WACCM and WACCM/CARMA studies at CU LASP: March 2009 Update

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Jeff France, Donavan Wheeler,
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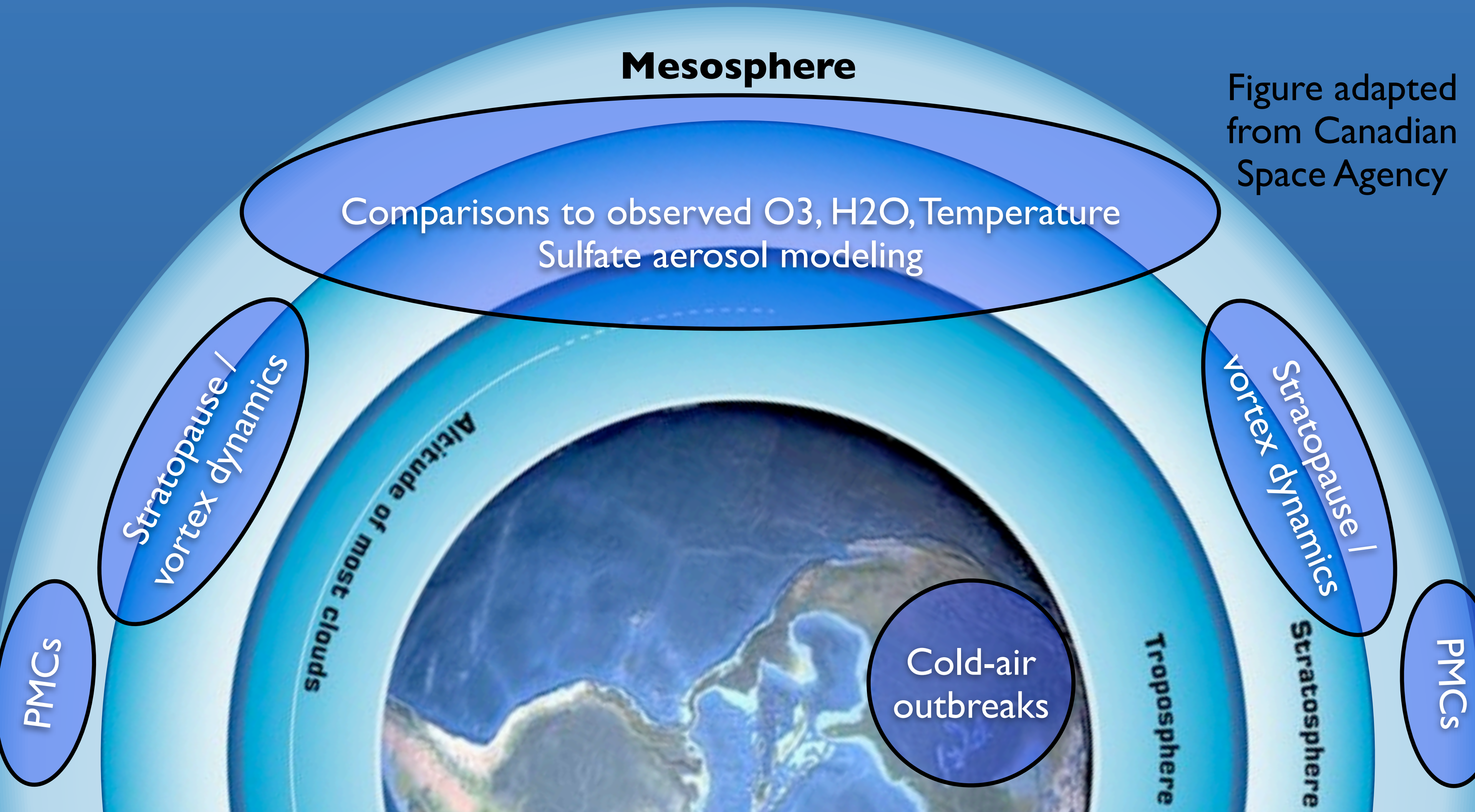
Charles Bardeen,
Dan Marsh,
Rolando Garcia,
Doug Kinnison,
Aimee Merkel,
Simone Tilmes,
Francis Vitt

NCAR

CU LASP's WACCM Activities Spanning the atmosphere



WACCM, CAM & CARMA at LASP

Talk outline:

- WACCM
  - compared to meteorological data
    - Polar vortex dynamics & sudden stratospheric warmings
    - Cold air outbreaks
  - compared to satellite data
    - SABER & MLS: Stratopause T & Z
    - MLS O_3, N_2O, H_2O & T
  - Energetic particle precipitation
  - Parameterized PMCs
    - Interhemispheric coupling
- WACCM/CARMA
  - Sulfate nucleation
  - PMCs, meteoritic dust
  - Mesospheric sulfate

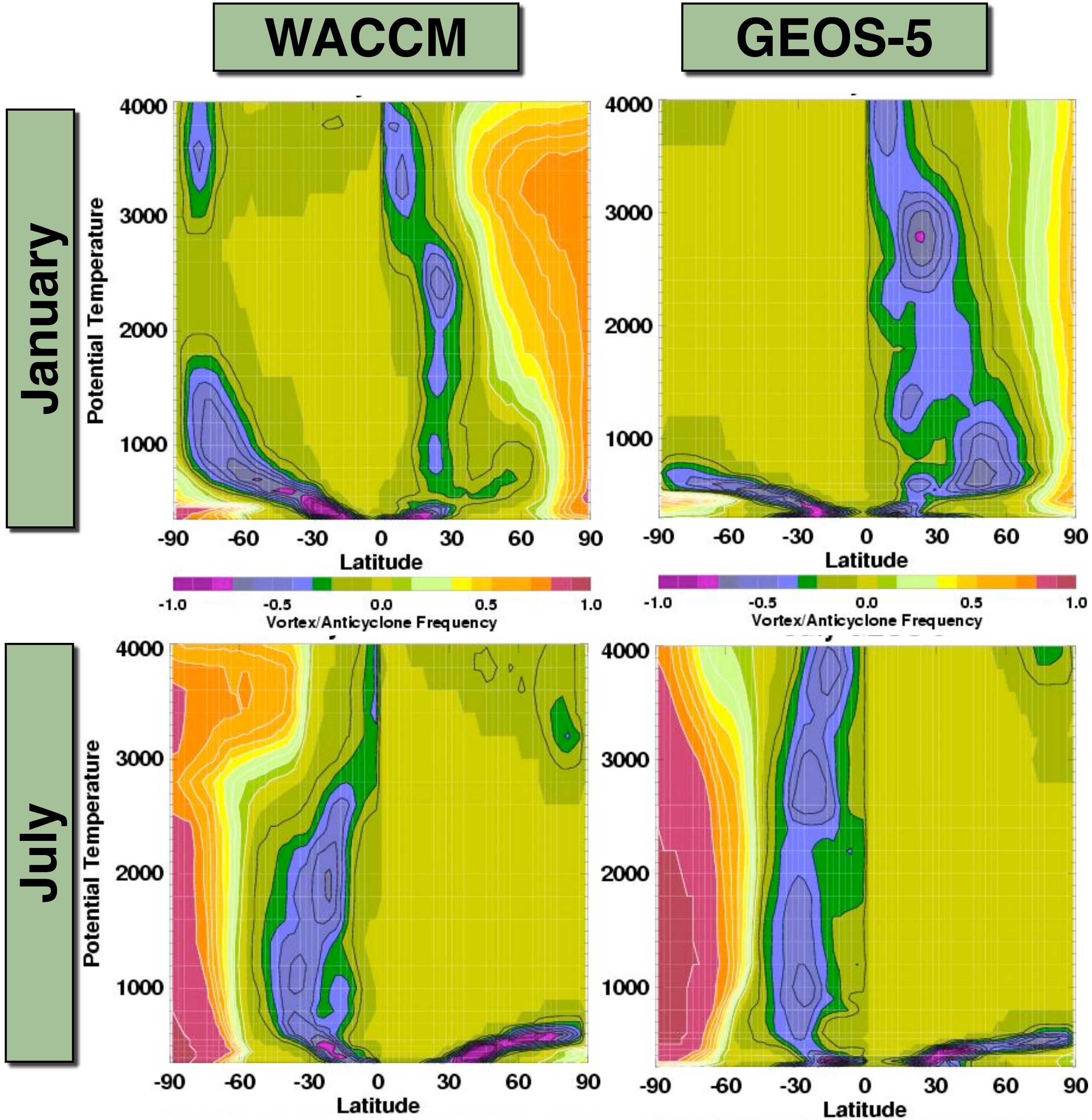
Additional ongoing Toon group studies:

- WACCM/CARMA
  - Early Earth hazes
- CAM/CARMA
  - Tropospheric dust
  - Sea salt
  - Titan
  - Mars
  - Subvisible cirrus

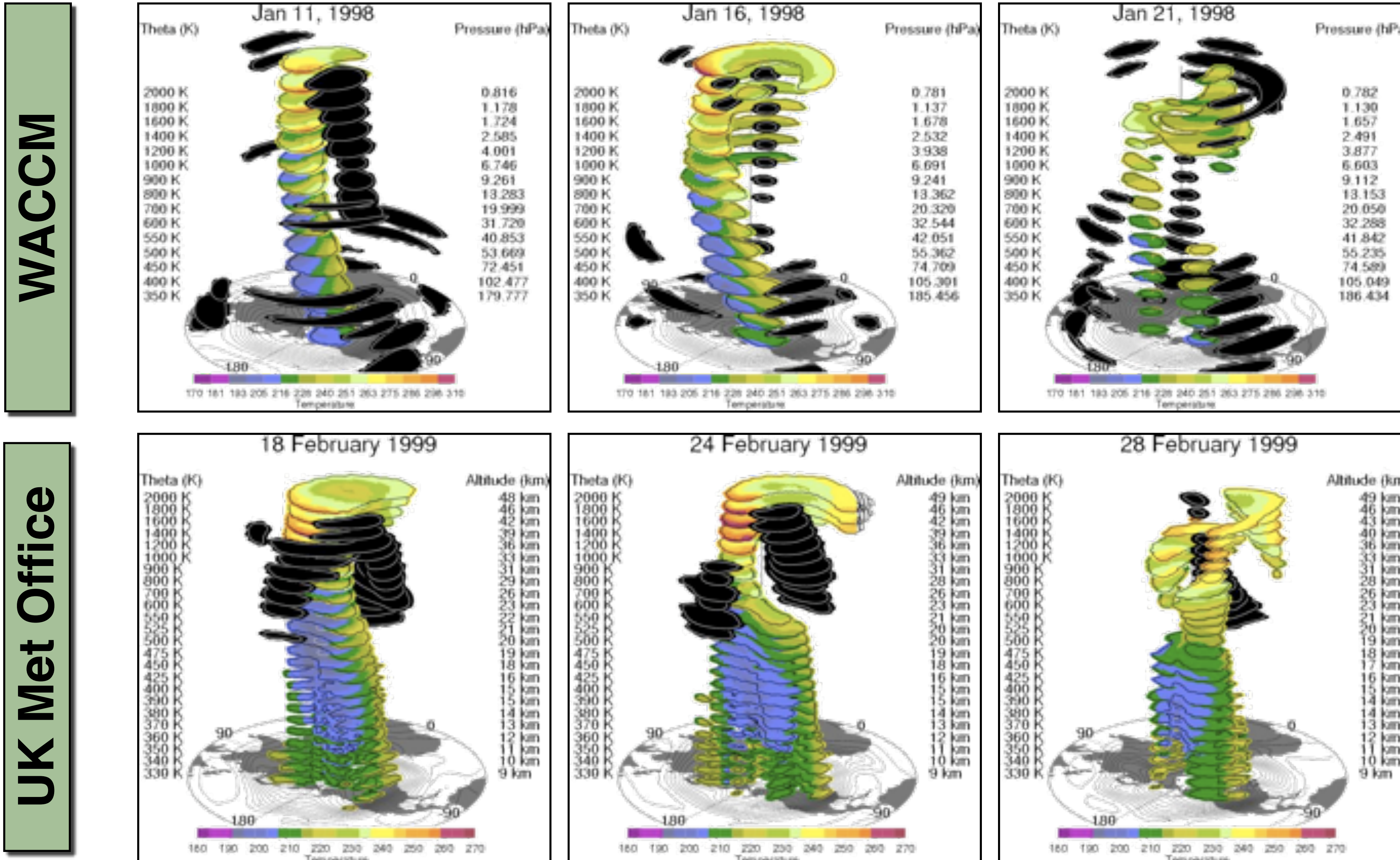
WACCM compared to meteorological data

Polar vortex dynamics & sudden stratospheric warmings (L. Harvey)
Cold-air outbreaks (D. Wheeler)

Zonal Mean Vortex and Anticyclone Frequencies

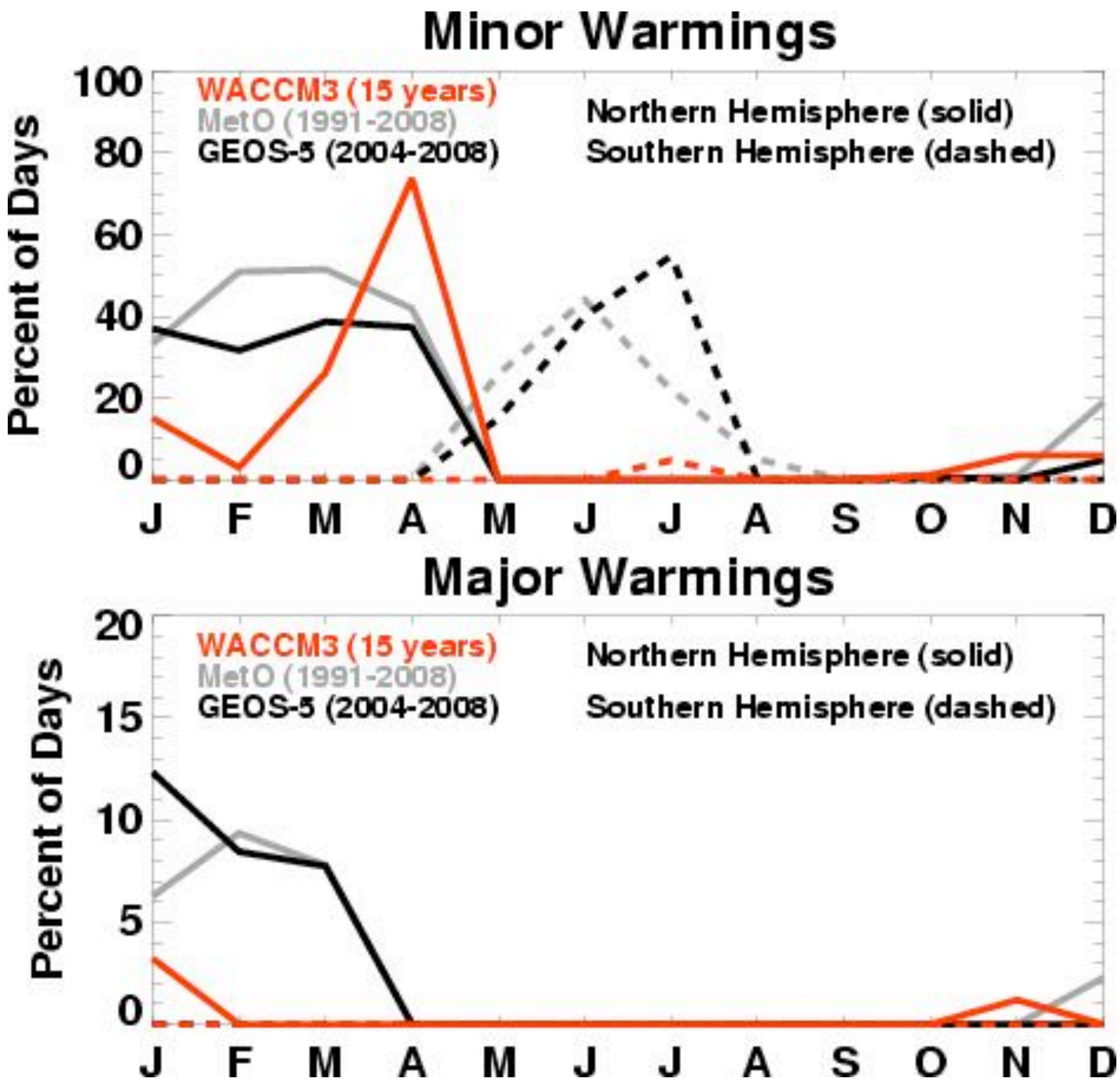


WACCM Simulation of Strat Warming is Reasonable



Courtesy of L. Harvey

10 hPa Strat Warming Diagnostics



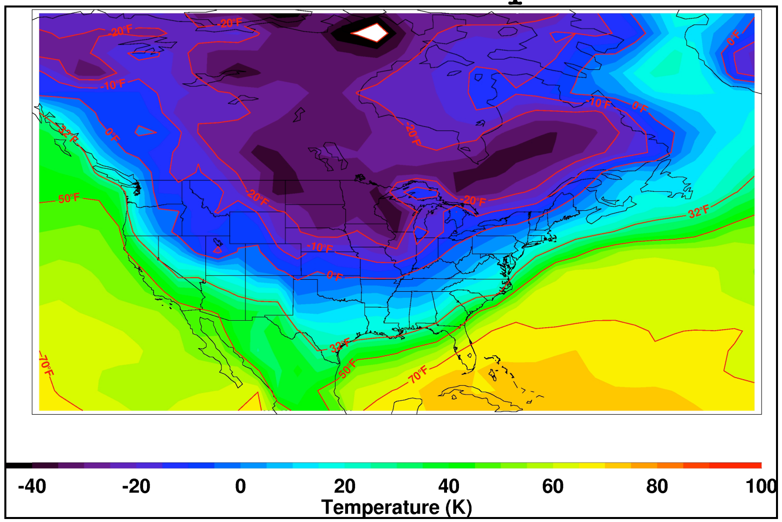
WACCM3
15 years,
MetO 1991-2008,
GEOS-5 2004-08

WACCM simulates fewer major and minor warmings than the analyses, except in April (final warming).

