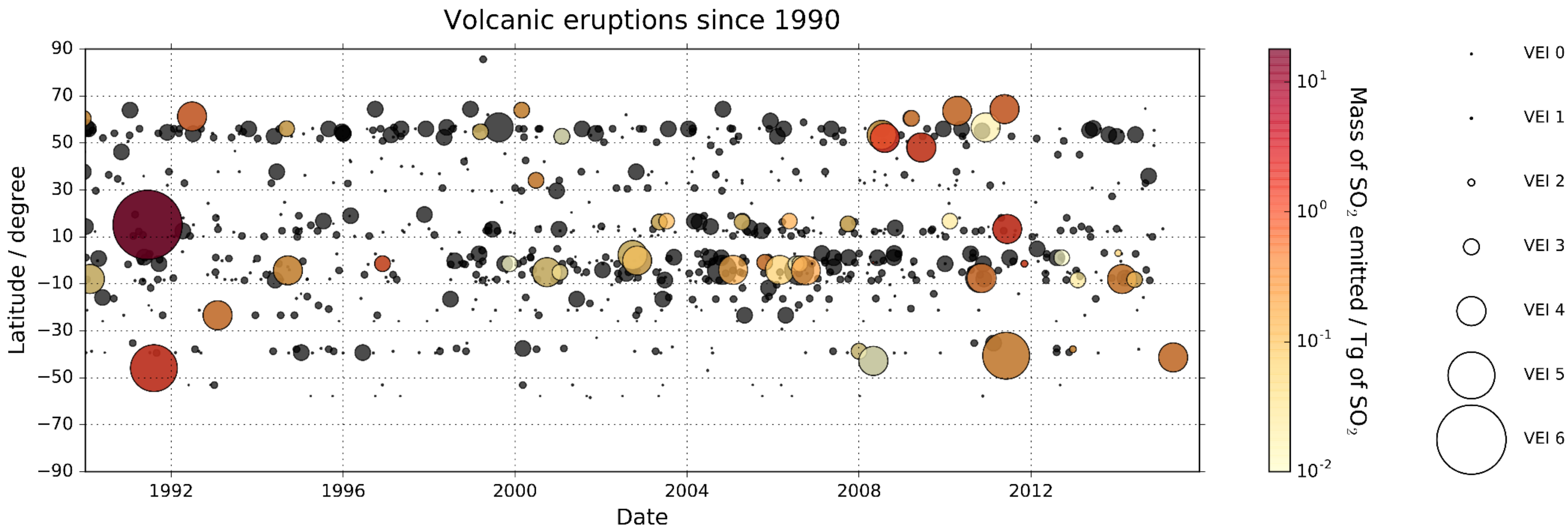
Volcanic eruptions SO_2 database (1850-2016)

Volcanic eruptions increasingly well characterized

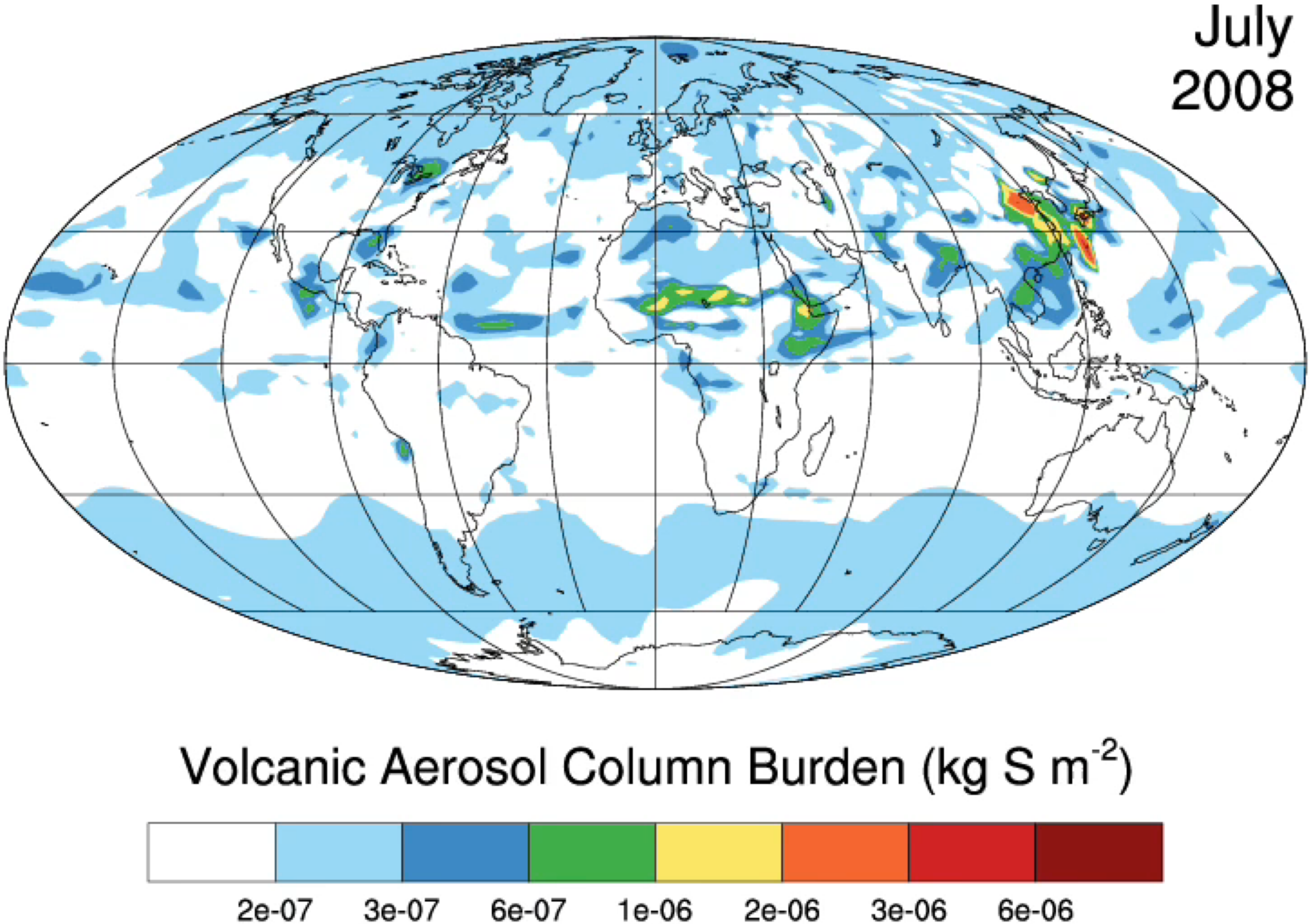
(Satellite retrievals, in-situ measurements, geochem. & geophys. monitoring)

