Energetic particles, meteoritic dust, PMCs, sulfate aerosol, and nuclear war:

WACCM and WACCM/CARMA studies at LASP

Michael Mills, Cora Randall, Brian Toon, Charles Bardeen, Lynn Harvey, Xiaohua Fang, Laura Holt, Jeff France, Donavan Wheeler:
University of Colorado

Rolando Garcia, Doug Kinnison, Dan Marsh:
NCAR

NCAR

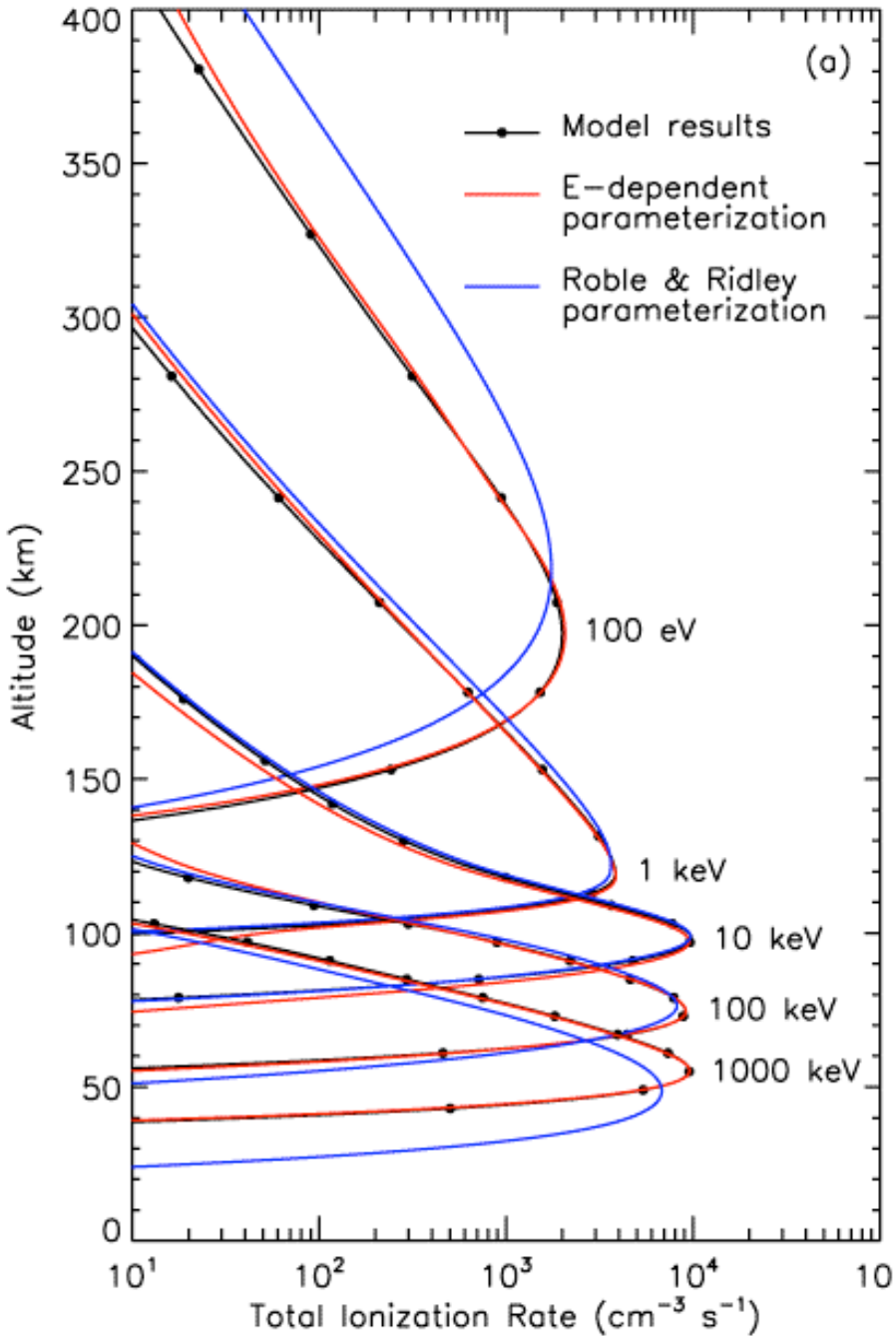
WACCM, CAM & CARMA at LASP

Talk outline:

- WACCM
  - Energetic particle precipitation - Cora Randall, Xiaohua Fang, Mike Mills, Laura Holt
  - Stratopause height & temperature - Jeff France, L. Holt, Lynn Harvey, C. Randall
  - Cold air outbreaks - Donovan Wheeler, Lynn Harvey
- WACCM/CARMA
  - PMCs, dust - Chuck Bardeen, Brian Toon
  - Stratospheric & mesospheric sulfate - Mike Mills, Brian Toon
  - Regional nuclear war - Mike Mills, Brian Toon

Ongoing Toon group studies:

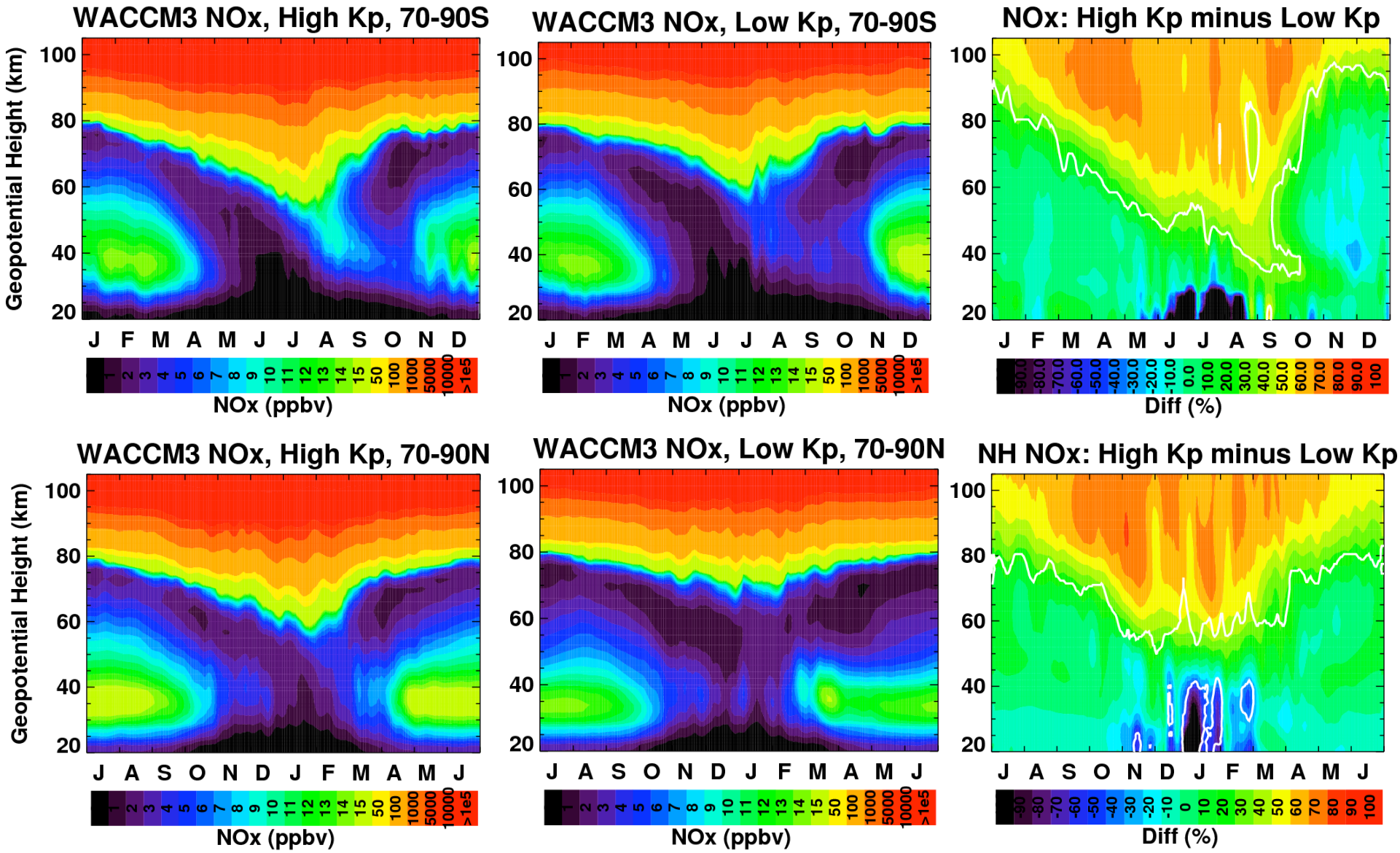
- WACCM/CARMA
  - Upper tropospheric sulfates - Jason English
  - Archean Earth - Eric Wolf
- CAM
  - Tropospheric dust - Lin Su
  - Sea salt - Tianyi Fan
  - Titan - Krystyna Dillard
  - Mars - Richard Urata
  - Subvisible cirrus - David Stokowski, Eric Jensen, Chuck Bardeen, Andrew Gettelman



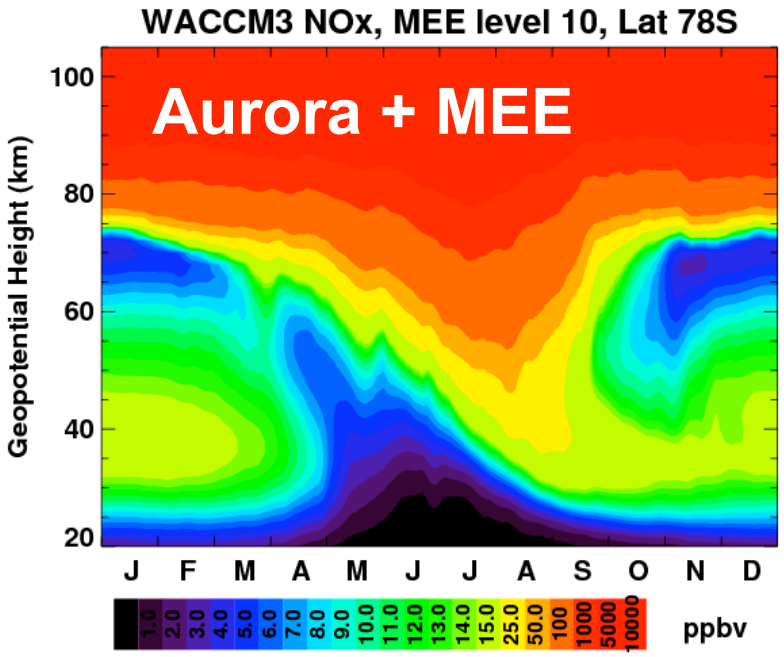
Energetic particle precipitation

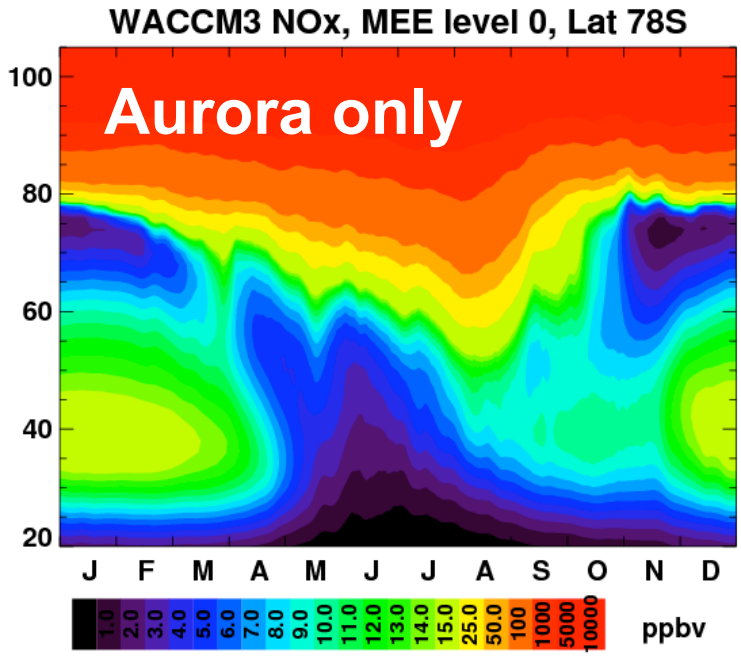
- Ionization: $N_2 \rightarrow NO_x$
- Auroral electrons
  - 1 - 30 kev
- Add medium-energy electrons (MEE)
  - 30 kev - 2.5 Mev

Figure from Fang *et al.*, submitted to JGR, 2008.

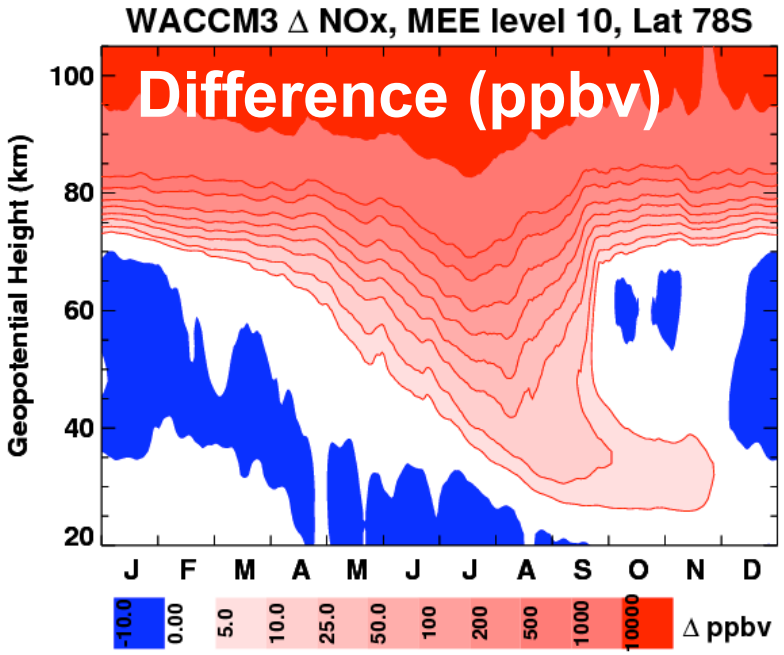


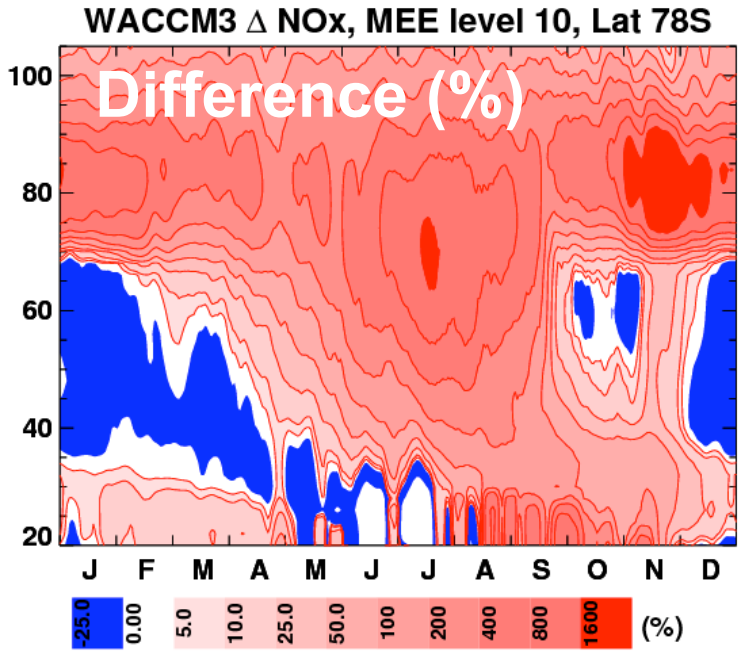
Randall *et al.* (AGU 2007): On average, auroral precipitation causes >10% increases in NO_x down to ~35 km in SH





