Prognostic stratospheric aerosols in CESM

CESM Joint Session:
- Atmosphere Model Working Group
- Chemistry Climate Working Group
- Whole Atmosphere Working Group

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Richard Easter, PNNL

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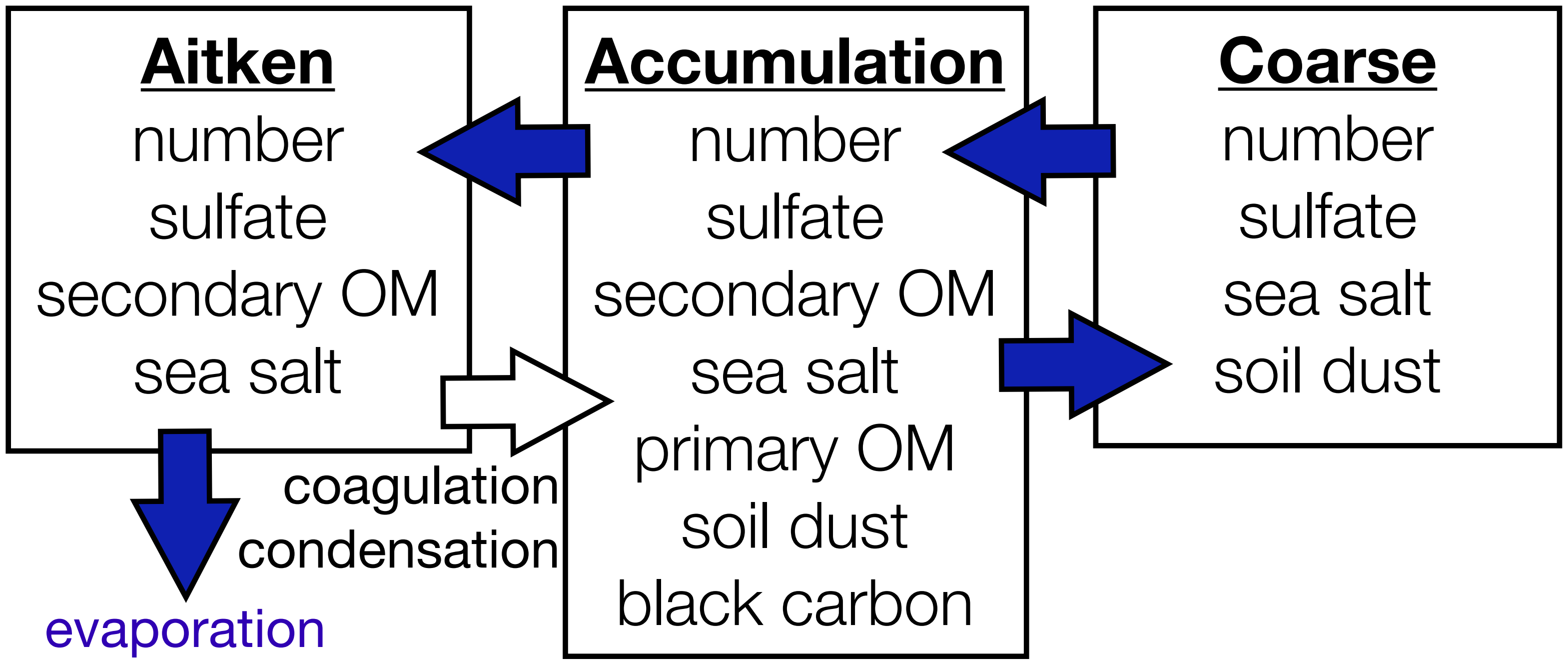
Extend modal aerosol model (MAM3) for stratospheric aerosols



Gas-phase species: H_2SO_4, SO_2, DMS, SOA (gas)

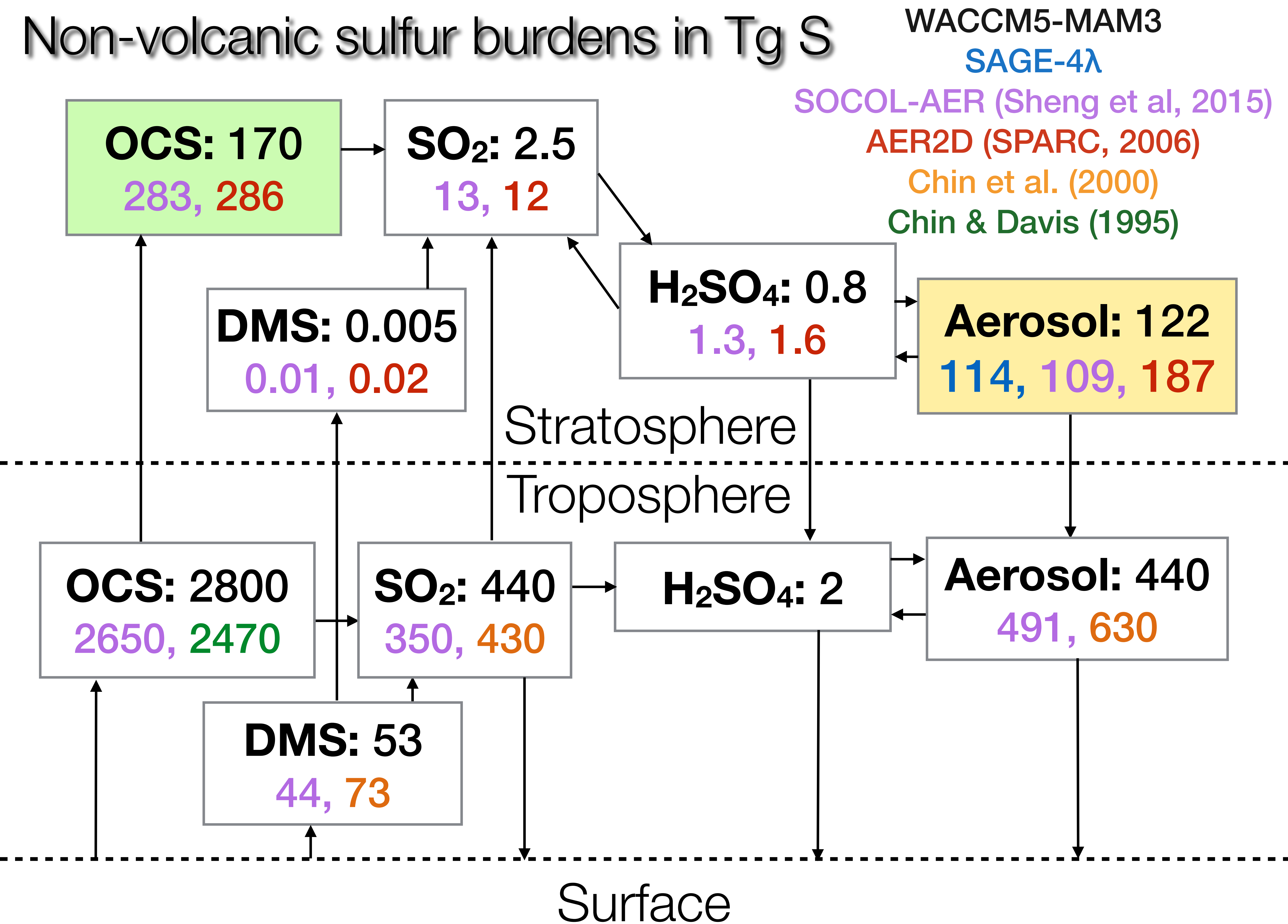
Added: OCS, S, SO, SO_3, HSO_3

Added sulfate evaporation above tropopause

Added growth between modes

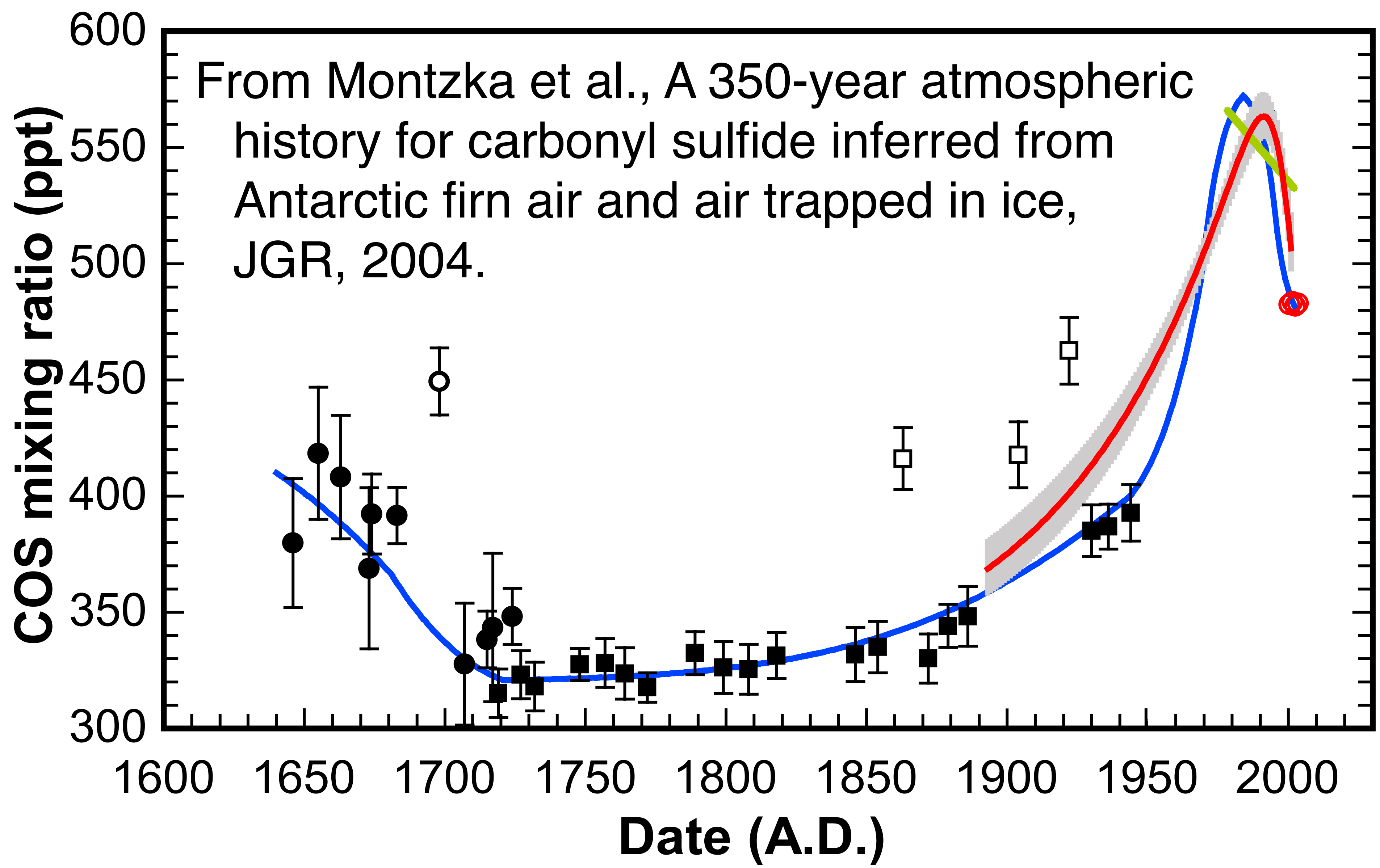
Adjusted diameter ranges, mode widths

Mode	Nucleation	Aitken	Accumulation	Coarse
Standard MAM3 radius (μm) geom. std. dev	N/A	0.00435 - 0.026 1.6	0.02675 - 0.22 1.8	0.5 - 2.0 1.8
Modified MAM3 radius (μm) geom. std. dev.	N/A	0.00435 - 0.026 1.6	0.02675 - 0.22 1.6	>0.22 1.2
ECHAM-M7 volcanic radius (μm) geom. std. dev.	<0.005 1.59	0.005 - 0.05 1.59	>0.05 1.2	N/A
ECHAM-M7 geoeng. radius (μm) geom. std. dev.	<0.005 1.59	0.005 - 0.05 1.59	0.05 - 0.2 1.59	>0.2 1.2



Non-volcanic sulfur burdens in Tg S
WACCM5-MAM3
SAGE-4λ
SOCOL-AER (Sheng et al, 2015)
AER2D (SPARC, 2006)
Chin et al. (2000)
Chin & Davis (1995)
OCS: 170
283, 286
SO2: 2.5
13, 12
H2SO4: 0.8
1.3, 1.6
Aerosol: 122
114, 109, 187
DMS: 0.005
0.01, 0.02
Stratosphere
Troposphere
OCS: 2800
2650, 2470
SO2: 440
350, 430
H2SO4: 2
Aerosol: 440
491, 630
DMS: 53
44, 73
Surface