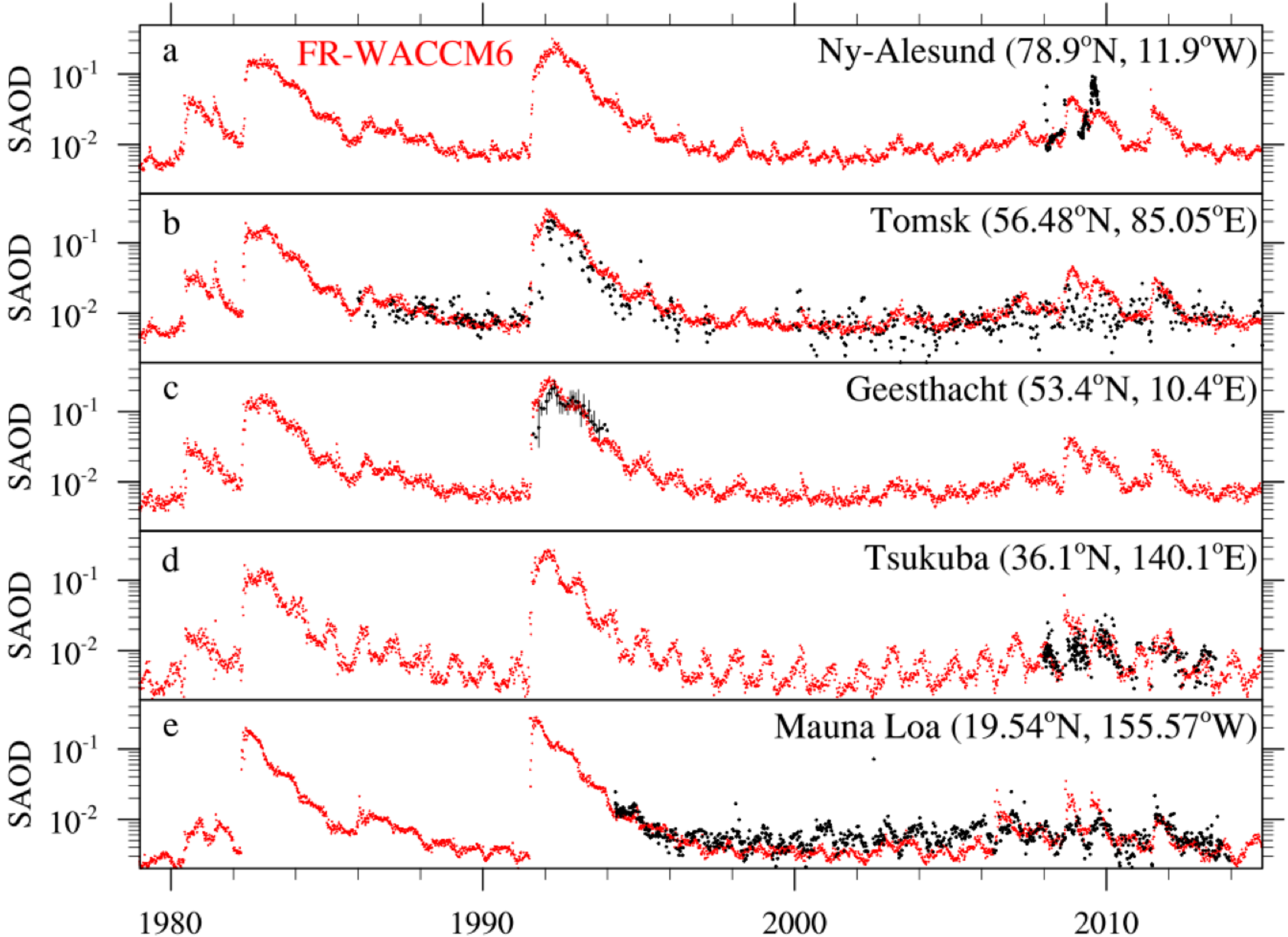
1979 first TOMS volcanic SO_2 retrievals