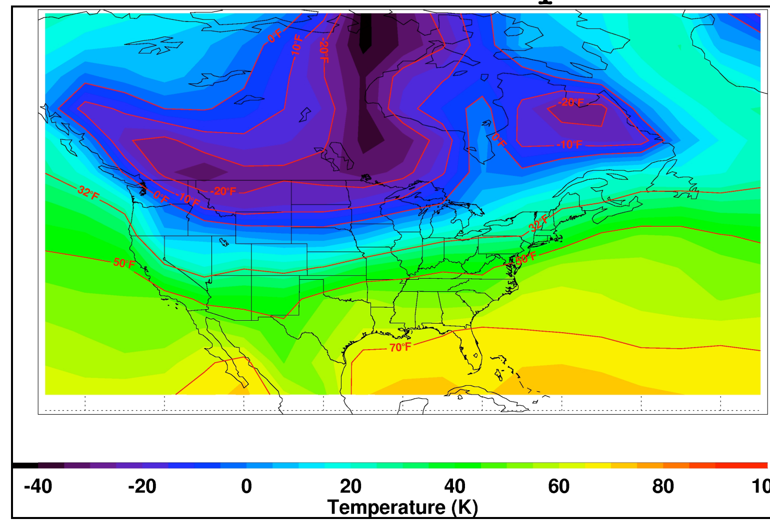
Courtesy of L. Harvey

WACCM and ERA-40 Cold-Air Outbreaks

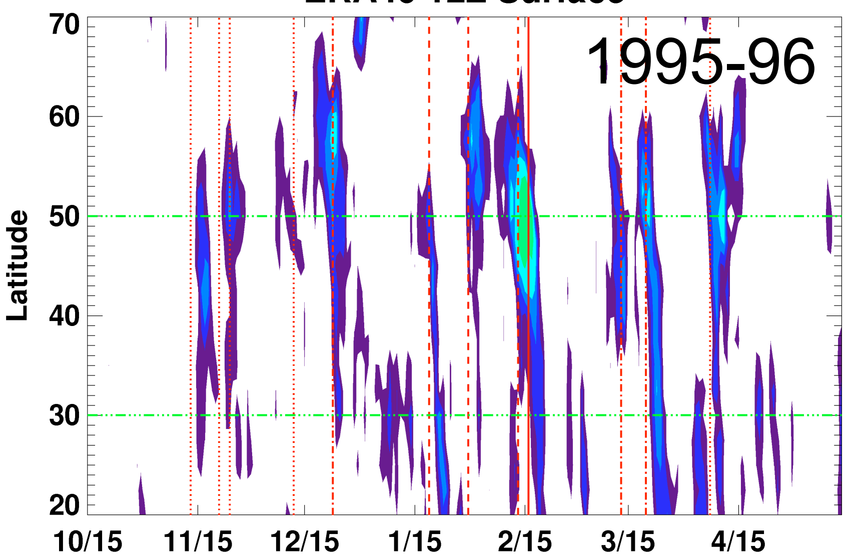
ERA-40 Surface Temperature



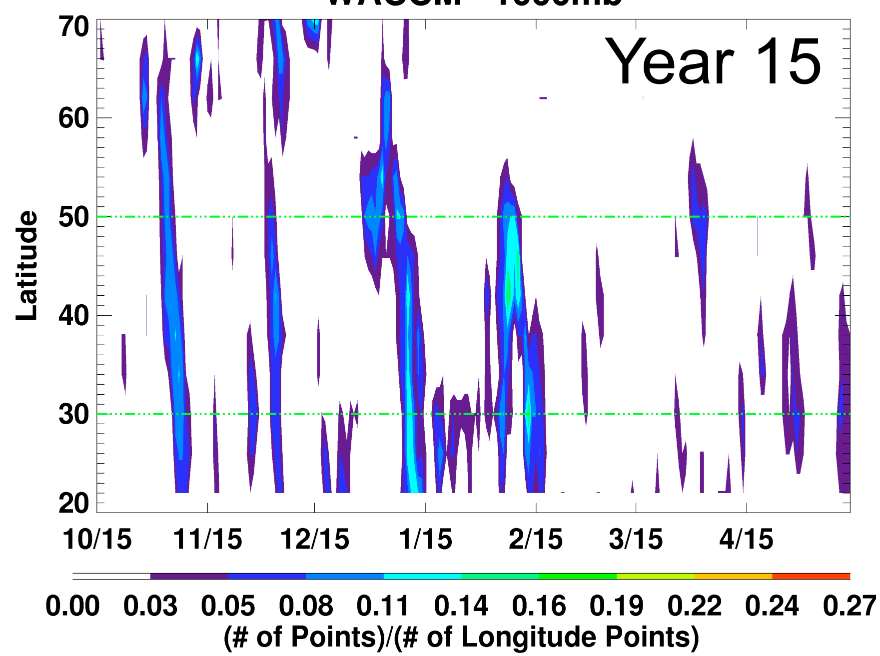
WACCM 1000 hPa Temperature



ERA40 12Z Surface

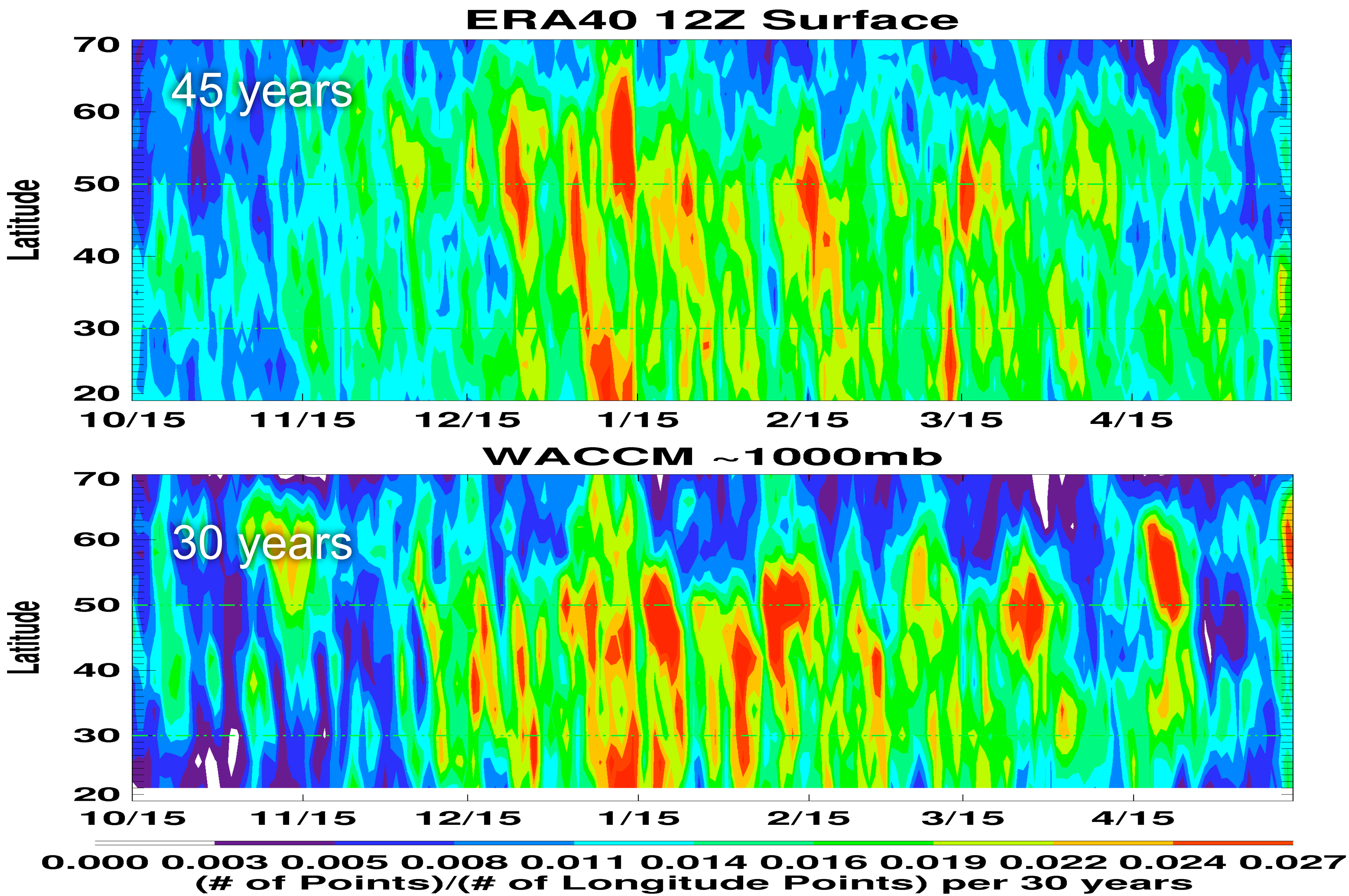


WACCM ~1000mb



Courtesy of D. Wheeler

Cold-Air Outbreak Climatology

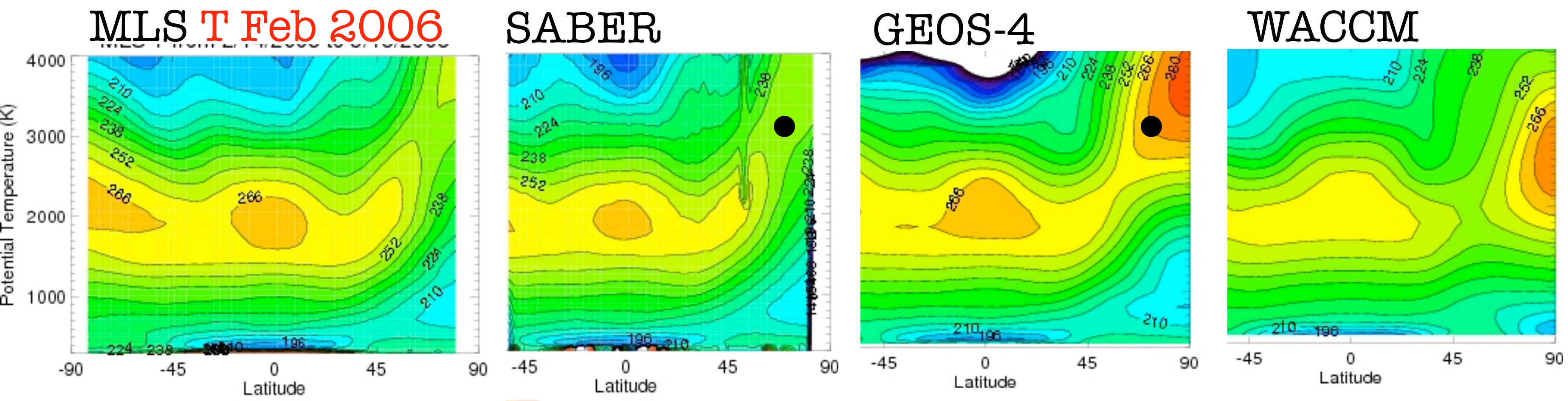


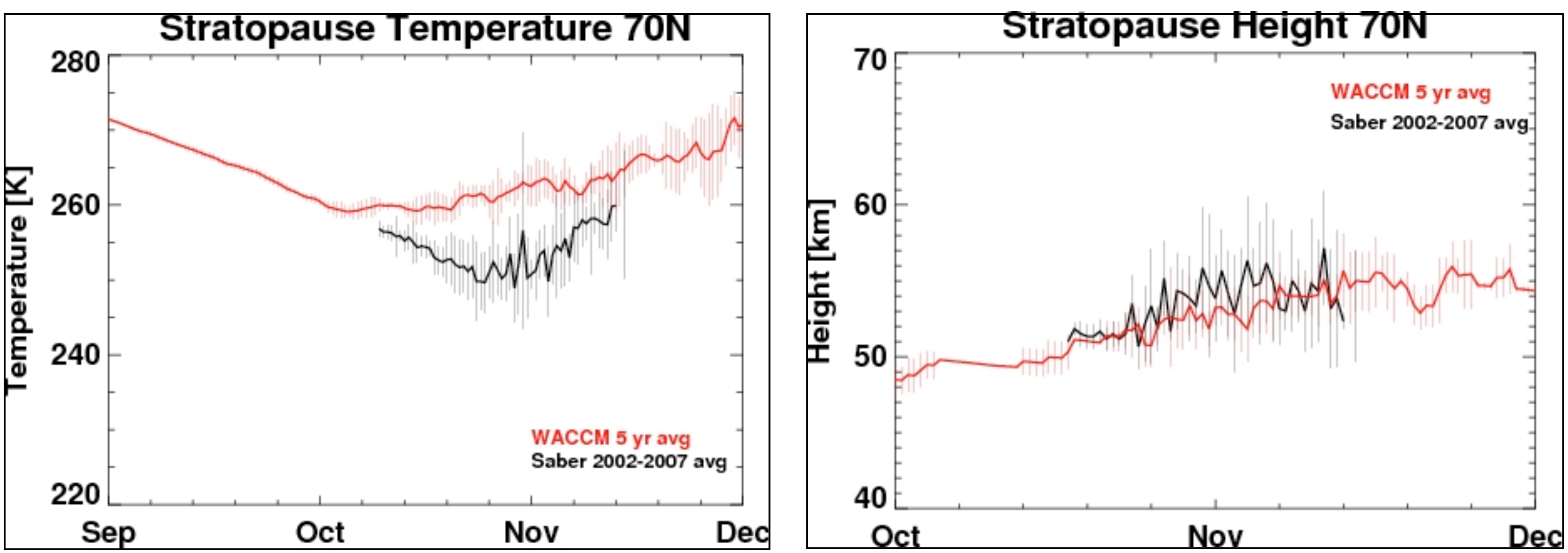
Courtesy of D. Wheeler

WACCM compared to satellite data

SABER & MLS: Stratopause T & Z (J. France, L. Holt)
MLS O_3, N_2O, H_2O & T (M. Brakebusch, S. Benze)

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



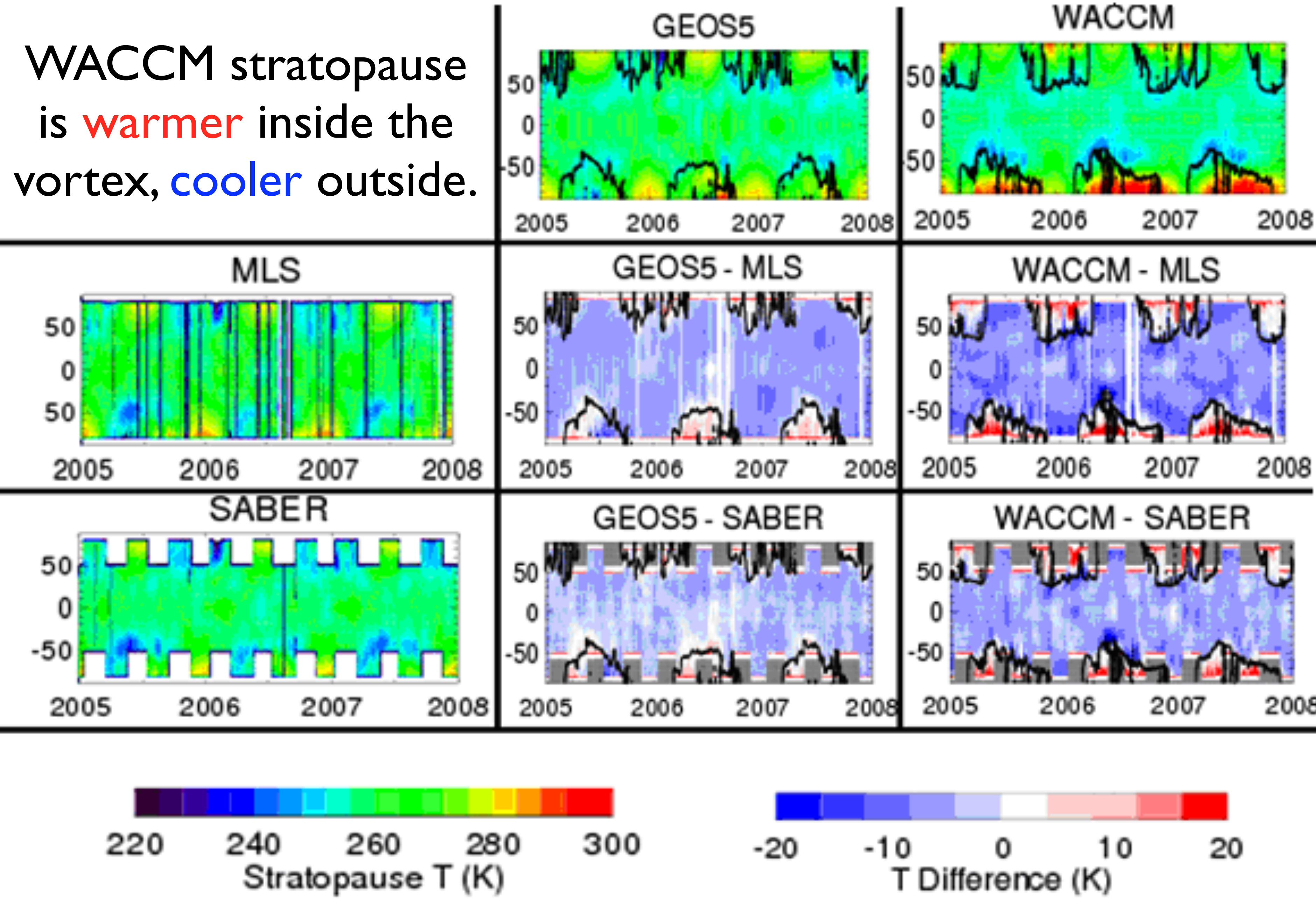


Courtesy of J. France and L. Holt

Latitude-Time Stratopause Temperature from 2005-2008

Courtesy of J. France

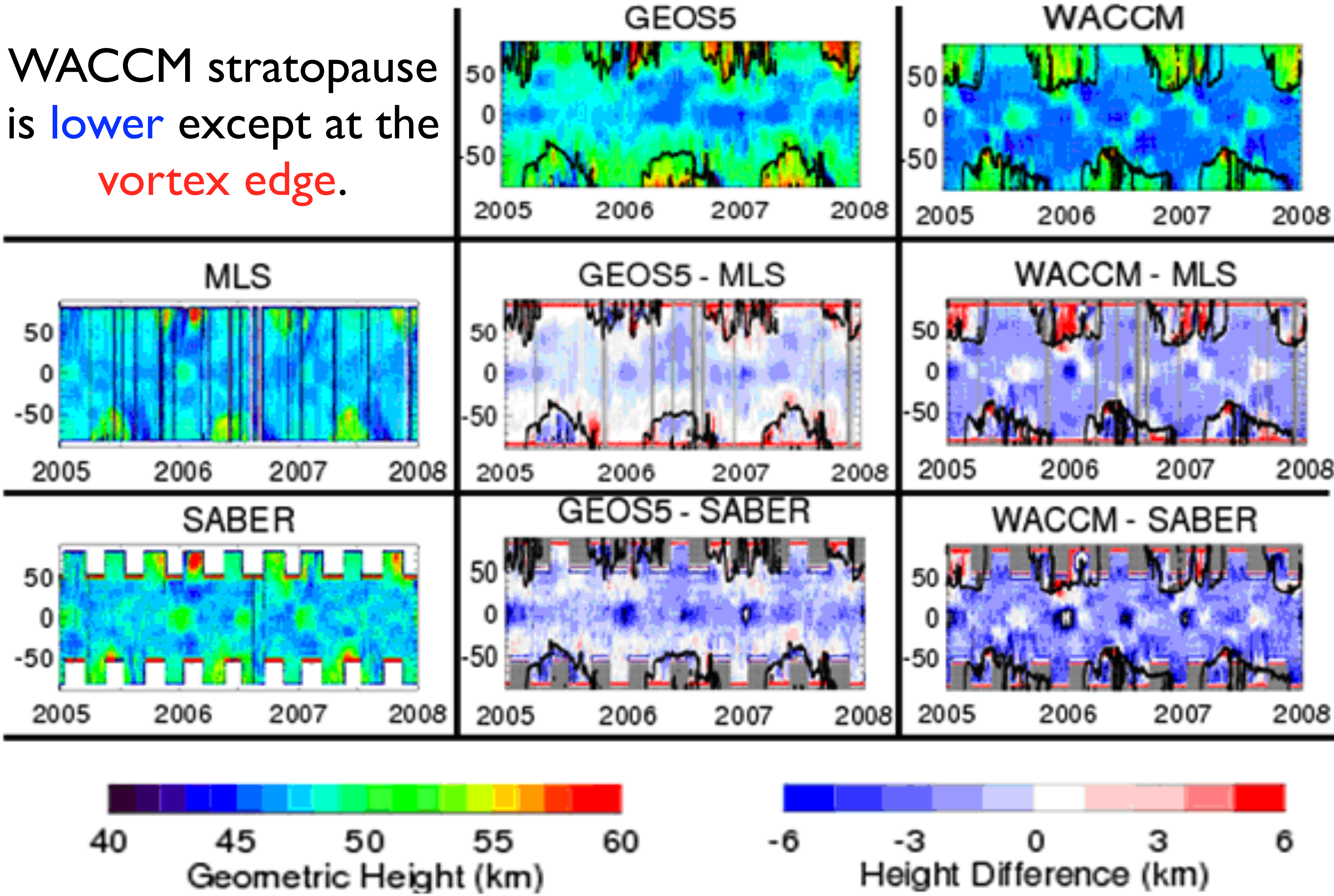
WACCM stratopause is warmer inside the vortex, cooler outside.