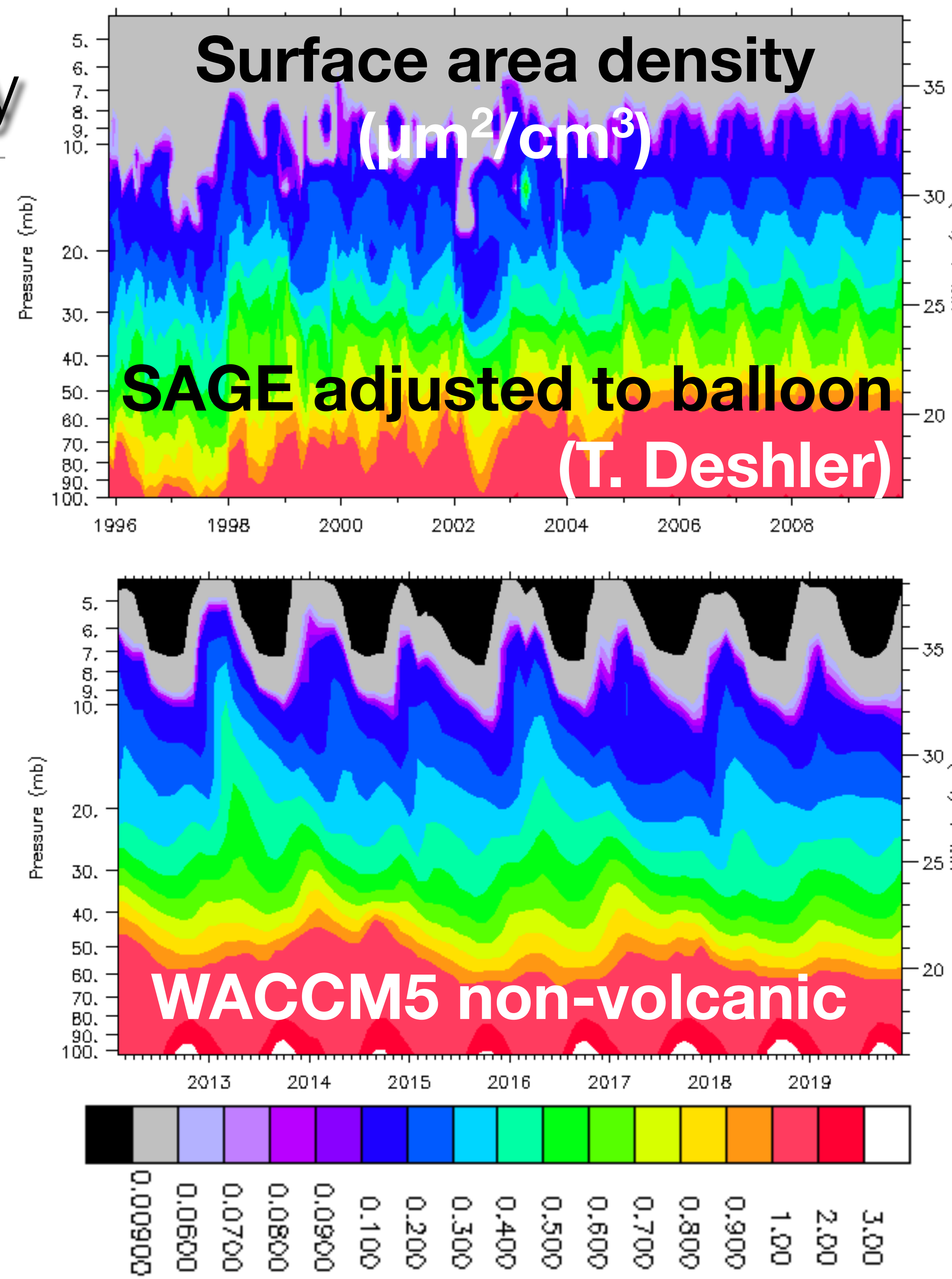
Time-varying lower boundary condition for OCS



- New LBC file for runs with chemistry (WACCM, CAM-chem)
- External forcing files developed for SO_2 produced from OCS oxidation in CAM without chemistry: 1850, 20th Century

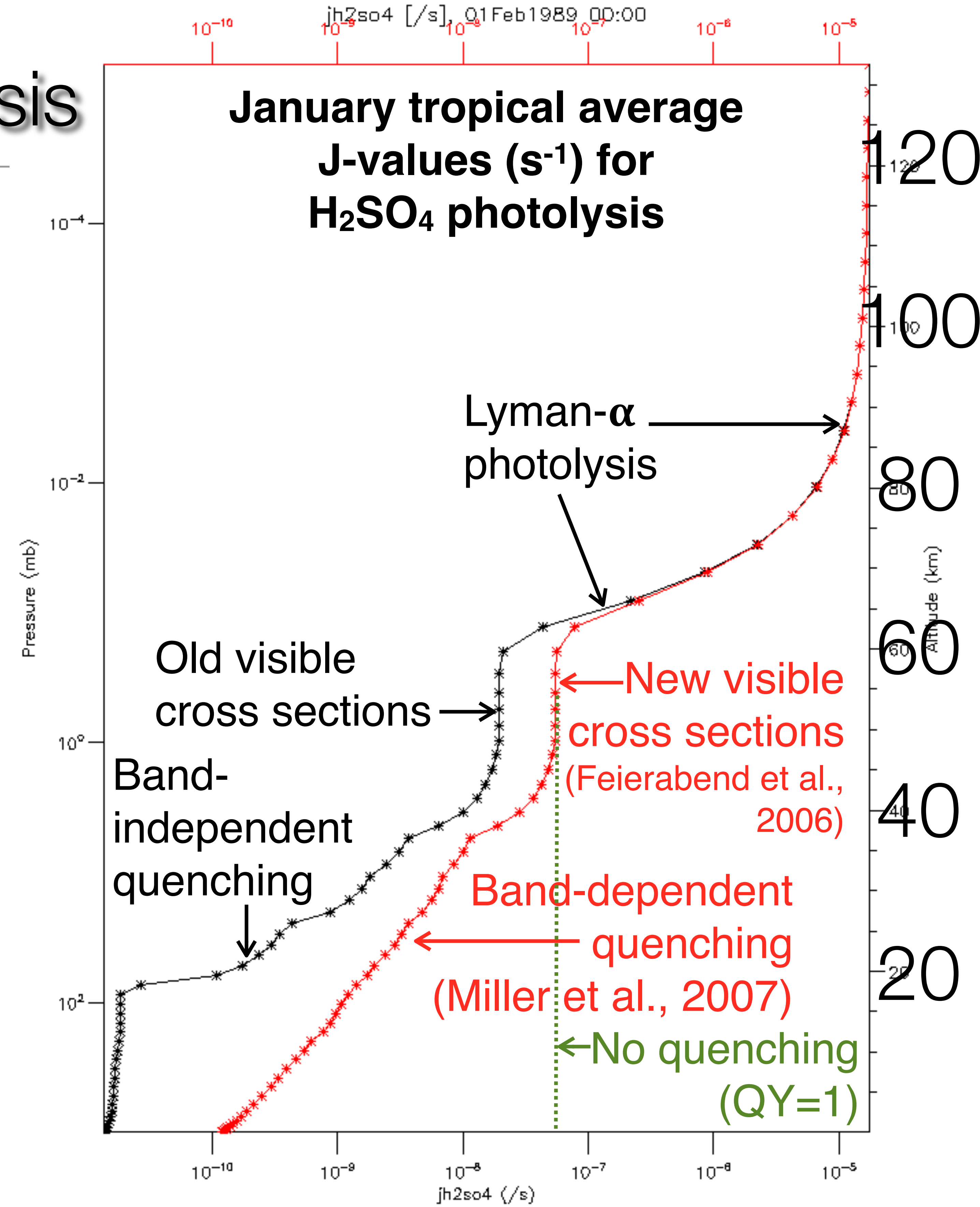
MAM coupled to chemistry

- Surface area densities from MAM used for heterogeneous reactions in stratosphere and troposphere
- Using ~140-species CCMI "TSMLT" chemistry: troposphere, stratosphere, mesosphere, lower thermosphere
- Will test impacts on ozone compared to historical 1979-present period in runs nudged with specified dynamics (SD) as well as free-running (FR)



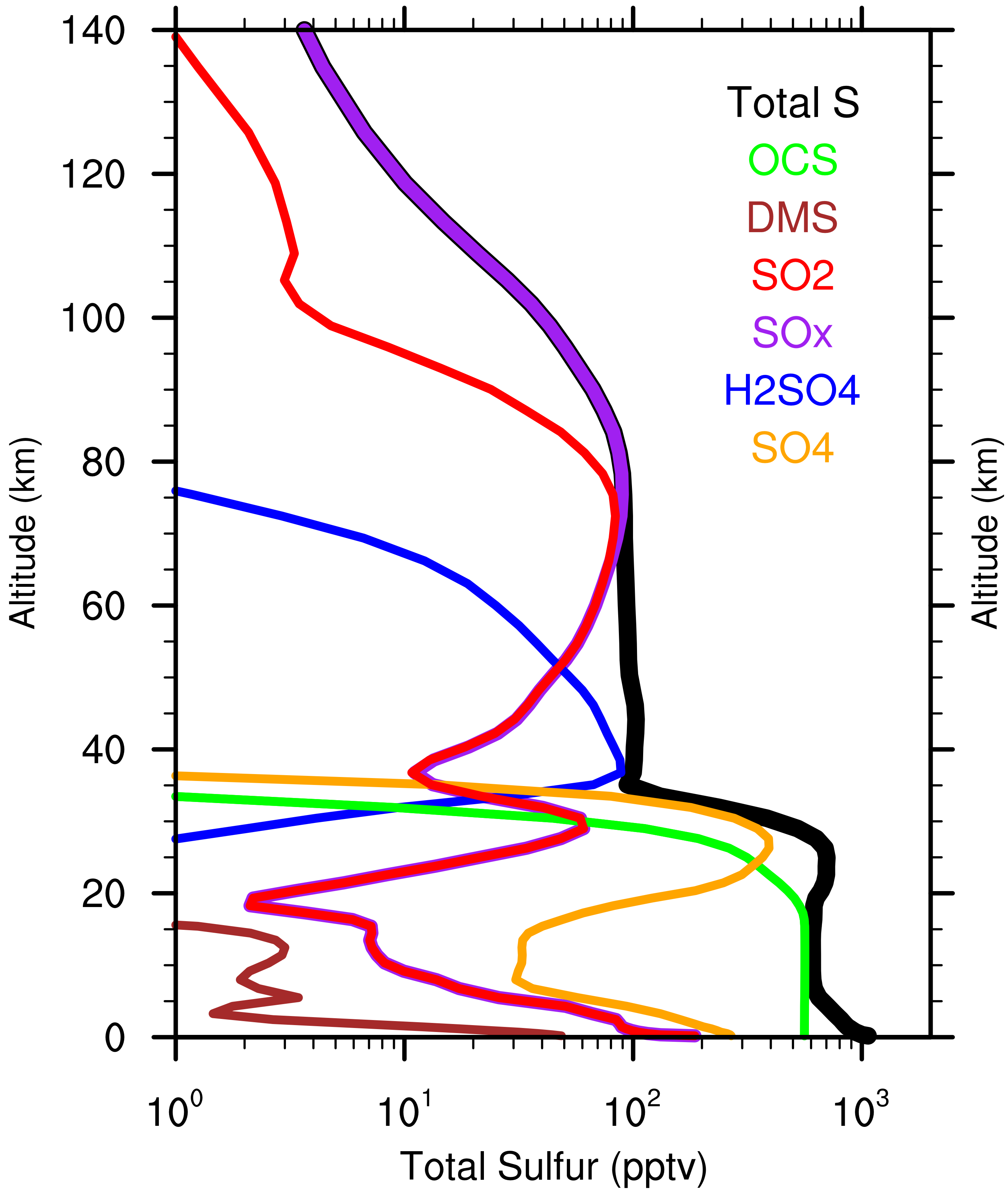
Updated H_2SO_4 photolysis

- $H_2SO_4 + h\nu \rightarrow SO_3 + H_2O$ by vibrational overtone pumping (Vaida et al., 2003)
- Visible cross sections updated, increasing photolysis at 40-60 km (Feierabend et al., 2006)
- Band-dependent quenching implemented as a lower limit on photolysis below 40 km (Miller et al, 2007)
- Upper limit: no quenching, constant J-value 0-60 km