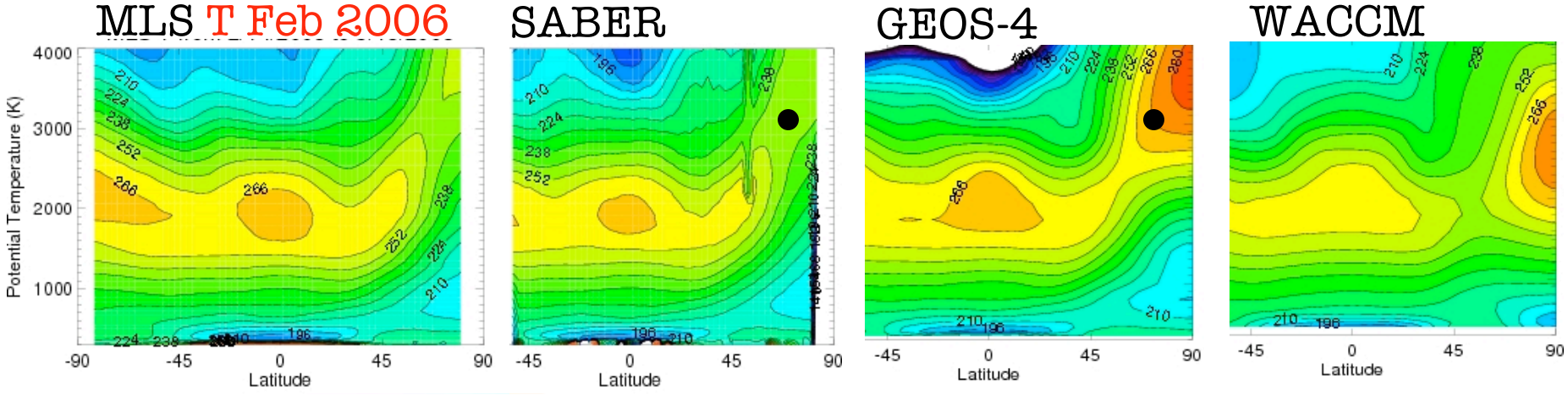
Courtesy of Cora Randall

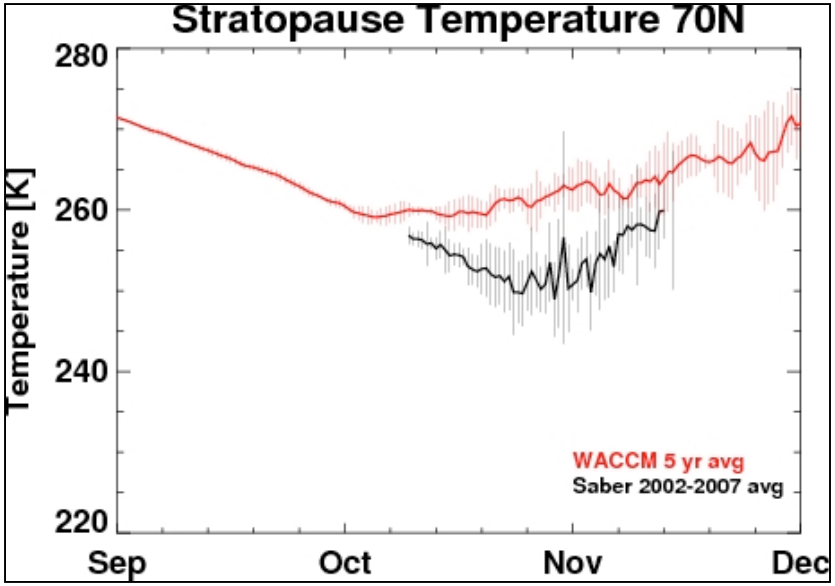


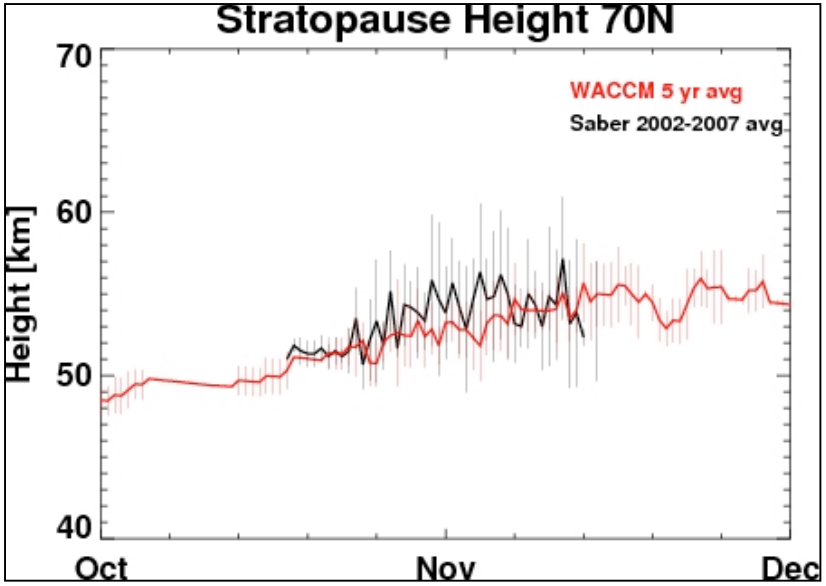


MEE increases NO_x > 25% down to 20 km

WACCM, GEOS, SABER, and MLS Stratopause Temperature and Height



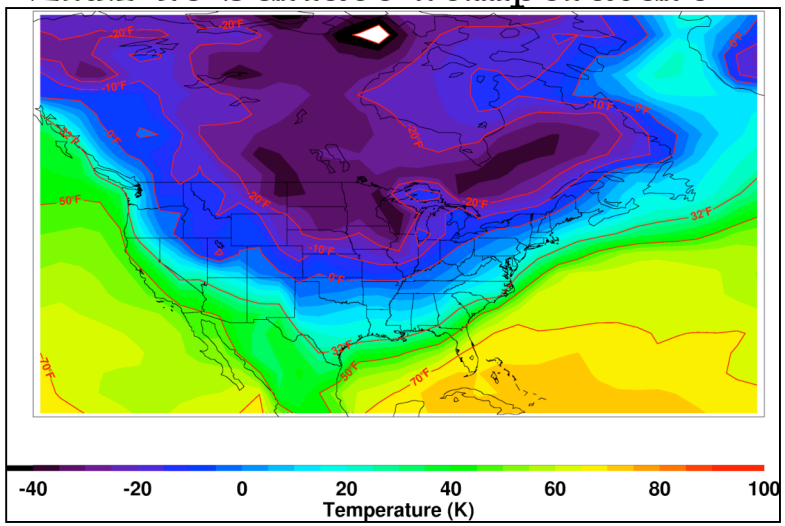




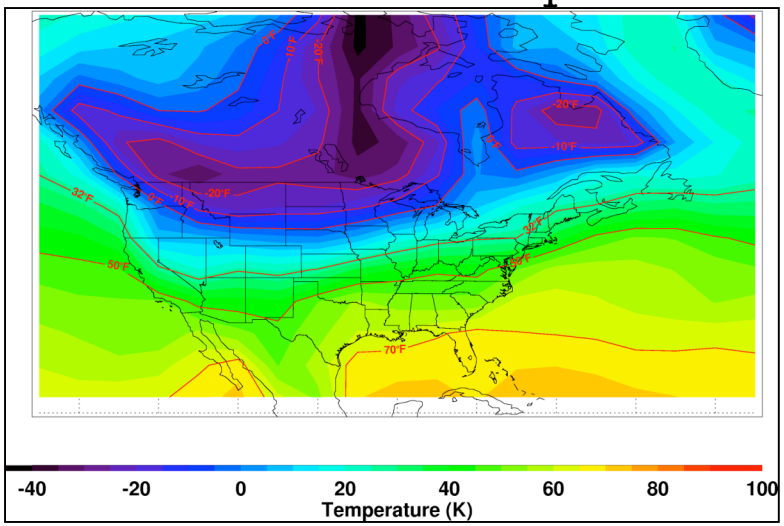
Courtesy of J. France and L. Holt

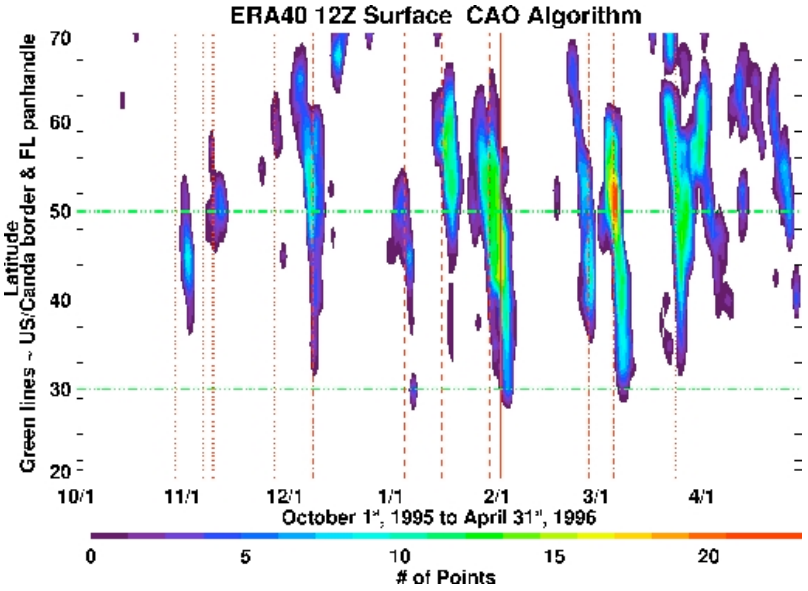
WACCM and ERA-40 Cold Air Outbreaks

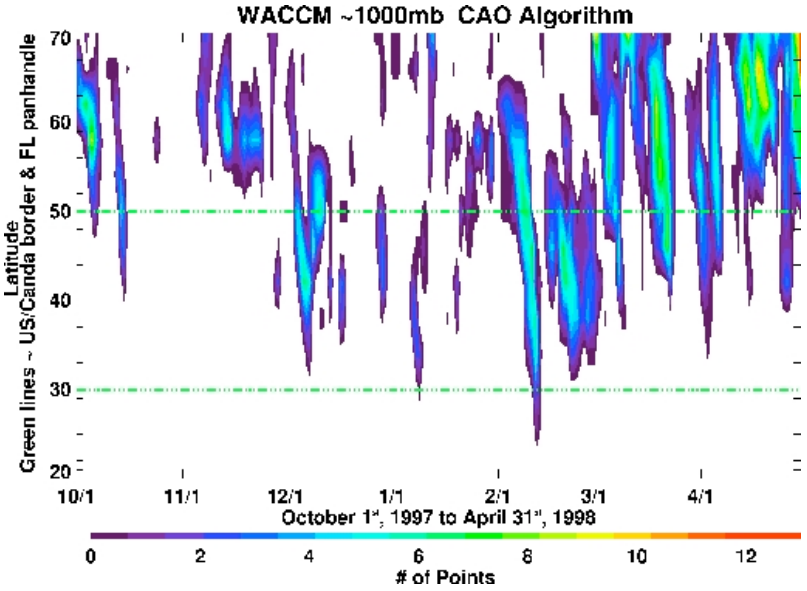
