NATURAL ENVIRONMENT RESEARCH COUNCIL

The influence of meteoric smoke particles (MSPs) on stratospheric aerosol properties

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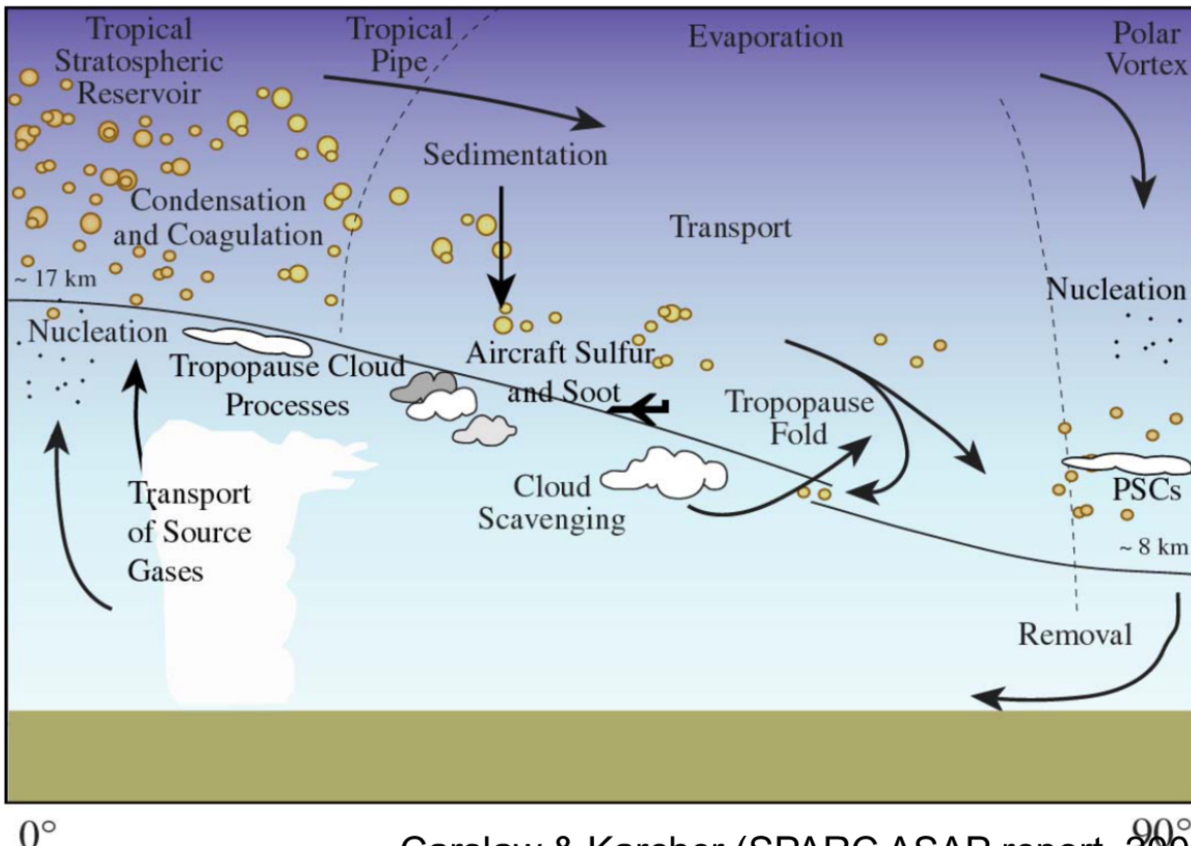
Meteoric Smoke Particles (MSP)

- Ablation of micrometeorites in the mesosphere results in the formation of MSPs -- initially at nm sizes (Hunten et al., 1980) but at number conc'ns ~1000 cm^{-3} in the upper stratosphere,
- Particle concentrations decrease and particle sizes increase during descent to the lower stratosphere and MSPs have the potential to strongly influence the Junge layer (Turco et al. 1982)
- The main way the MSPs influence the Junge layer is to provide additional condensation nuclei which compete with homogeneously-nucleated particles for available H_2SO_4 vapour
- Reactive uptake of gas phase sulphuric acid to MSP surfaces also occurs above 35km where H_2SO_4-H_2O particles evaporate.
- MSPs are most prevalent in the wintertime polar vortex COPAS measurements (Curtius et al. 2005) show ~12-45% of particles contain refractory cores outside of polar vortex
- Aircraft measurements (Murphy et al., 1998; Cziczo et al., 2001) ~50% strat aerosol particles contain ~1-2 wt% meteoric material.