Latitude-Time Stratopause Height from 2005-2008

Courtesy of J. France

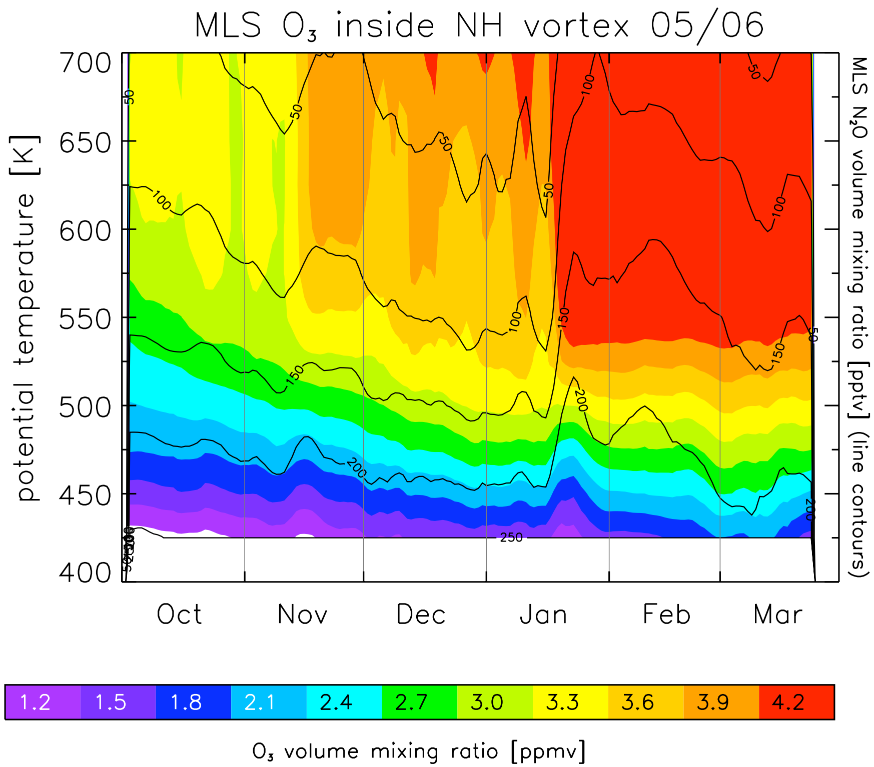
WACCM stratopause is lower except at the vortex edge.