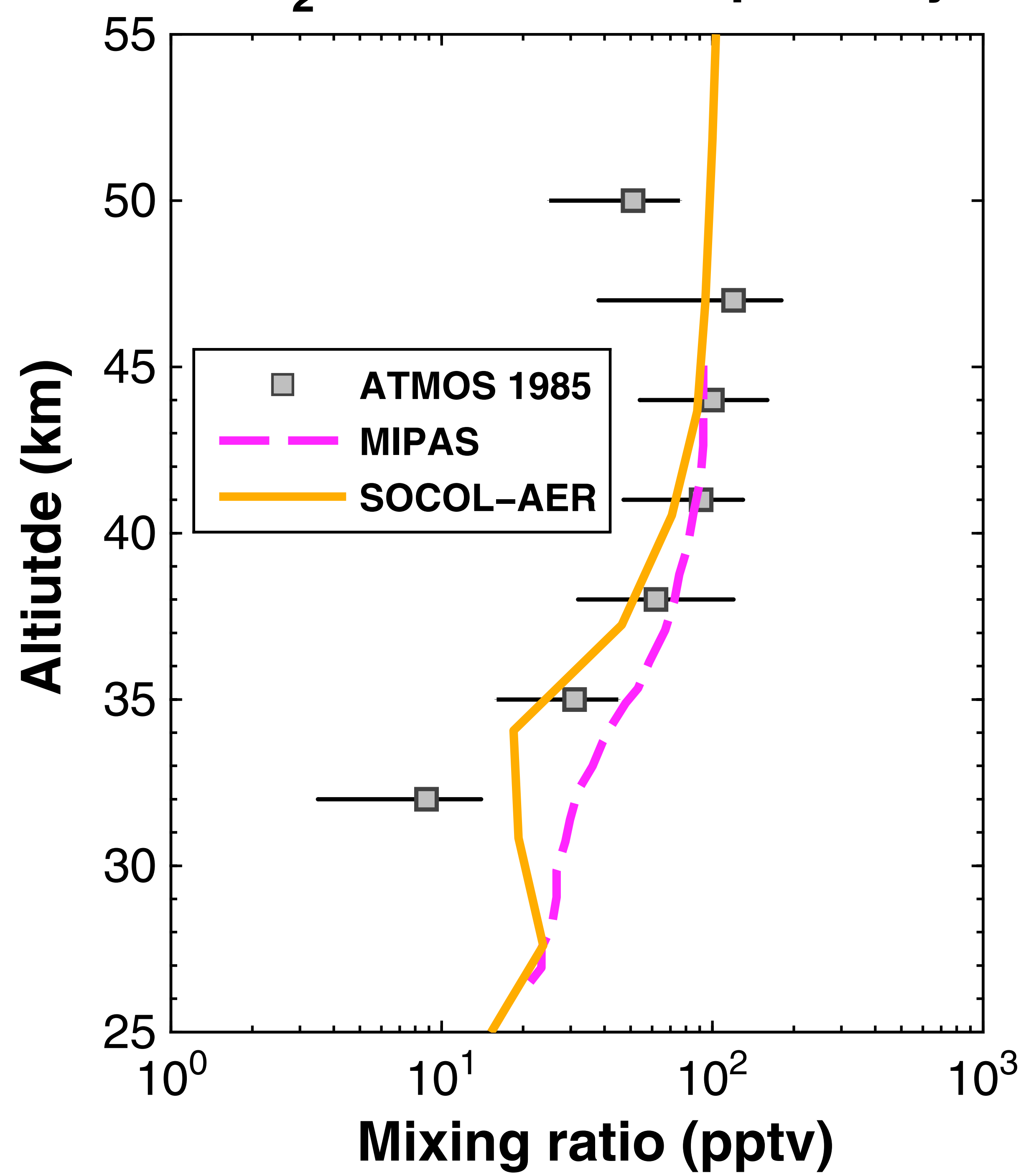
WACCM5-MAM3

Annual average, 0-20°N

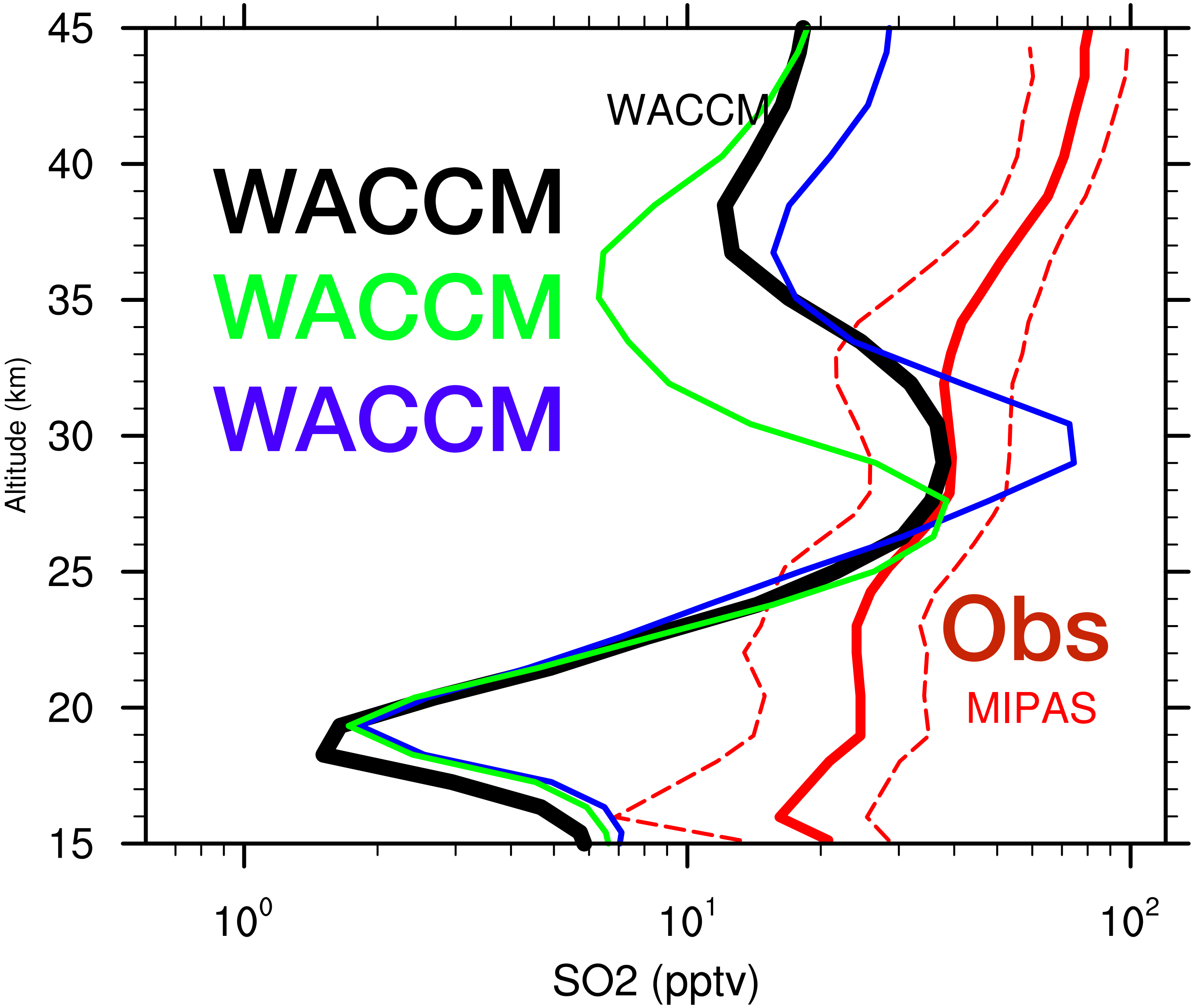


SOCAL-AER model vs Observations

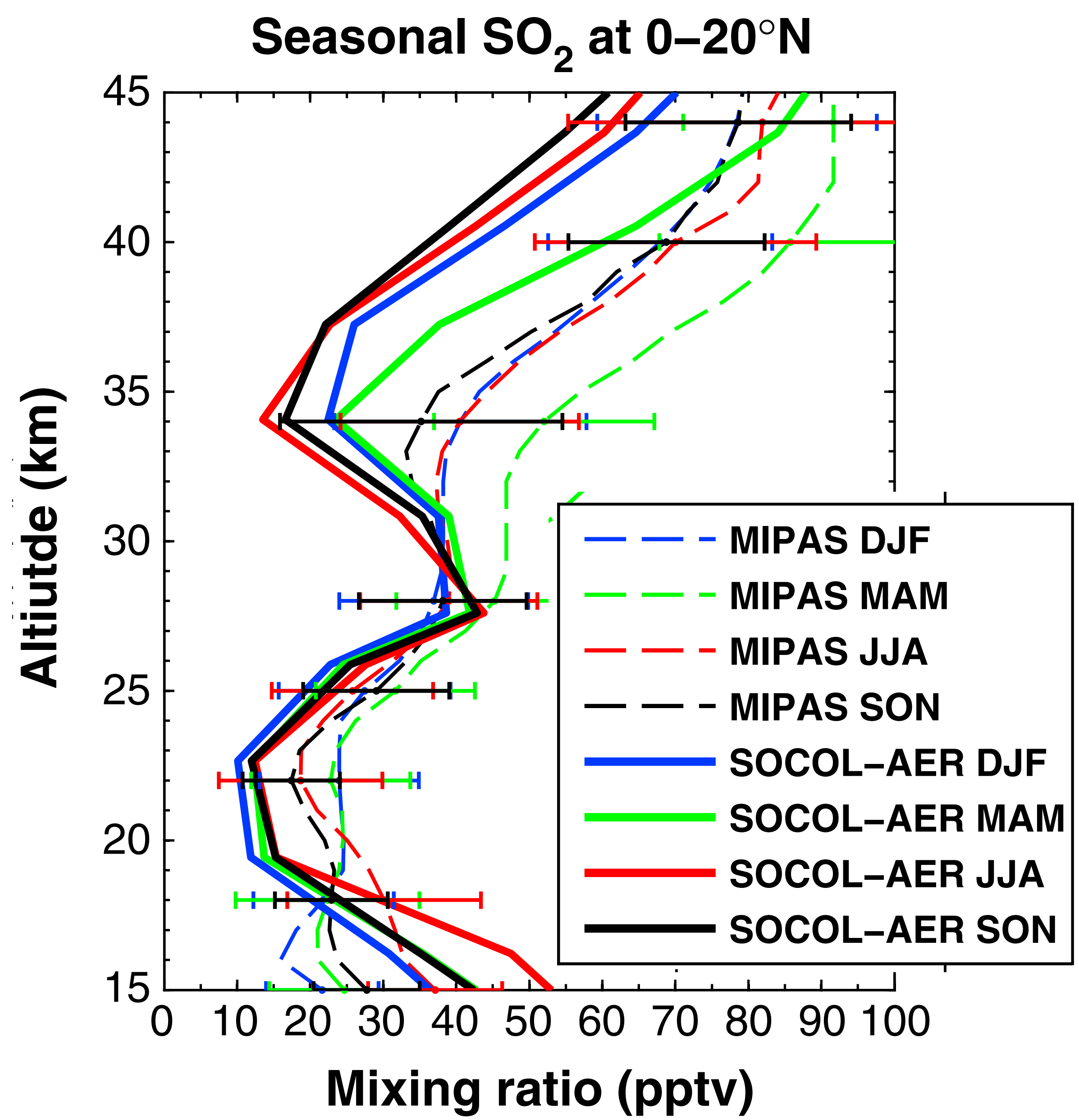
SO_2 at 26–32°N in April–May



WACCM5-MAM3
MIPAS (obs)
DJF, 0-20°N

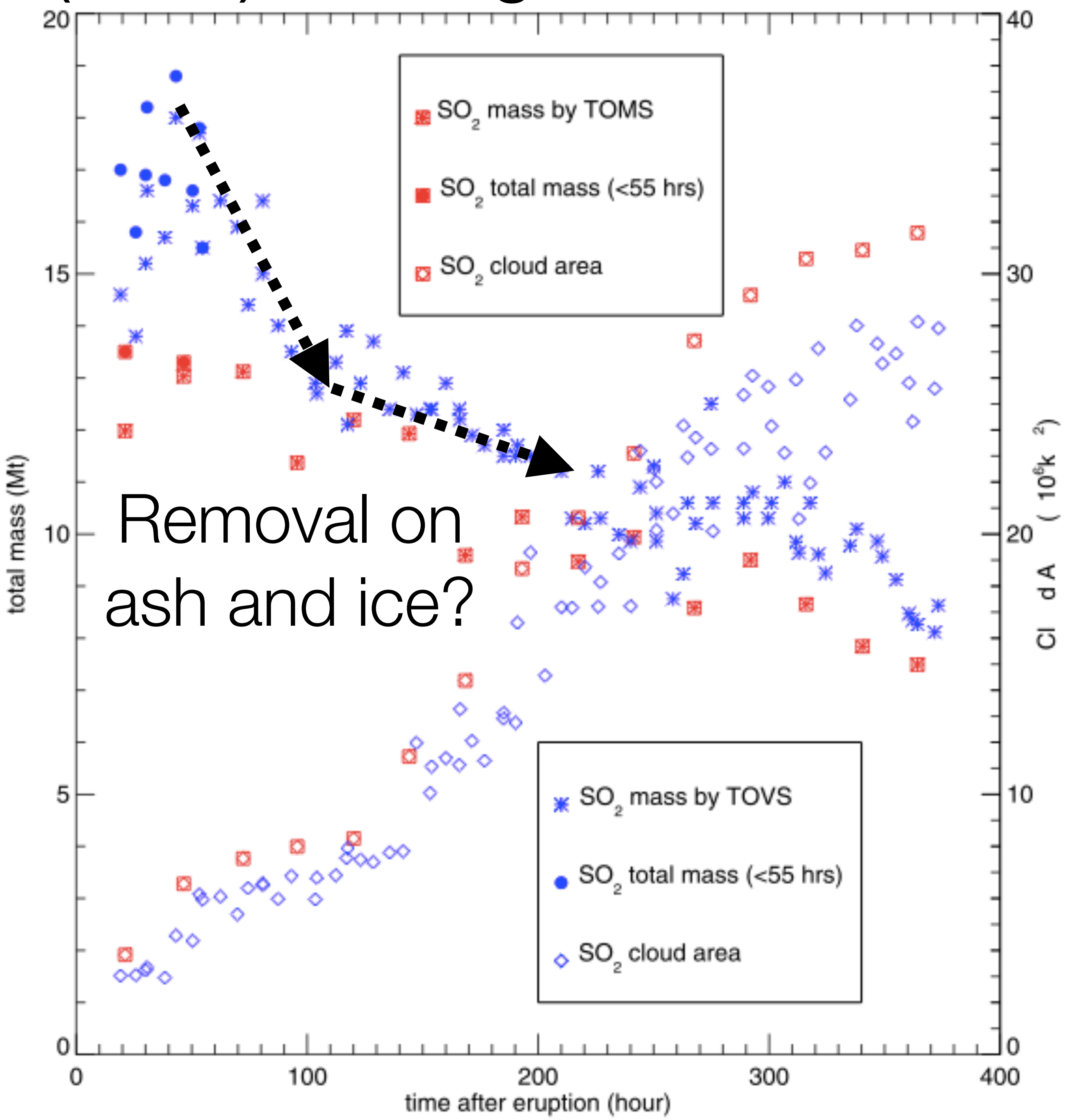


SOCOL-AER (model)
MIPAS (obs)
Sheng *et al.*, 2015

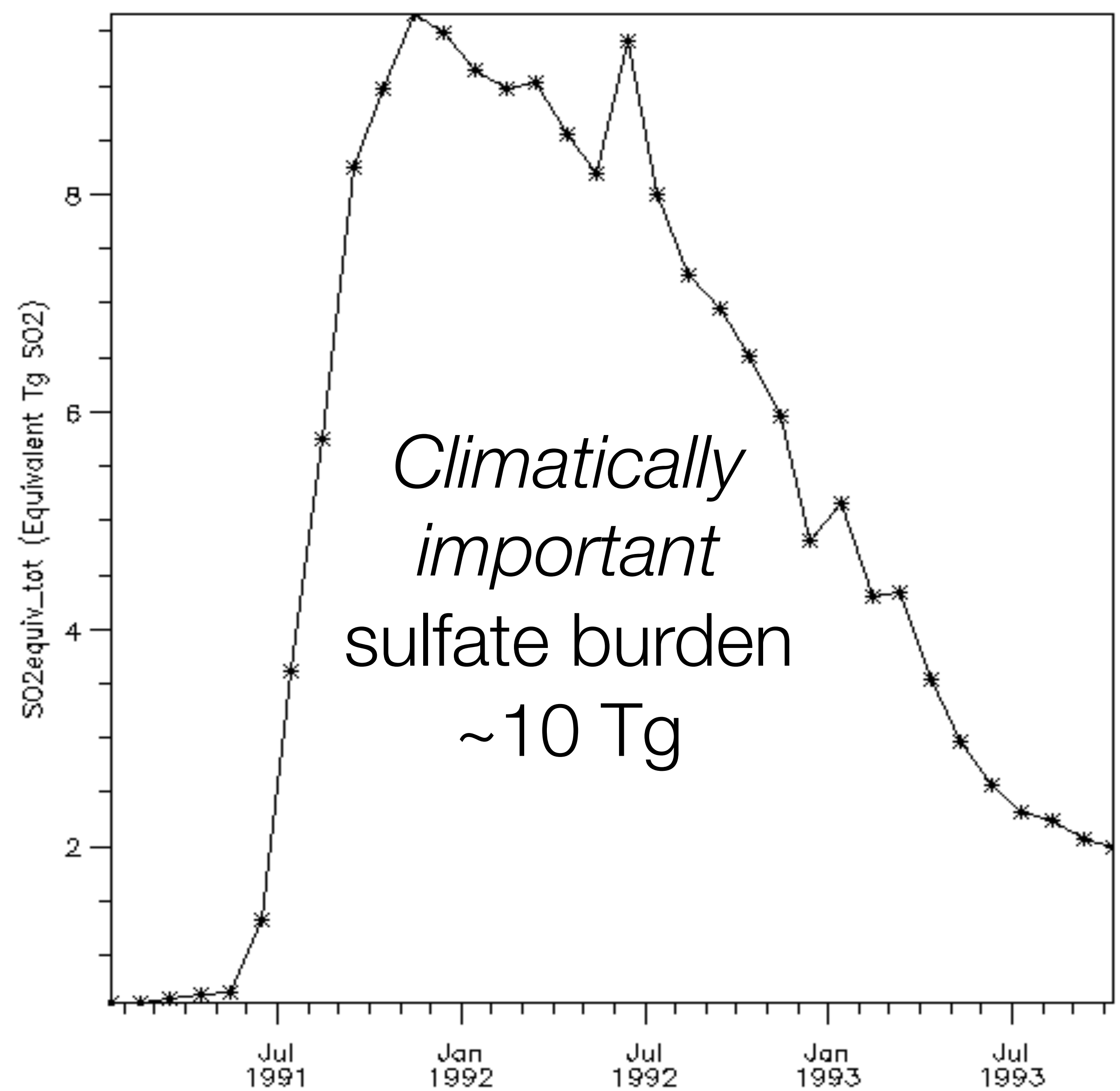