Compiled volcanic emission dataset for use in climate models



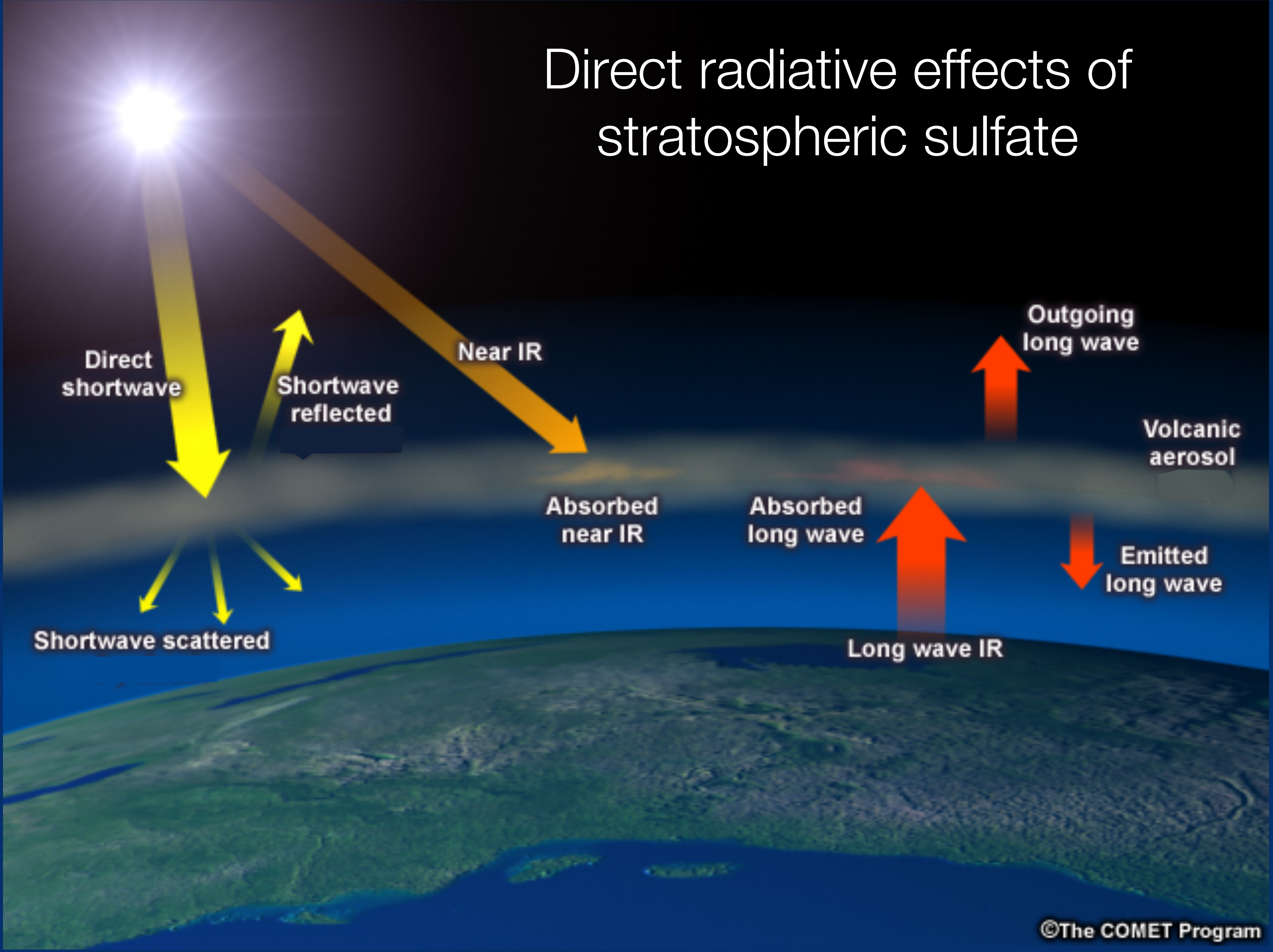
1990-1994	1995-1999	2000-2004	2005-2009	2010-2015
12.85 Tg of SO_2	0.93 Tg of SO_2	0.93 Tg of SO_2	7.56 Tg of SO_2	8.55 Tg of SO_2


July
2008
Volcanic Aerosol Column Burden (kg S m-2)
2e-07
3e-07
6e-07
1e-06
2e-06
3e-06
6e-06



Volcanic aerosol optical depth agrees well with lidar observations at multiple latitudes.