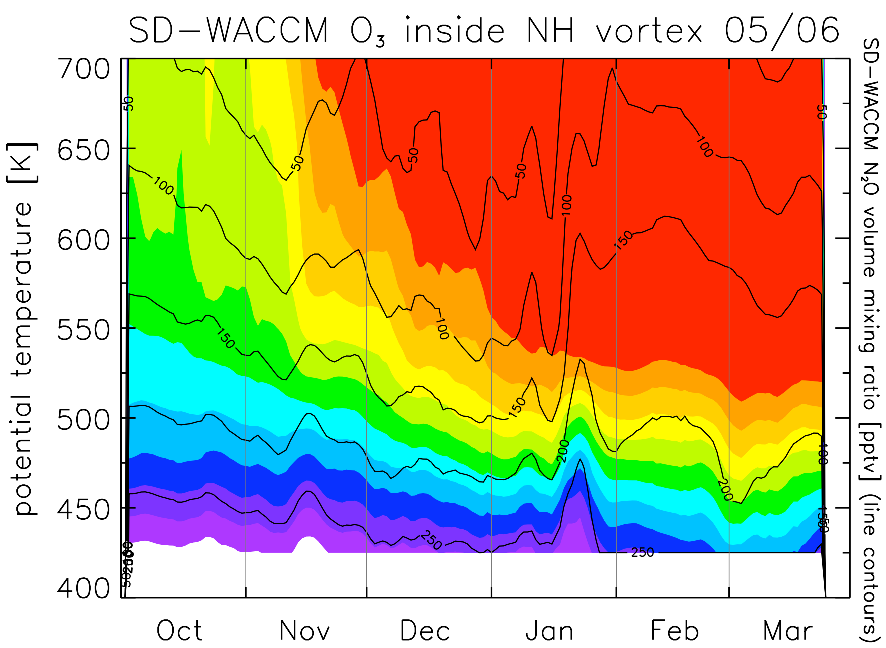


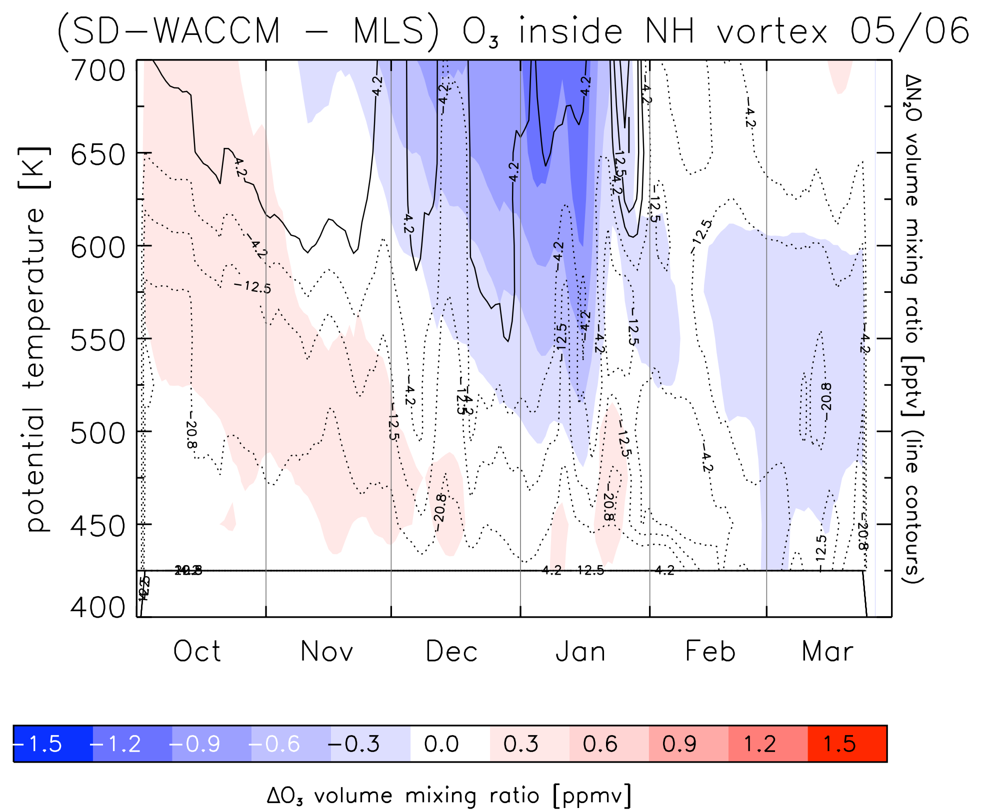
SD-WACCM vs. MLS O_3 & N_2O

Color contours: O_3

Black contours: N_2O

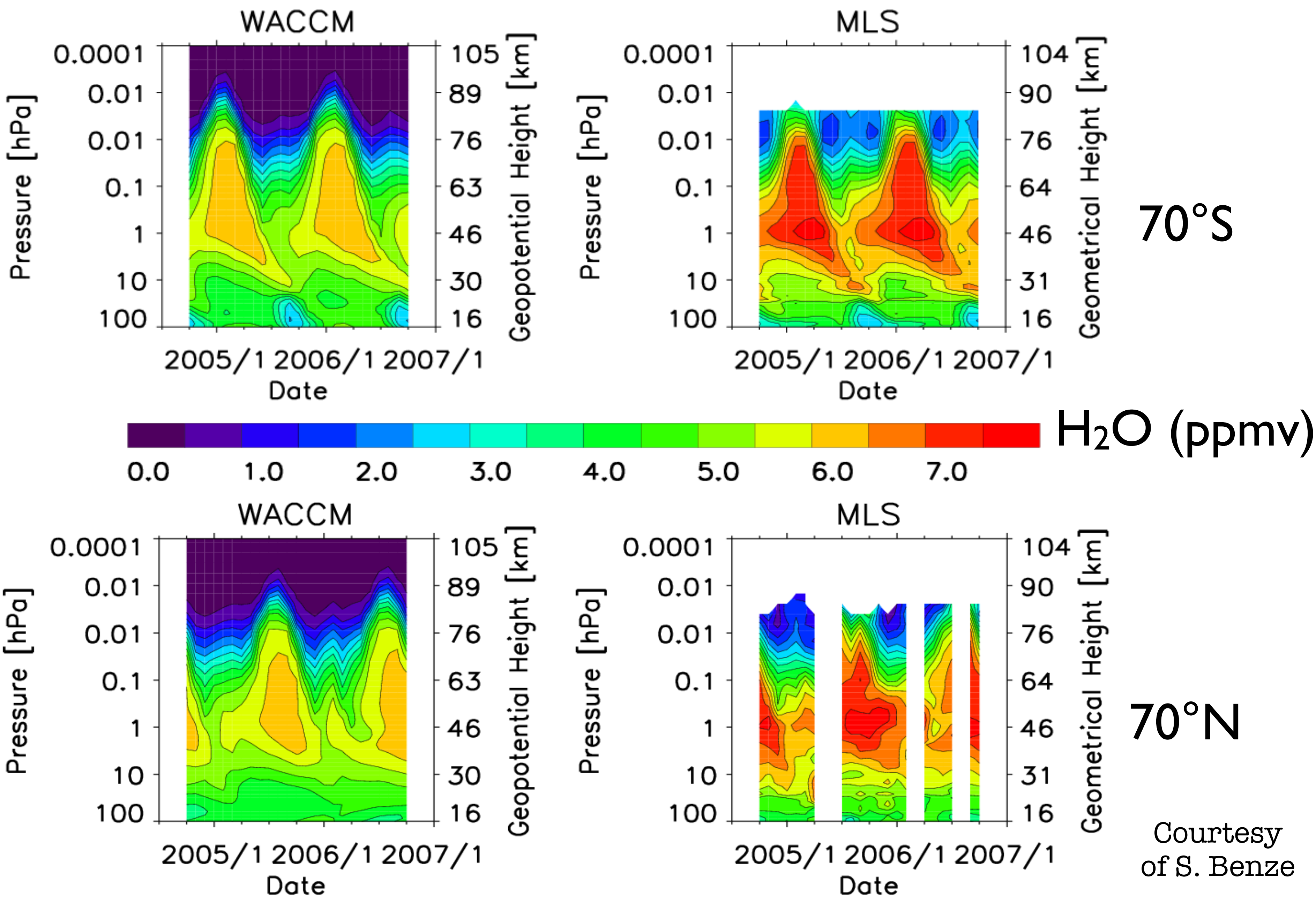






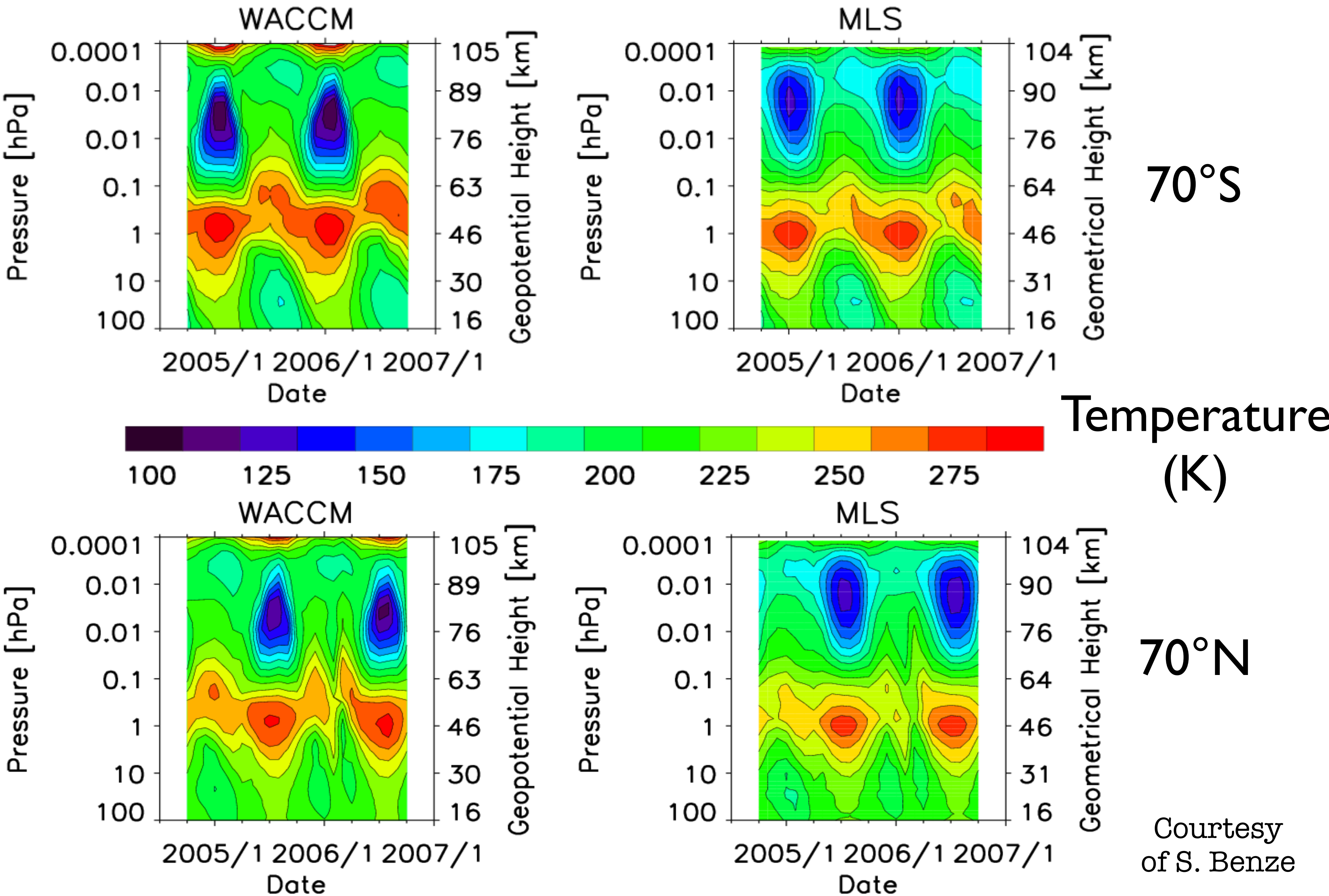
Courtesy of M. Brakebusch

SD-WACCM vs. MLS: H_2O

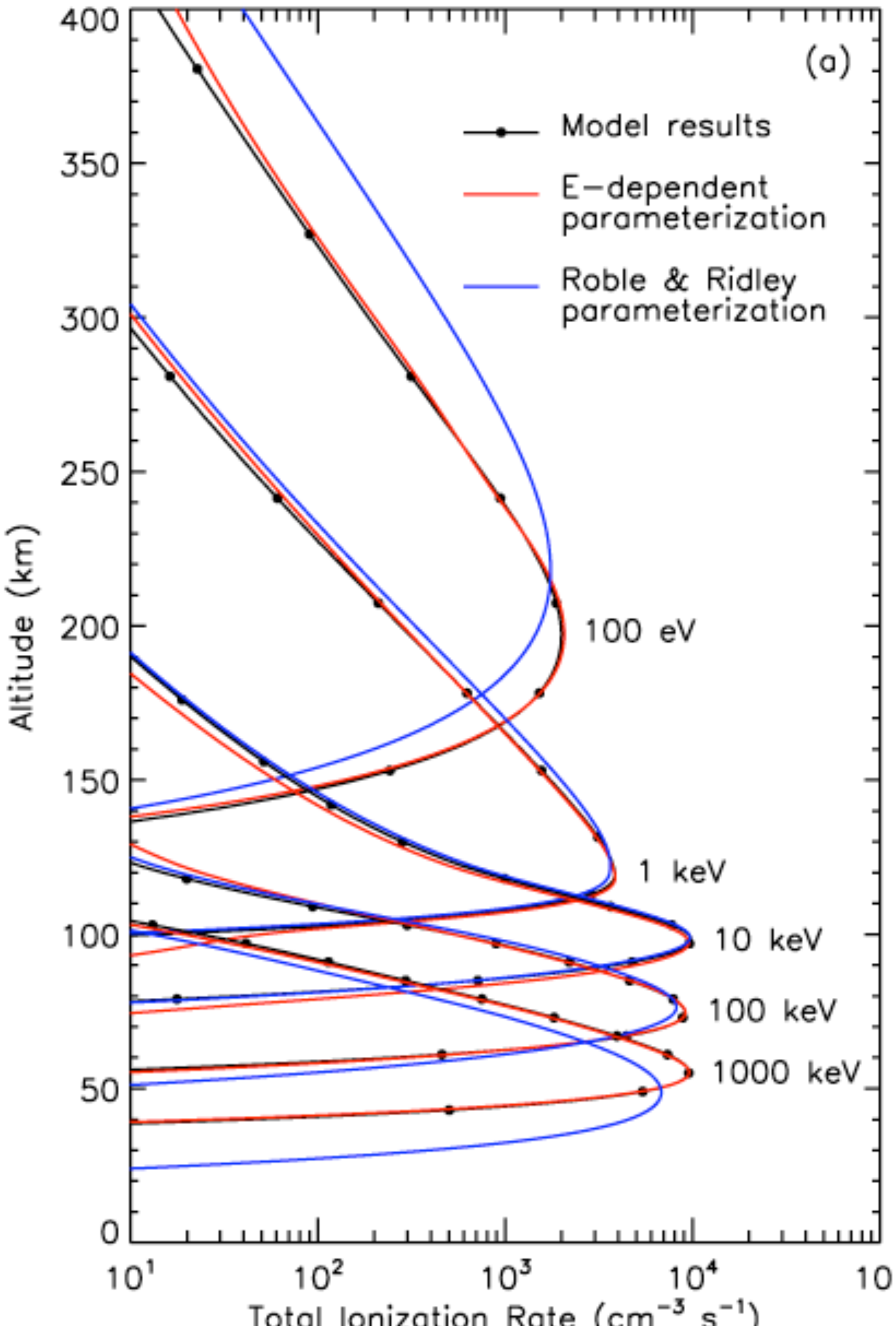


Courtesy of S. Benze

SD-WACCM vs. MLS: Temperature



Courtesy of S. Benze

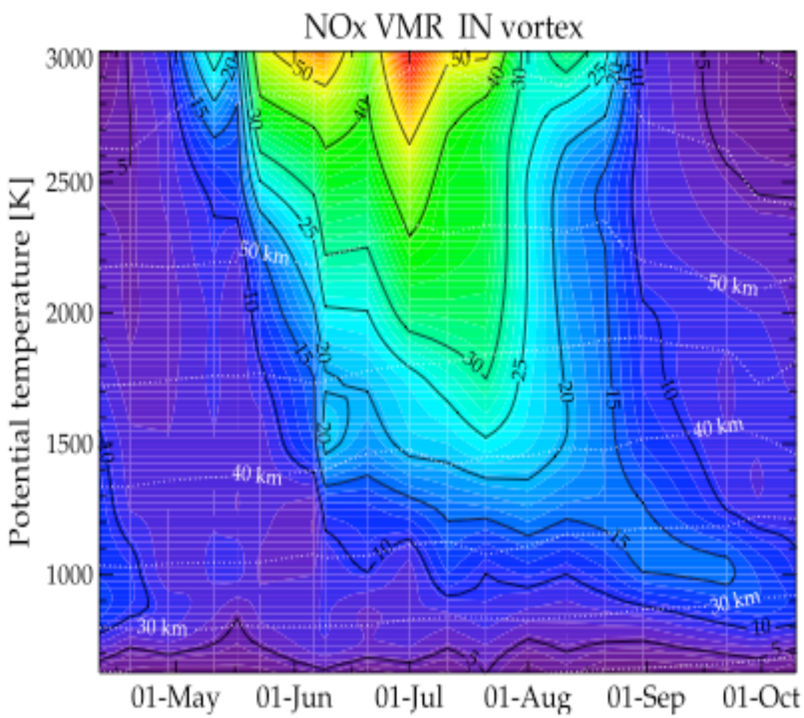


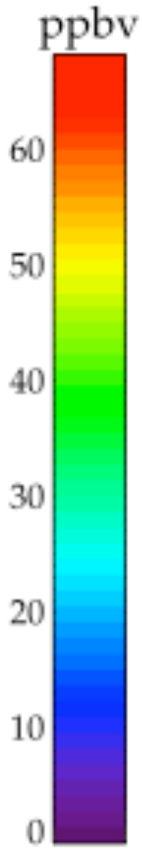
Energetic particle precipitation

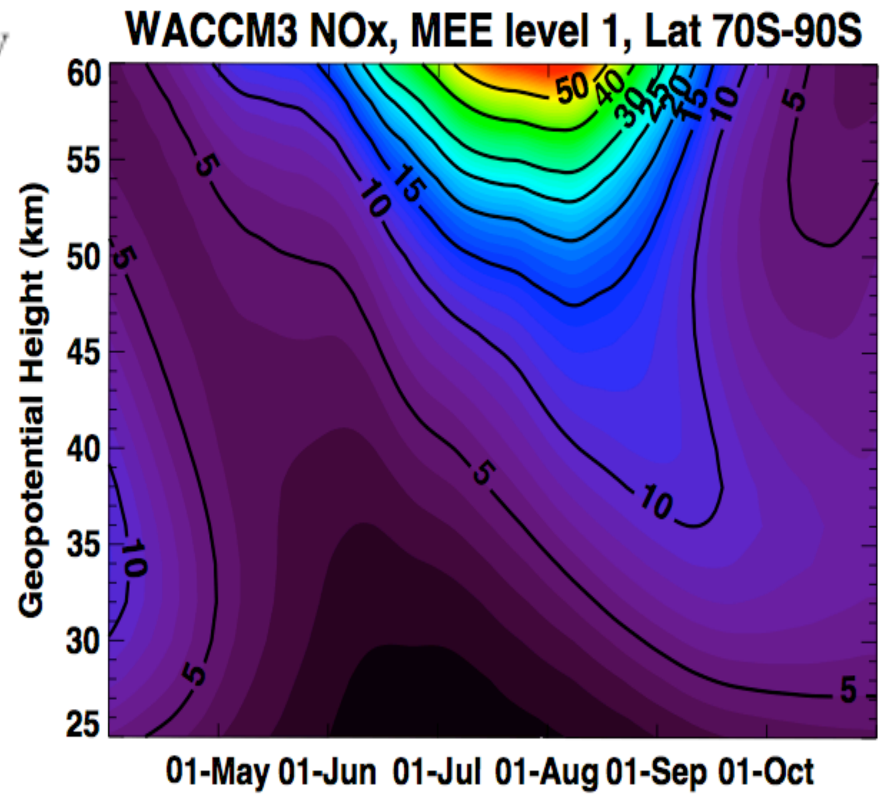
- Ionization: $N_2 \rightarrow NO_x$
- Auroral electrons
  - 1 - 30 kev
- Add medium-energy electrons (MEE)
  - 30 kev - 2.5 Mev

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

NO_x descent with medium-energy electron precipitation





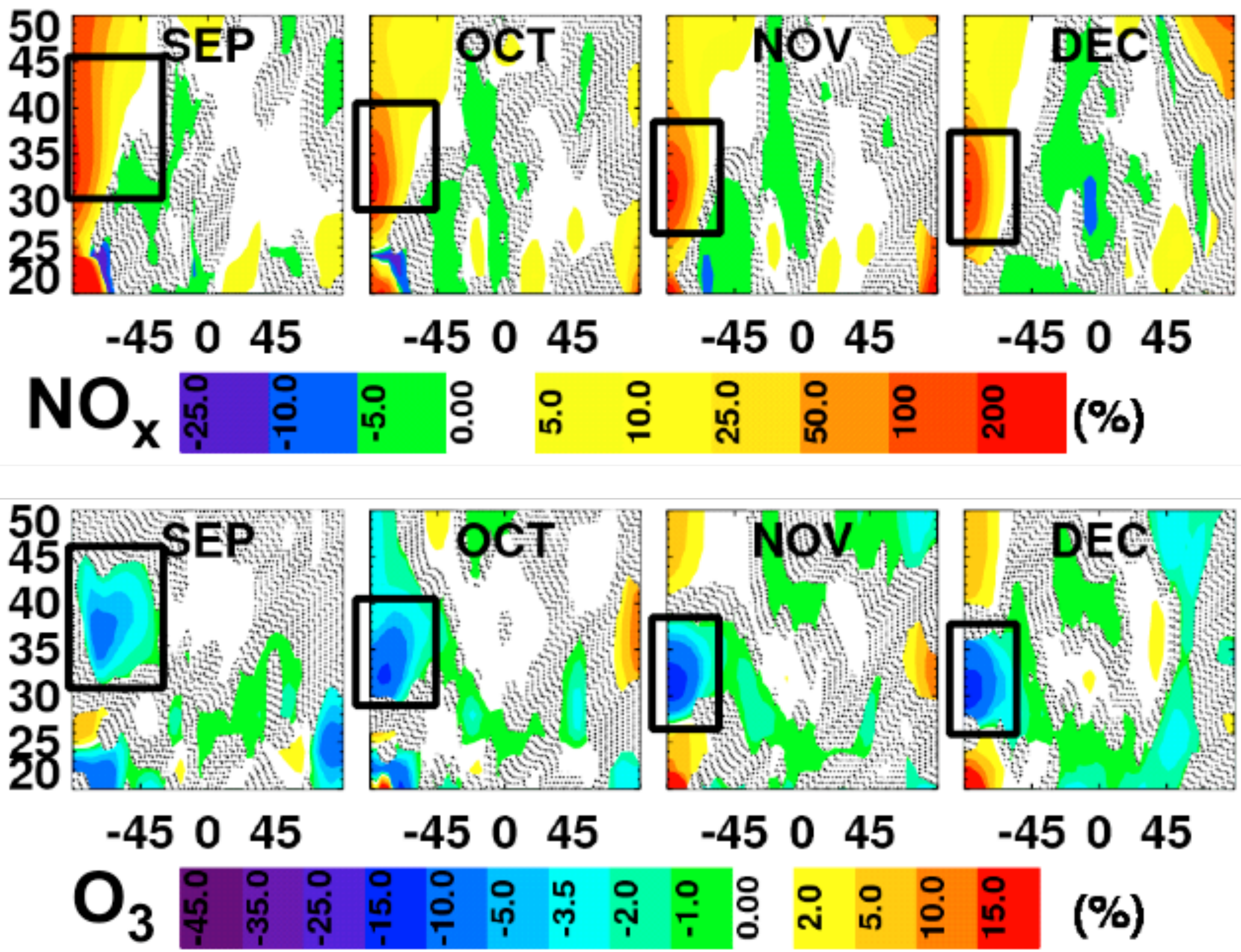


MIPAS, Antarctic Winter 2003

WACCM with MEPED activity level 1

Courtesy of C. Randall

Medium-energy electrons induce O_3 depletion



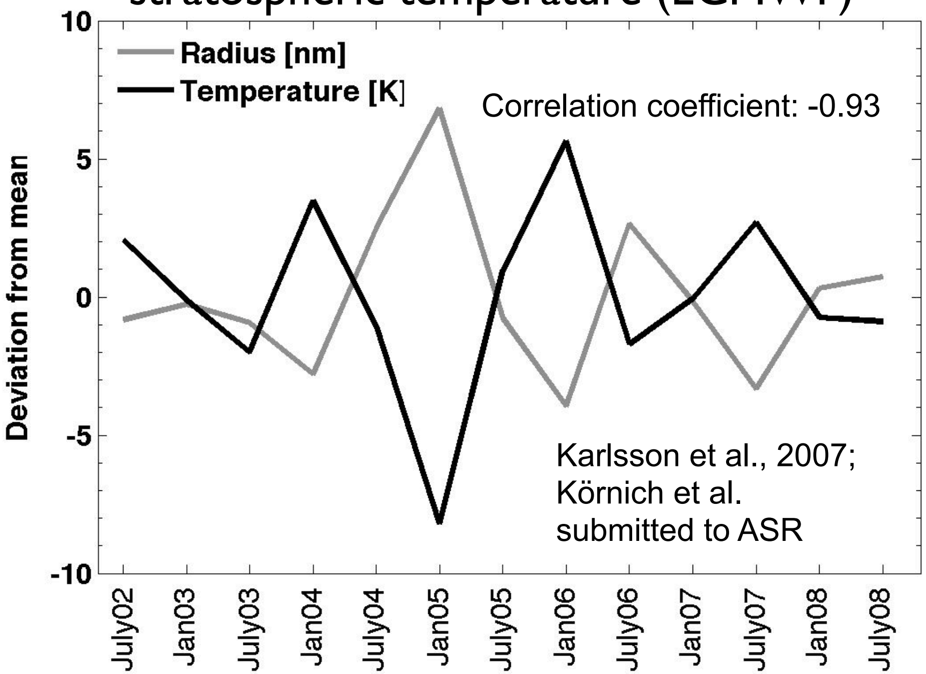
Courtesy of C. Randall

Parameterized Polar Mesospheric Clouds in WACCM

Interhemispheric coupling in WACCM (B. Karlsson)

Interhemispheric Coupling

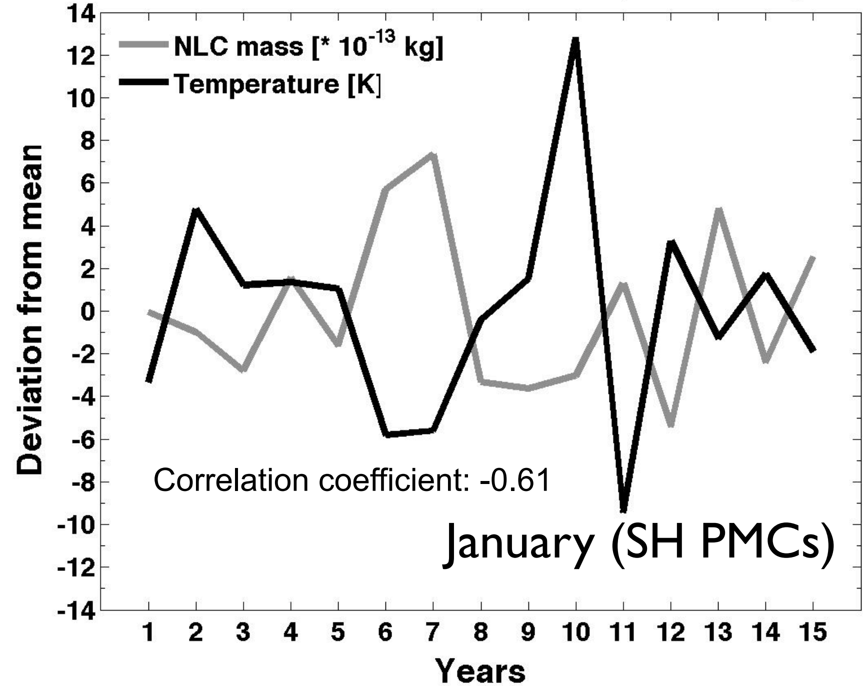
Observed PMC radius (OSIRIS) vs. winter stratospheric temperature (ECMWF)