ERA-40 Surface Temperature



WACCM 1000 hPa Temperature

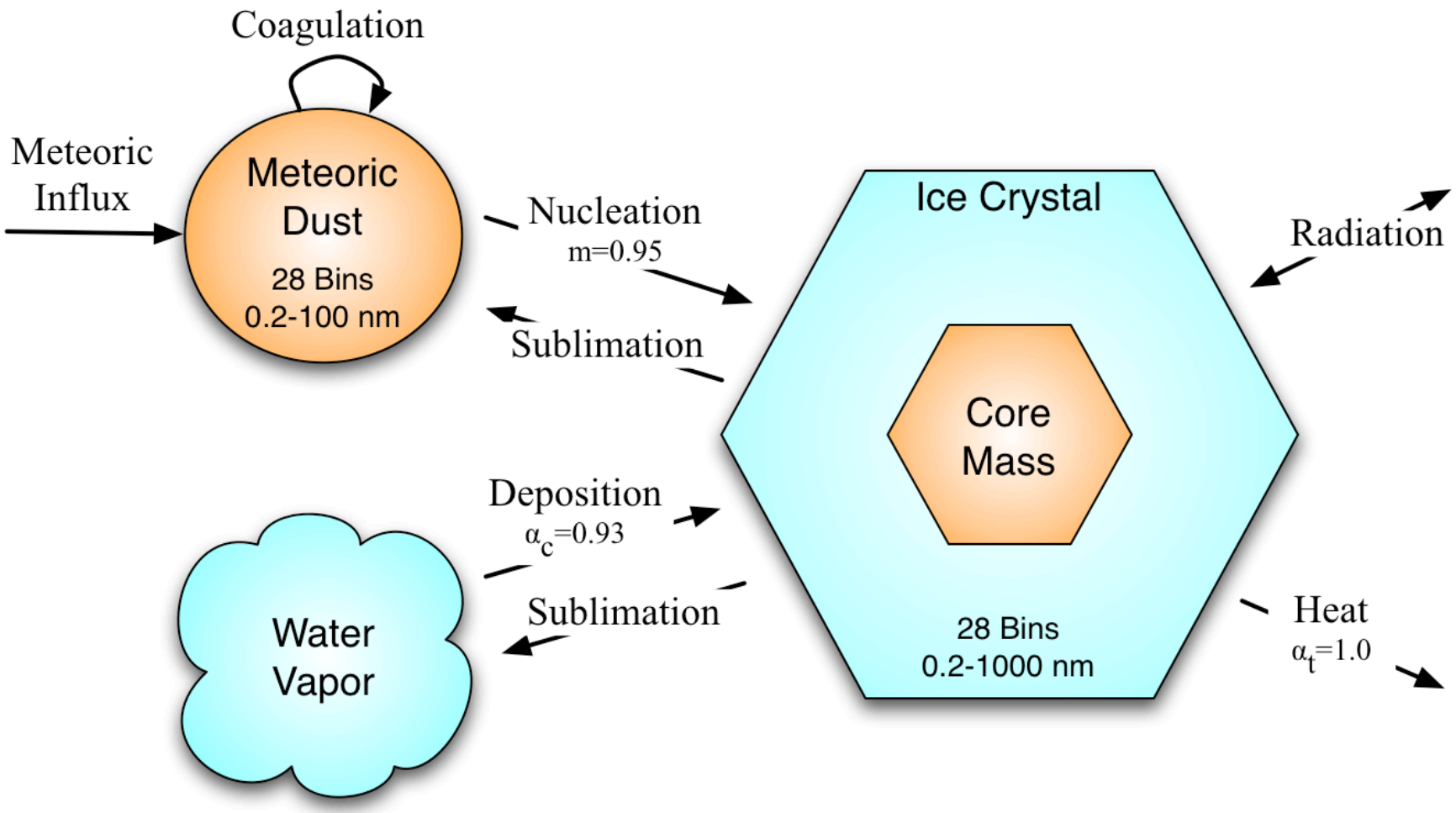






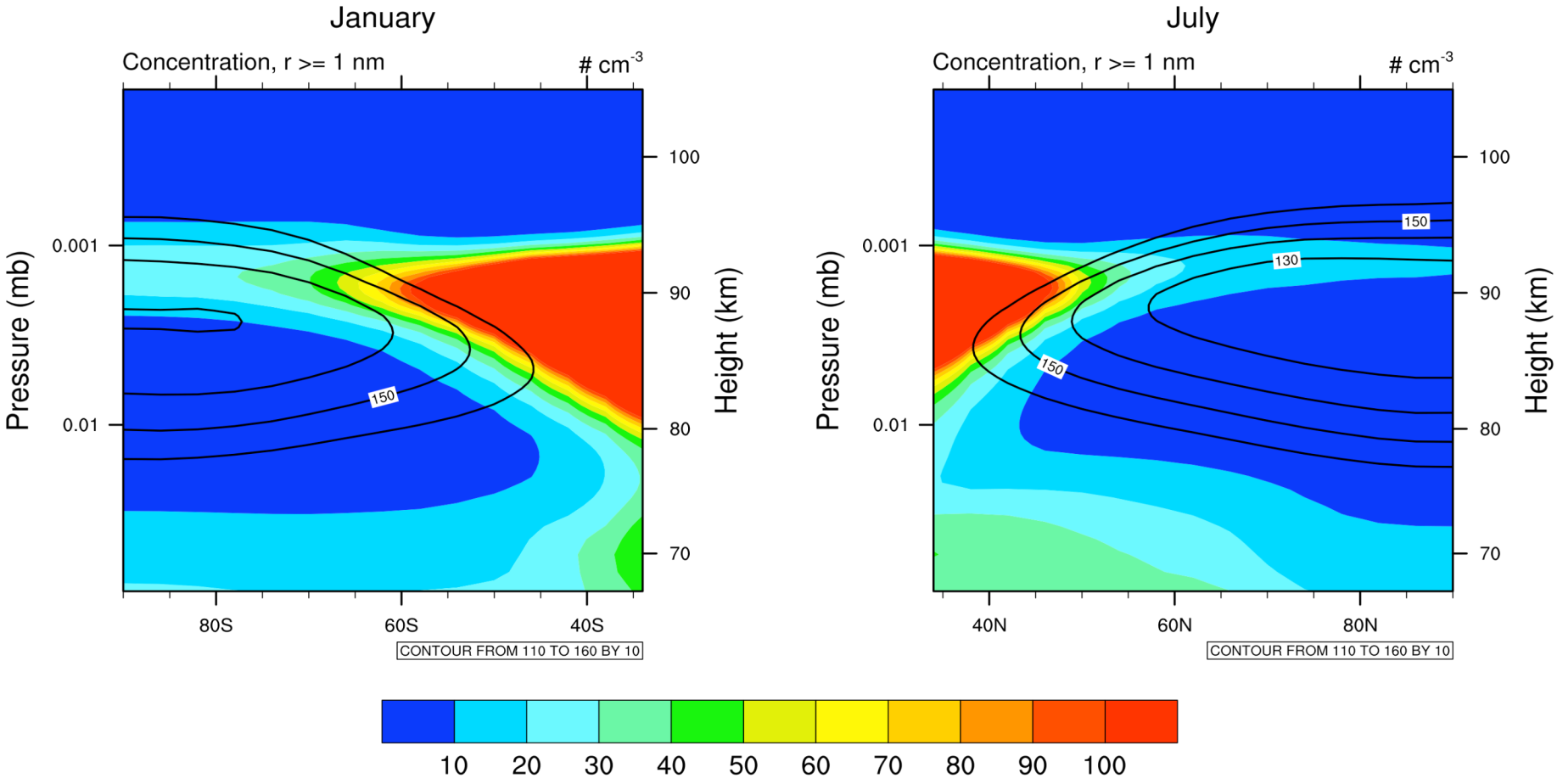
Courtesy of D. Wheeler

CARMA Microphysical Model



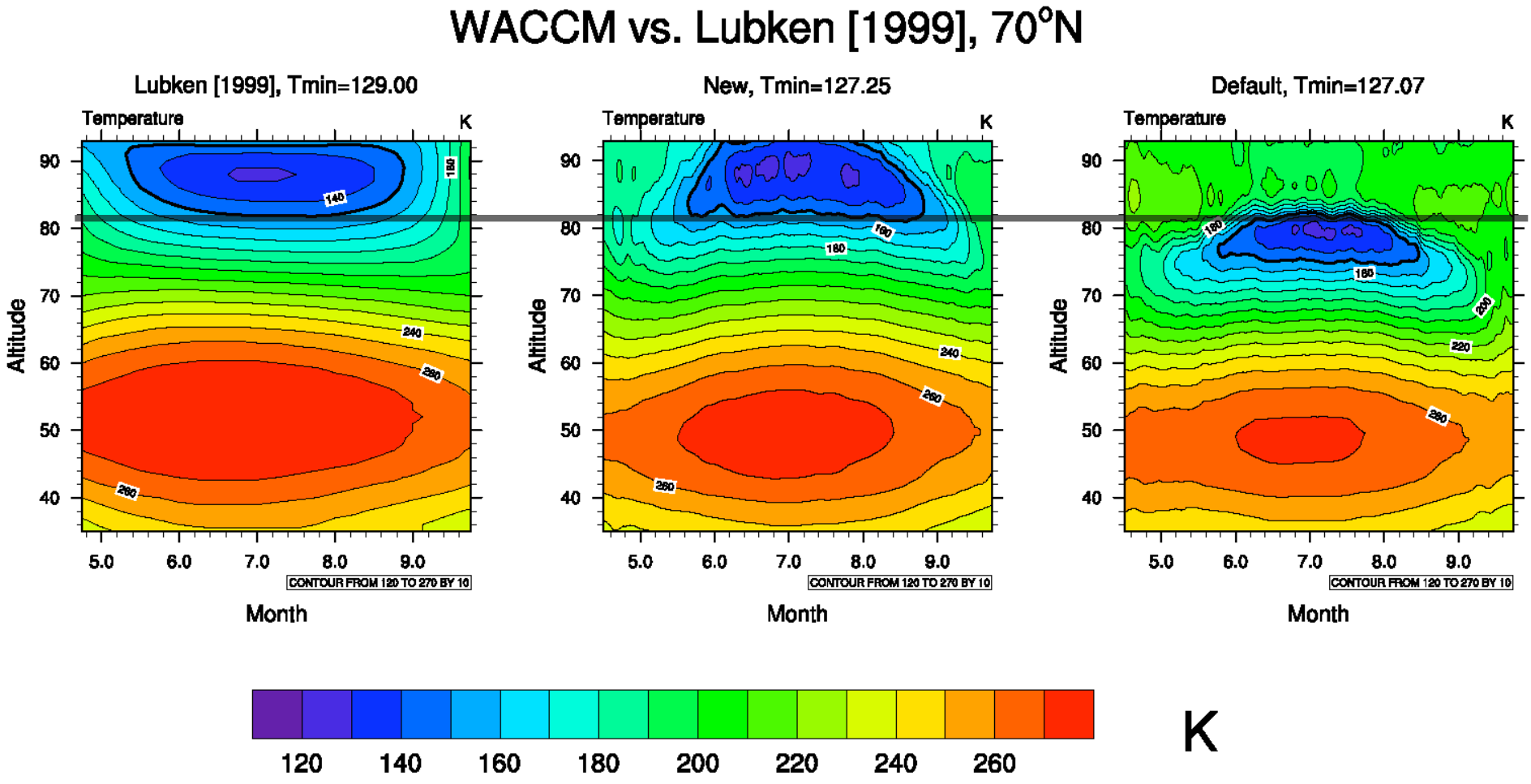
Courtesy of Chuck Bardeen

Reduced Dust At Summer Mesopause



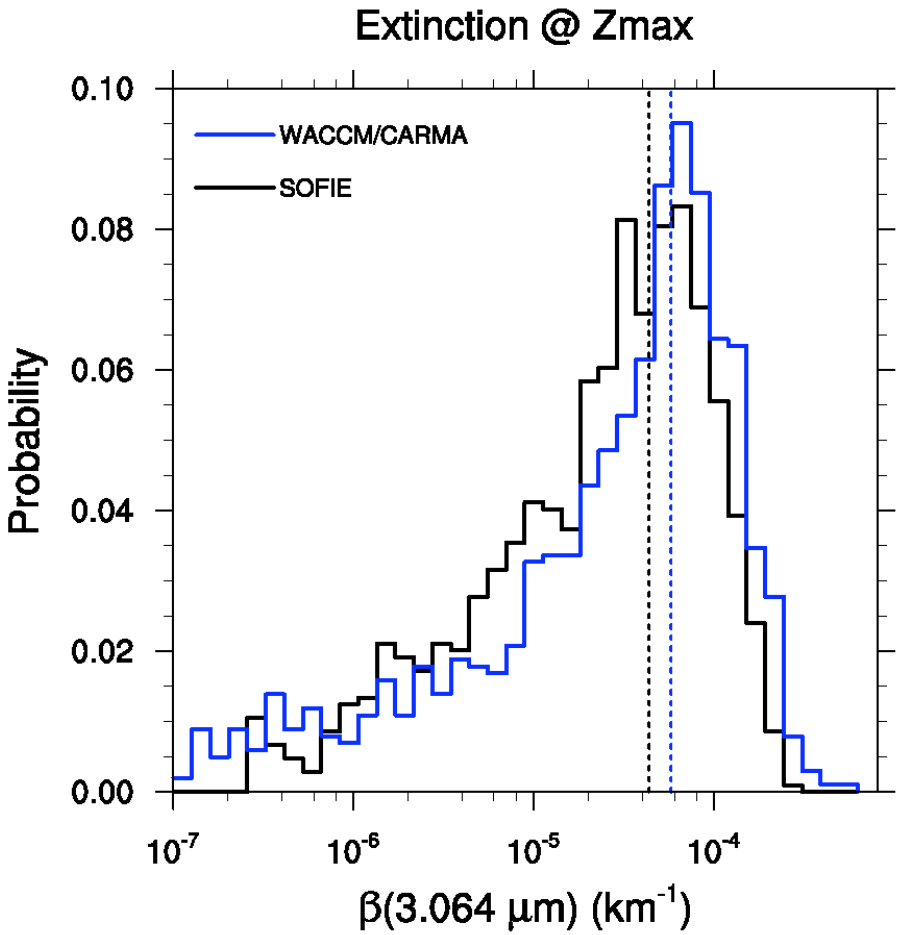
Bardeen *et al.* (JGR, 2008)

Polar Mesopause Temperatures



Courtesy of Chuck Bardeen

How Does WACCM/CARMA Compare To SOFIE on AIM?