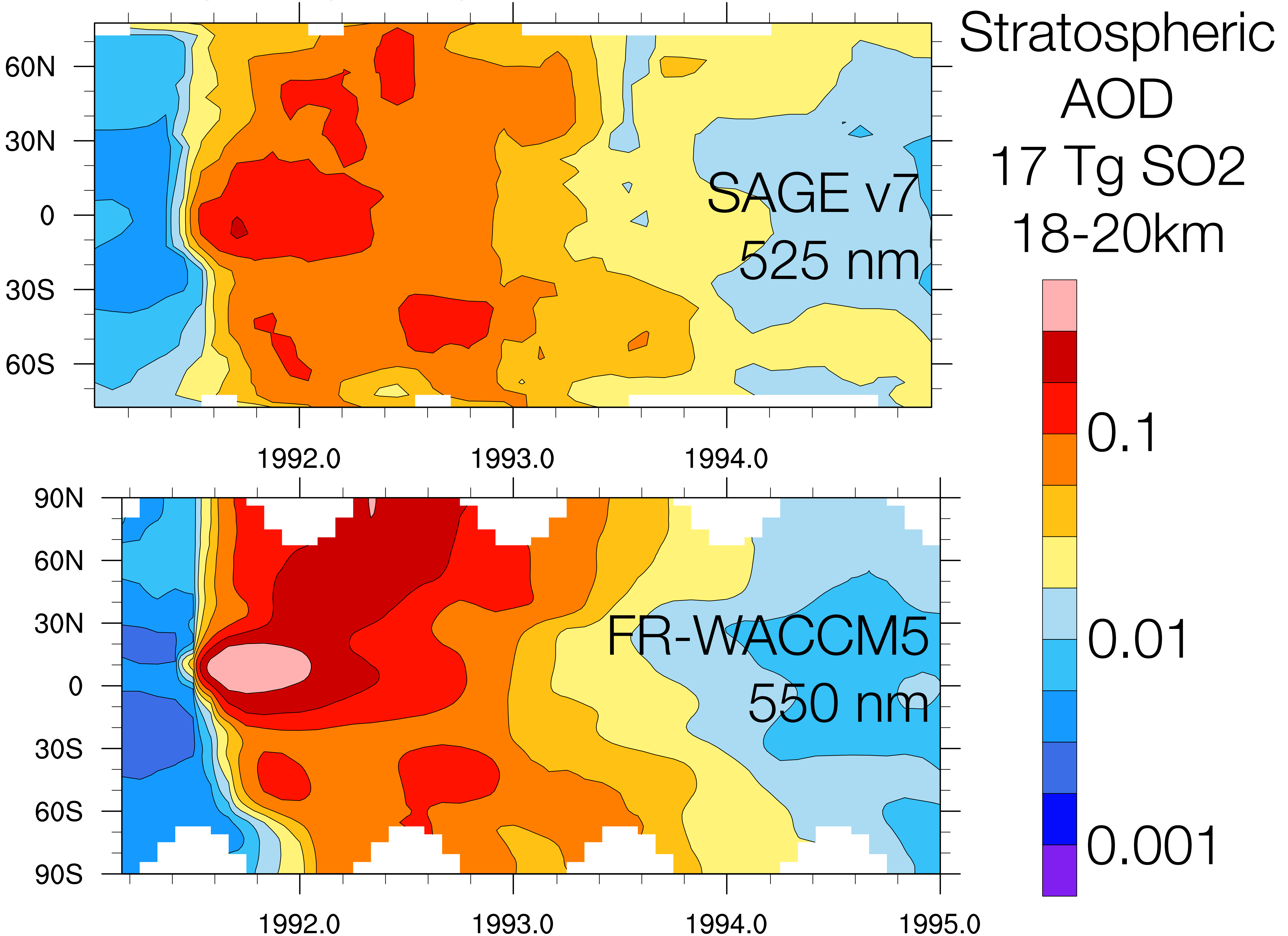
Pinatubo simulation: How much SO_2?

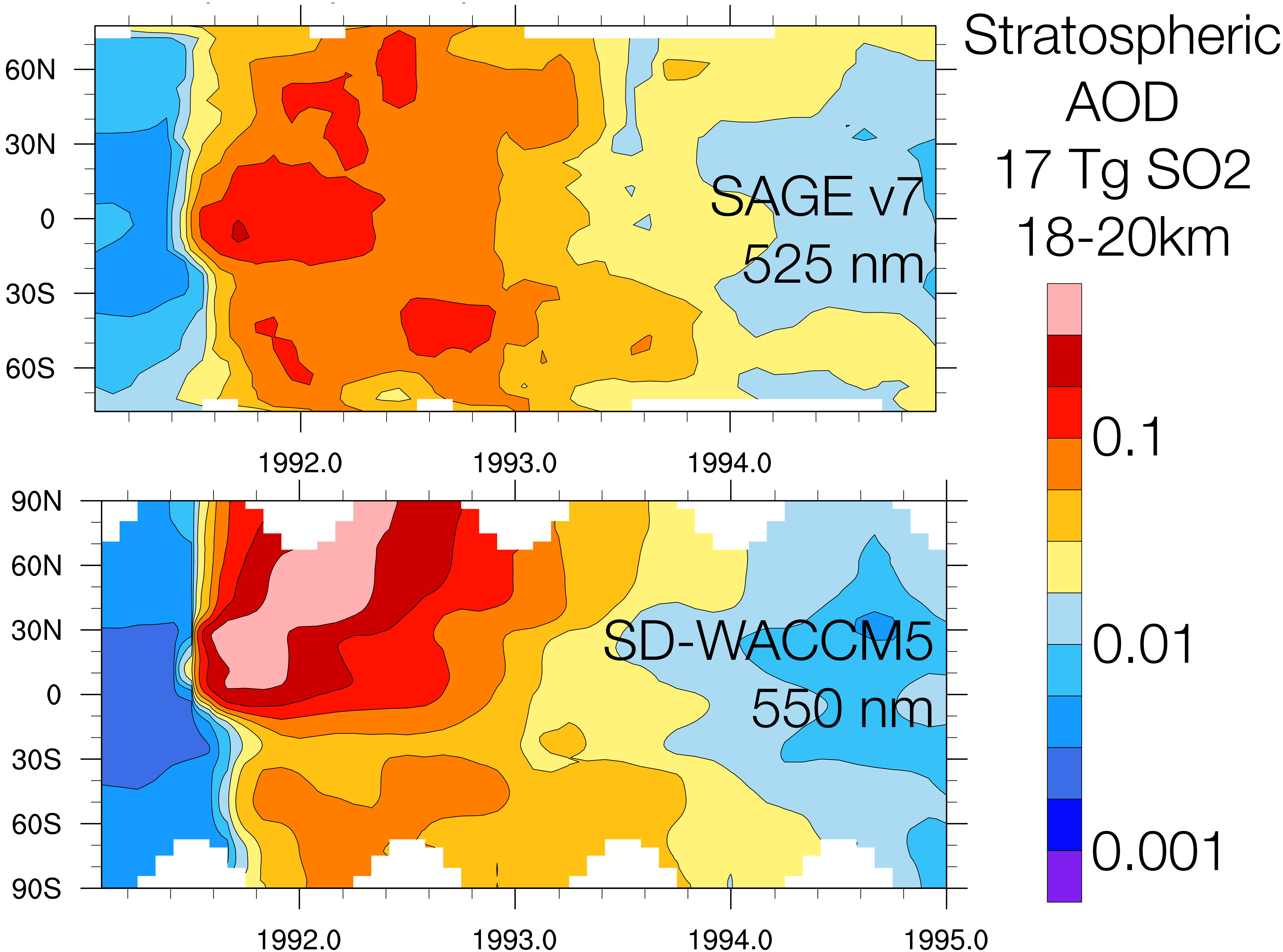
Guo et al., 2004: 15-19 Tg (initial), ~10 Tg within 1 week



CCMI input data file based on SAGE 4λ: 9.7 Tg (Arfeuille et al., 2013)




Stratospheric
AOD
17 Tg SO2
18-20km
SAGE v7
525 nm
FR-WACCM5
550 nm
60N
30N
0
30S
60S
90N
90S
1992.0
1993.0
1994.0
1995.0
0.1
0.01
0.001