Direct radiative effects of stratospheric sulfate



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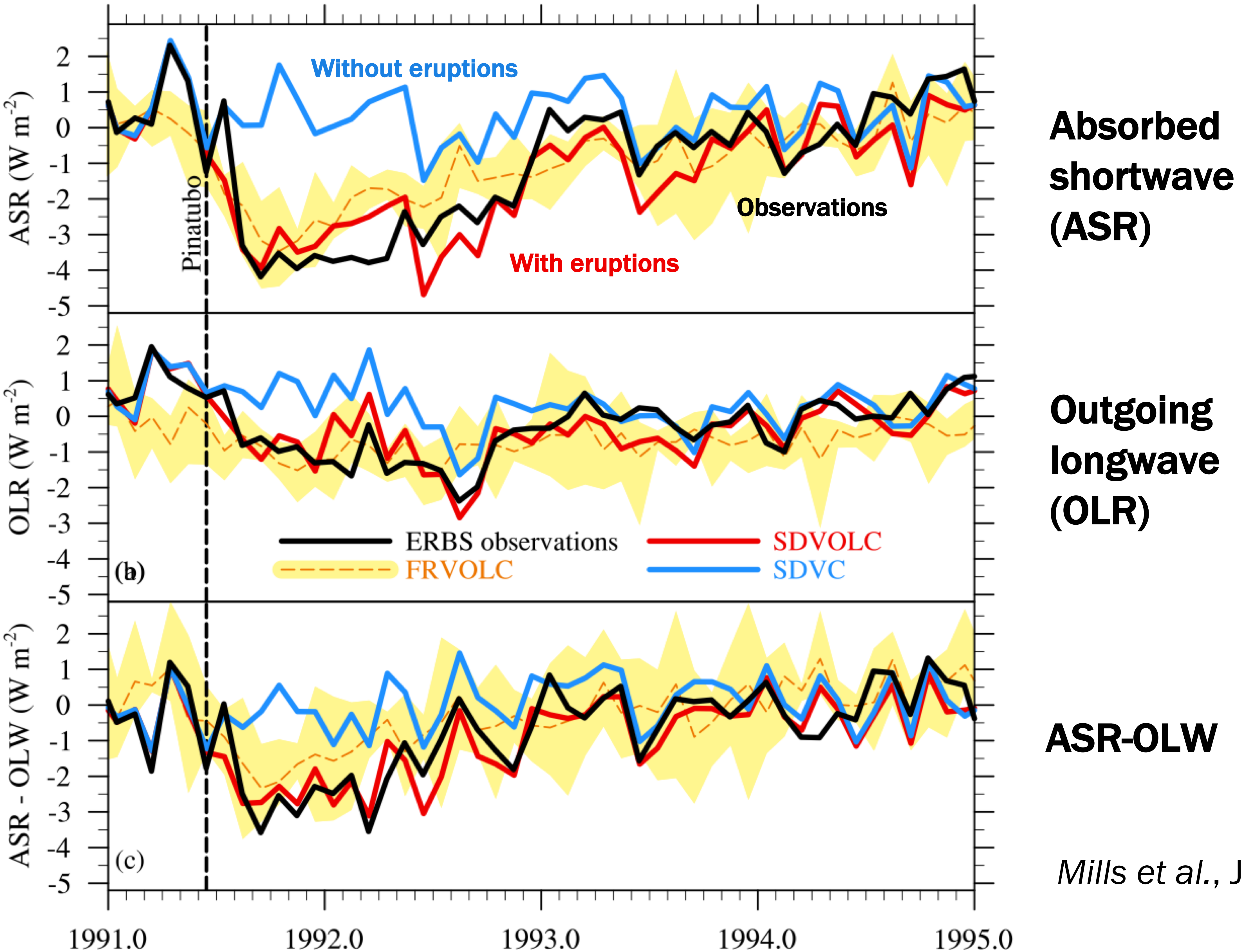
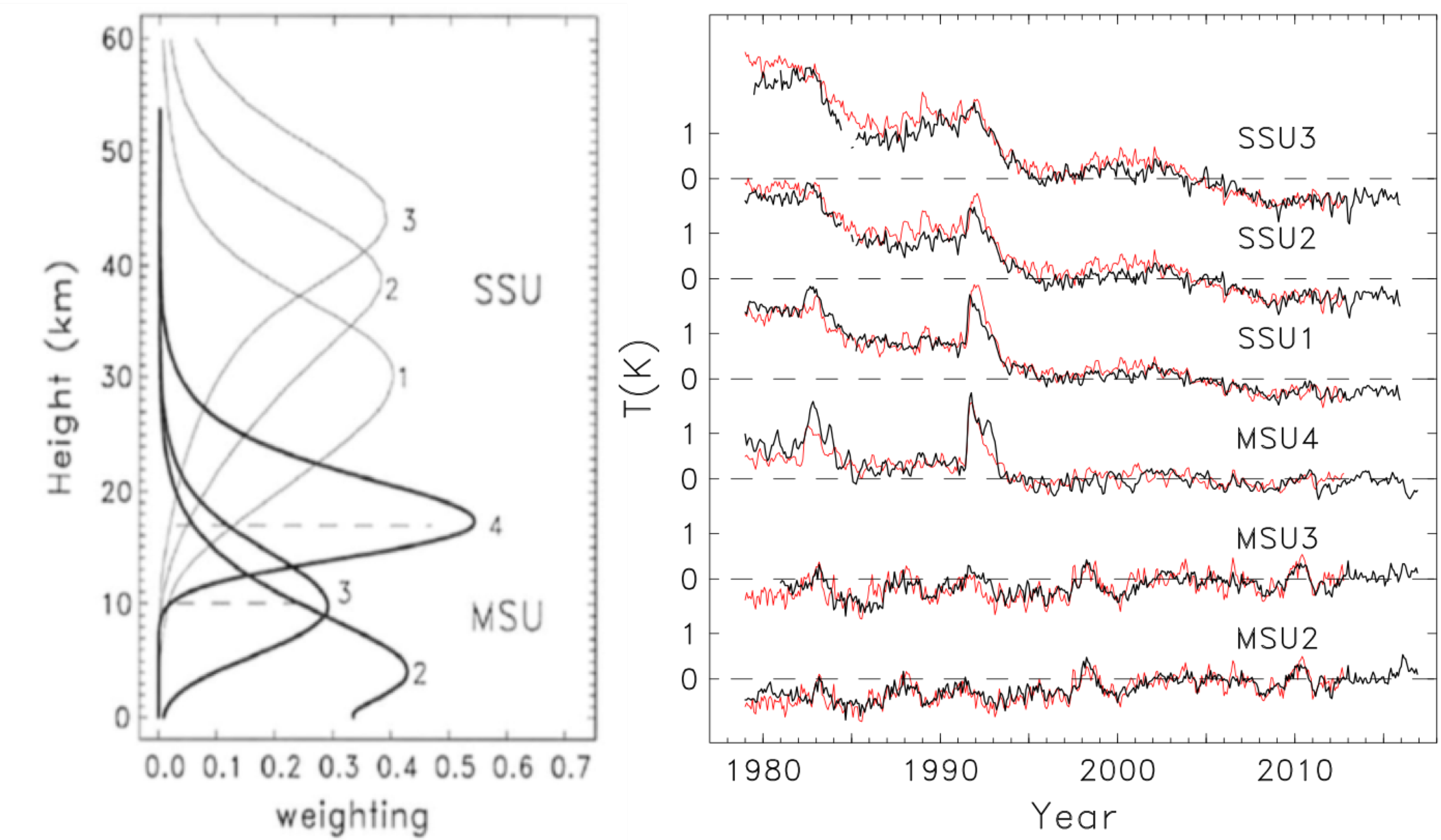


Mills et al., JGR, 2017

Top-of-atmosphere radiative flux response to Pinatubo eruption agrees well with satellite observations.