MSPs & stratospheric aerosol

- Meteoric smoke particles form in mesosphere & transported into the polar stratosphere but interactive stratospheric aerosol models include only limited representation of their effects (if any)

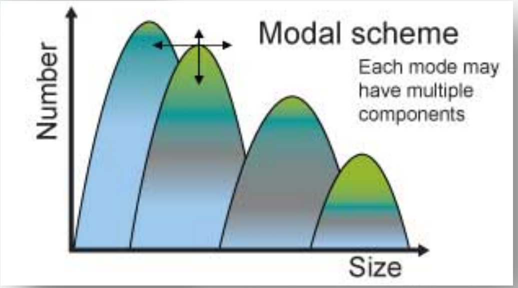
Q: How does the presence of the MSPs alongside the homogeously nucleated particles affect the Junge layer?



Carslaw & Karcher (SPARC ASAP report, 2006)

UK Chemistry and Aerosol project

- Collaboration between UK National Centre for Atmospheric Science (Leeds, Cambridge, Oxford) & UK Met Office since 2005
- Has built aerosol-chemistry sub-model in the UK Met Office Unified Model, being applied for a range of applications (climate, air quality, Earth system science, weather)
- Chemistry schemes & aerosol configurations including for stratosphere-troposphere



- Multi-component aerosol microphysics scheme (GLOMAP)
- Global variations in particle size distribution → sedimentation and SW & LW radiative effects