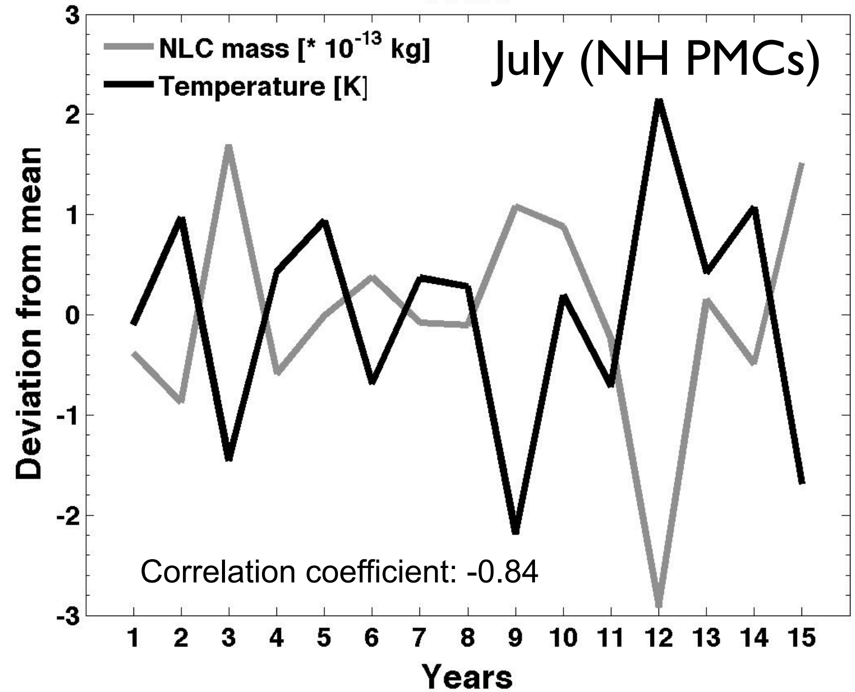


Temperatures averaged 60-90°, 10-100 hPa

Courtesy of B. Karlsson

WACCM PMC mass vs winter stratospheric temperature



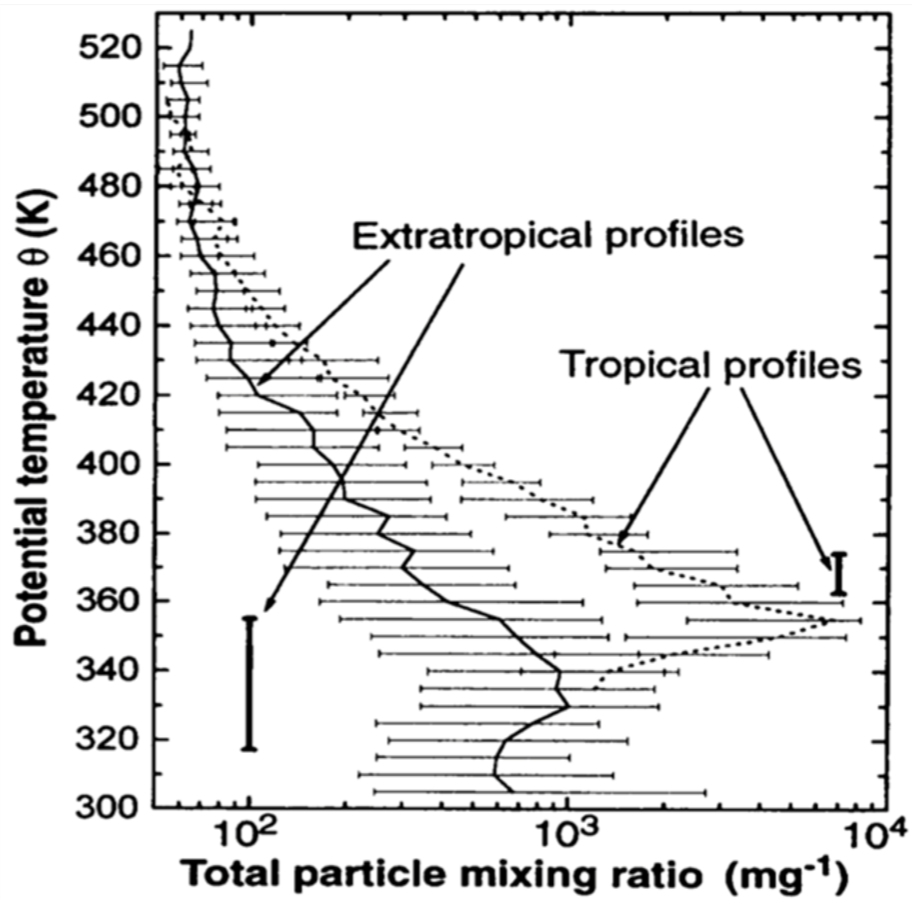


WACCM/CARMA

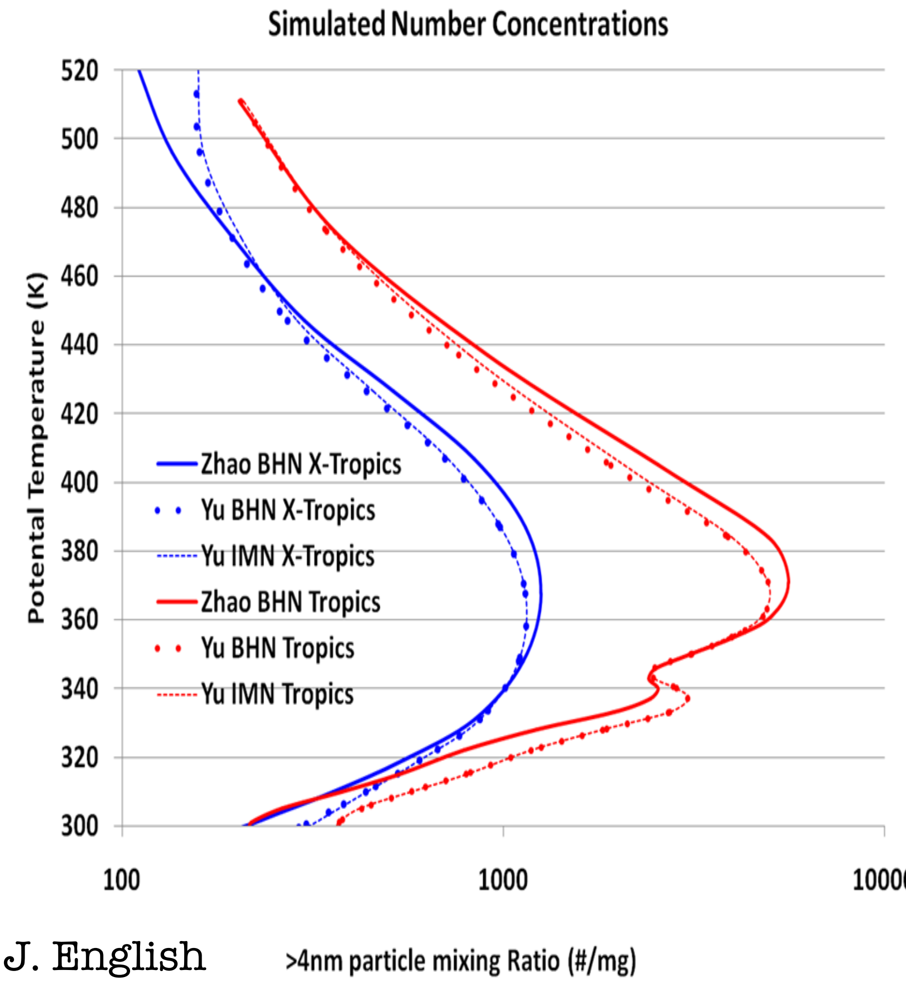
Sulfate nucleation at the tropopause (J. English)
PMCs with dust nuclei (C. Bardeen)
Mesospheric sulfate as PMC nuclei (M. Mills)
Early Earth haze (E. Wolf)

Sulfate nucleation schemes

Observations: Brock *et al.*, 1995

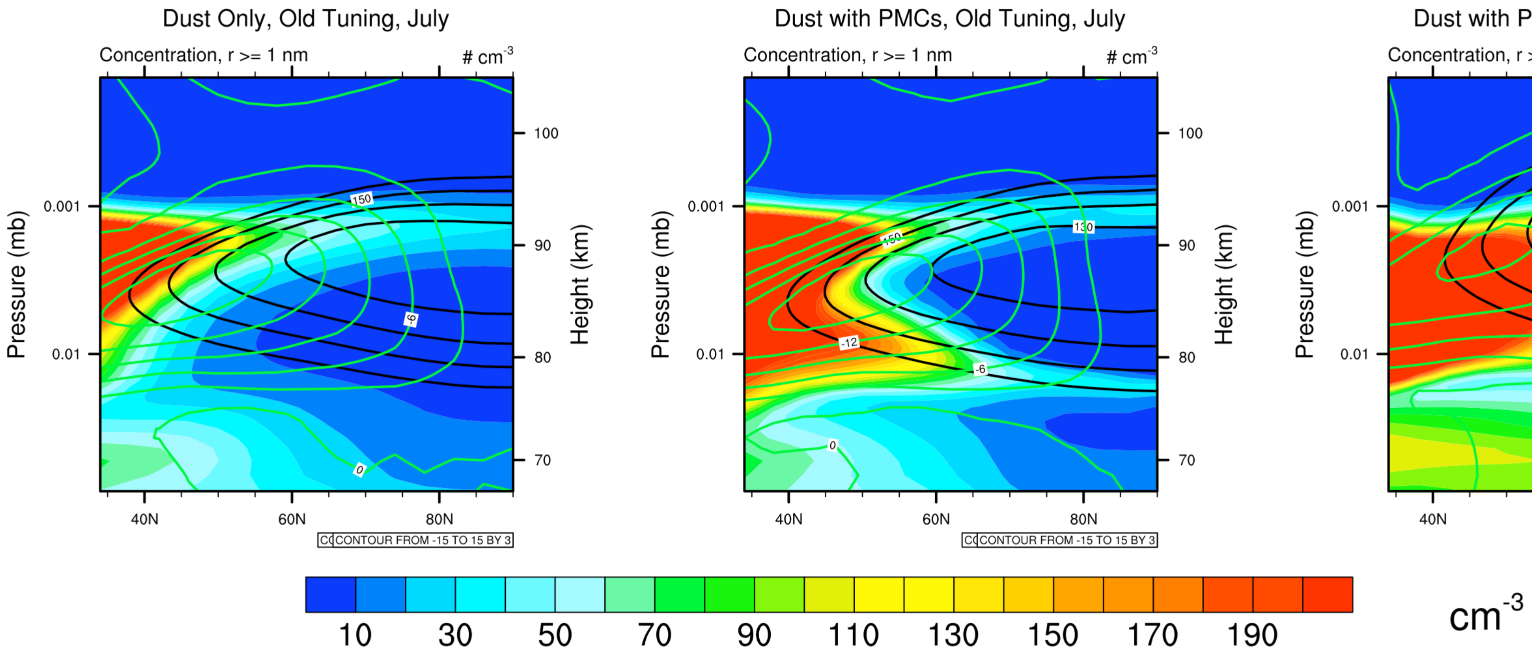


Binary homogeneous nucleation calculation (Zhao) compared to LUTs for BHN and for ion-mediated nucleation (Yu)



Courtesy of J. English

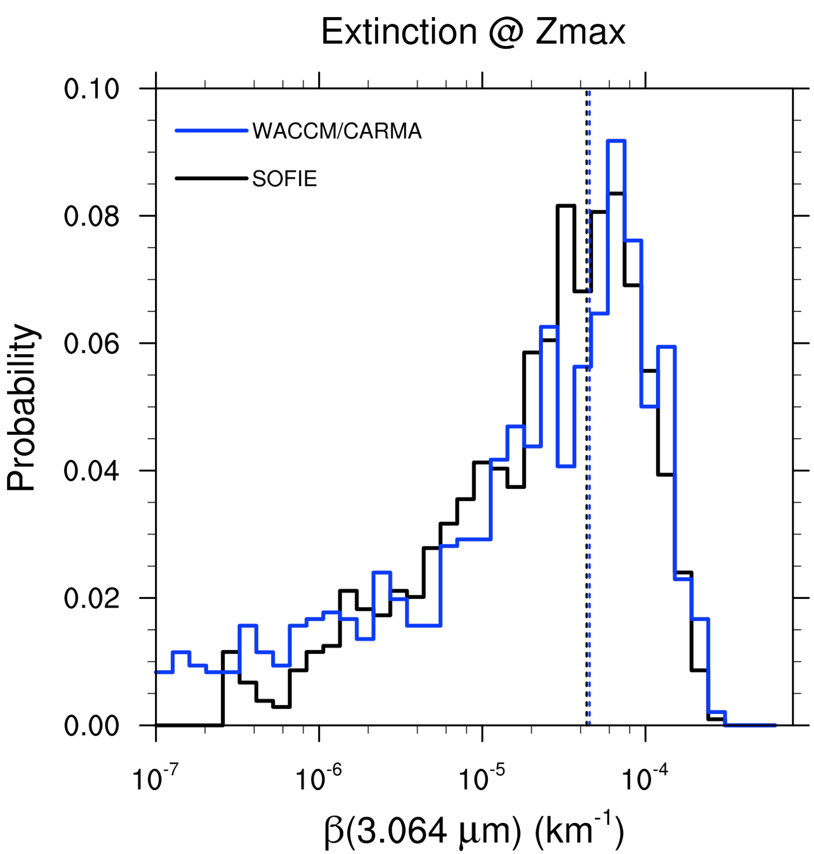
Meteoritic Dust as PMC Nuclei



Dust concentrations highly sensitive to gravity wave tuning.

Courtesy of C. Bardeen

WACCM/CARMA PMC statistics compared to SOFIE observations



Courtesy of C. Bardeen

Summary

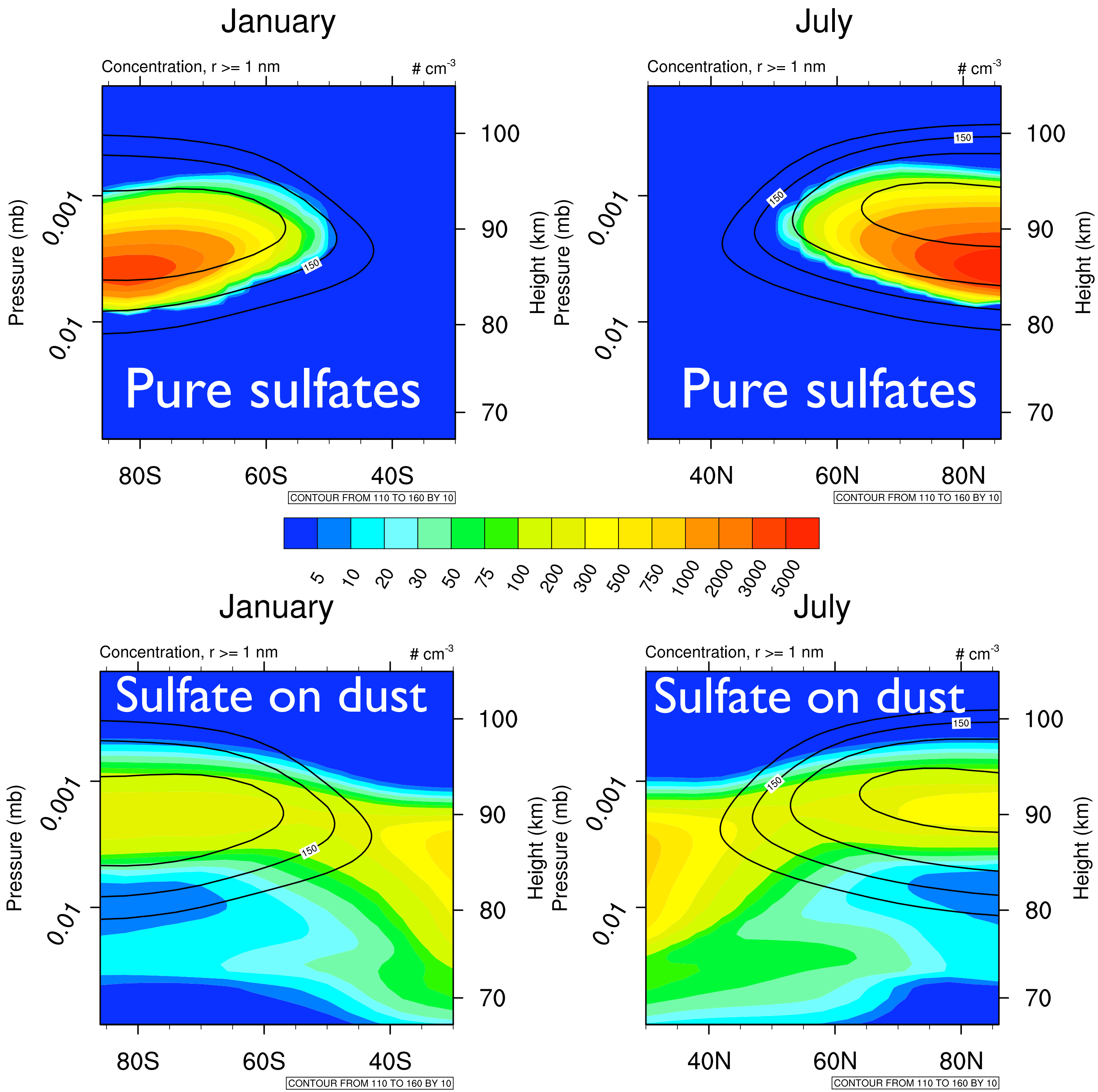
	SOFIE v1.01		WACCM/CARMA	
Events	1432		1432	
Clouds	1130	78.9%	959	66.9%
Zmax < 79 km	88	6.2%	0	0.00%

Seasonal Mean

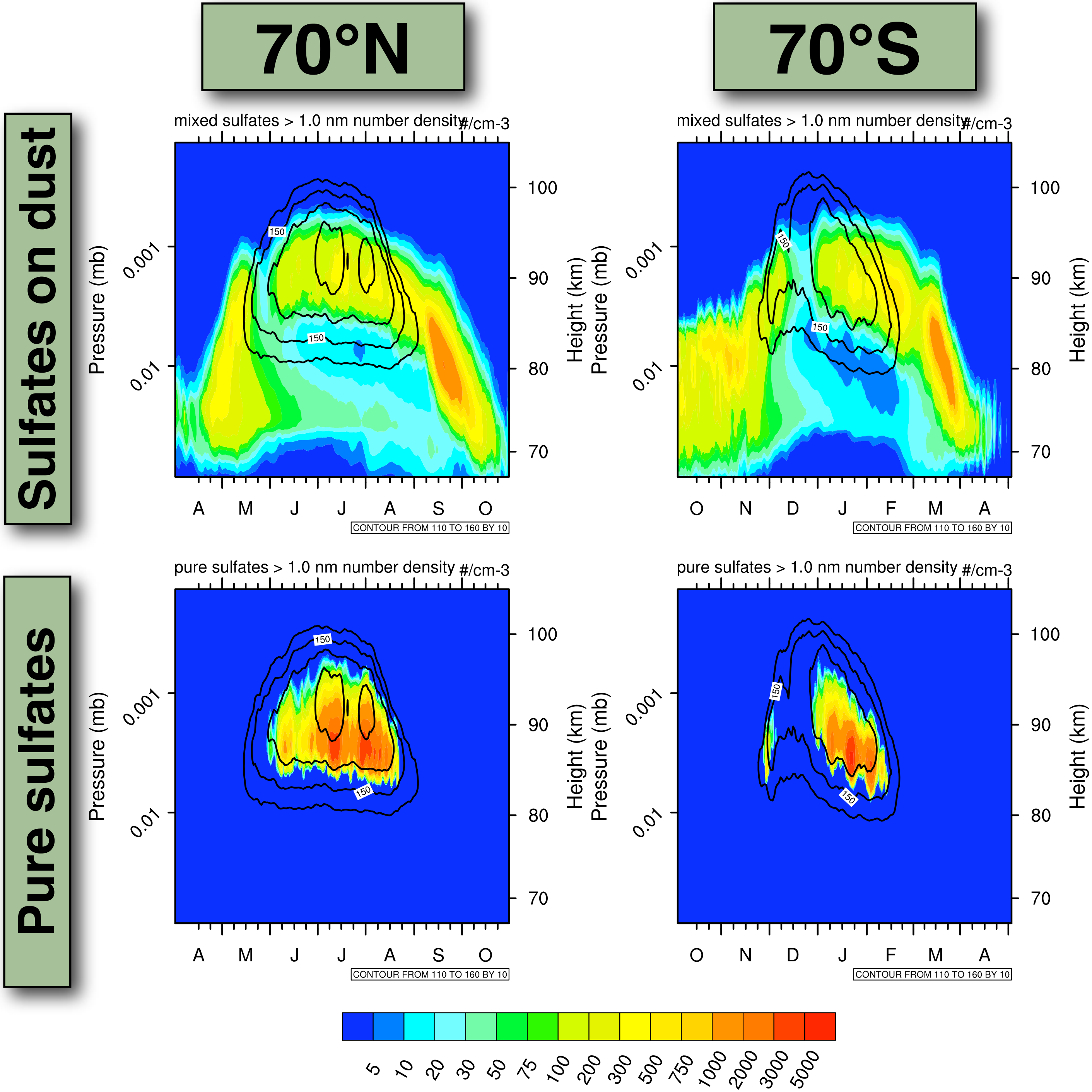
	Units	SOFIE	WACCM	Difference
Height	km	83.53	83.26	-0.27 km
Base	km	80.16	80.78	0.62 km
Top	km	87.01	87.69	0.68 km
Thickness	km	6.85	6.92	0.96%
Column IWC	$ug\ m^{-2}$	36.65	30.32	-17.26%
B(3.064)	km^{-1}	4.36E-05	4.54E-05	4.18%
Re	nm	35.68	42.43	18.91%
Mass	$ng\ m^{-3}$	13.45	13.68	1.69%
Number	cm^{-3}	406.68	75.95	-81.33%
Water Vapor	ppmv	4.35	4.90	12.53%