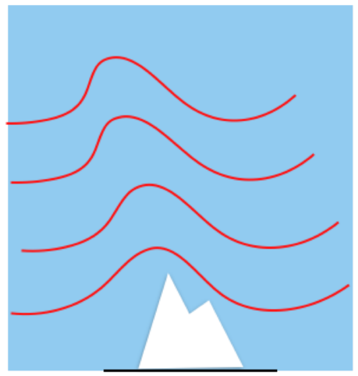
al stratospheric temperatures compare very well to observations, including volc

Figure courtesy of Doug Kinnison, Fei Wu and Bill Randel, NCAR.

WACCM Gravity Wave Parameterization

1. Orographic GWs:

Uncertain: Efficiency

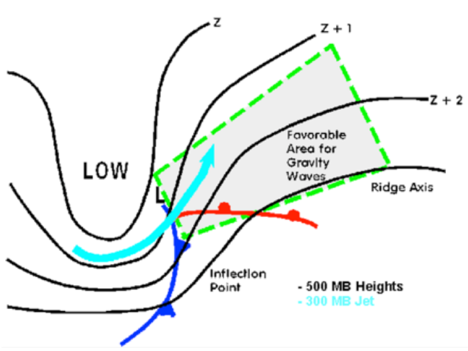


Orographic GWs:

- McFarlane (1987)
- 1 wave with c = 0
- Amplitude dependent on orography height and wean wind

2. Frontally generated GWs:

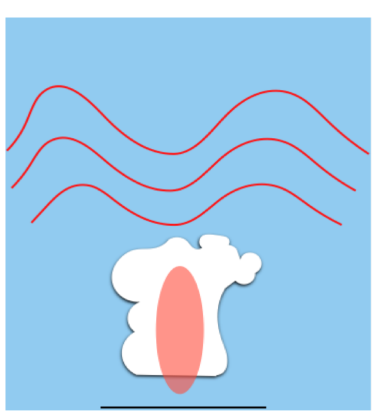
Uncertain: Efficiency, amplitude, phase speeds



- 40 waves with -100 < c < 100 m/s
- Gaussian distribution in phase speed centered at U 600 mb
- Constant wave amplitude

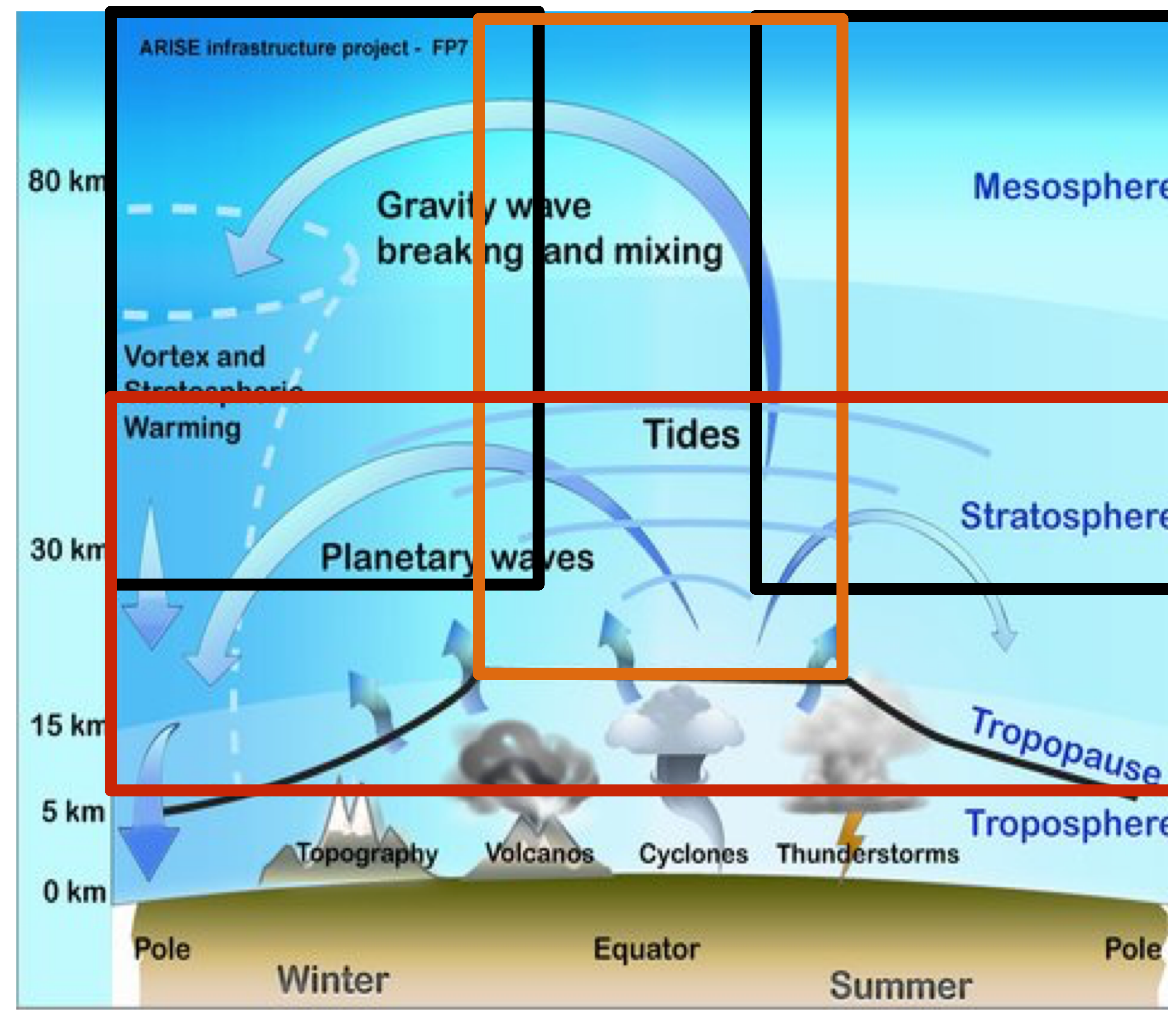
3. Convectively generated GWs:

Uncertain: Efficiency, amplitude conversion



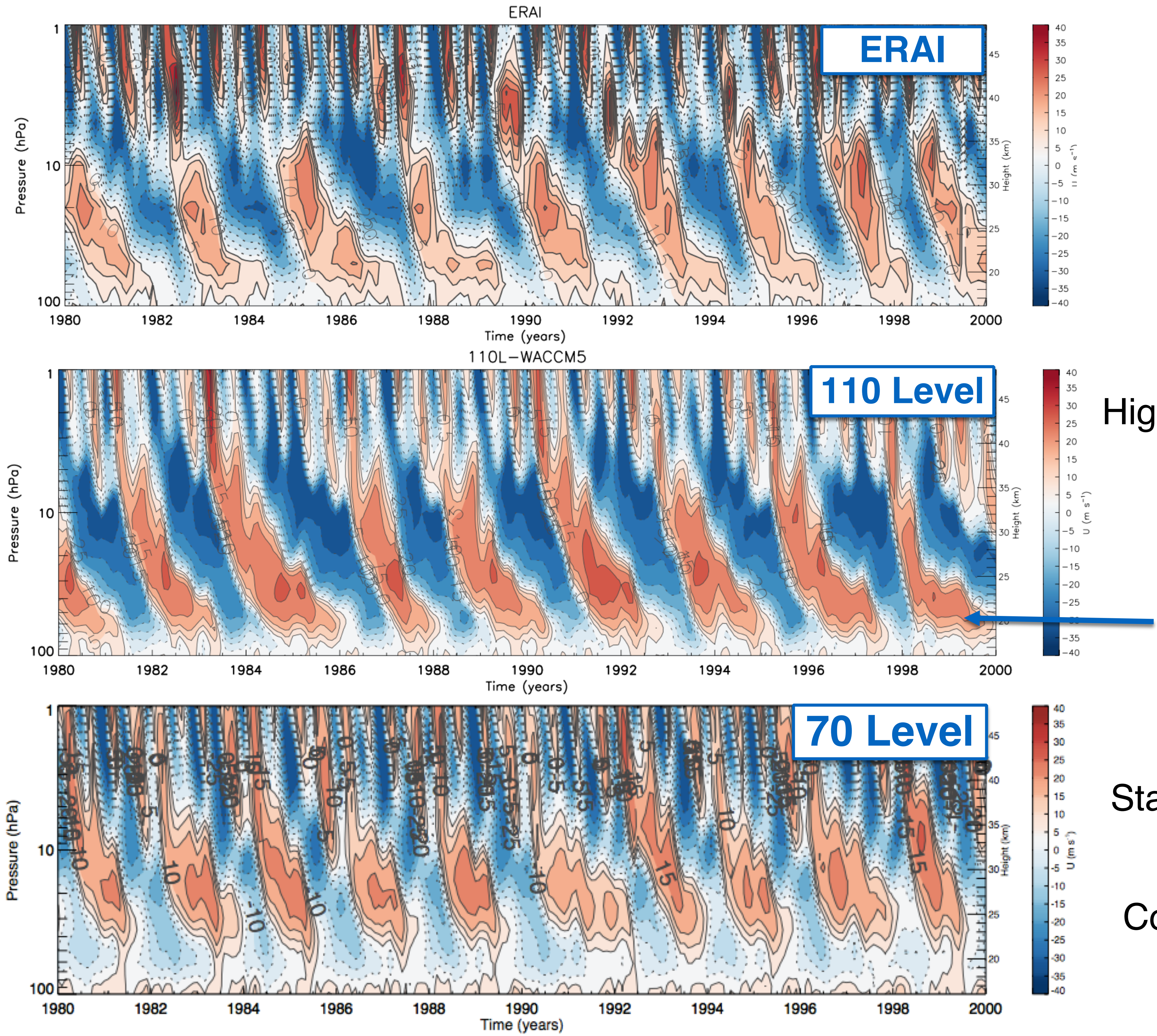
- 40 waves with -100 < c < 100 m/s
- Dominant c related to h (depth of heating)
- Wave Amplitude ∝ Q^2
- Wave spectrum impacted by wind in heating

Beres et al. 2004 (Beres = Richter)