Stratospheric
AOD
17 Tg SO2
18-20km
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525 nm
SD-WACCM5
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60N
30N
0
30S
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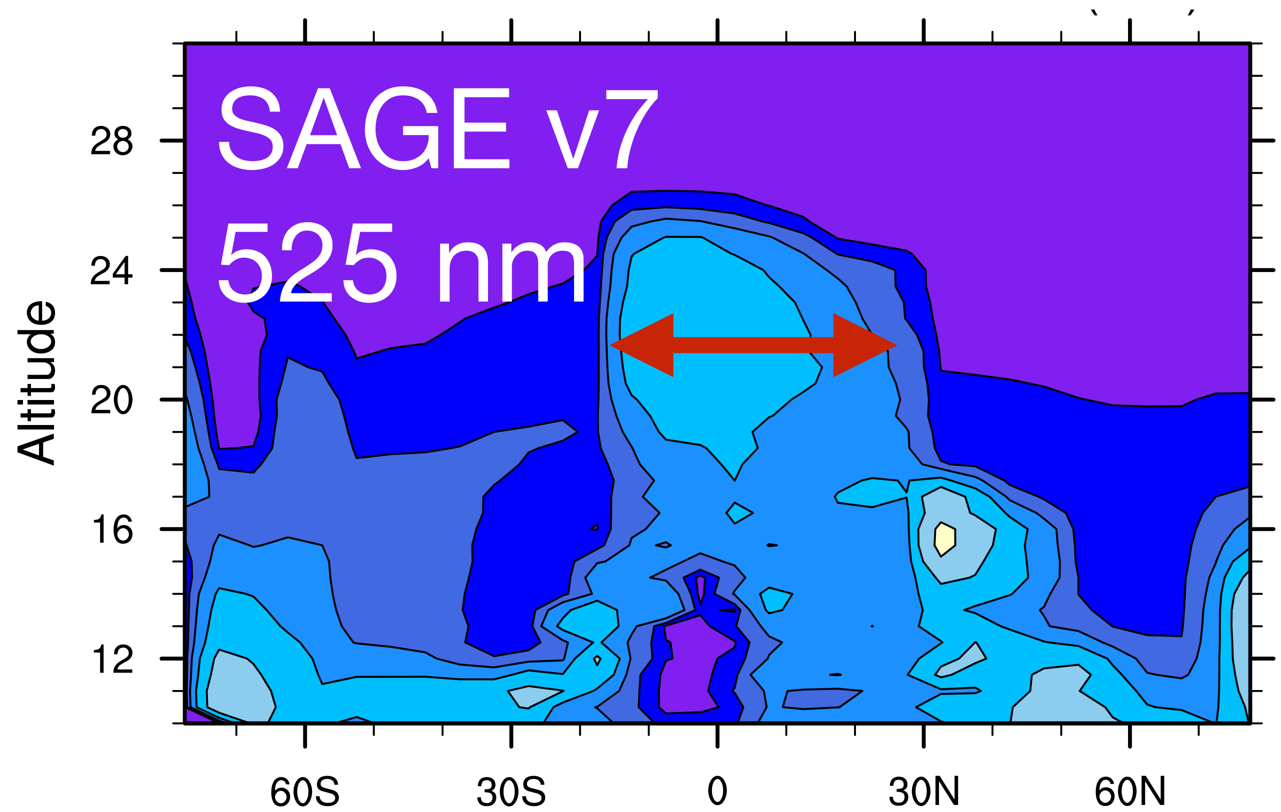
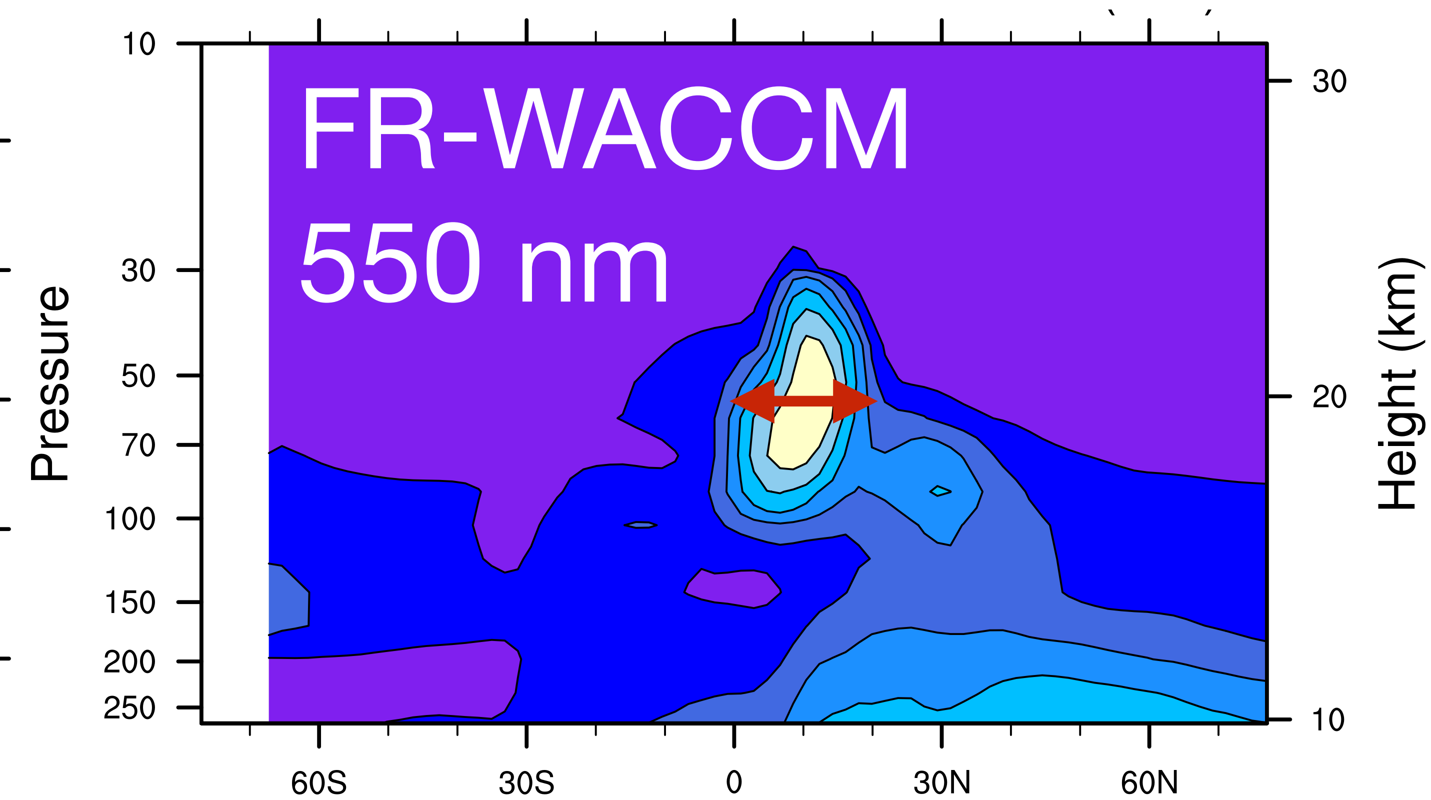
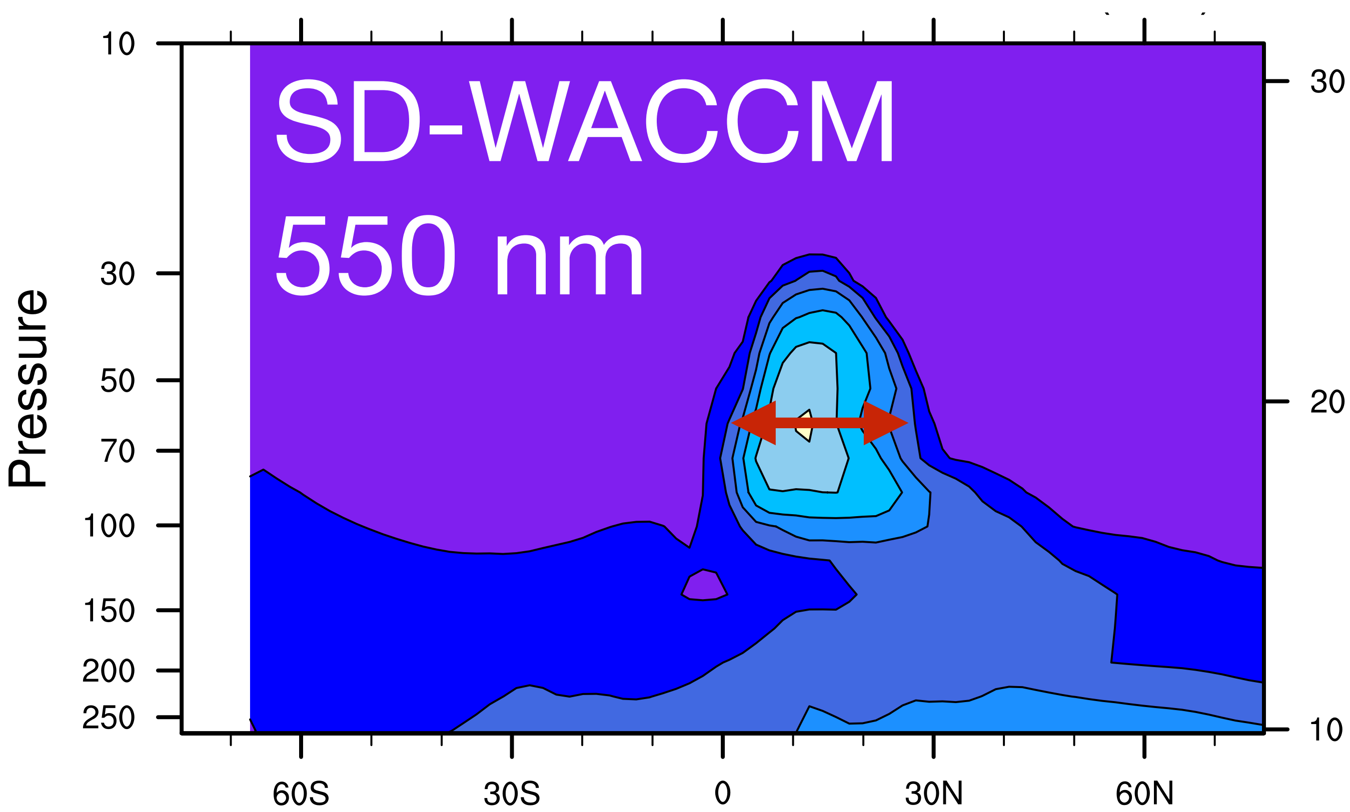
1993.0
1994.0
1995.0