Sulfate as PMC nuclei

Hundreds to thousands per cm^3 available nuclei



Mesospheric sulfate seasonality



WACCM4/CARMA

- Better WACCM integration
  - Supports Open/MP and Hybrid Modes
  - Handles Restarts Properly
  - Integrated with Radiation Code (RRTMG)

- New Version of CARMA
  - Fortran 90
  - Thread Safe
  - Globally Adjusted Kernels & Coefficients
  - Improved Substepping (No Crashing)

Courtesy of C. Bardeen

WACCM, CAM & CARMA at LASP

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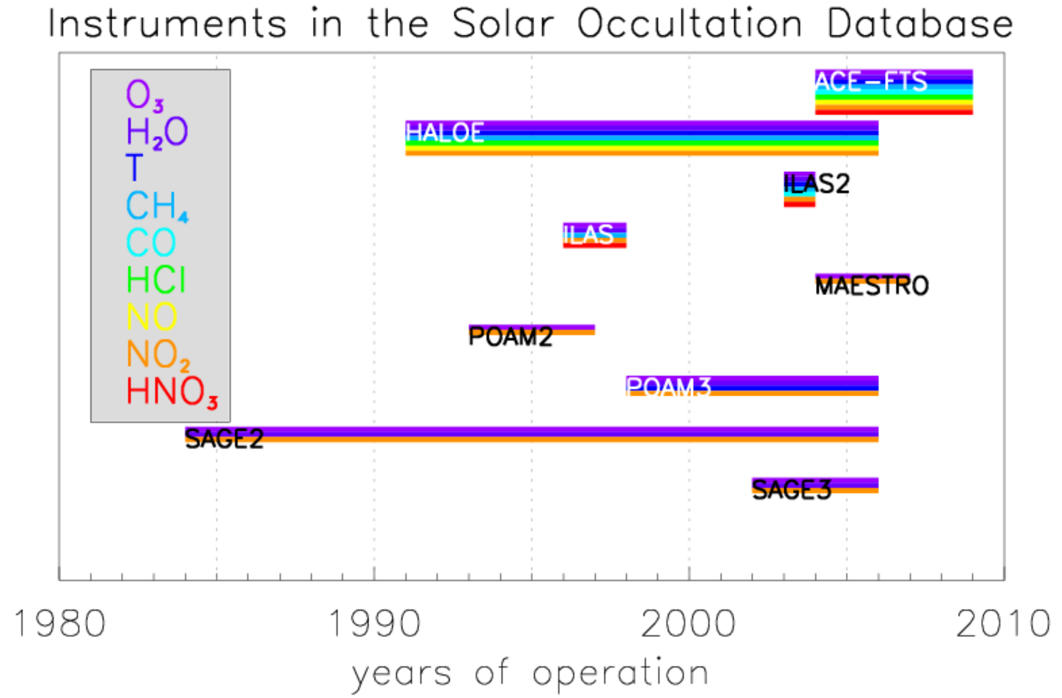
  - Sea salt
  - Titan
  - Mars
  - Subvisible cirrus

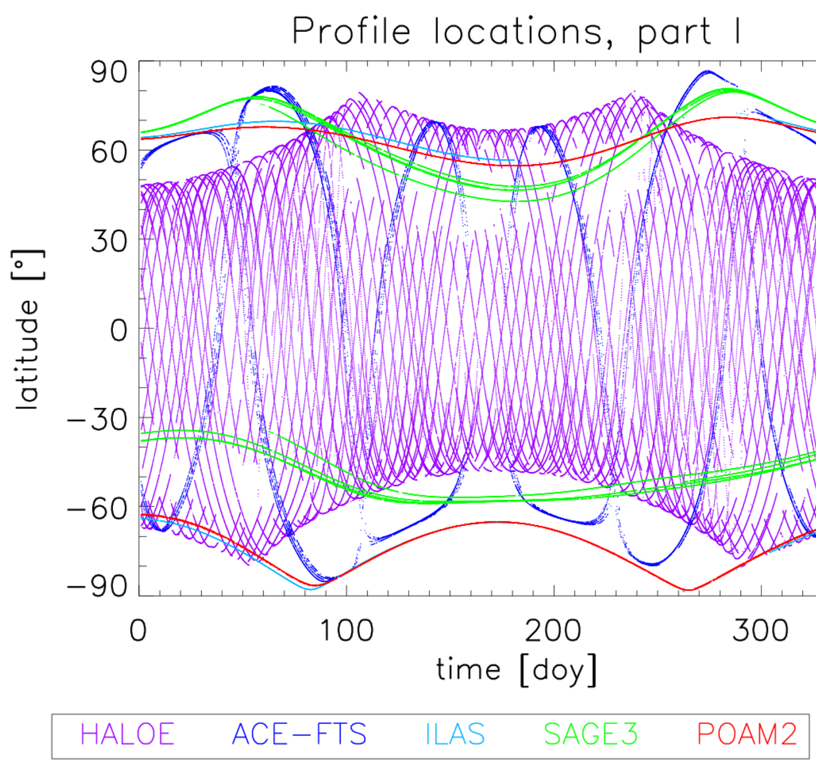
Solar Occultation Database

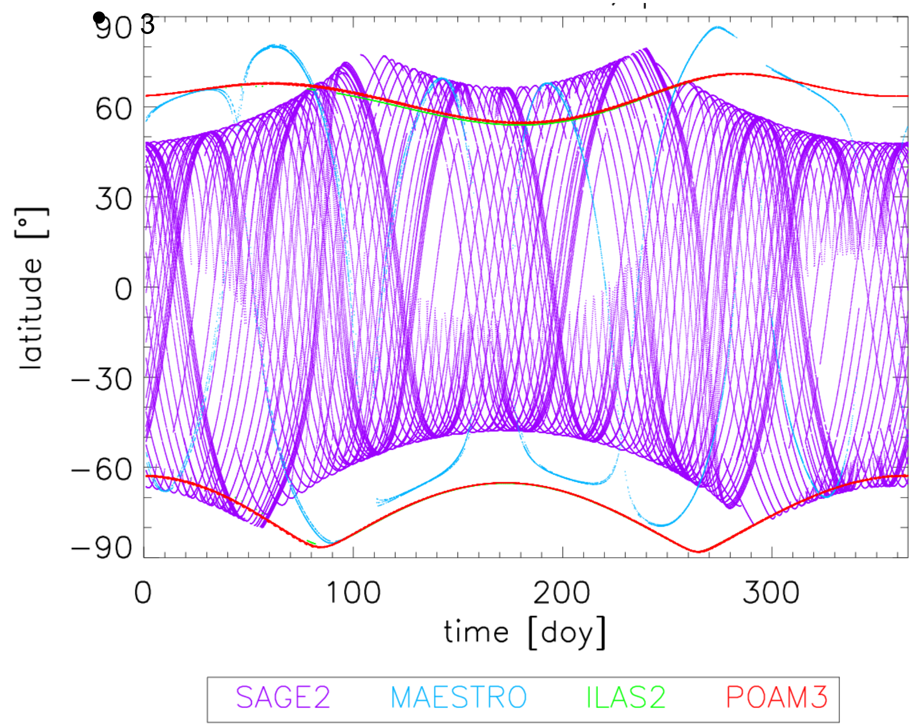
10 satellite instruments

Currently operating:
MAESTRO, ACE-FTS & SOFIE

Courtesy of M. Brakebusch



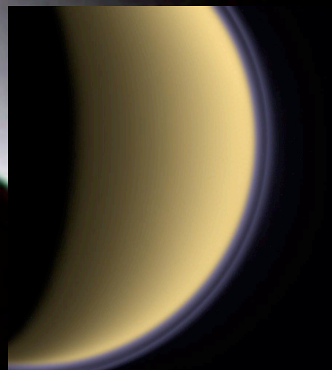




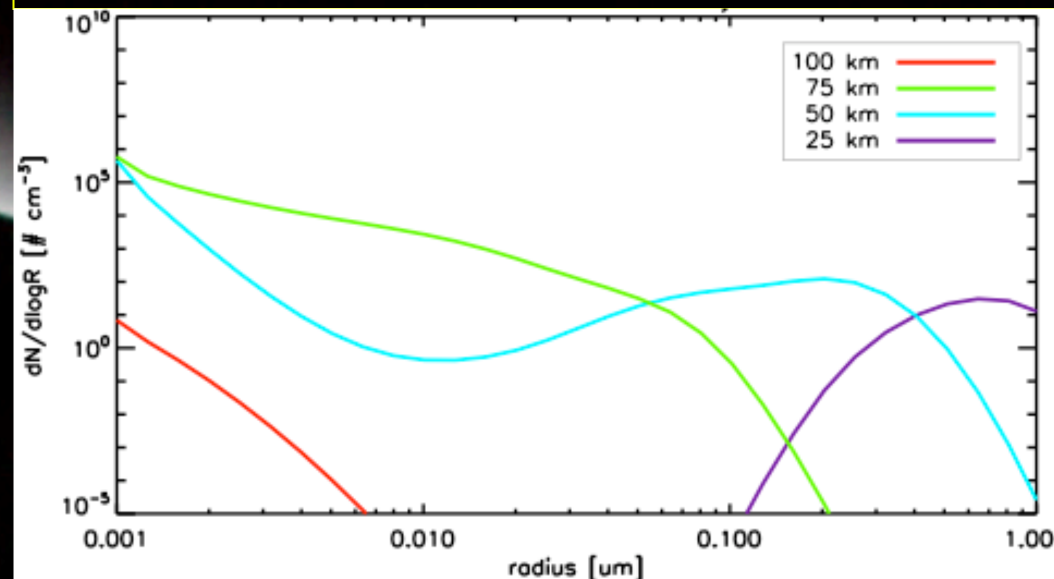
Modeling Early Earth Organic Hazes Using WACCM/CARMA

Eric Wolf
University of Colorado

A Titan-like organic haze layer covered the young Earth.



Particle size distributions for early Earth organic hazes at various altitudes derived from WACCM/CARMA.



RESULTS:

Thicker hazes will cause anti-greenhouse cooling.

- UV shielding minimal

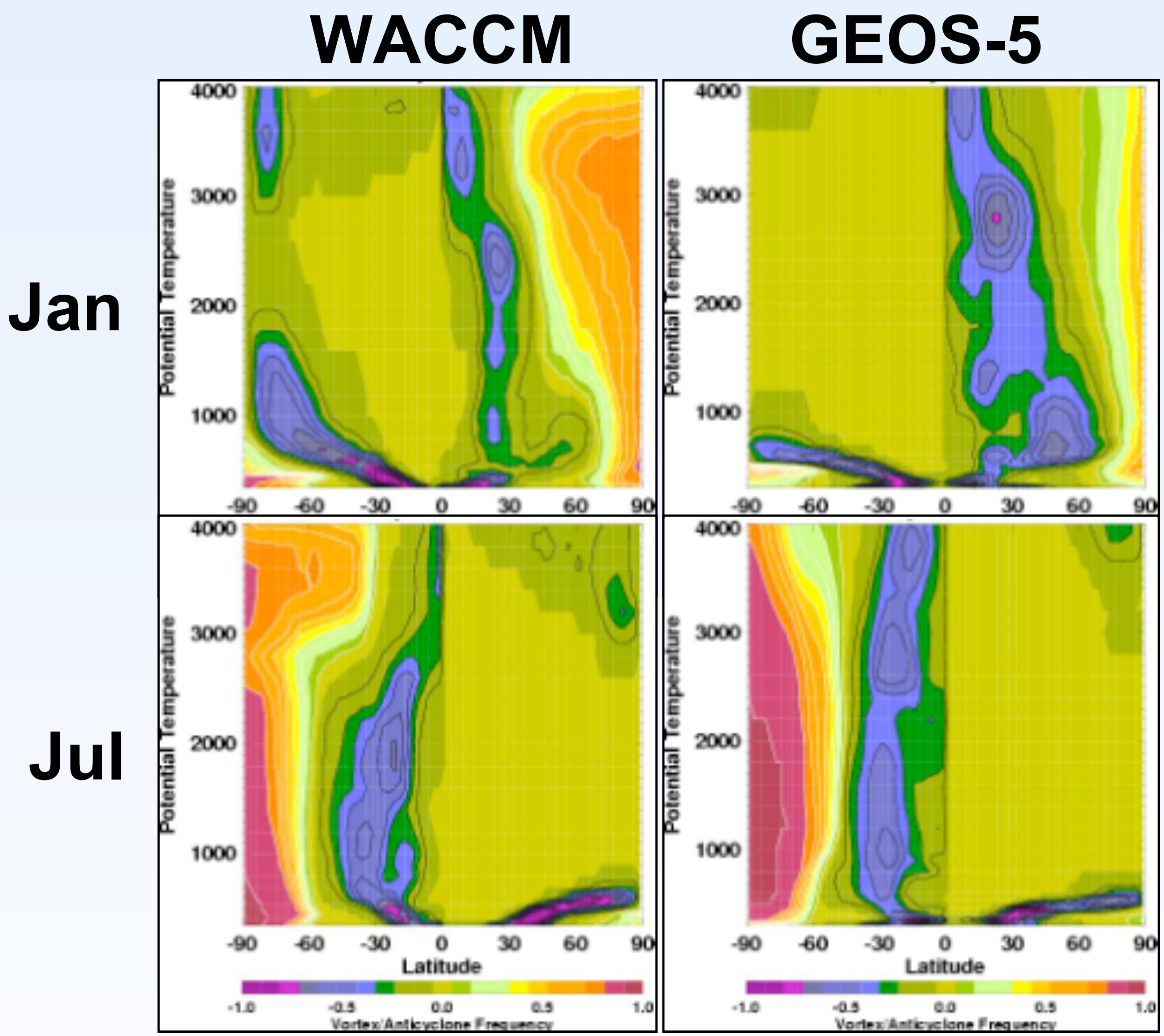
FUTURE QUESTIONS:

- How will fractal particles alter haze properties?
- How do organic hazes affect solutions to the Faint Young Sun problem?

UV and VIS absorption optical depths for Early Earth hazes for various production rates.

Haze production rate (g yr^{-1})	10^{12}	10^{13}	10^{14}	10^{15}
τ_{uv}	0.026	0.112	0.47	2.31
τ_{vis}	0.005	0.04	0.249	1.63
τ_{uv}/τ_{vis}	4.79	2.78	1.89	1.42

Zonal Mean Vortex and Anticyclone Frequencies



Polar vortex (red) and anticyclone (blue) zonal mean frequency.

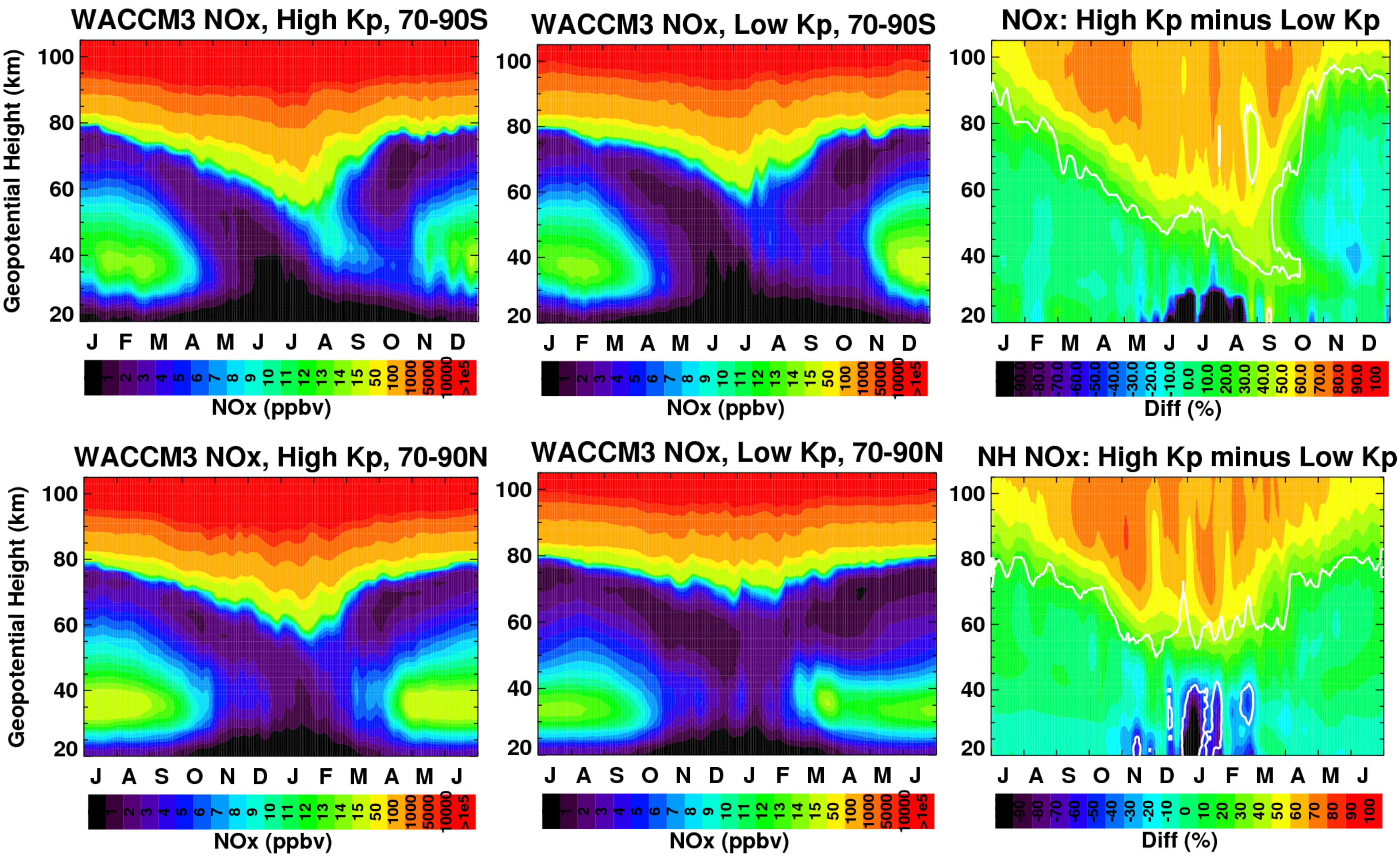
<u>NH winter anticyclone</u> in WACCM too weak.