Richter et al. 2010

QBO: 70 vs 110L WACCM



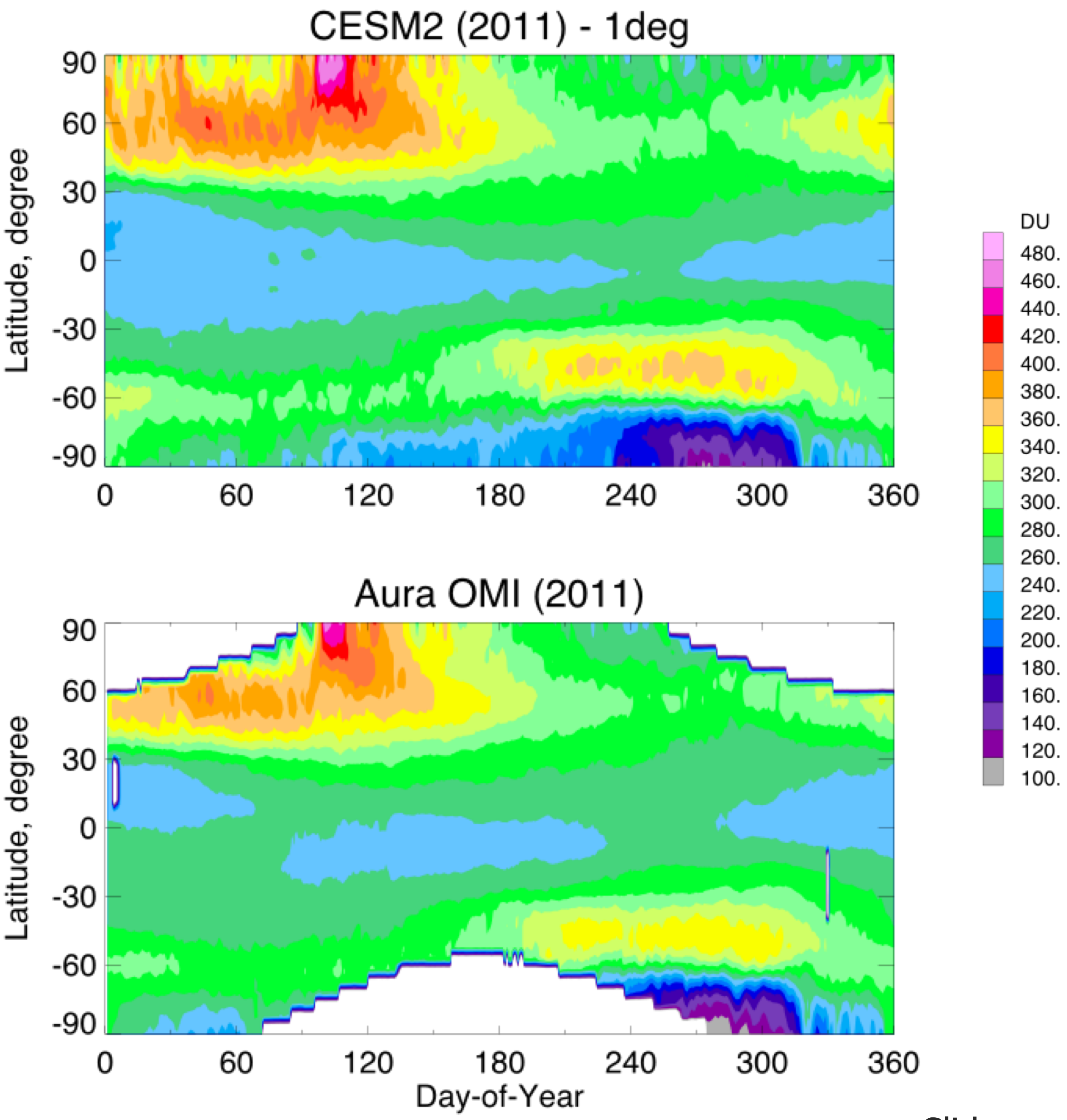
Higher vertical resolution

QBO descends to 100 hPa as observed (tropical Kelvin and RG waves are well resolved in the 110L model)