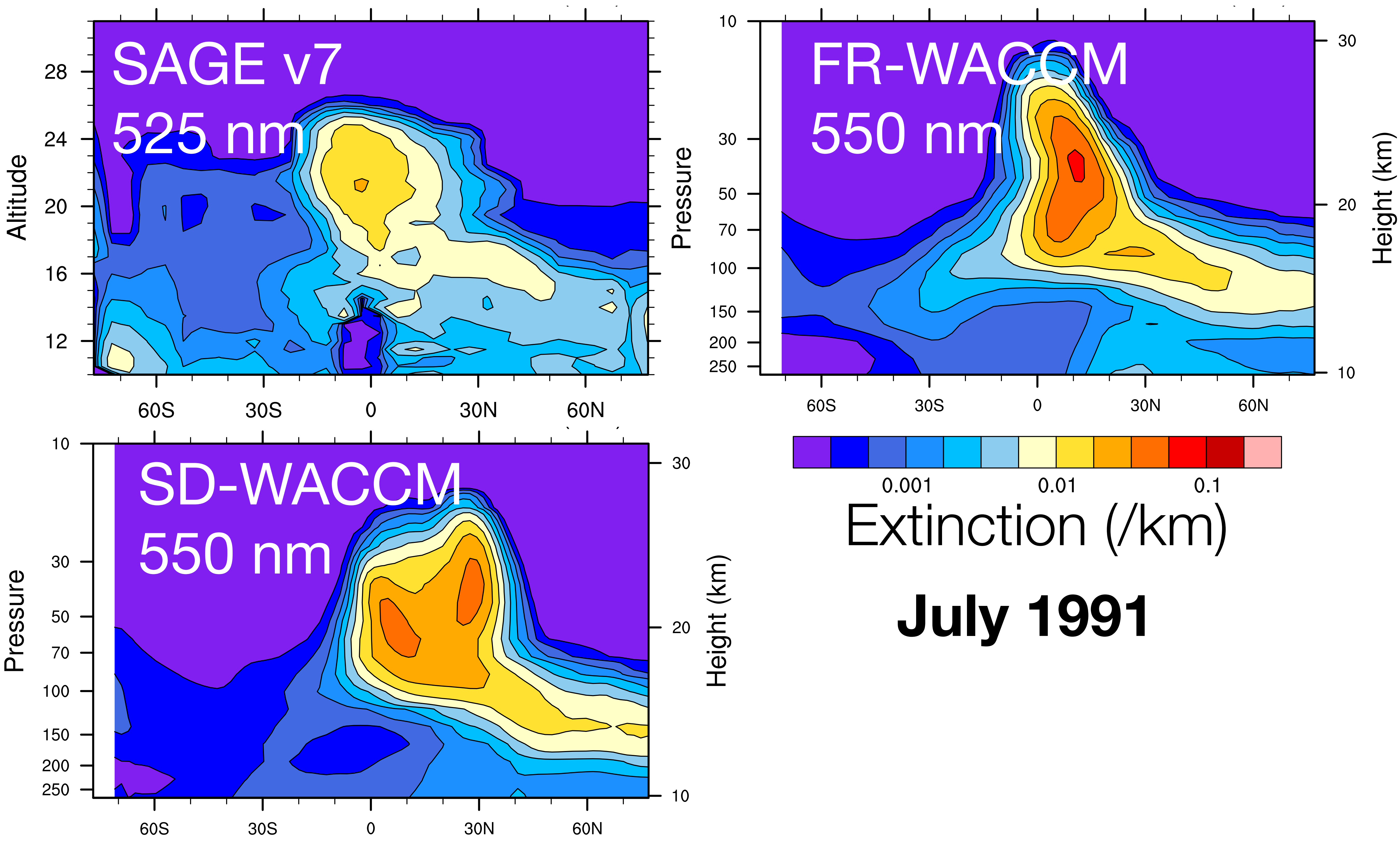


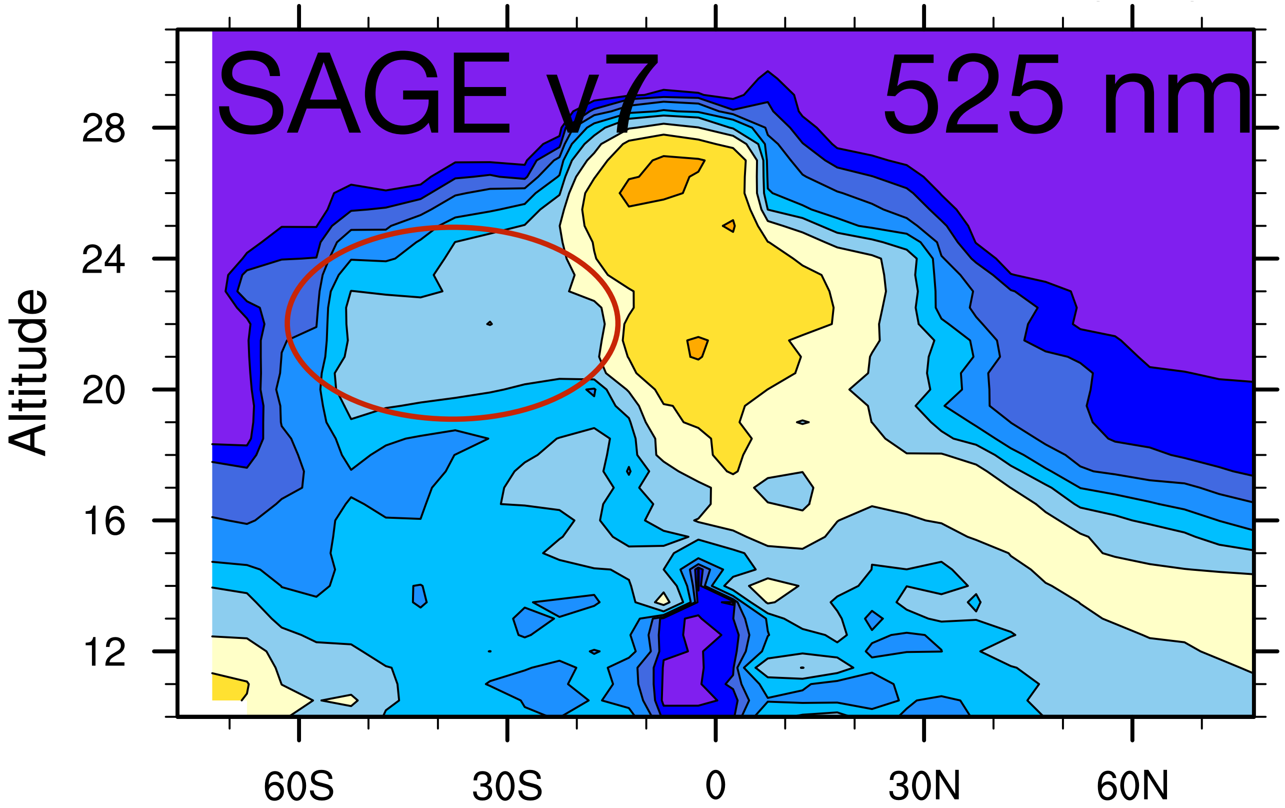


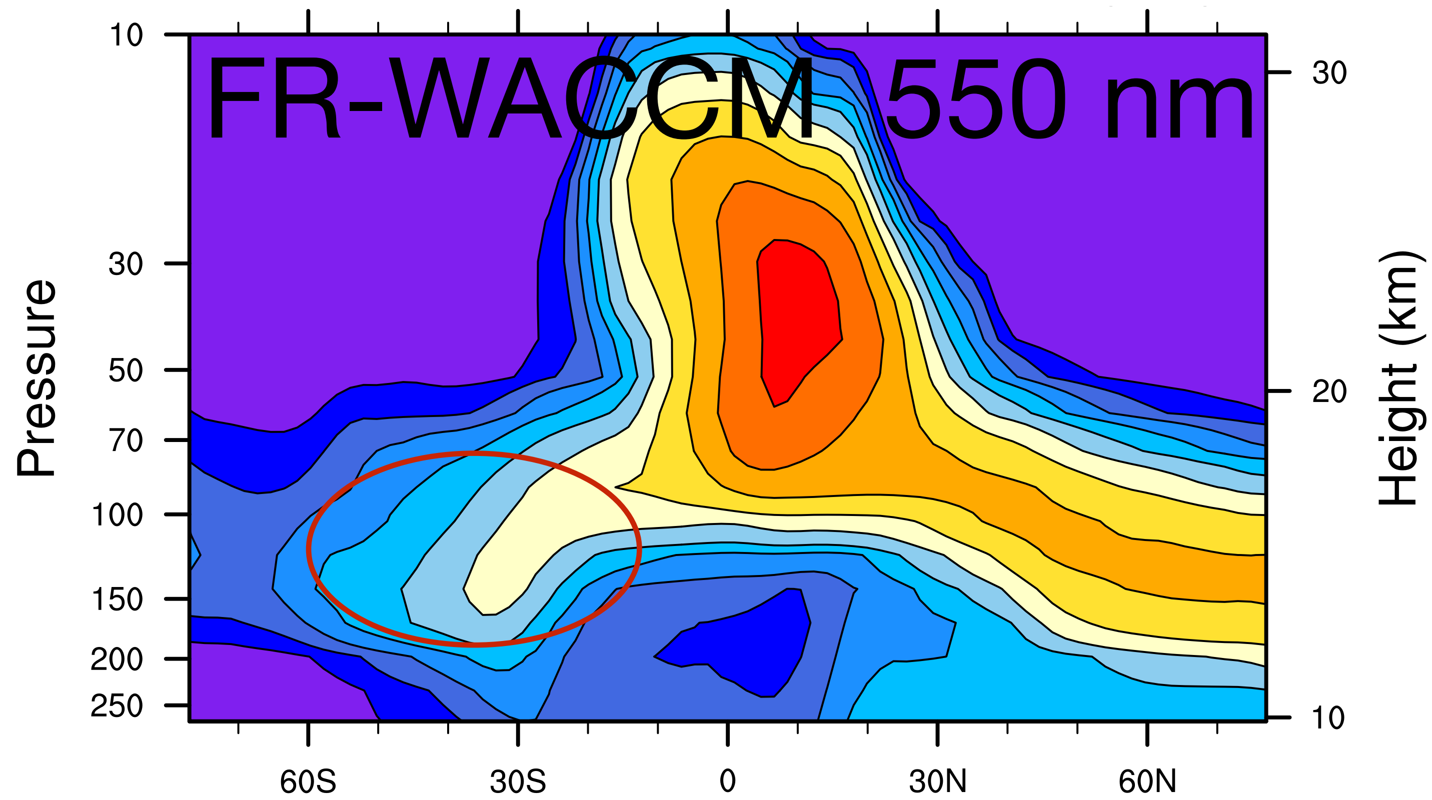


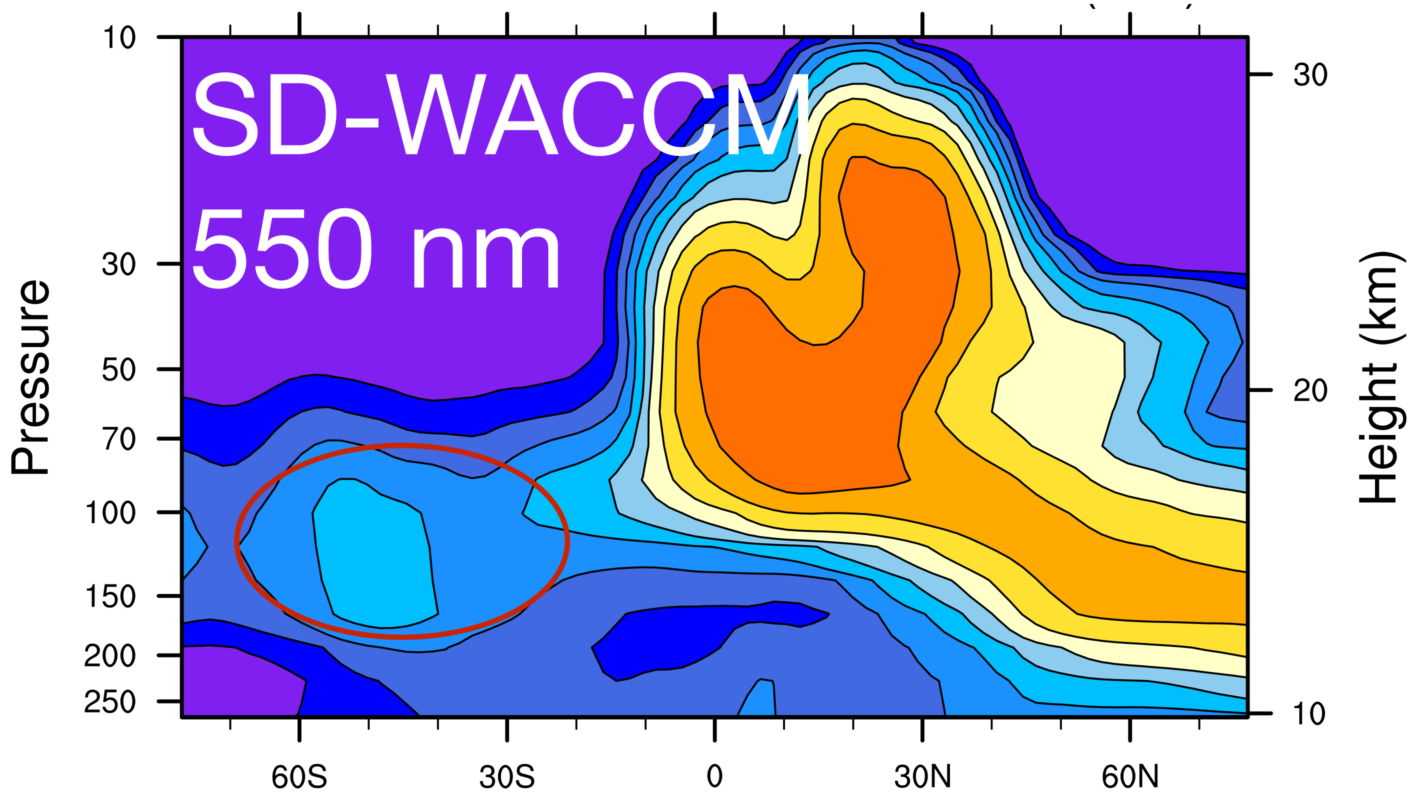
June 1991

Pinatubo


SAGE v7
525 nm
Altitude
28
24
20
16
12
60S
30S
0
30N
60N
FR-WACCM
550 nm
Pressure
10
30
50
70
100
150
200
250
Height (km)
30
20
10
SD-WACCM
550 nm
0.001
0.01
0.1
Extinction (/km)
July 1991