<u>NH vortex</u> too strong.

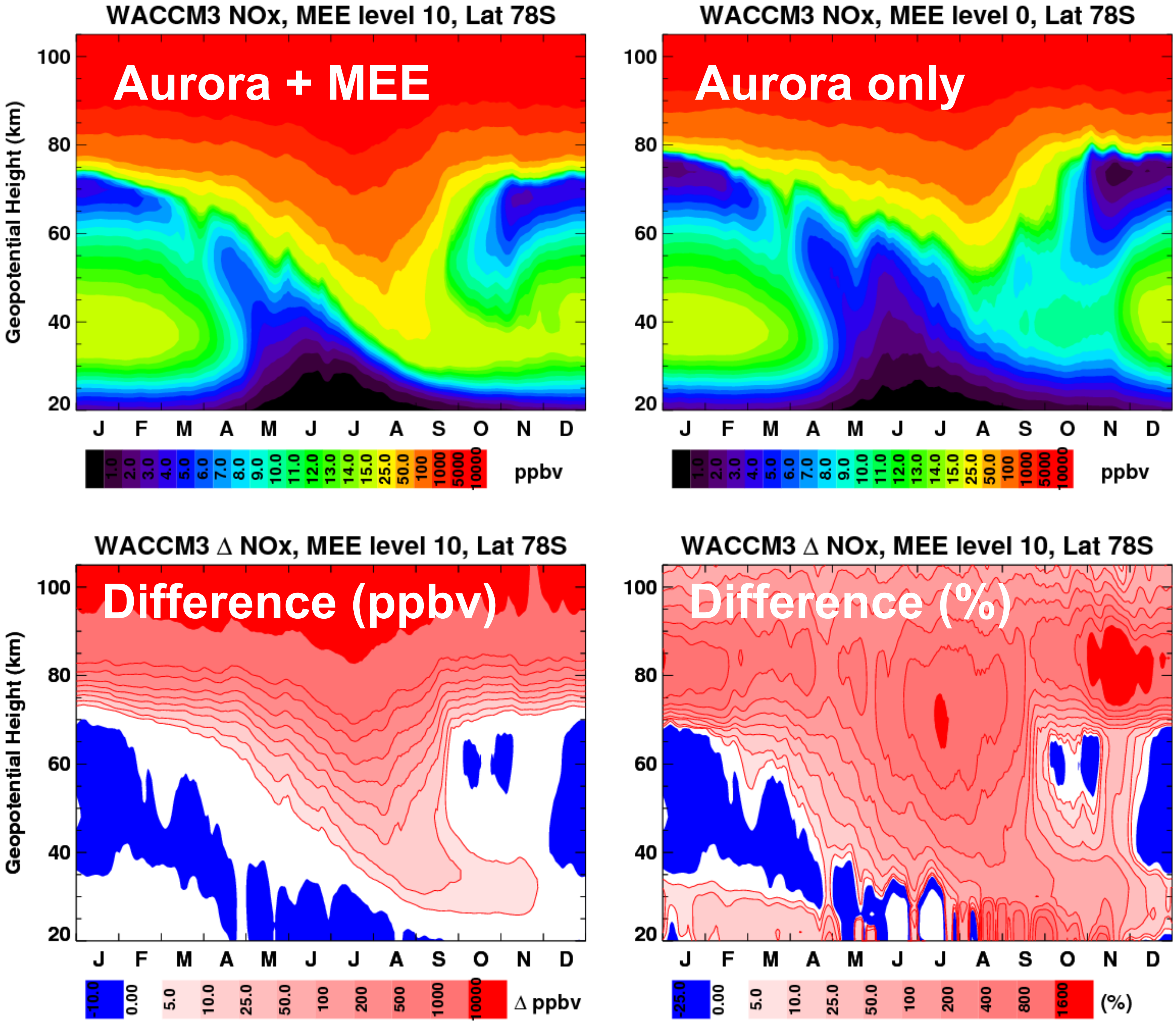
<u>SH winter anticyclone</u> in WACCM too strong in stratosphere and too weak in mesosphere.

<u>SH vortex</u> too weak in stratosphere and too strong in mesosphere.

Courtesy of L. Harvey



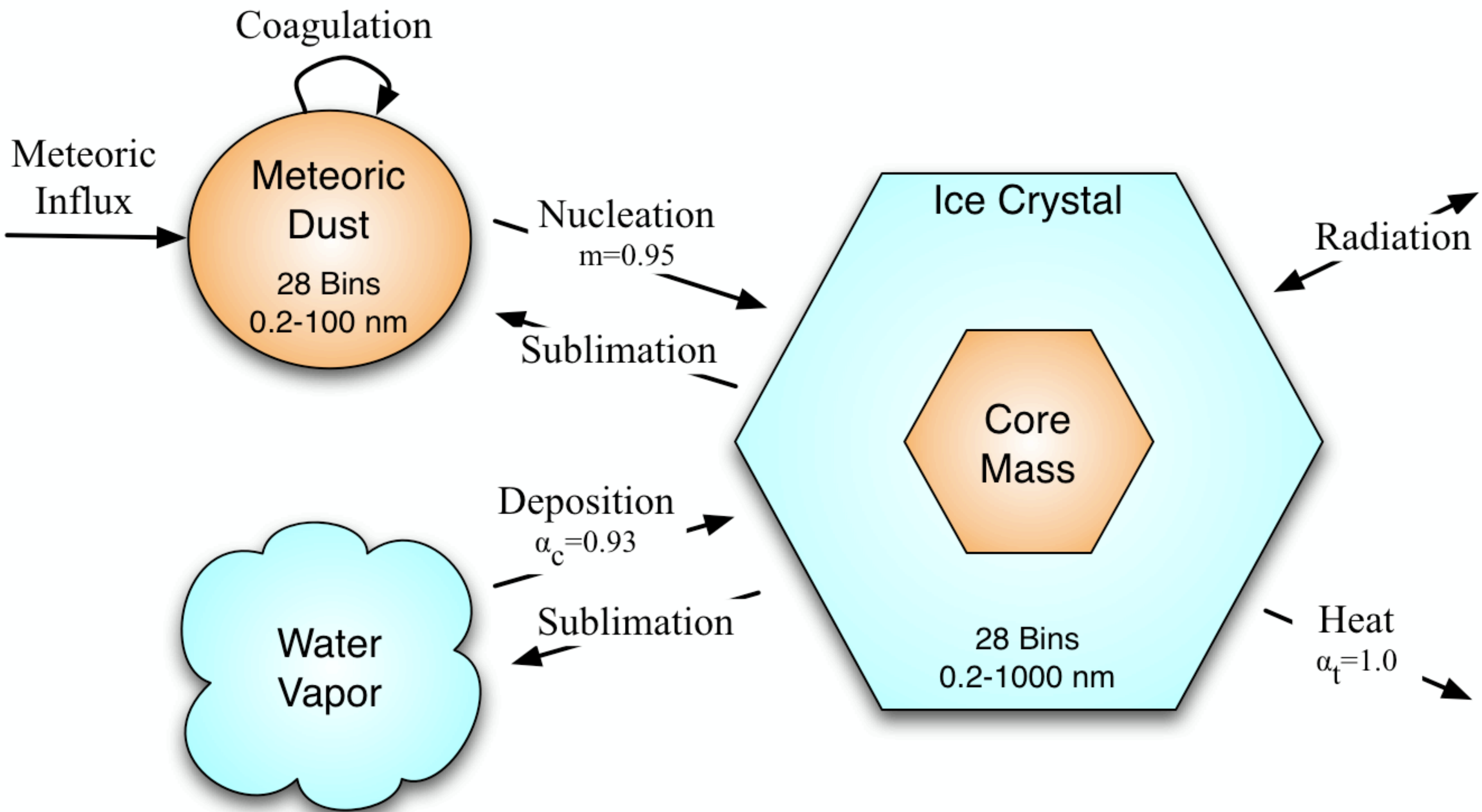
Randall *et al.* (AGU 2007): On average, auroral precipitation causes >10% increases in NO_x down to ~35 km in SH



Courtesy of Cora Randall

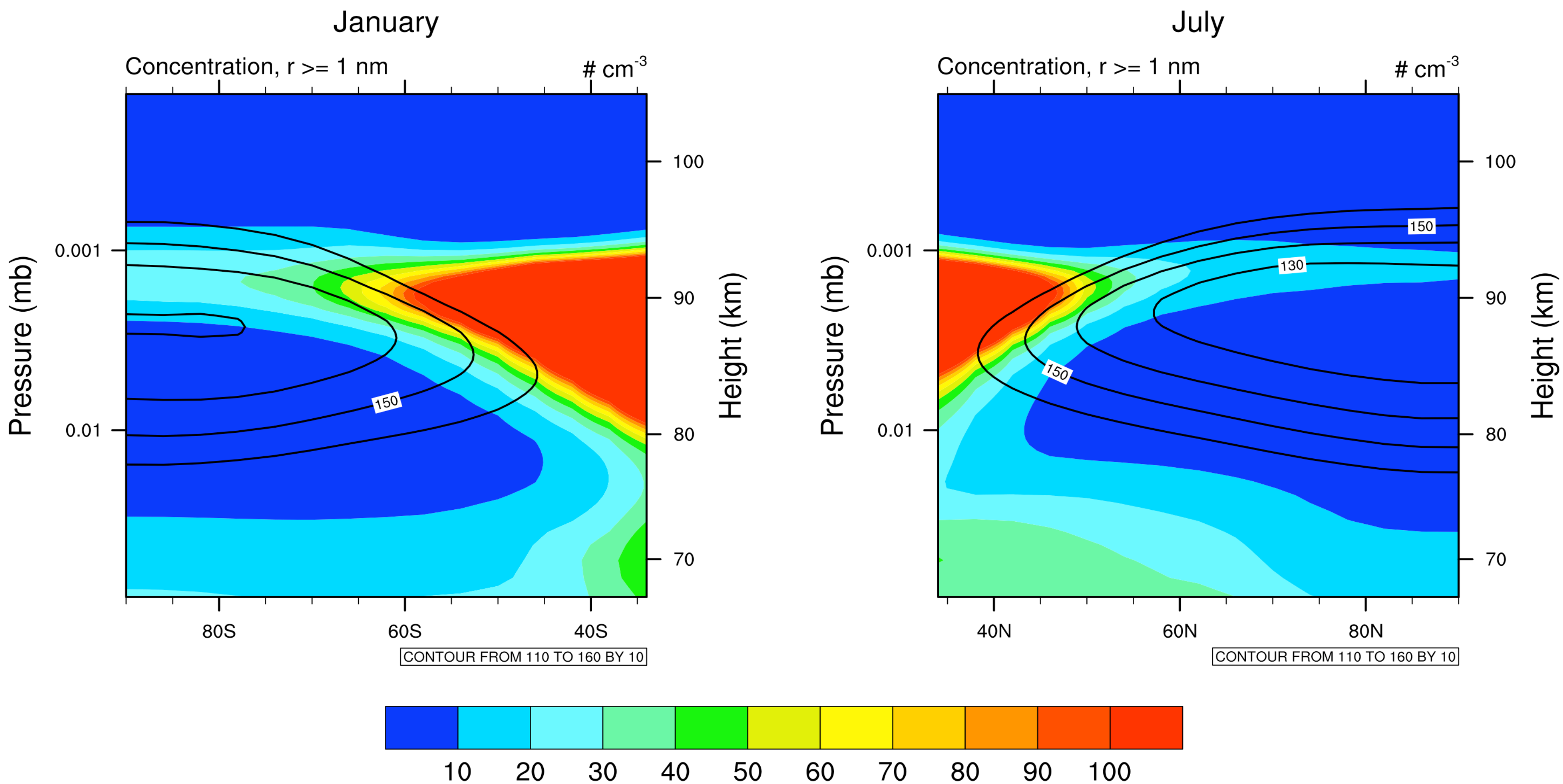
MEE increases NO_x > 25% down to 20 km

CARMA Microphysical Model



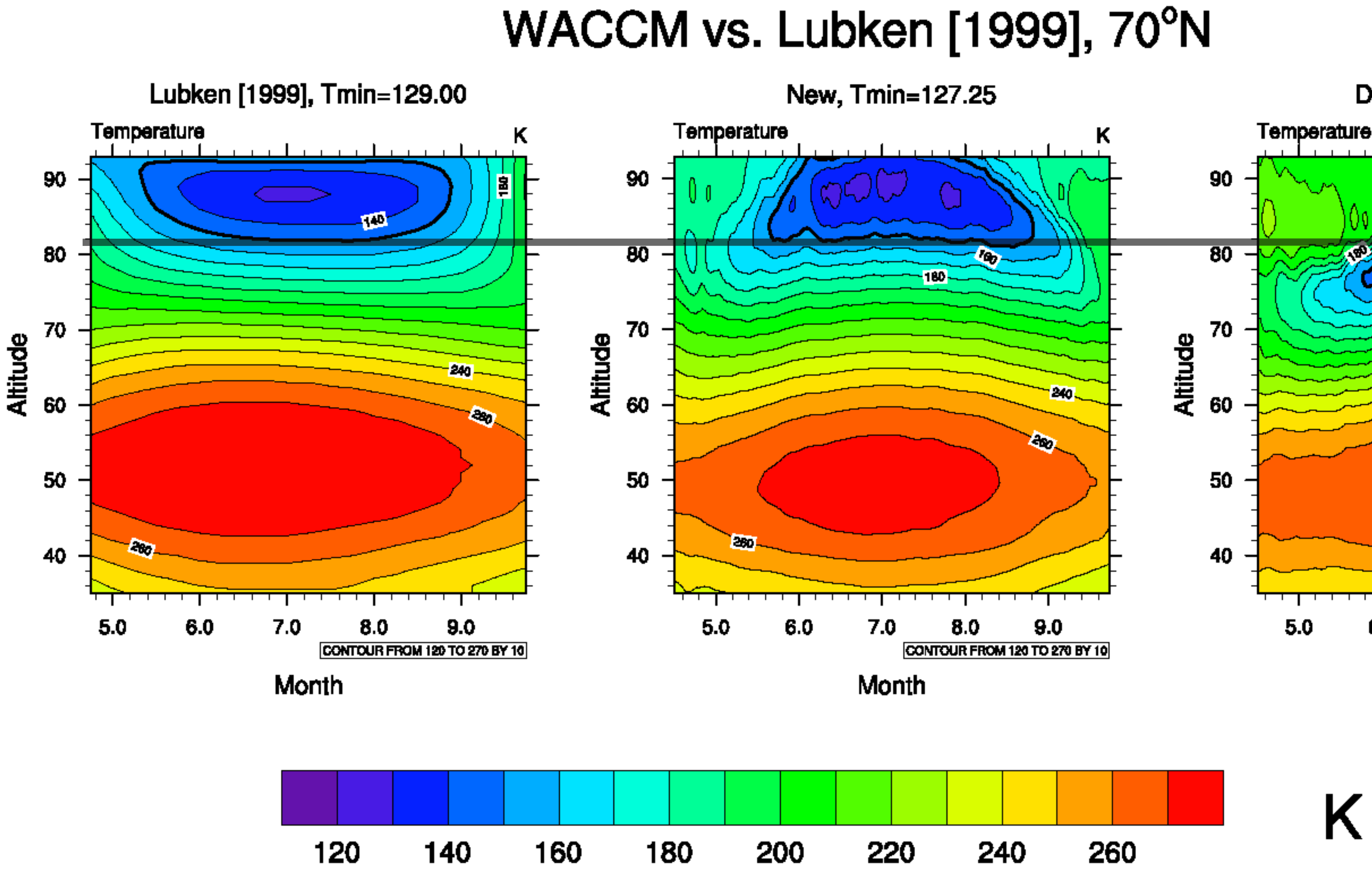
Courtesy of Chuck Bardeen

Reduced Dust At Summer Mesopause



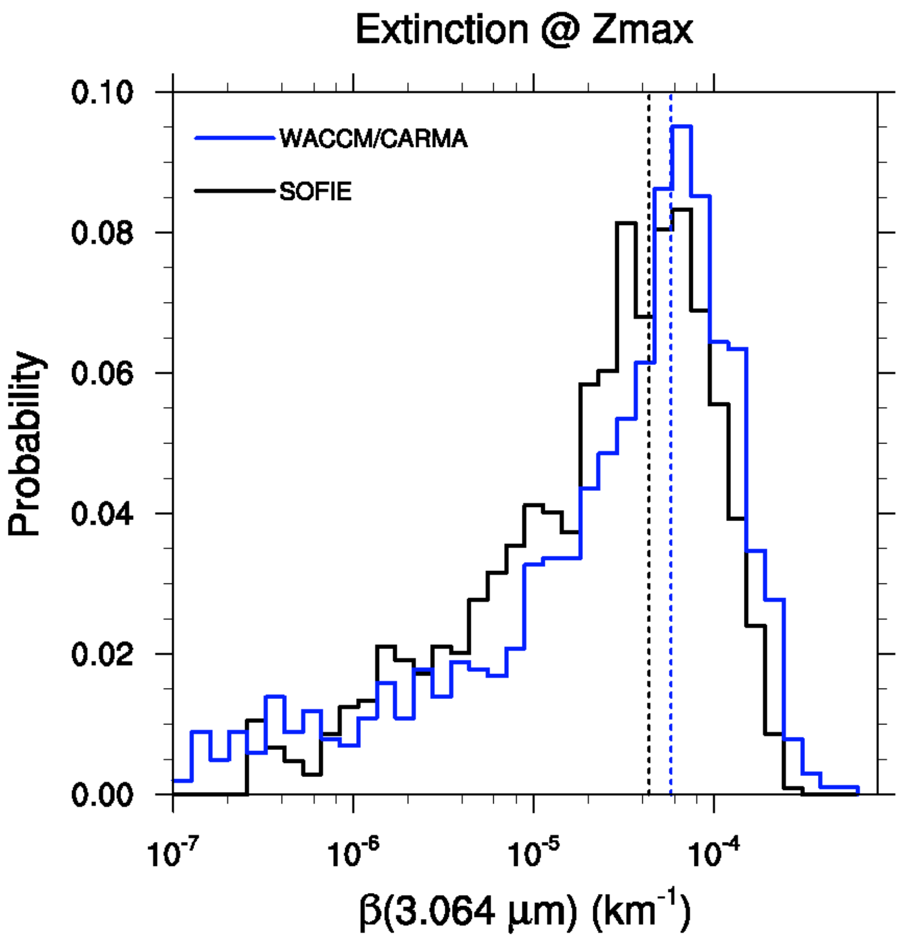
Bardeen *et al.* (JGR, 2008)

Polar Mesopause Temperatures



Courtesy of Chuck Bardeen

How Does WACCM/CARMA Compare To SOFIE on AIM?