Standard WACCM6

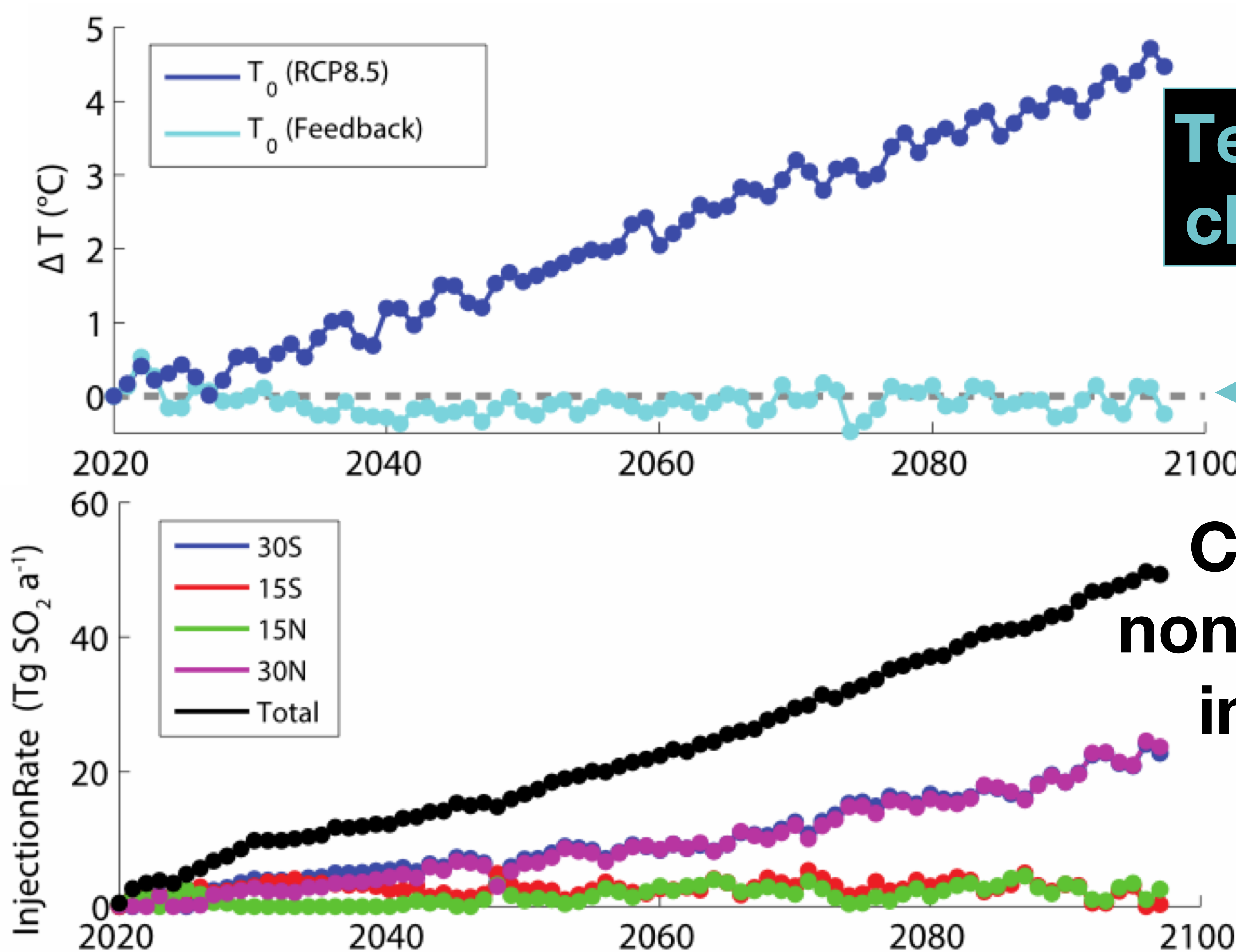
Courtesy Yaga Richter

Total Column Ozone (TOZ), SD configuration



Slide courtesy of D. Kinnison.

WACCM Sulfate Geoengineering Feedback Simulations



Temperature change goal

Combined non-equatorial injections

Kravitz et al. (2017)

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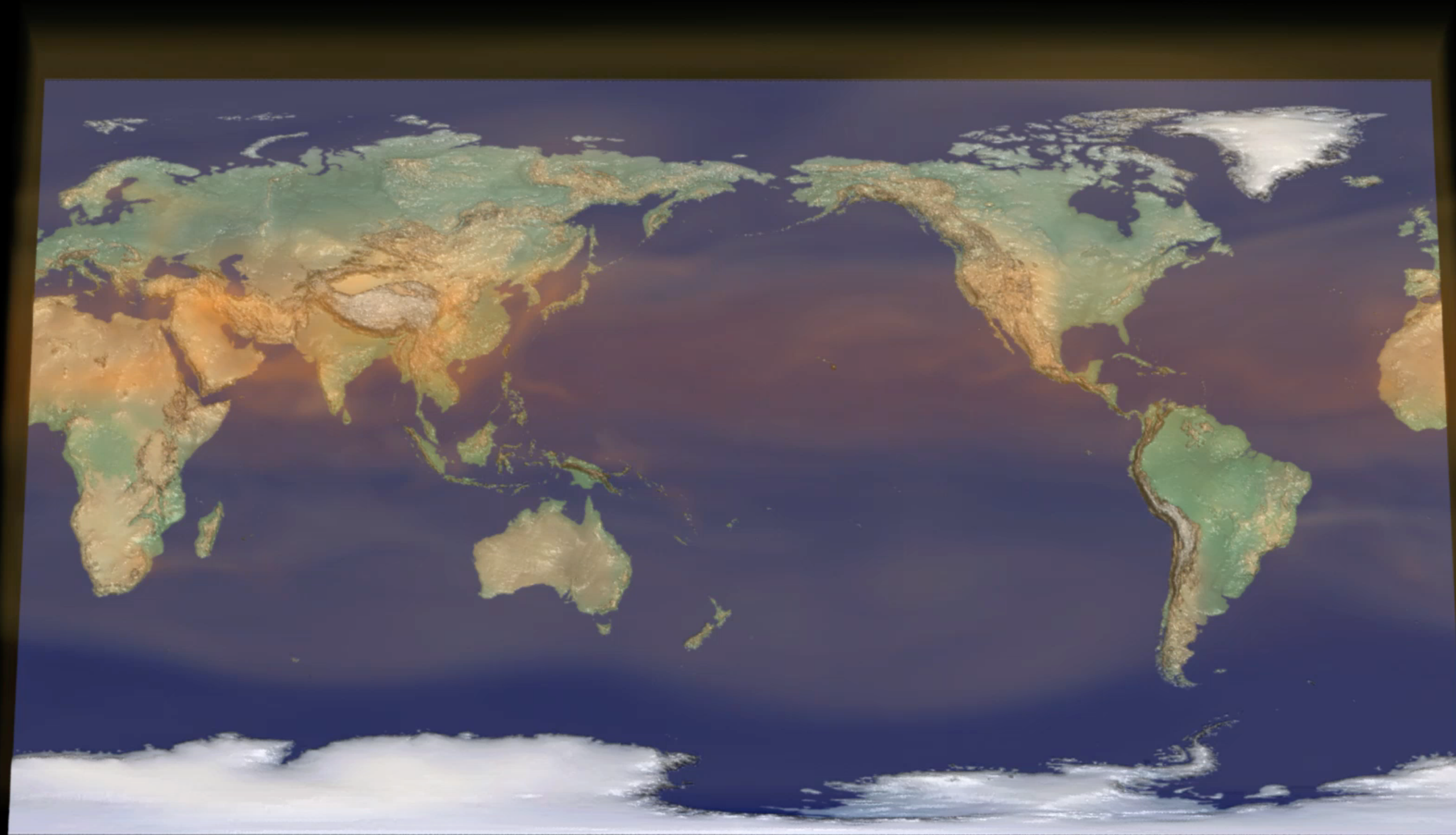
WACCM

Whole Atmosphere Community Climate Model

Aerosol Radius (µm)

0.00 0.03 0.05 0.08 0.10 0.13 0.15 0.18 0.20

Oct 26 2020



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