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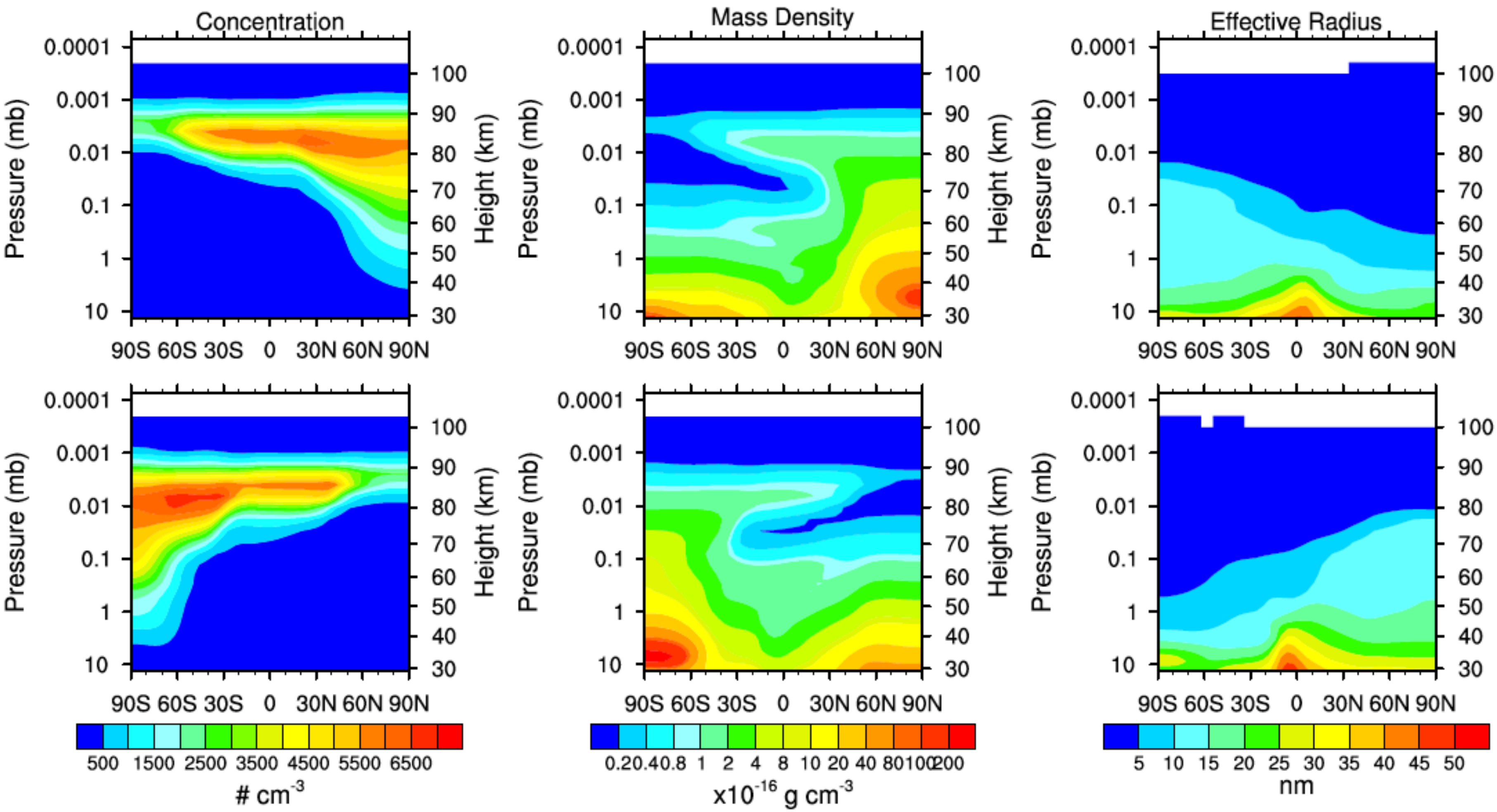
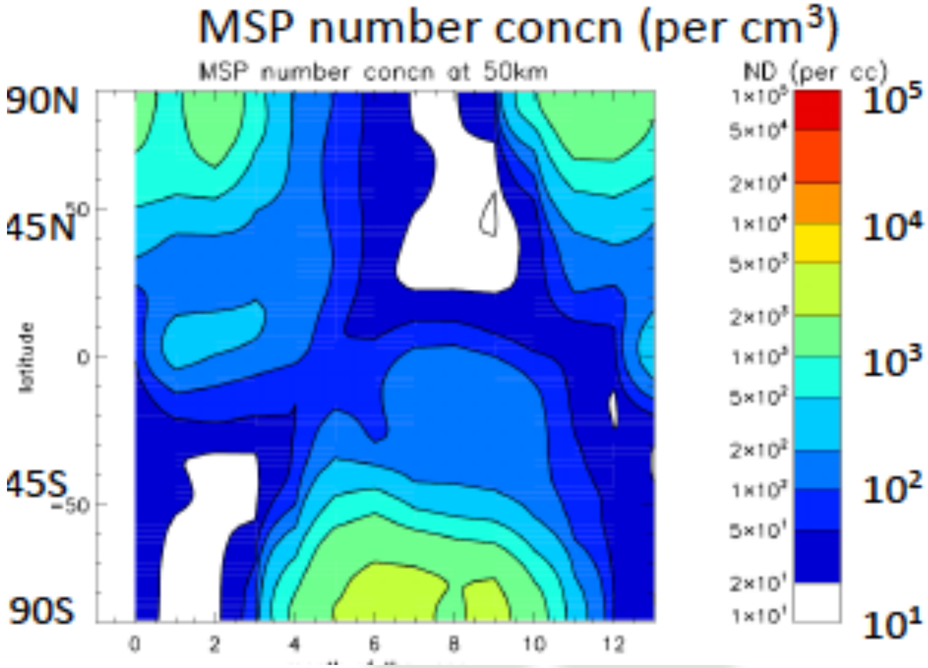
- UK Earth System model in development (UKESM) will simulate strat-trop ozone and strat-trop aerosol interactively and radiatively coupled with composition-dynamics interactions

Distribution of MSP simulated by WACCM-CARMA (120km top, bin-resolved aerosol scheme)