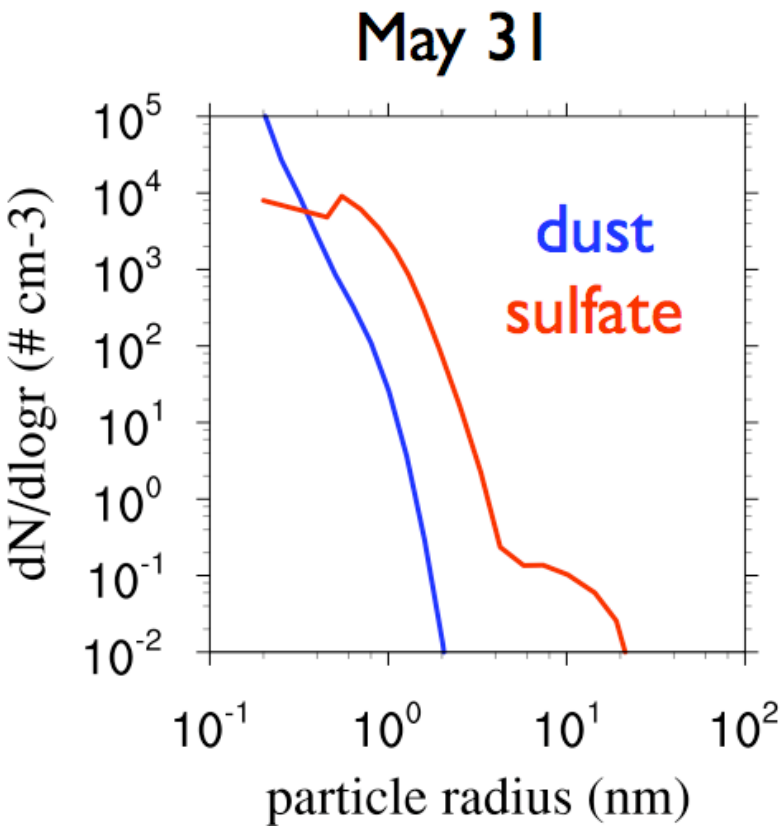


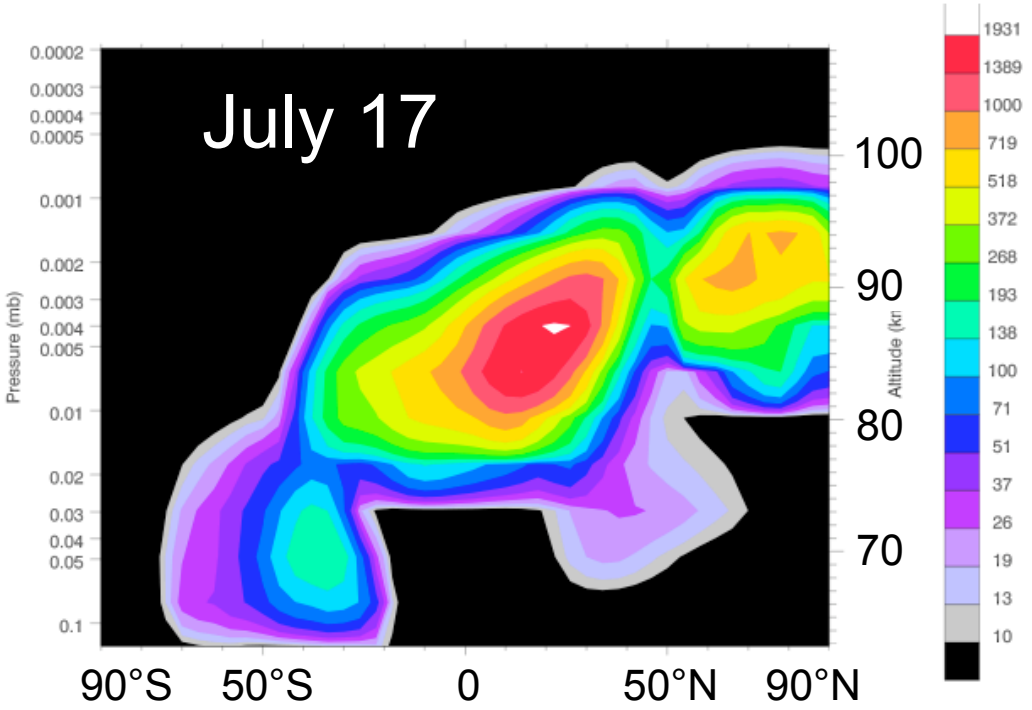
Summary

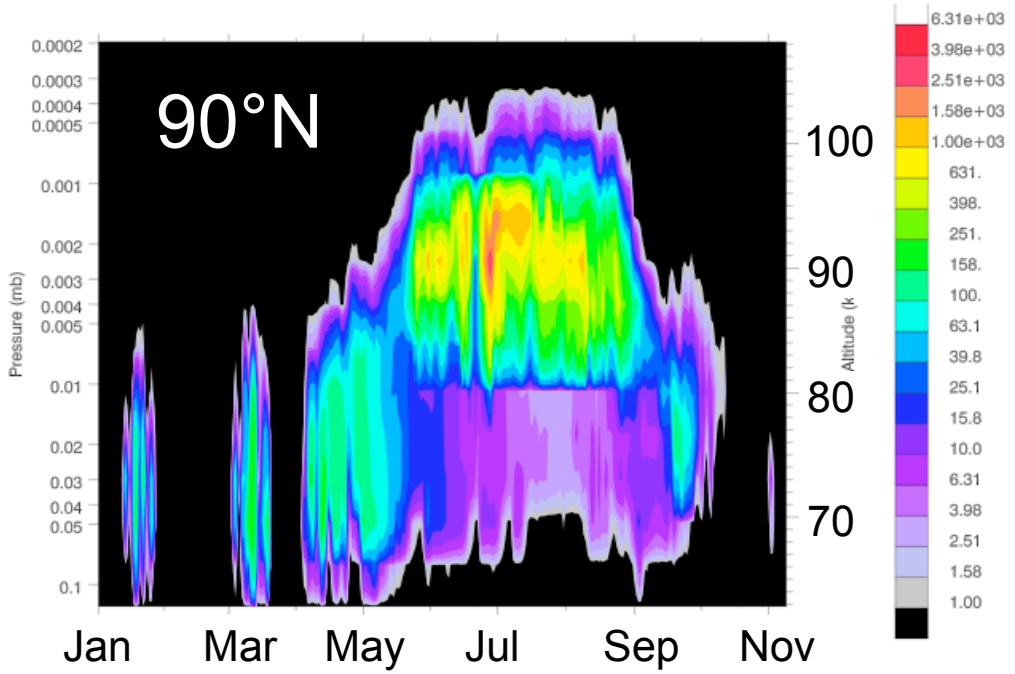
	SOFIE		WACCM/CARMA	
Events	1423		1423	
Clouds	1134	79.69%	1010	70.98%
Zmax < 79 km	289	20.31%	0	0.00%

Zonal average sulfate concentration (r>1 nm) [# cm^{-3}]

>1000 cm^{-3}

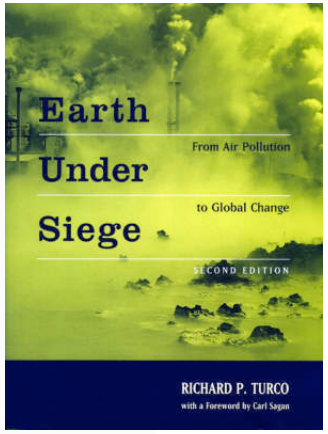






Sulfate Geoengineering

(Rich Turco, 1997)



20% →

STRATOSPHERE

$h\nu$ 20 Tg SO_2/y

O_2

Photochemical oxidation

Aerosol formation

Shortwave radiation scattering

COS → SO_2 → (OH) H_2SO_4

Tropopause

TROPOSPHERE

Atmospheric transport

COS

COS → (OH) SO_x

H_2SO_4

Emission by power stations

Longwave radiation trapping

Sedimentation, rainout of sulfate

Decomposition by plants and soils

50 Tg S/y →

100 Tg OCS/y

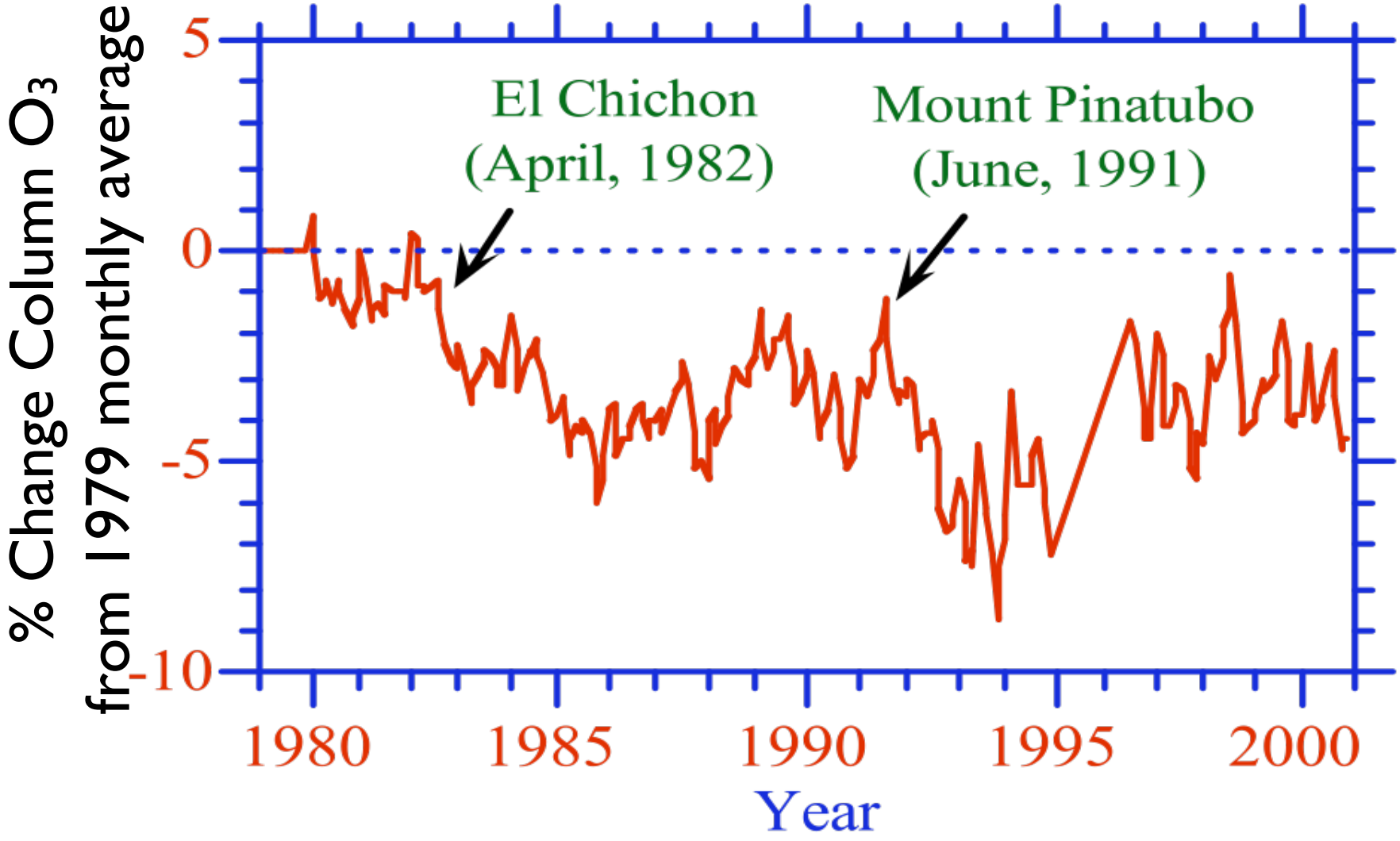
~80% loss in troposphere

cooling: several °C

Tropospheric OCS x 300

~170 ppbv

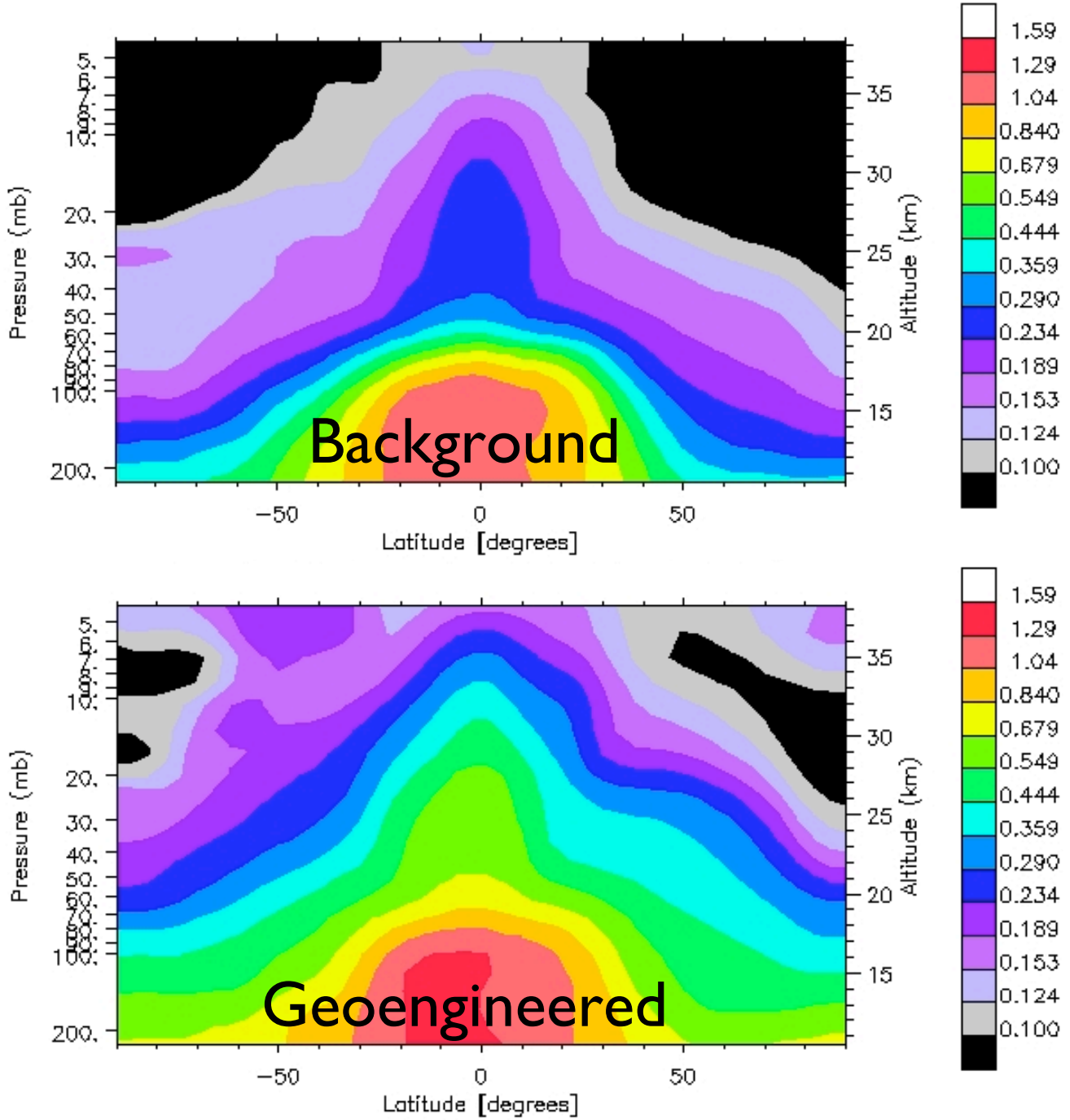
Changes in Monthly-Averaged Global Ozone From 1979-2001

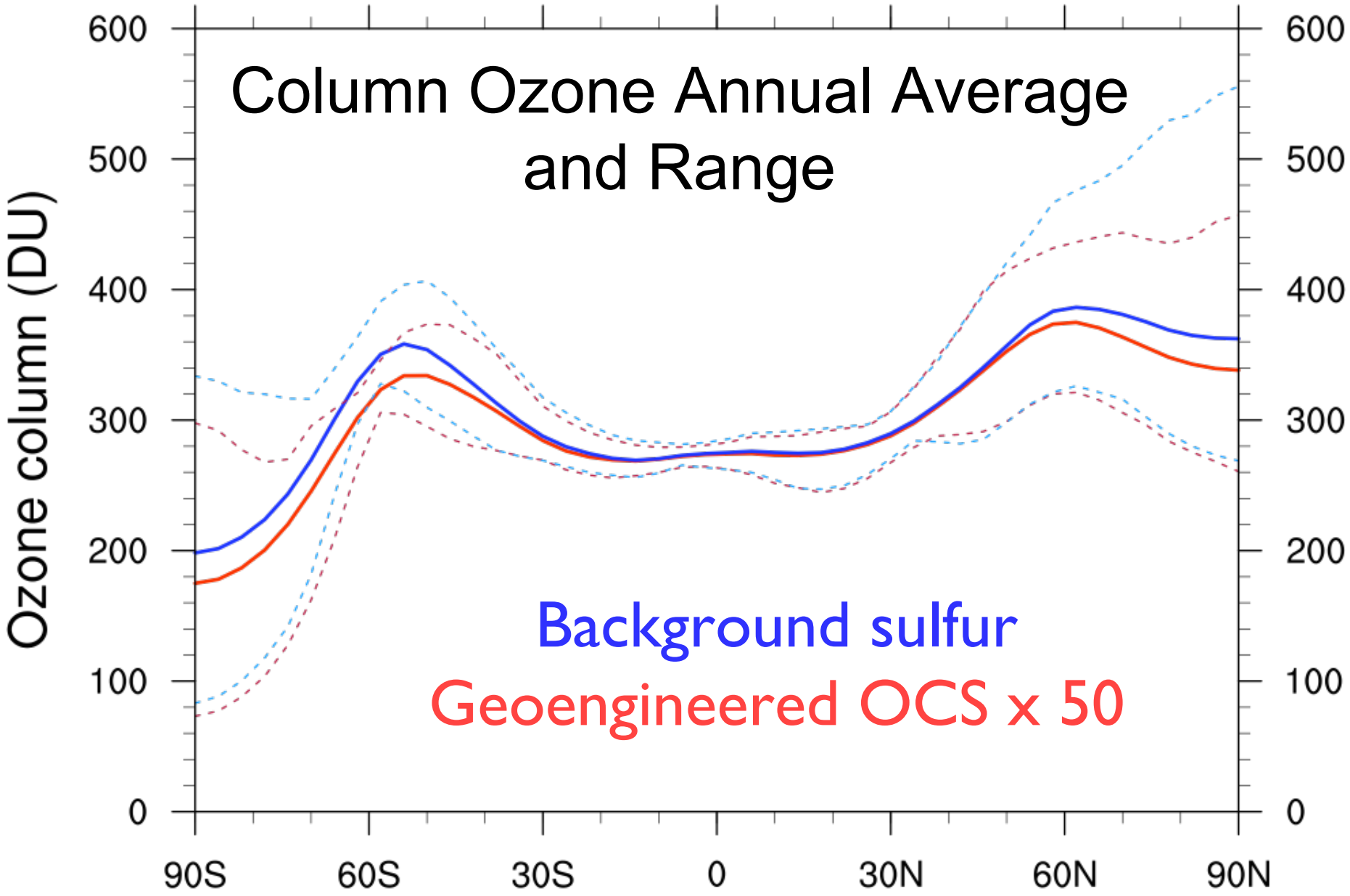


Source: TOMS (NASA) via Mark Jacobson, *Atmospheric Pollution*

Effective radius (μm)