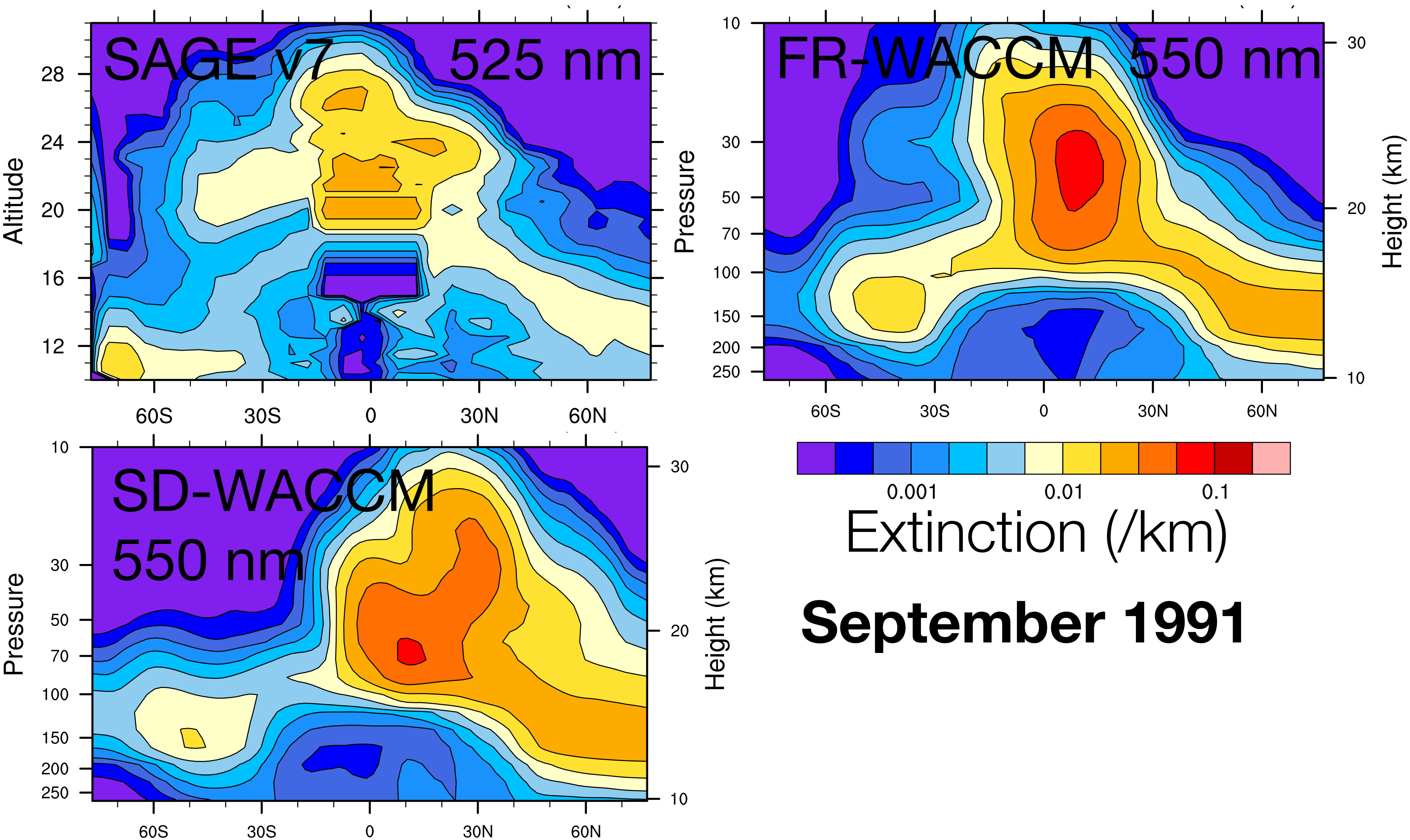




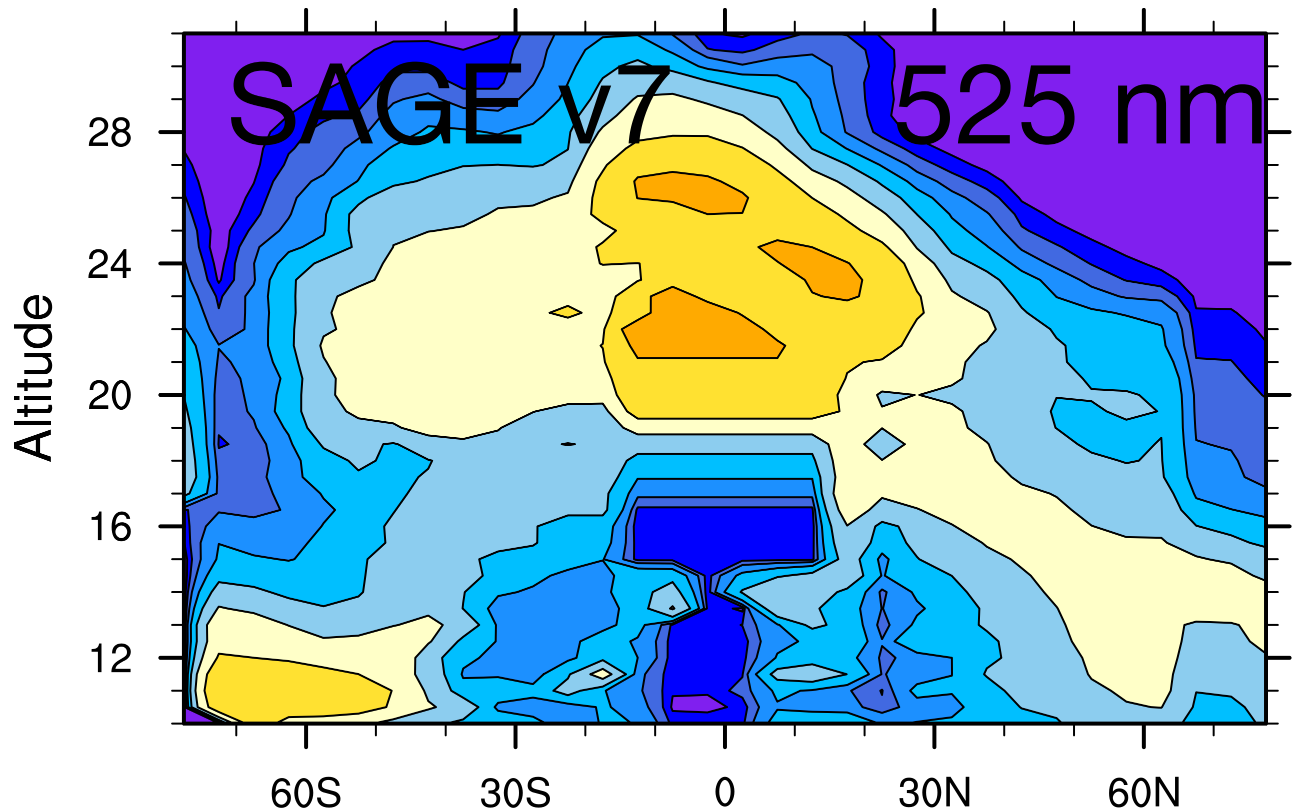


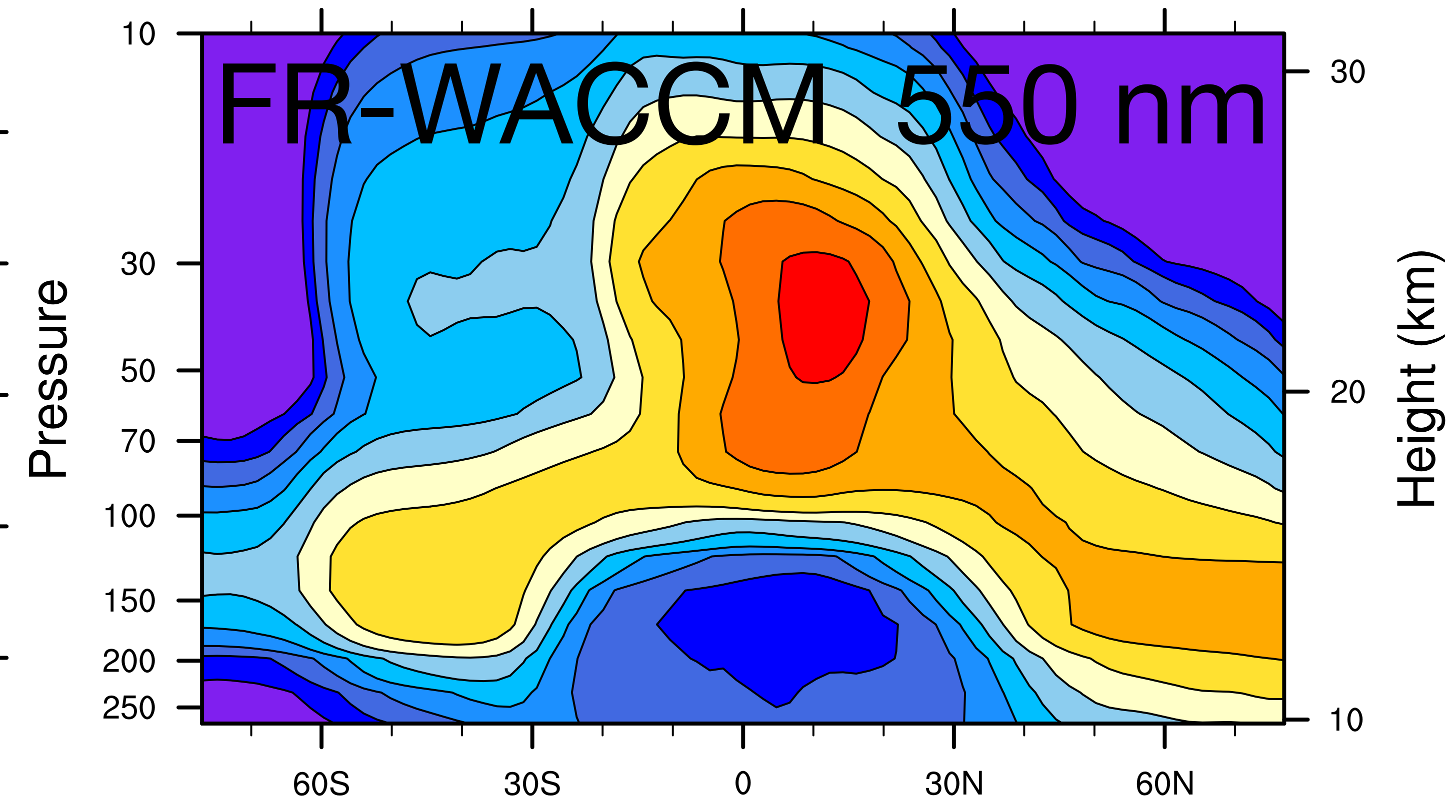
August 1991

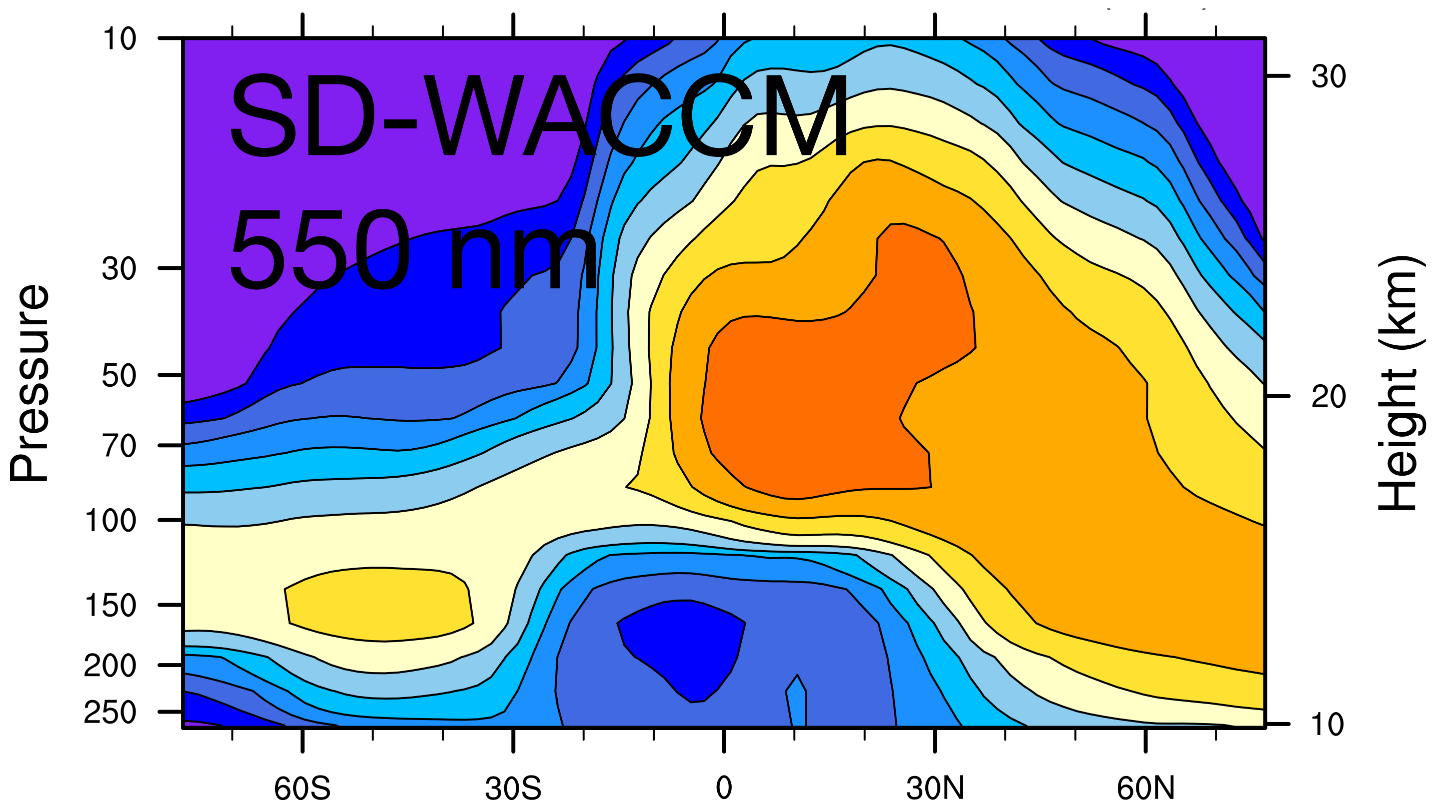
Cerro Hudson

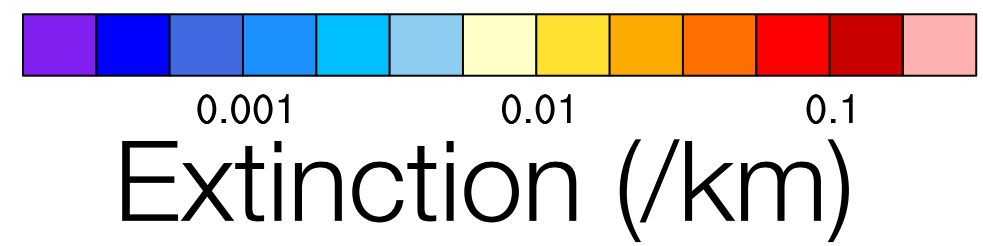


September 1991

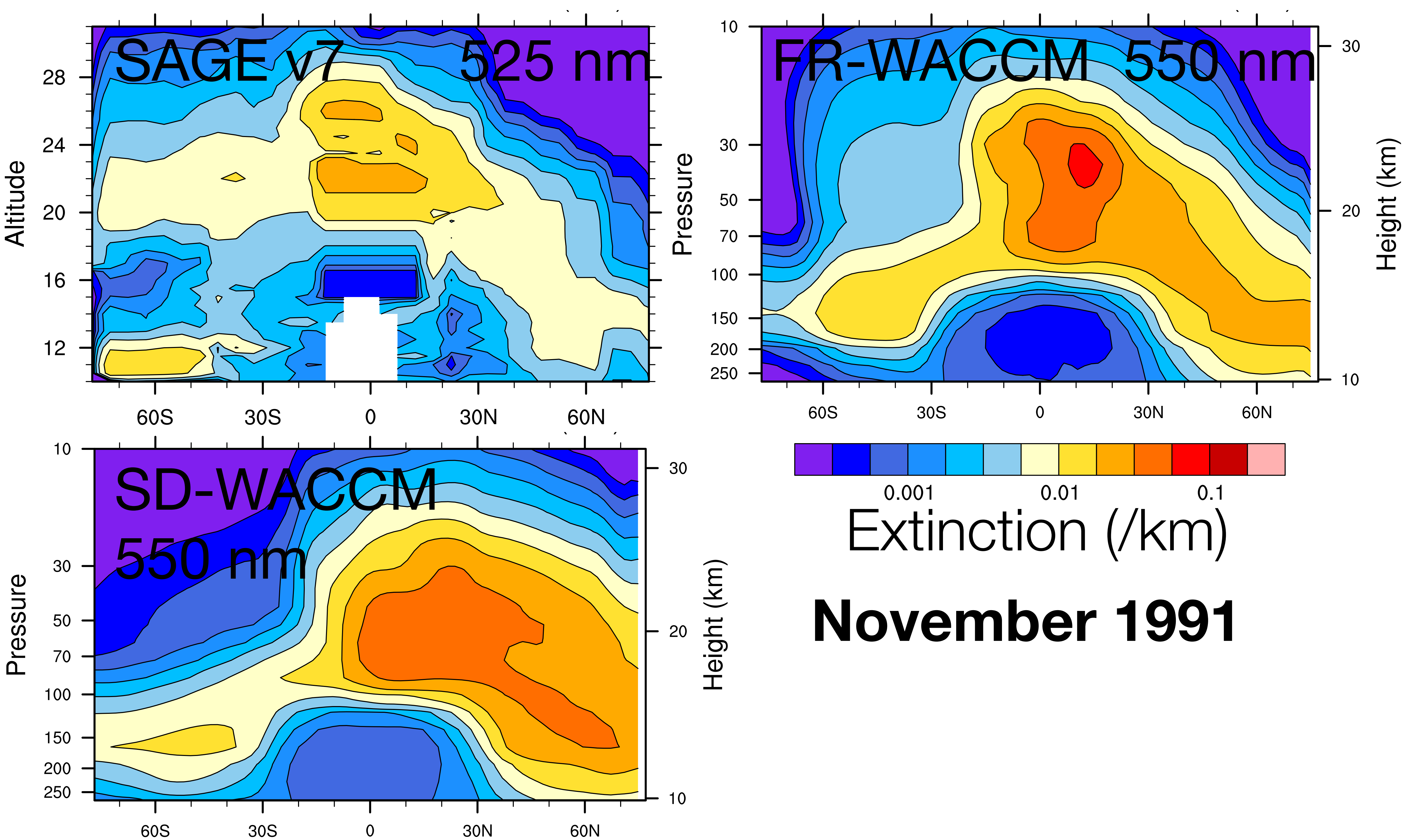




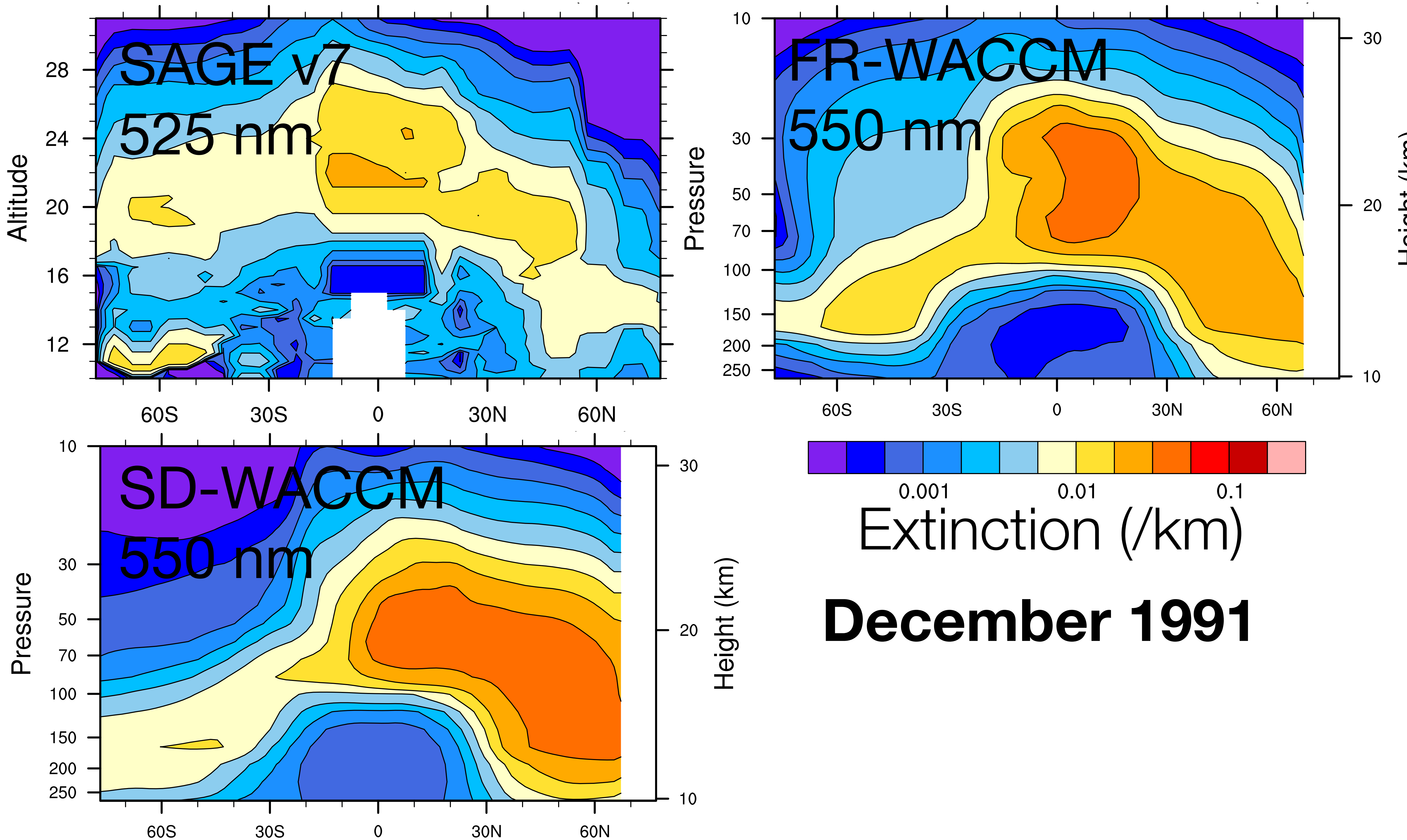




October 1991

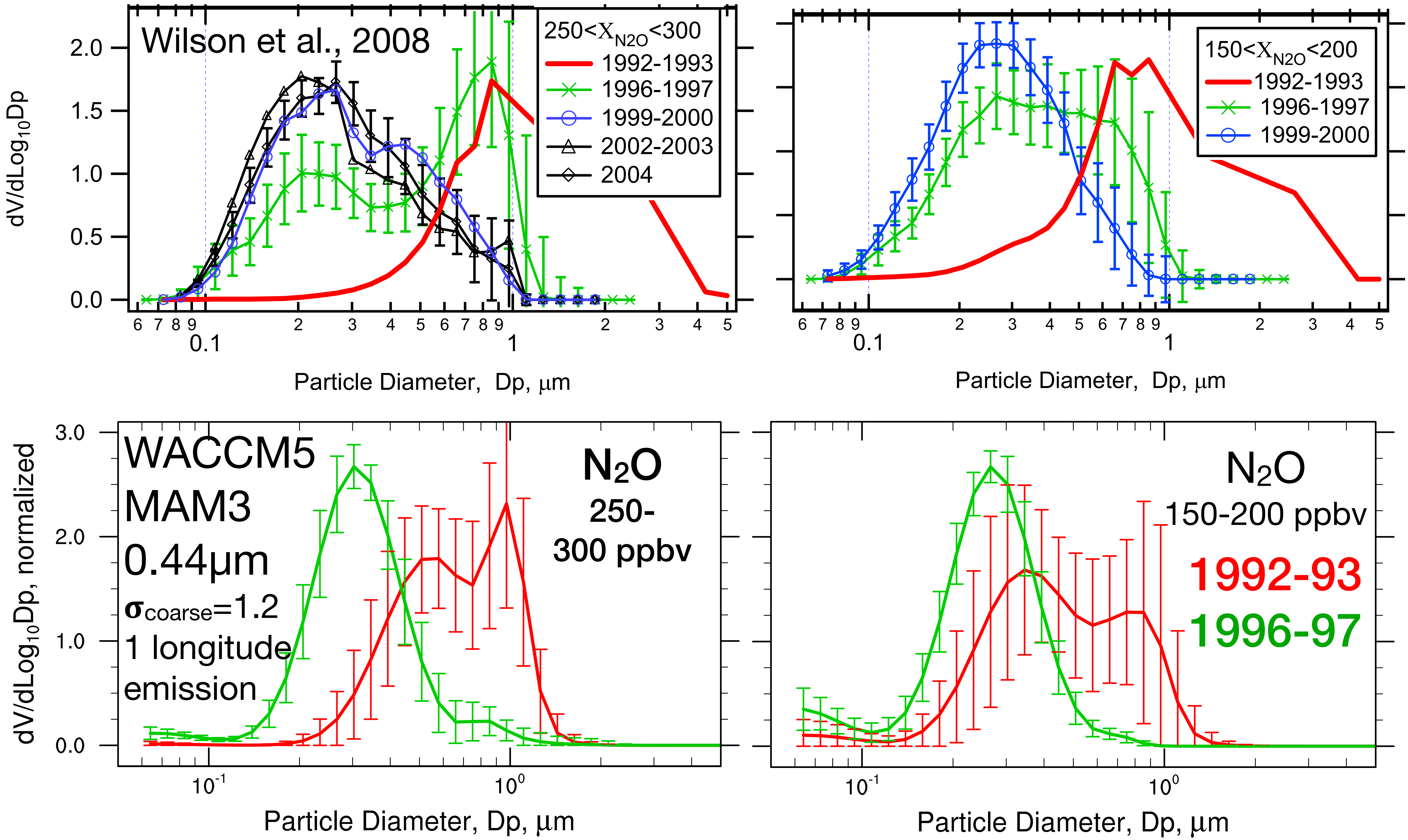


November 1991



December 1991

Volume size distributions compared to observations



Summary: prognostic stratospheric sulfates with MAM

- MAM3 adapted for stratospheric sulfates: mode definition, accumulation-coarse exchange, sulfate evaporation above the tropopause
- Time-varying OCS LBC added for WACCM & CAM-chem runs, SO_2 external forcing file developed for CAM
- 1850 control run with CCMI chemistry tuned, 20th Century run completed with no volcanoes prior to Pinatubo
- Volcanic input file developed for 1990-2011, plans to extend back to 1850
- Currently testing sensitivity to input altitude, latitude, and mass with comparison to SAGE v7 data set of extinction and optical depth
- Preparing GeoMIP “G4” experiment, years 2020-2070 with 5 Tg SO2/year compared to control