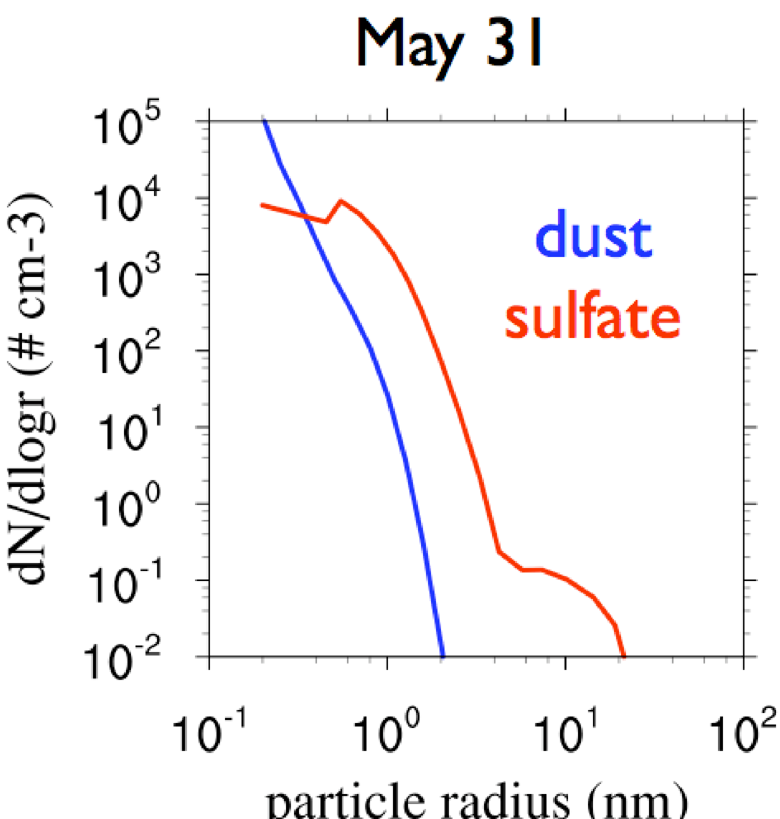


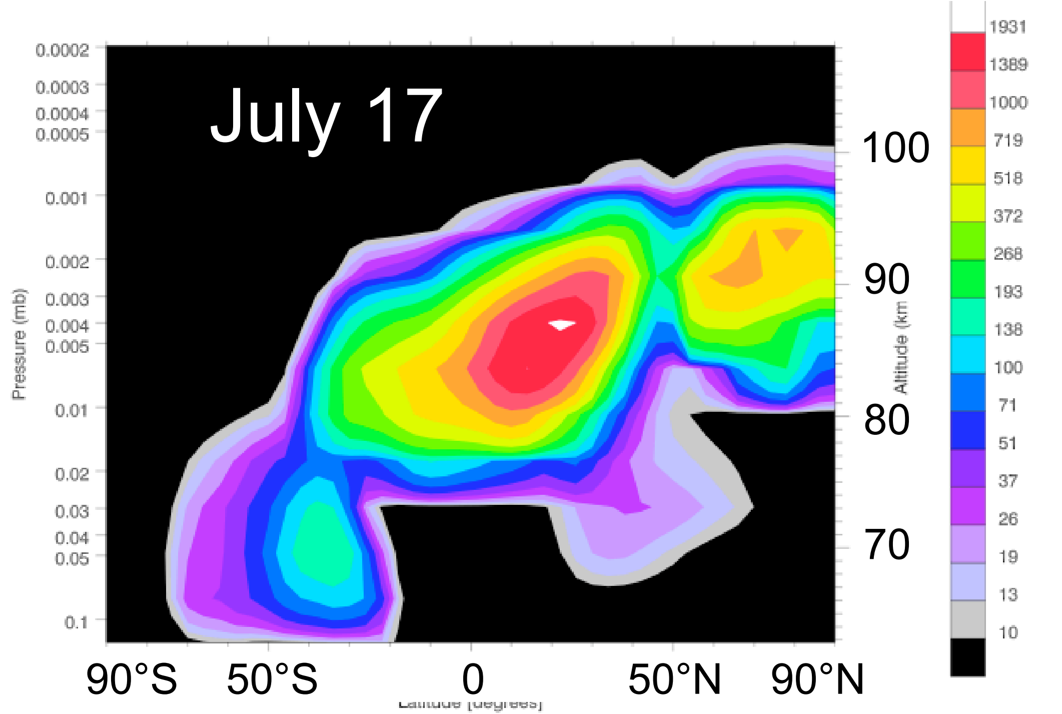
Summary

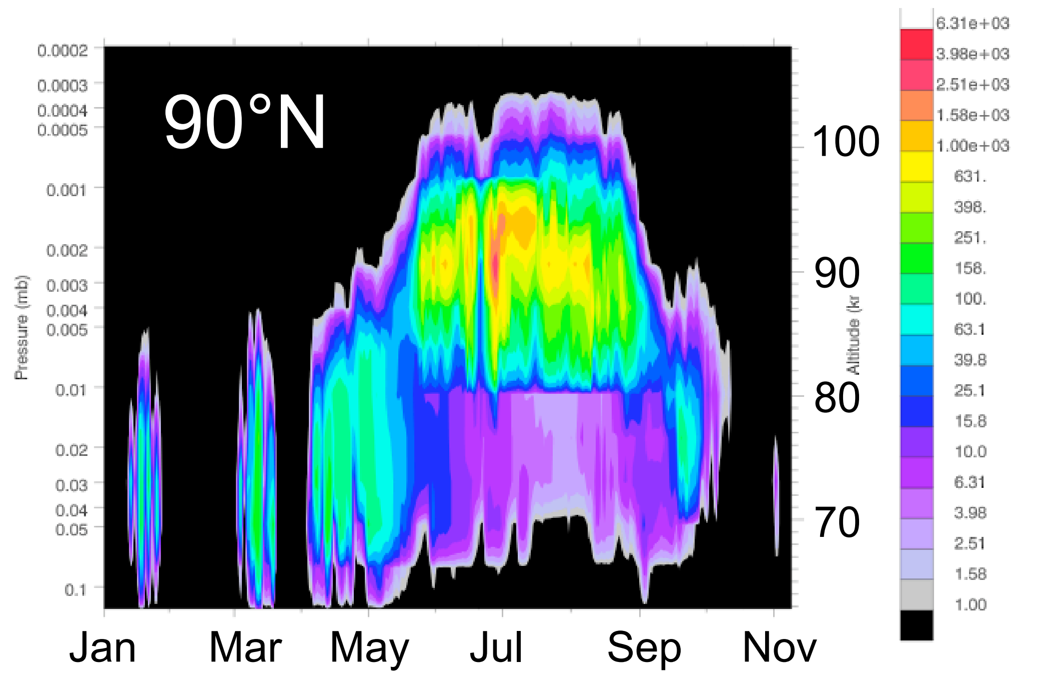
	SOFIE		WACCM/CARMA	
Events	1423		1423	
Clouds	1134	79.69%	1010	70.98%
Zmax < 79 km	289	20.31%	0	0.00%

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

>1000 cm^{-3}

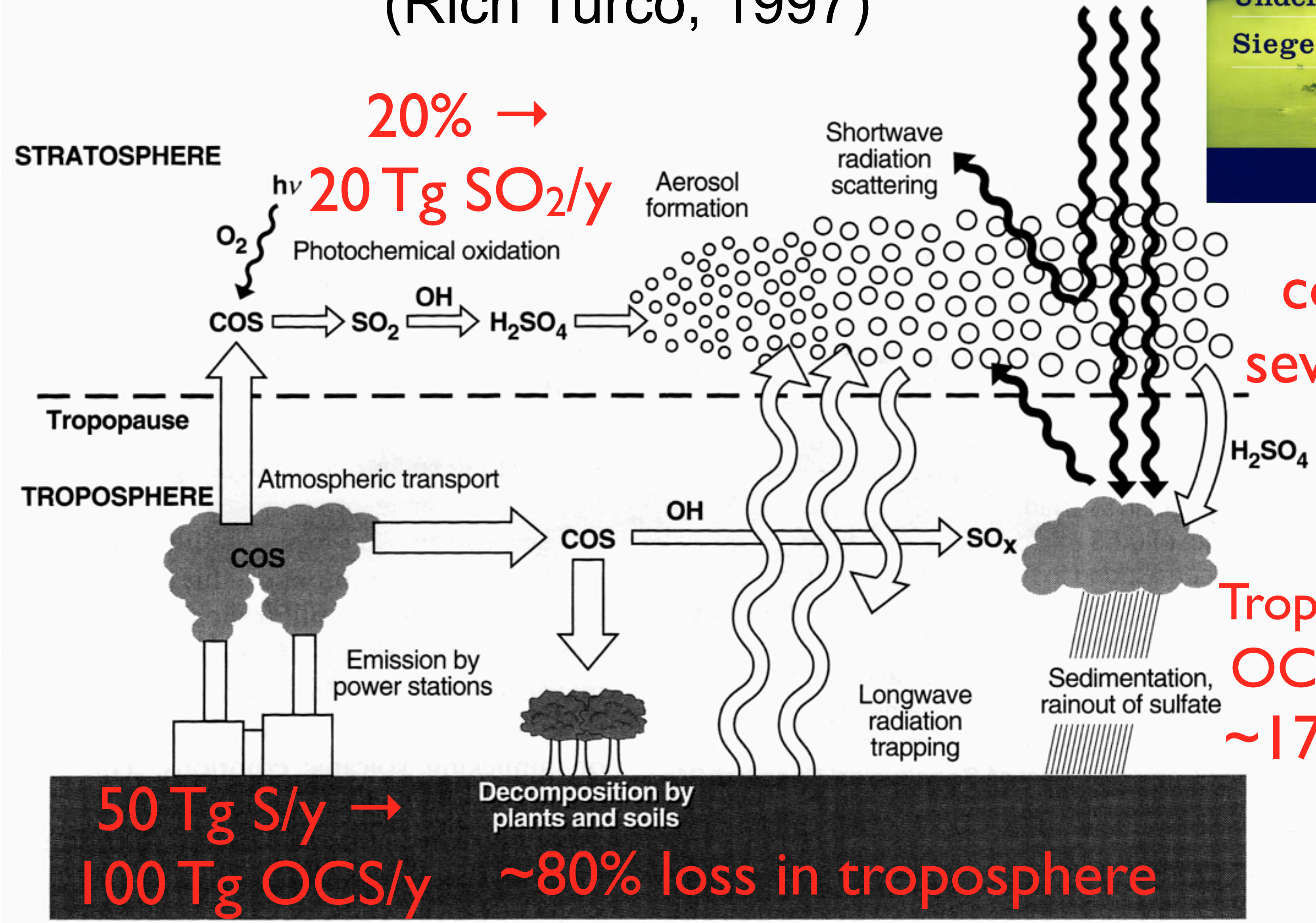


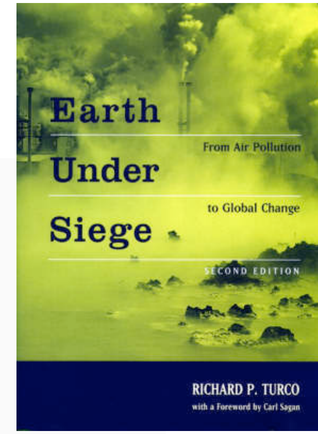




Sulfate Geoengineering

(Rich Turco, 1997)





20% →
20 Tg SO_2/y

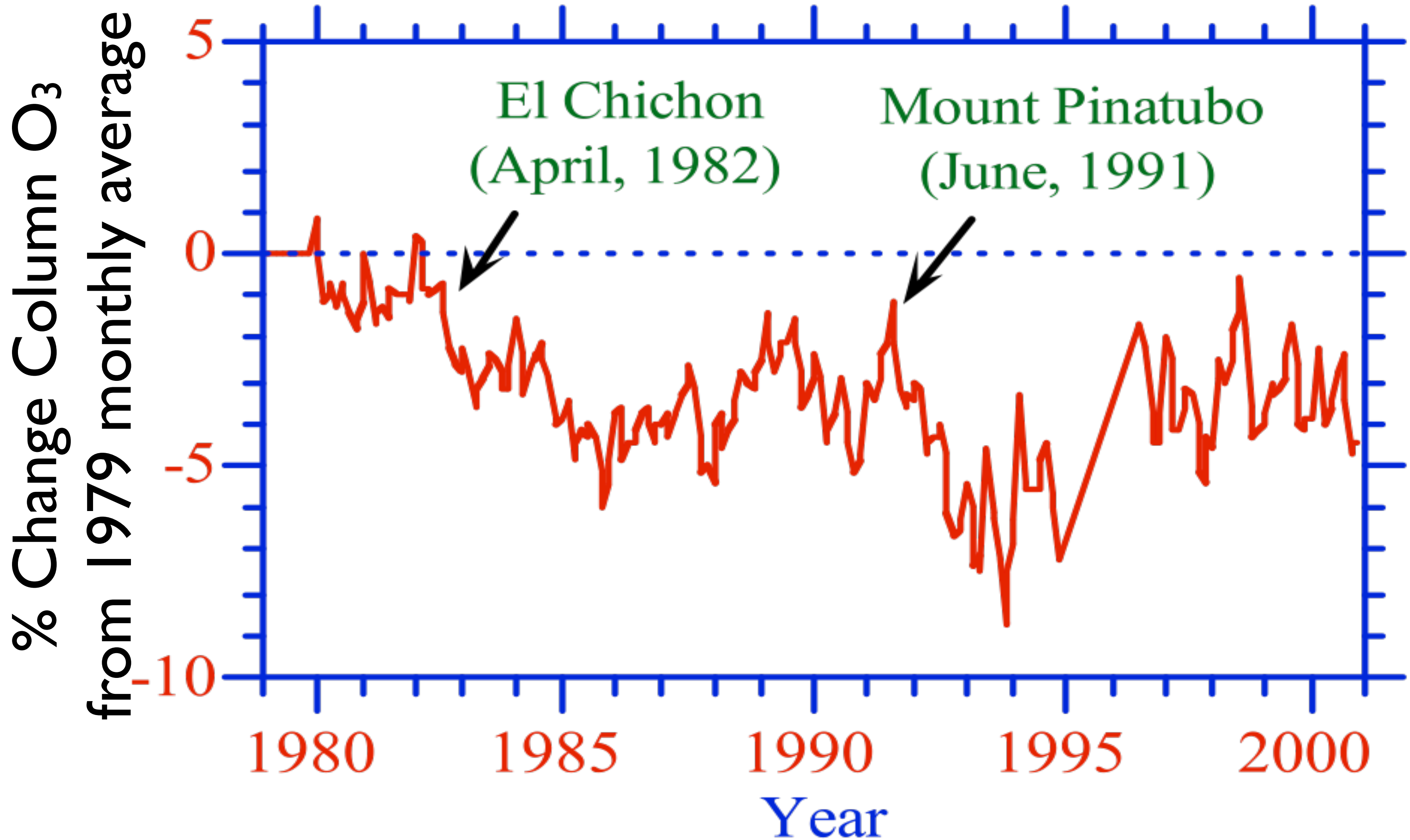
cooling: several °C

Tropospheric OCS x 300
~170 ppbv

50 Tg S/y →
100 Tg OCS/y

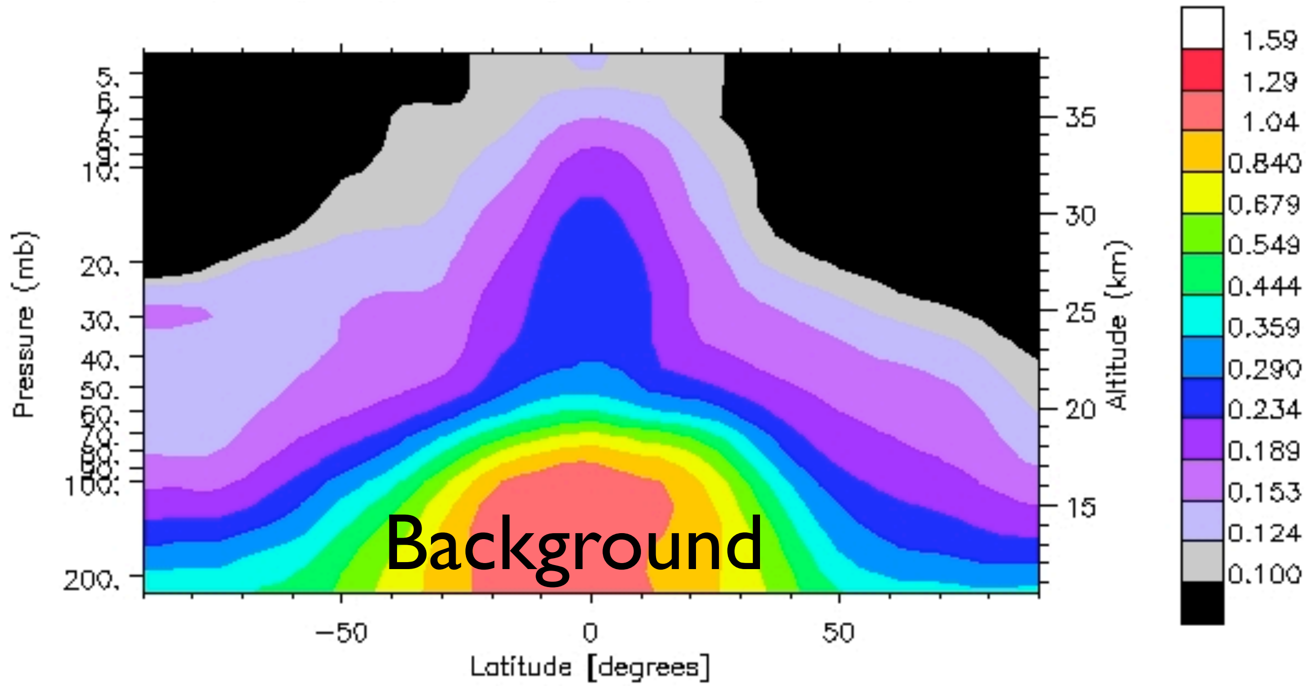
~80% loss in troposphere

Changes in Monthly-Averaged Global Ozone From 1979-2001



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

Effective radius (μm)



March Zonal Average