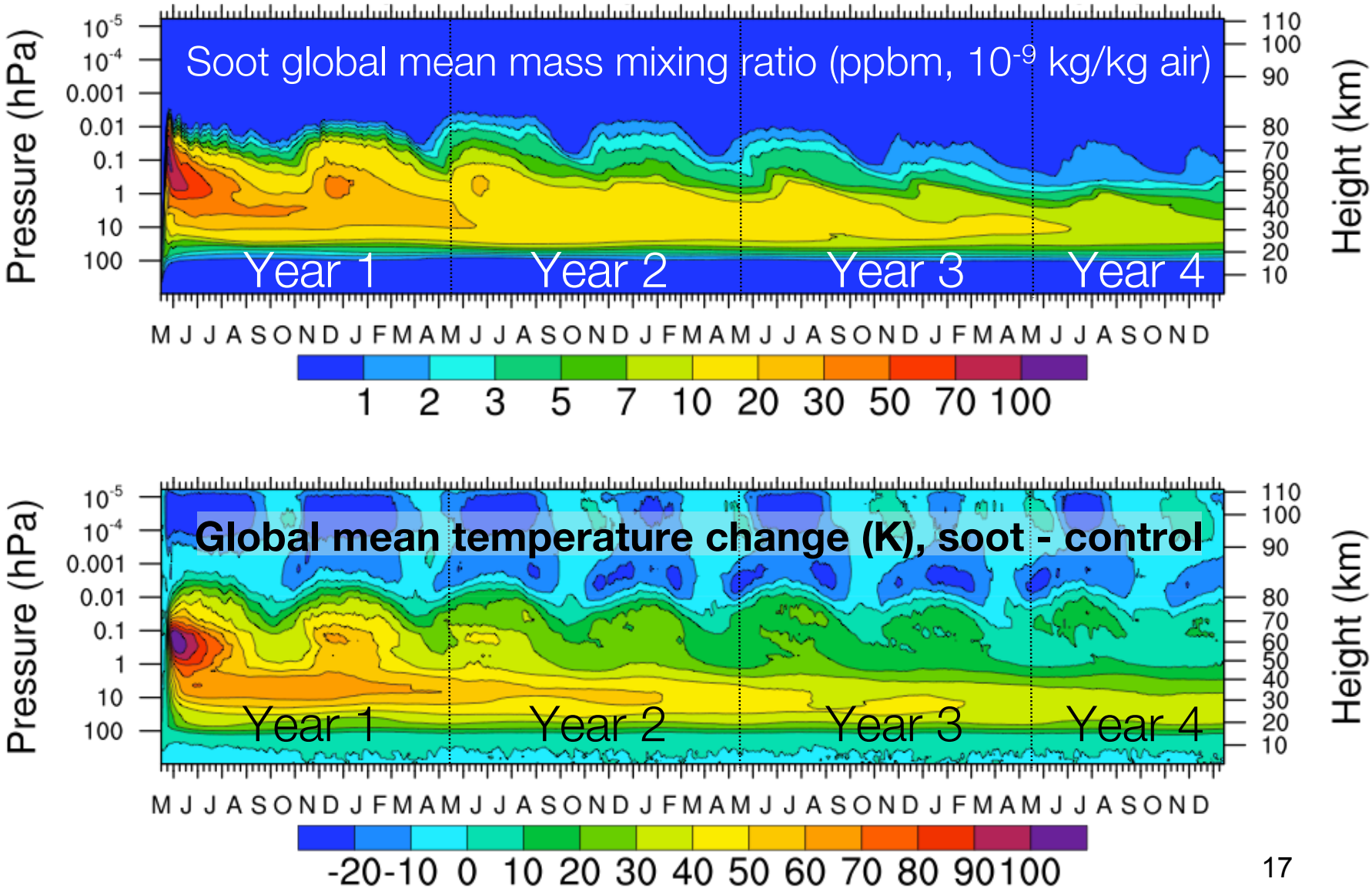
March Zonal Average

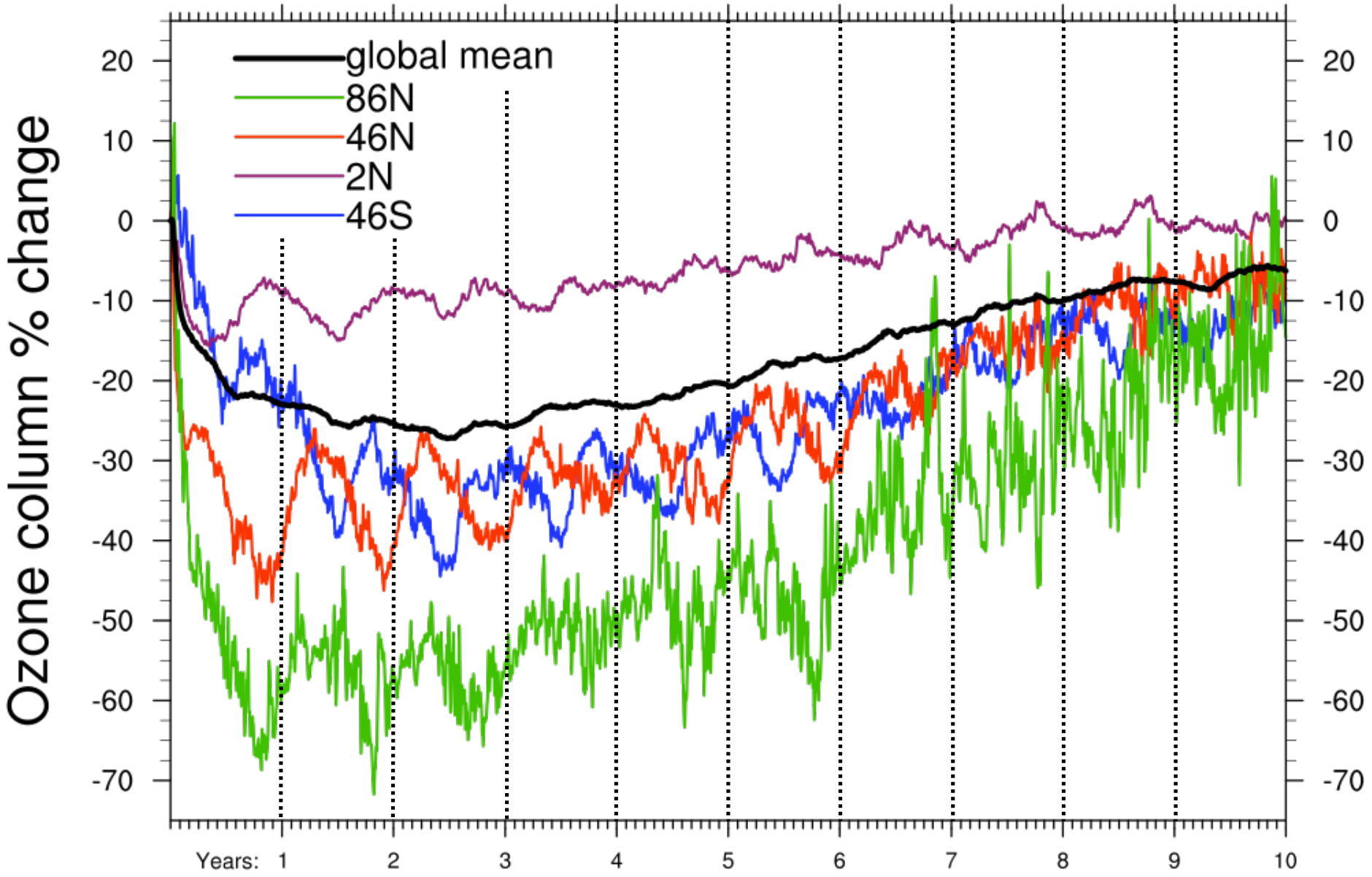



Column Ozone Annual Average
and Range
Ozone column (DU)
600
500
400
300
200
100
0
90S
60S
30S
0
30N
60N
90N
Background sulfur
Geoengineered OCS x 50

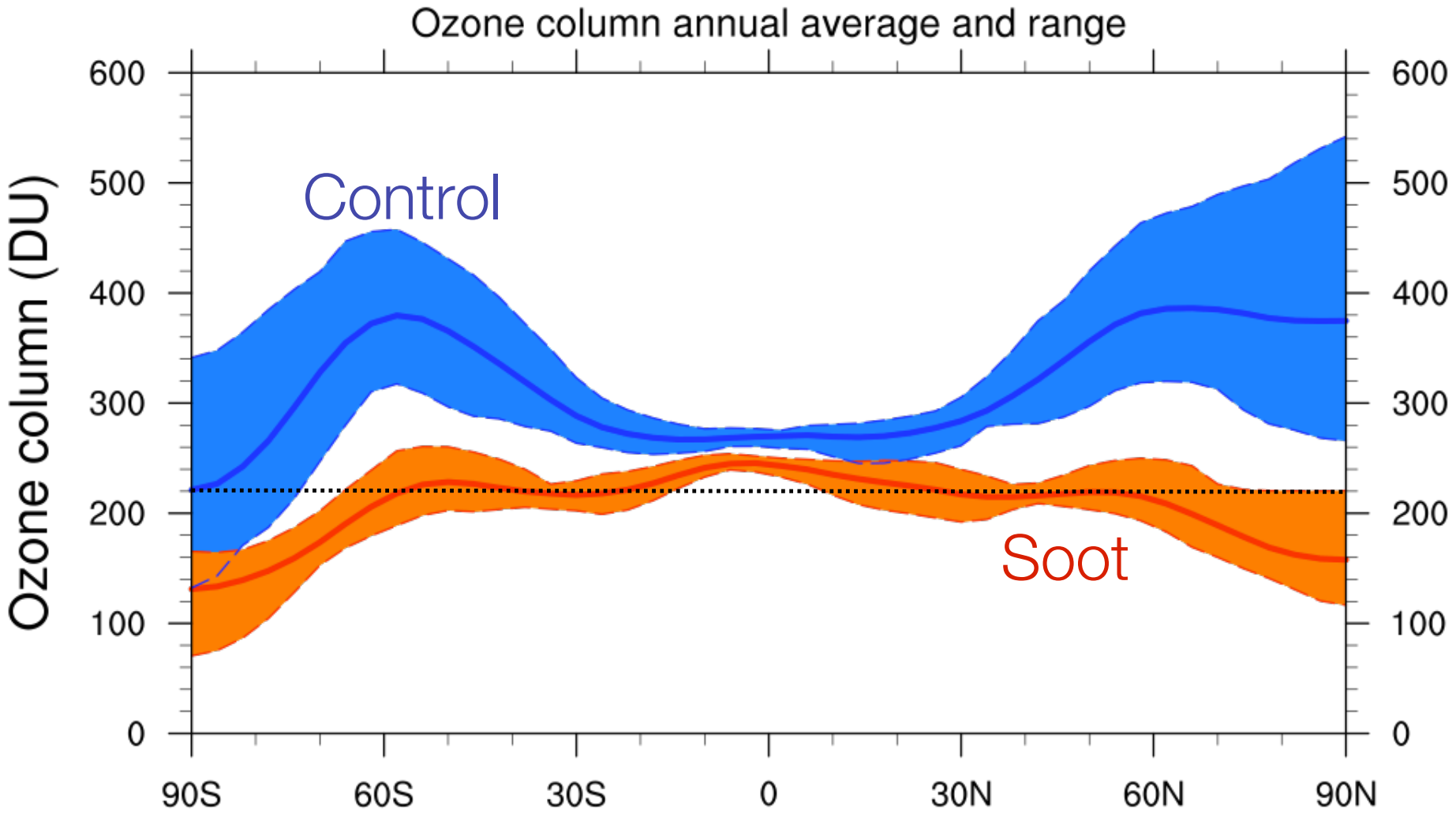
Global effects of regional nuclear war

Mills *et al.*, *PNAS*, 2008.





"Massive global ozone loss predicted following regional nuclear conflict," Mills *et al.*, *PNAS*, 2008.