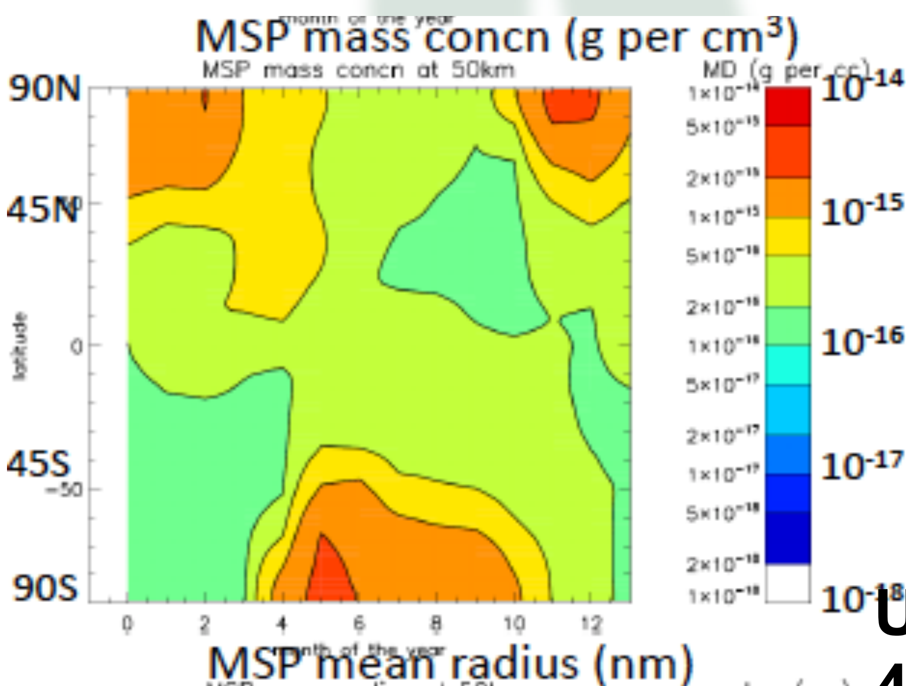
Top: January-mean
Bottom: July-mean

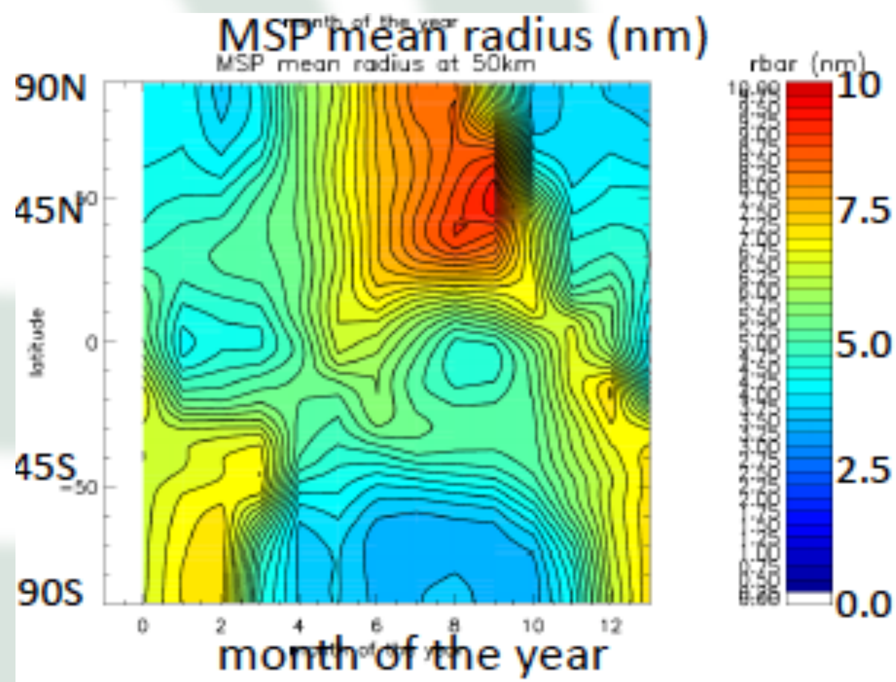
Bardeen et al. (2008)



Introduce zonal-mean MSP number & mass mixing ratio from WACCM-CARMA into UM-UKCA

Over-write UM-UKCA tracer values for p<0.2hPa





Upper limit MSP input flux of 40 kt/yr (Love & Brownlee, 1993)

3. MSP added to UM-UKCA within GLOMAP-mode

a) Include MSPs within existing accumulation insoluble mode (but size restrictions removed to allow to cover terrestrial and extra-terrestrial dust.