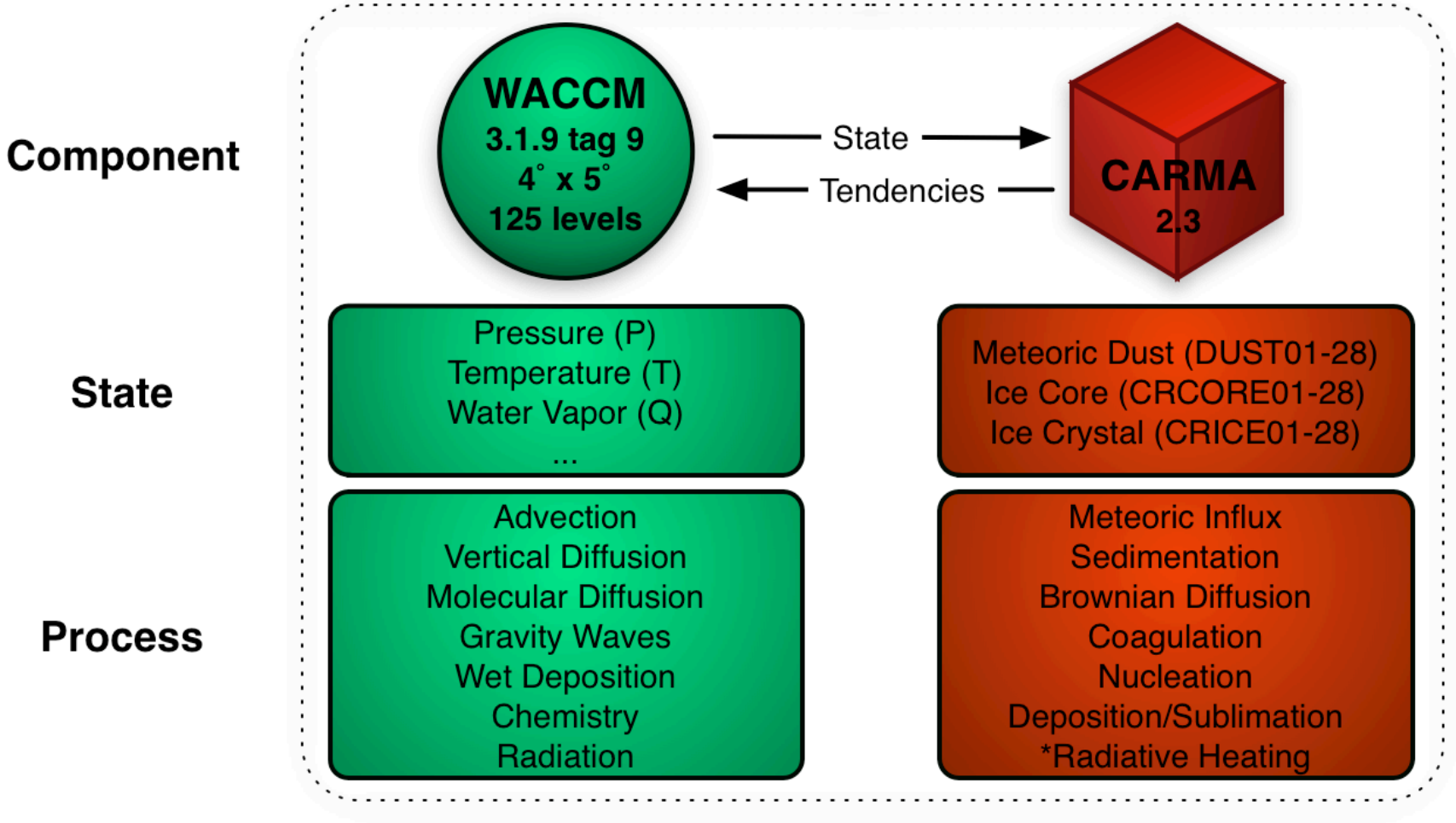
Year 2 ozone column

Near-global ozone hole (< 220 DU)

Conclusions & Poster Plugs

- Energetic particle precipitation (poster, Randall et al.)
  - Aurora: >10% NOx increase down to 35 km
  - MEE: >25% NOx increases down to 20 km
- WACCM stratopause (poster, Harvey *et al.*): ~10K warmer than SABER in November
- Cold air outbreaks (poster, Harvey *et al.*): WACCM produces statistics similar to ERA40 observations
- PMCs & meteoritic dust (poster, Bardeen *et al.*):
  - Winds deplete meteoritic dust at summer mesopause
  - WACCM/CARMA tuned to observed temperatures produces PMCs in agreement with SOFIE observations
- Mesospheric sulfates: sufficient concentrations at summer mesopause for PMC nuclei
- Sulfate geo-engineering: O_3 depletion ~2% globally, ~10% near poles
- Regional nuclear war: could produce a near-global ozone hole.

WACCM/CARMA



Courtesy of Chuck Bardeen

Polar Mesospheric Clouds

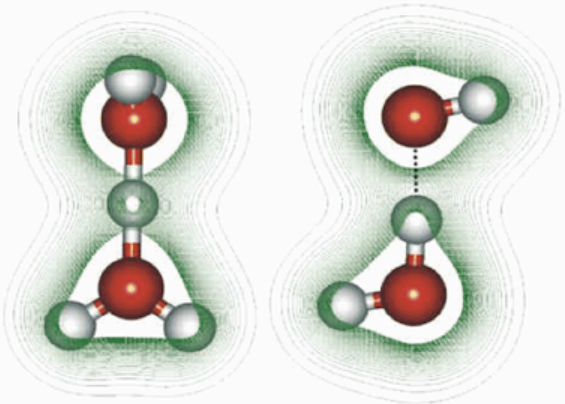
PMC Nucleation

Homogeneous nucleation of water vapor is too slow to account for observed PMC particles.

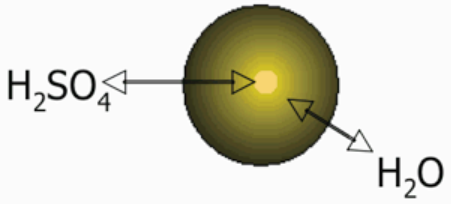
Proposed nuclei:

meteoritic dust

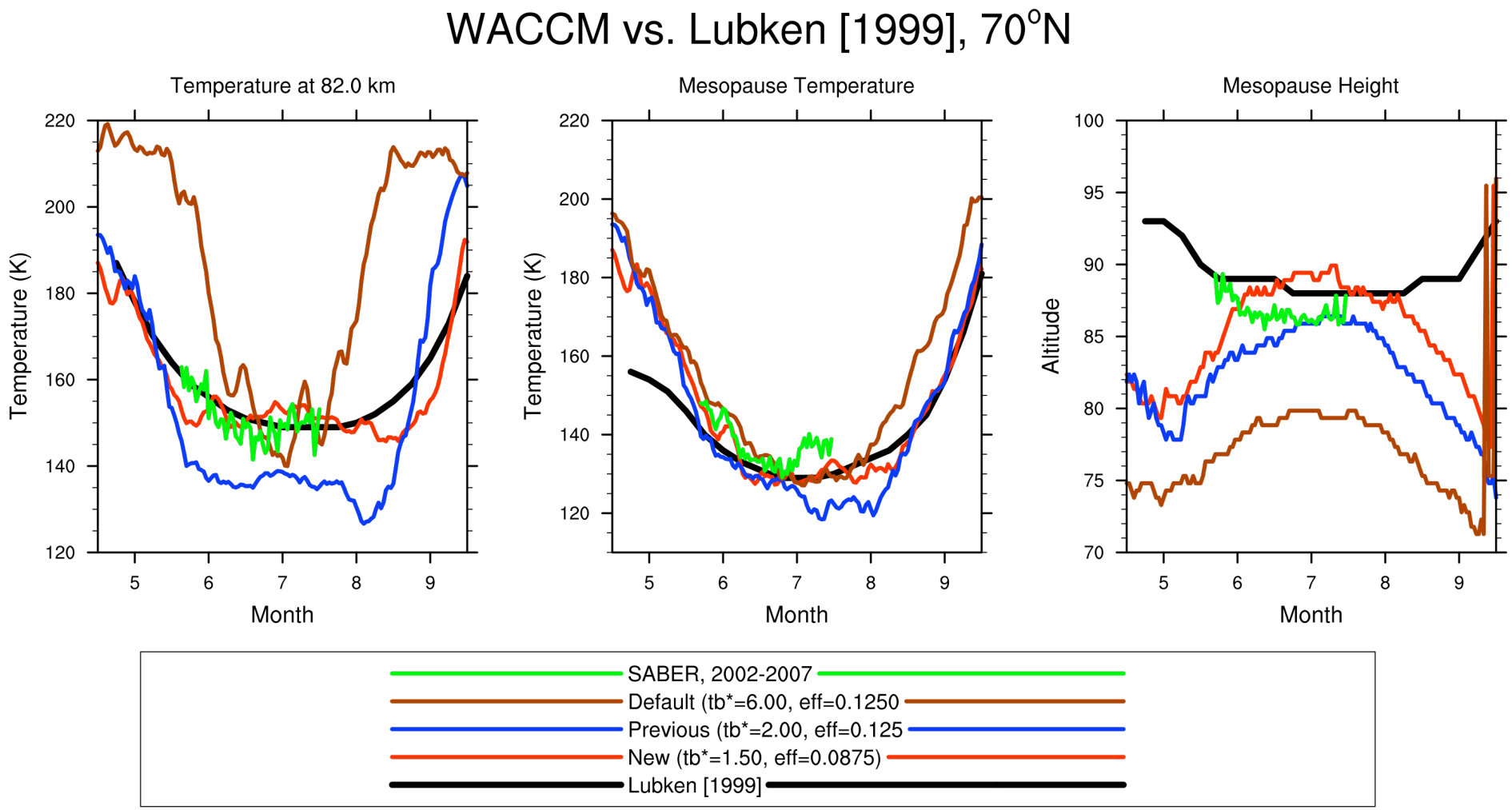
proton hydrates



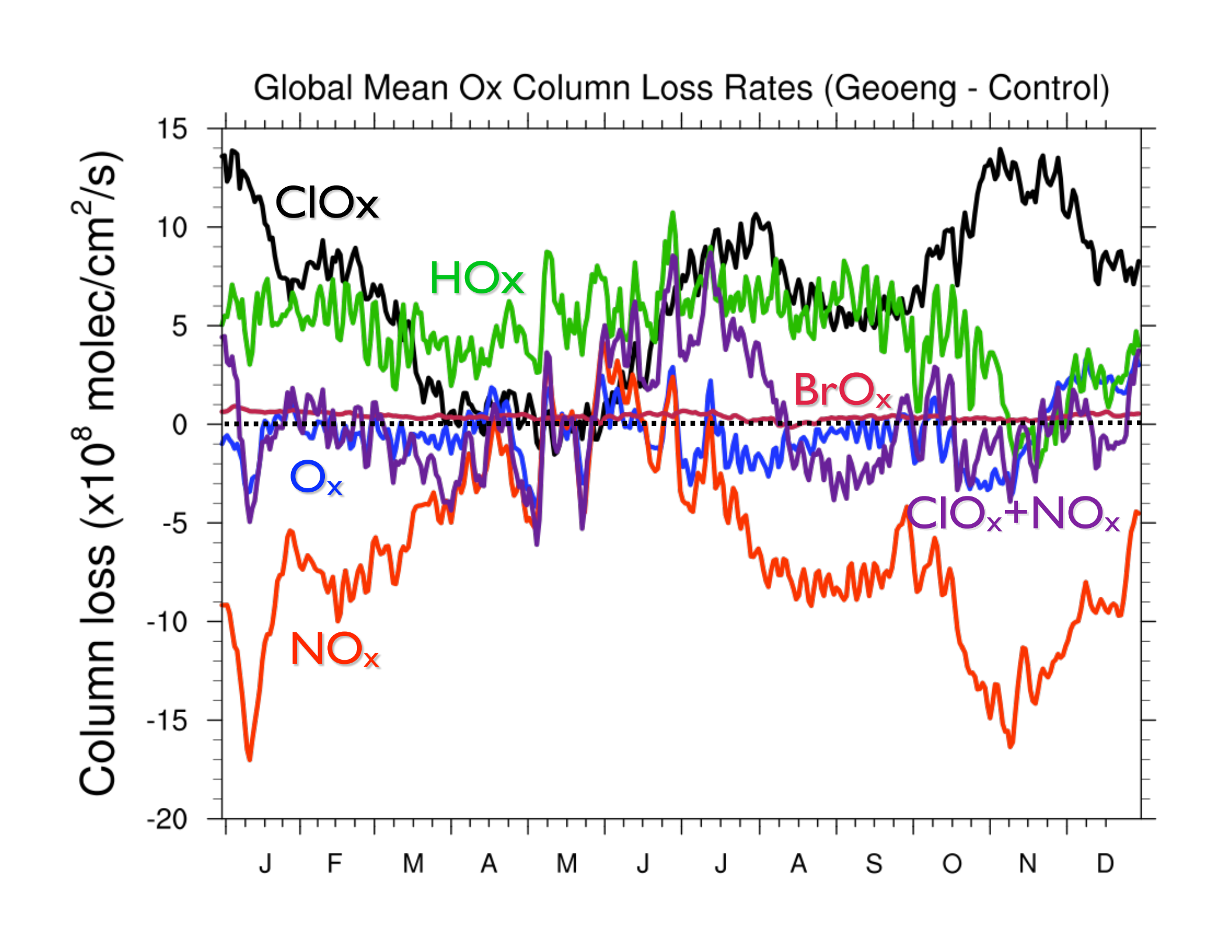
sulfates



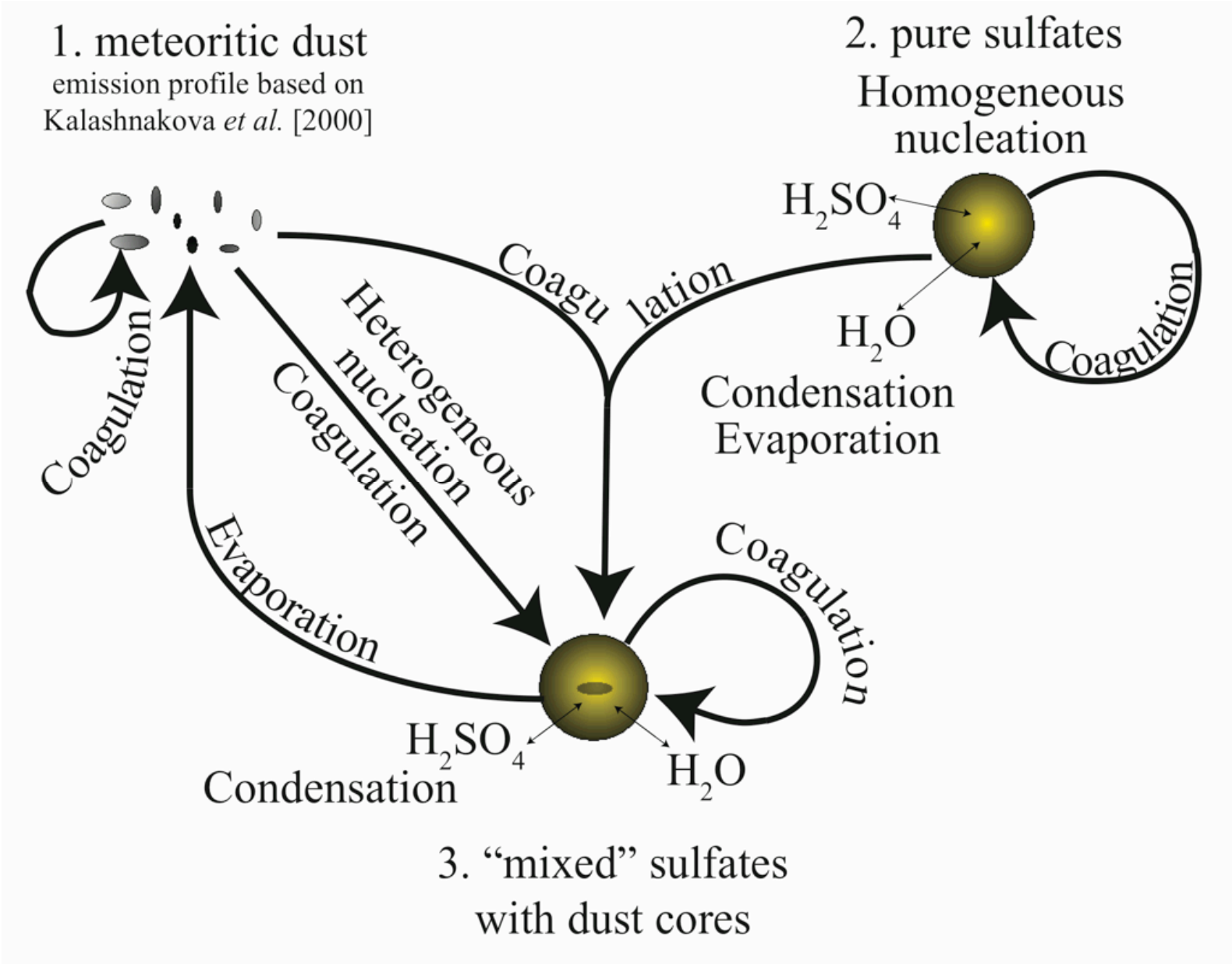
Important PMC Temperatures



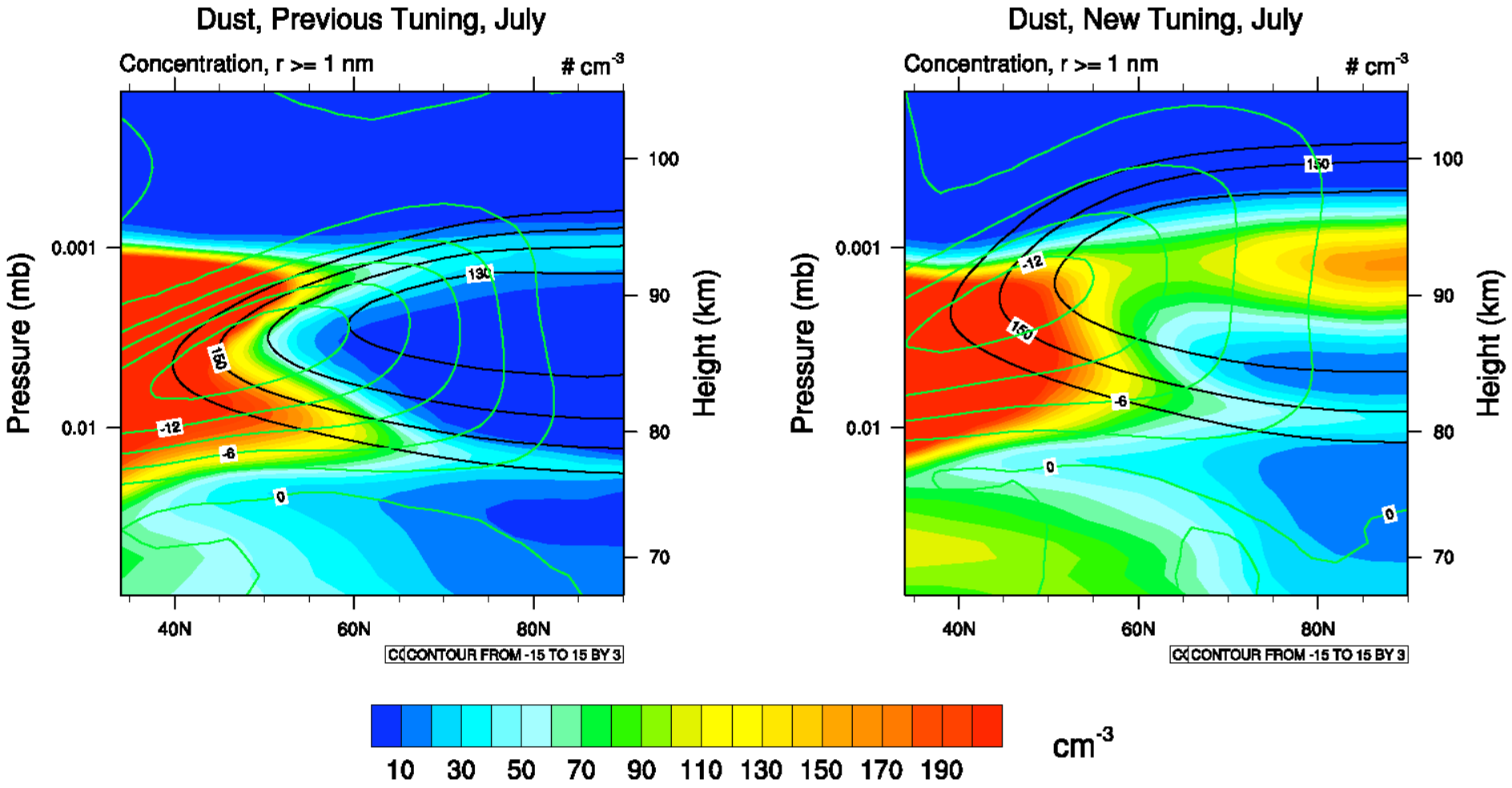
Courtesy of Chuck Bardeen


Global Mean Ox Column Loss Rates (Geoeng - Control)
Column loss (x10^8 molec/cm^2/s)
15
10
5
0
-5
-10
-15
-20
J
F
M
A
M
J
J
A
S
O
N
D
ClOx
HOx
BrOx
Ox
ClOx+NOx
NOx

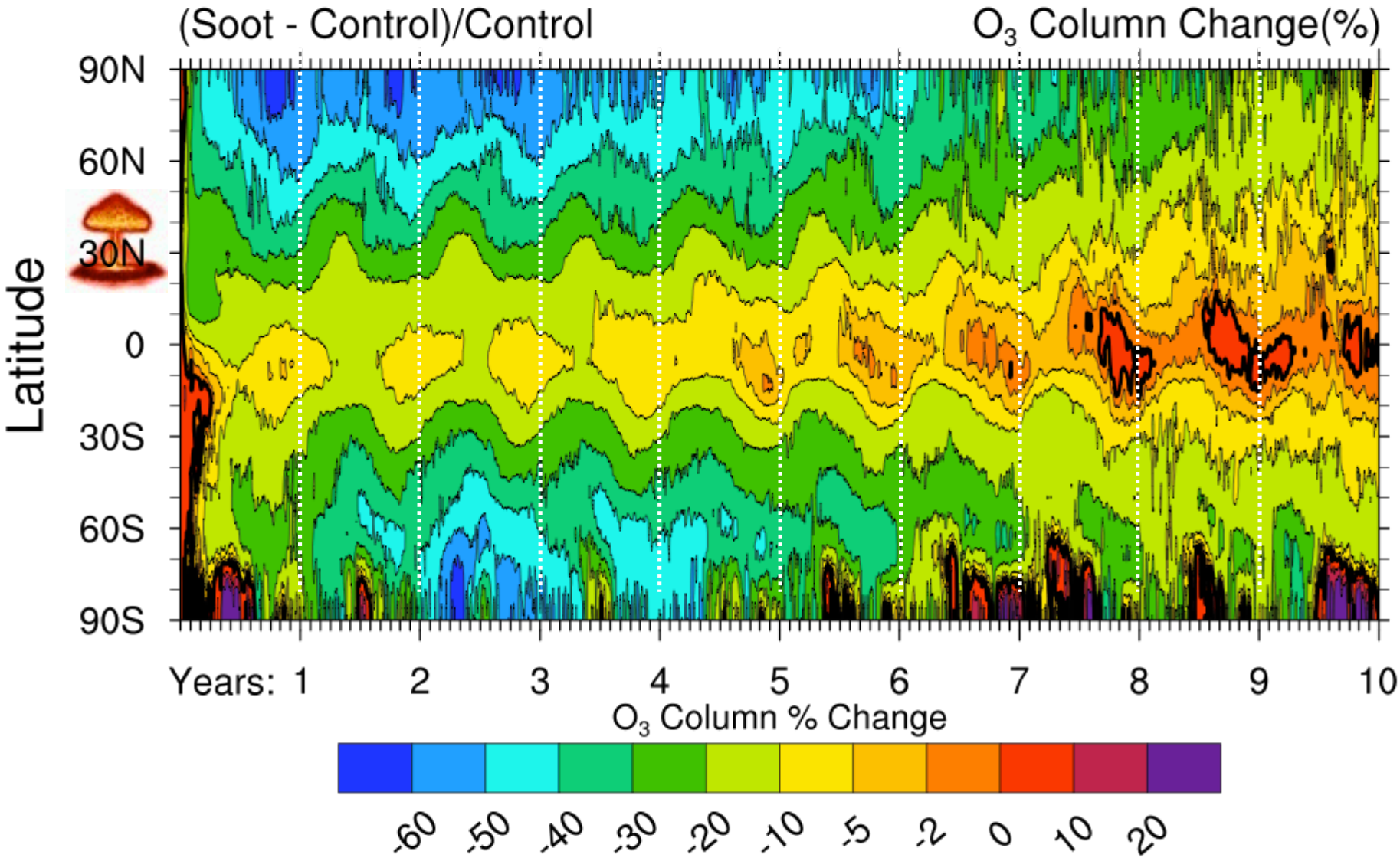
Sulfate Microphysical Model



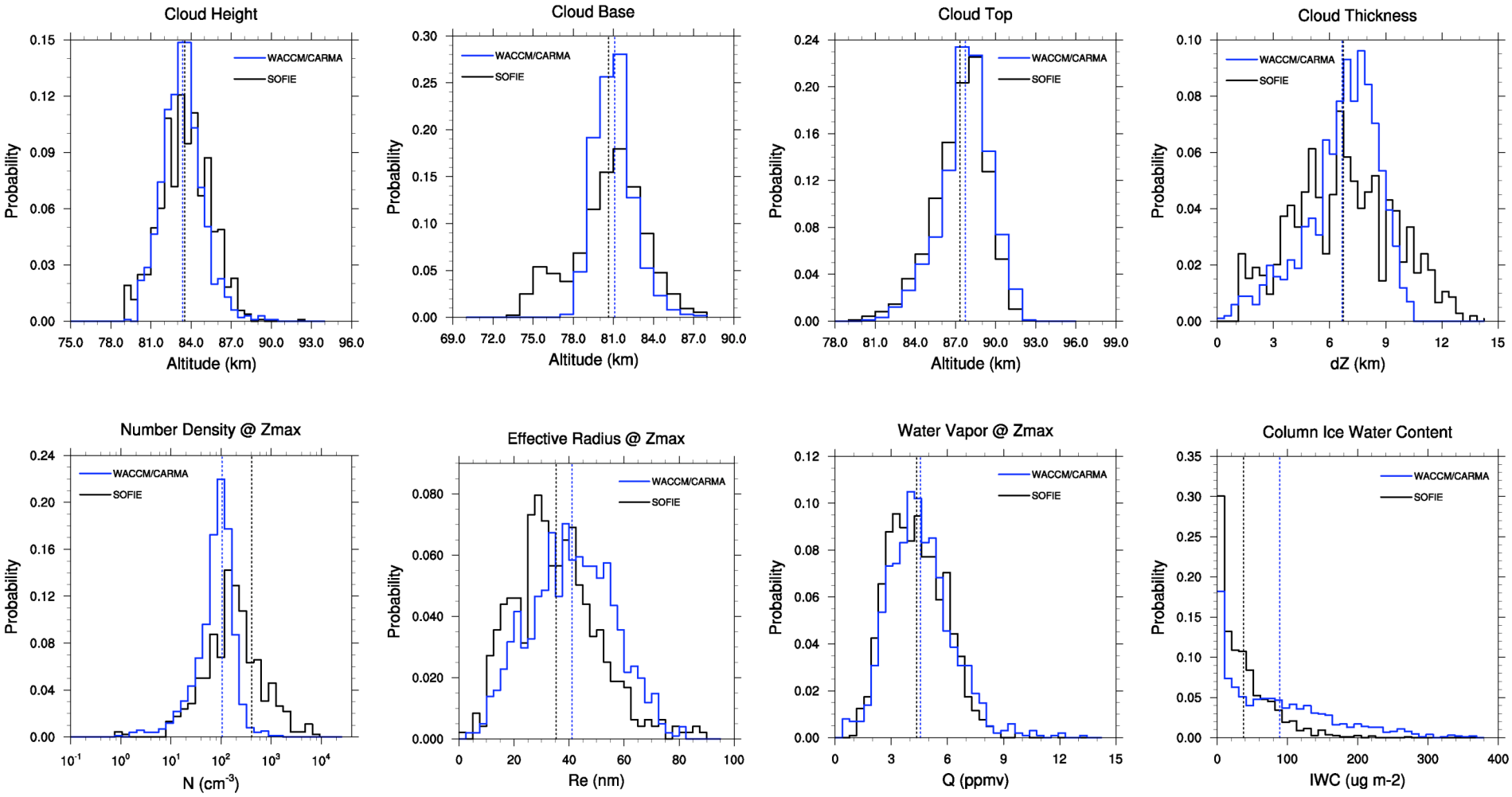
How Does GW Tuning Impact CN?



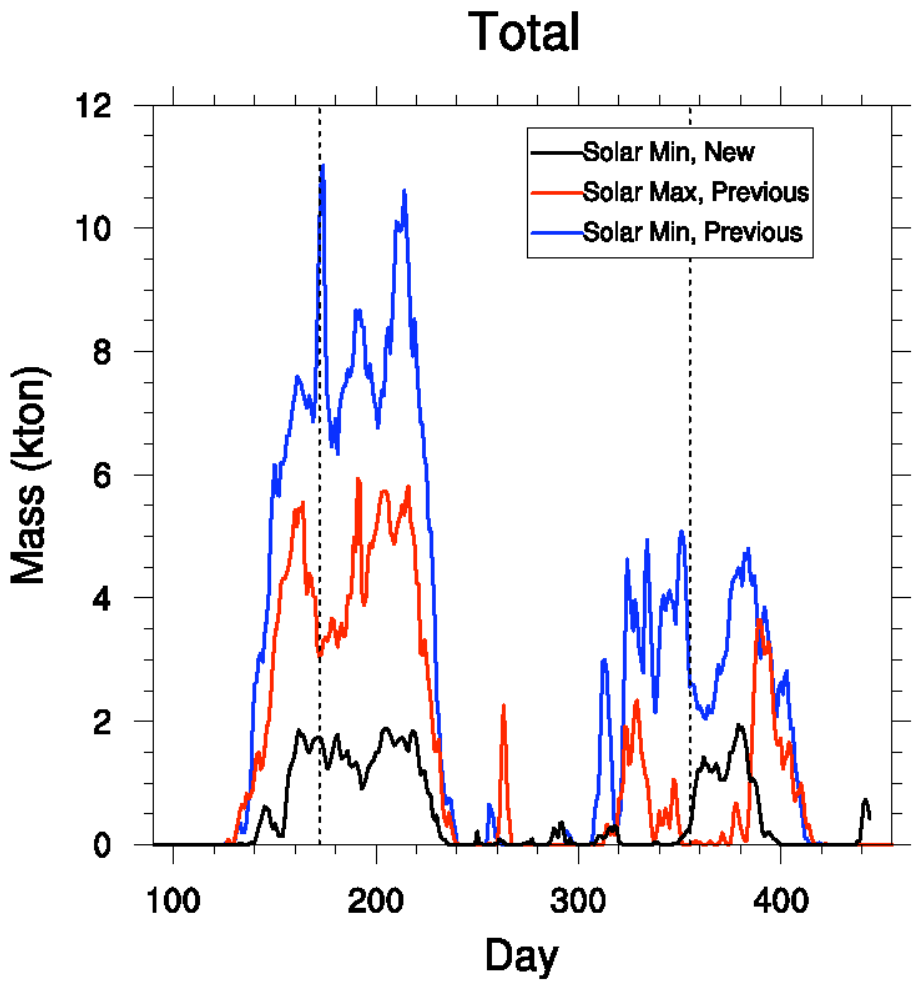
Total Ozone Loss

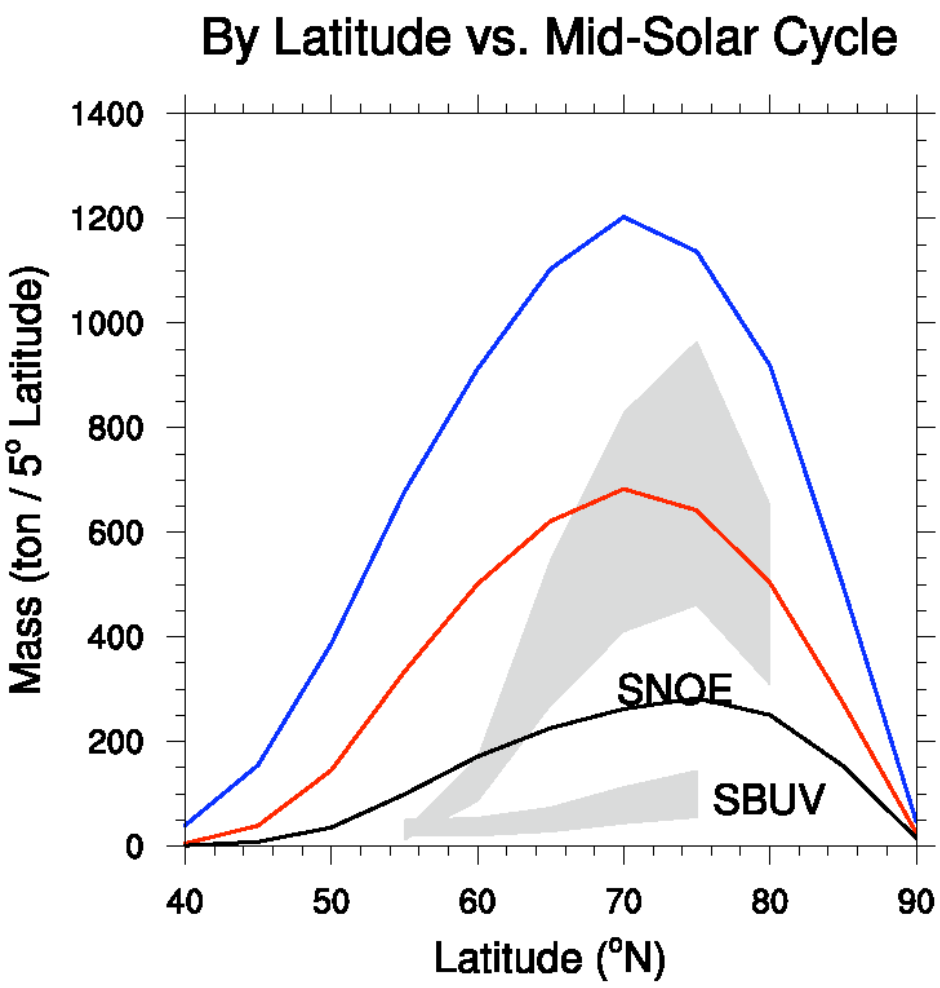


Other Properties …



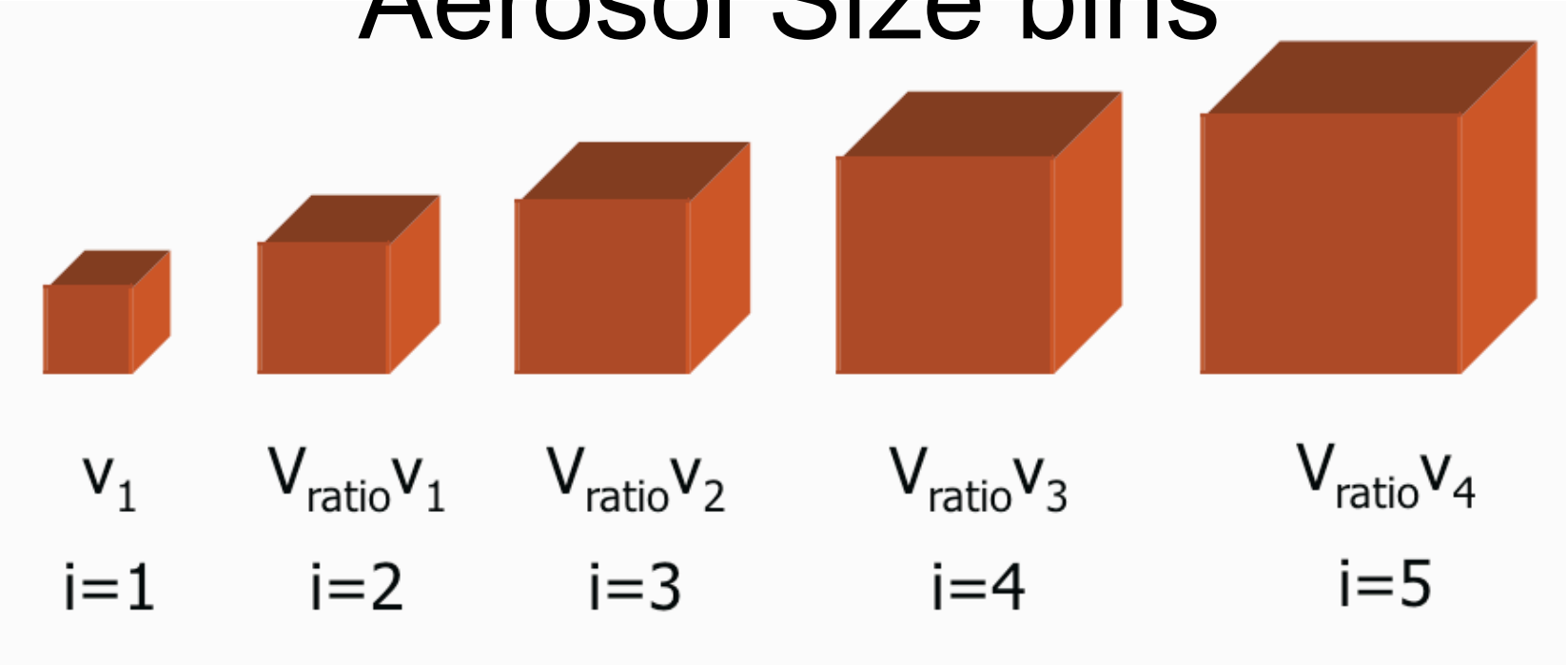
Less Total Ice Mass Than Estimates?





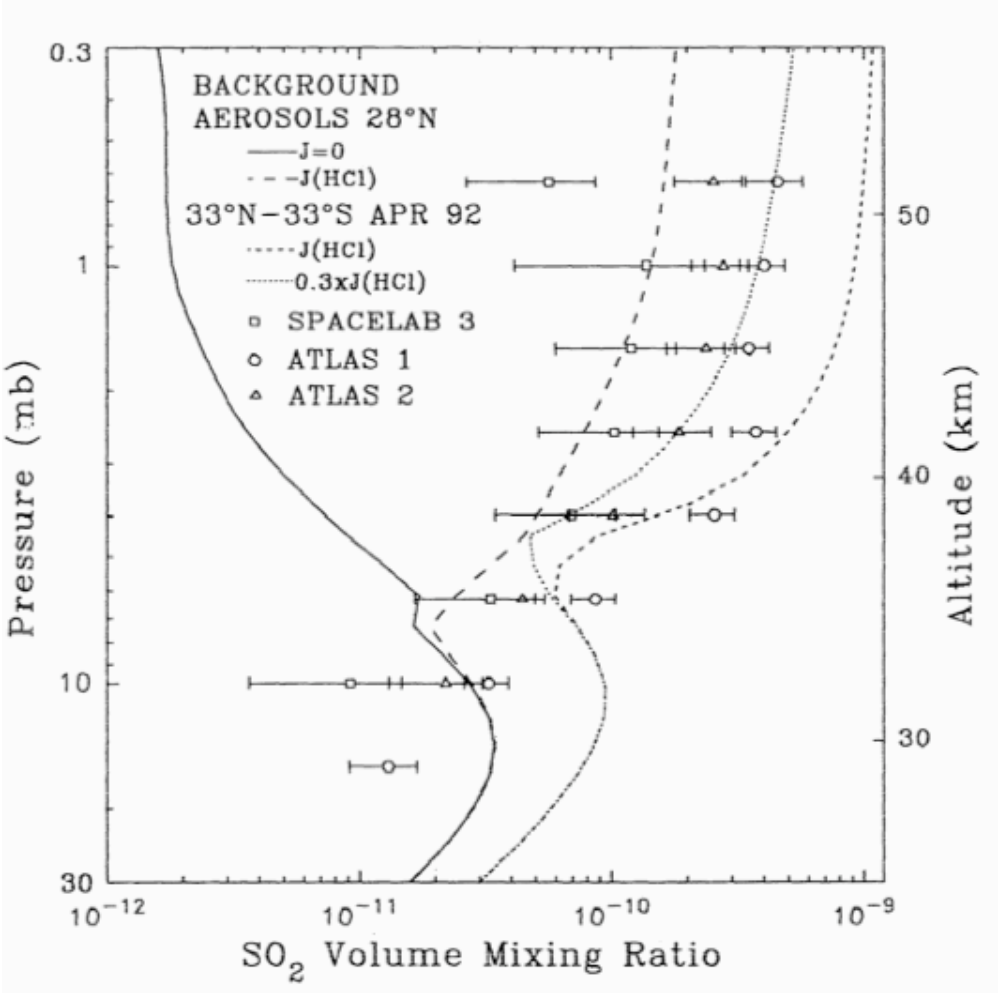
[Stevens et al. 2007]

Aerosol Size bins



- 38 aerosol size bins x 3 groups
- volume doubling
- minimum radius 0.1 nm

$H_2SO_4 + h\nu \rightarrow SO_2$



Rinsland *et al.*, GRL, 1995.

- ✱ UV ruled out [Burkholder *et al.*, 2000]
- ✓ Visible + near IR proposed [Vaida *et al.*, 2003]
- ➡ rate does not increase exponentially with altitude

Garcia-Solomon 2D Model

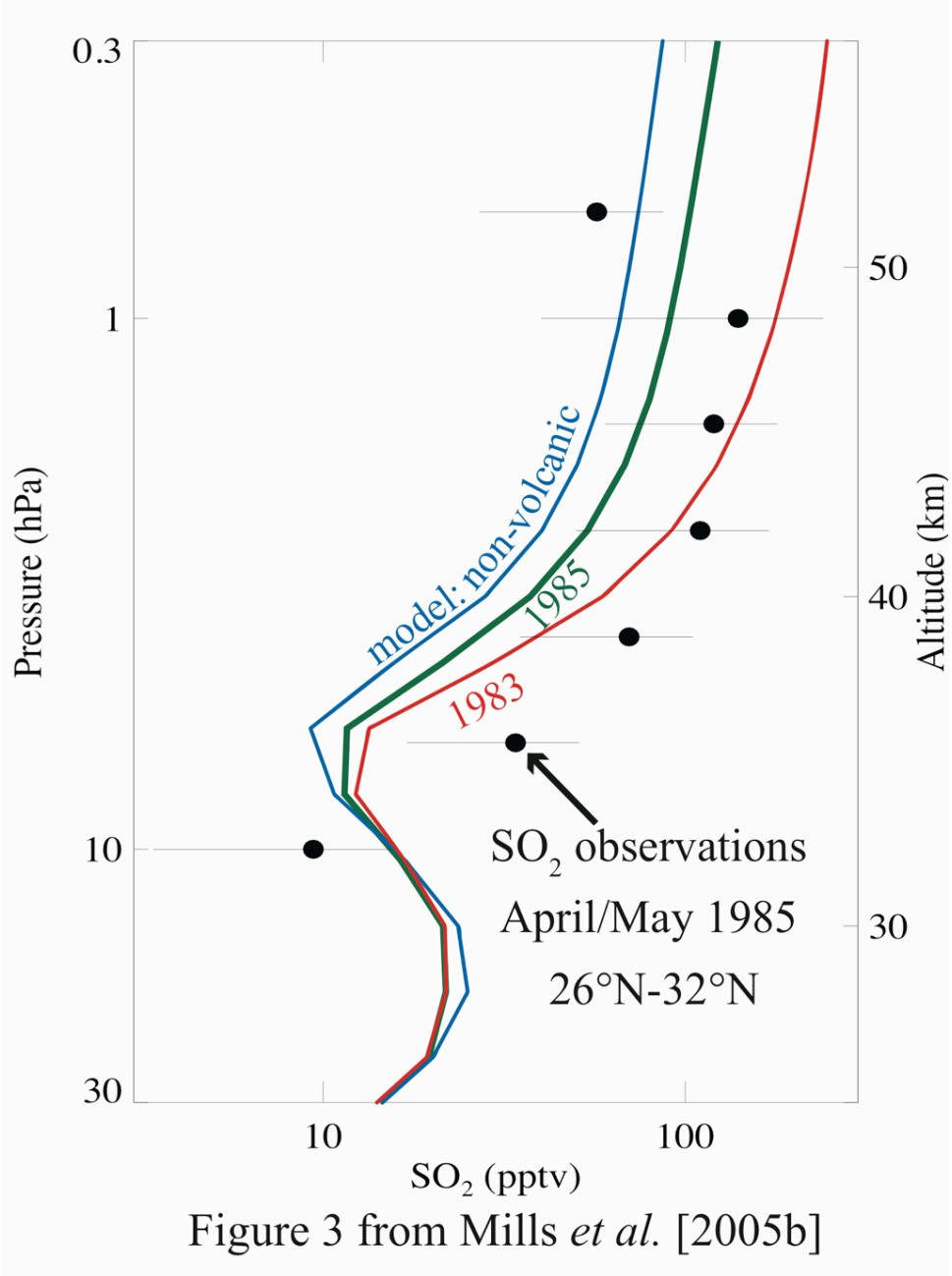


Figure 3 from Mills *et al.* [2005b]

WACCM/CARMA