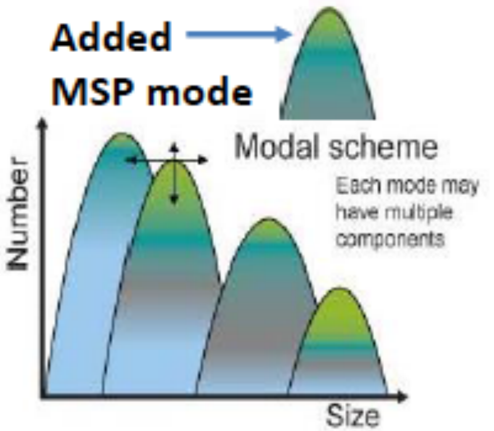


Fig 2a. Schematic of modal representation GLOMAP-mode aerosol microphysics scheme (Mann et al., 2010)

(*) We prescribe number- and mass- mixing ratios of MSP p<0.2hPa based on WACCM-CARMA sectional runs (Bardeen et al. , 2008).

b)

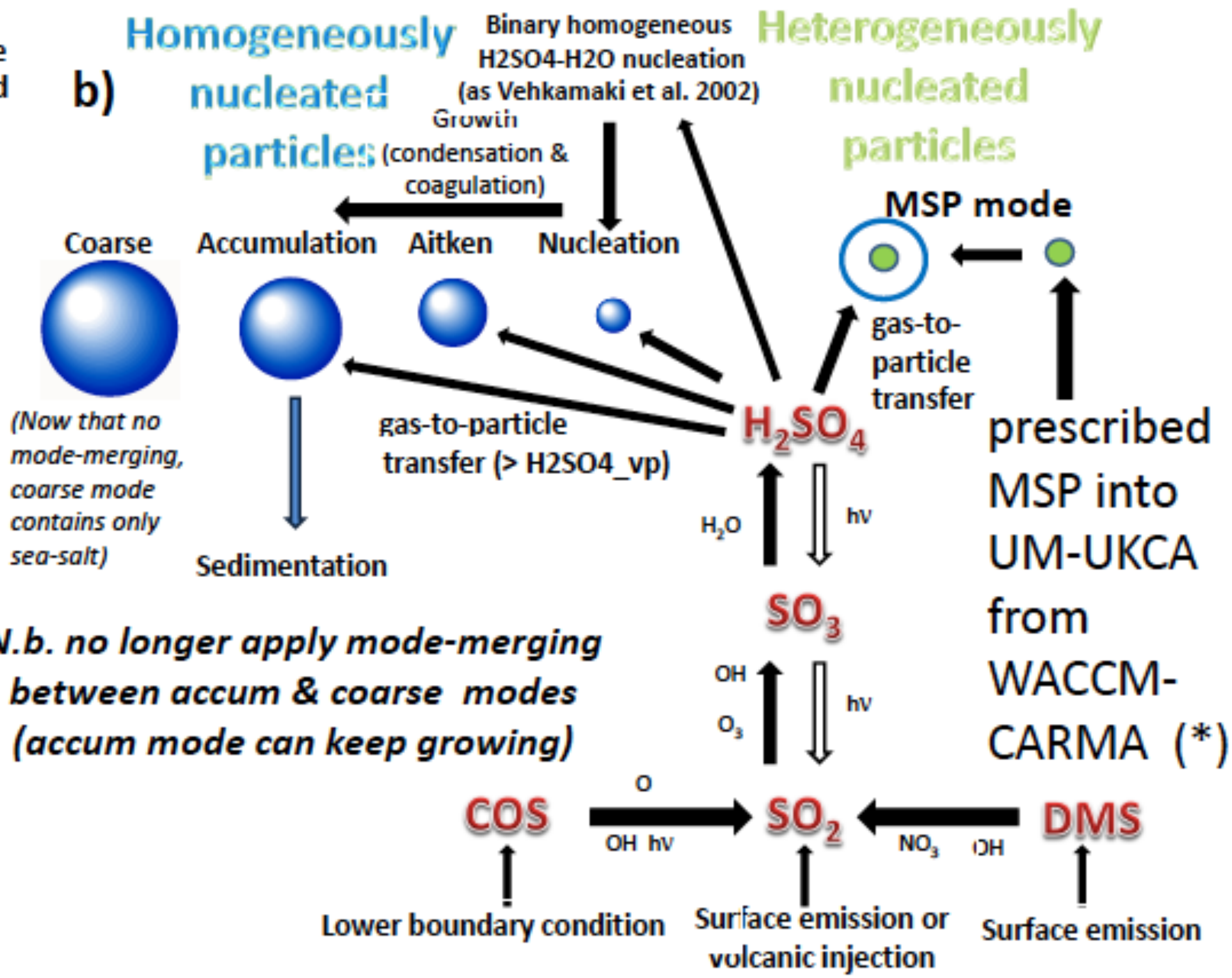
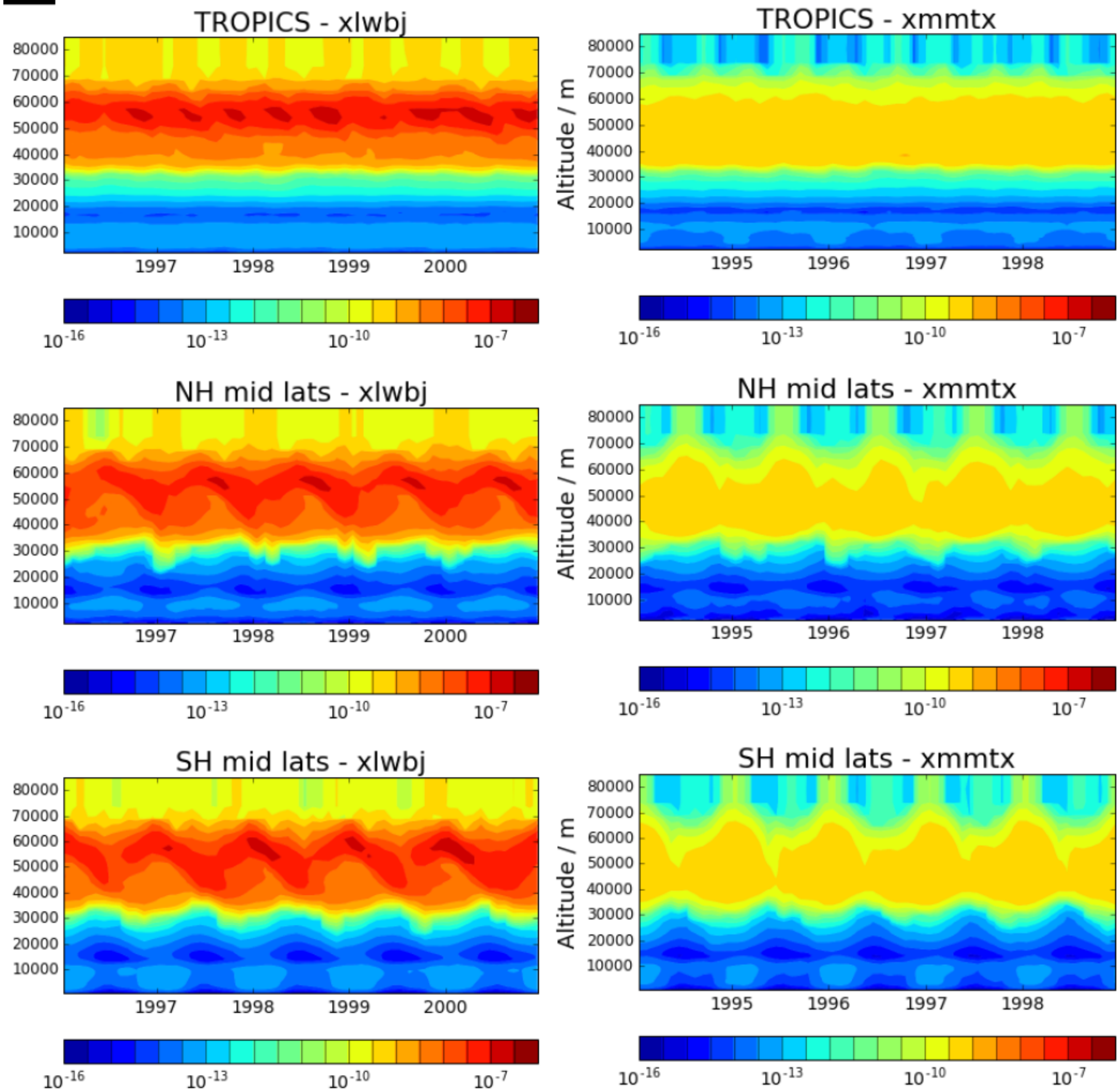


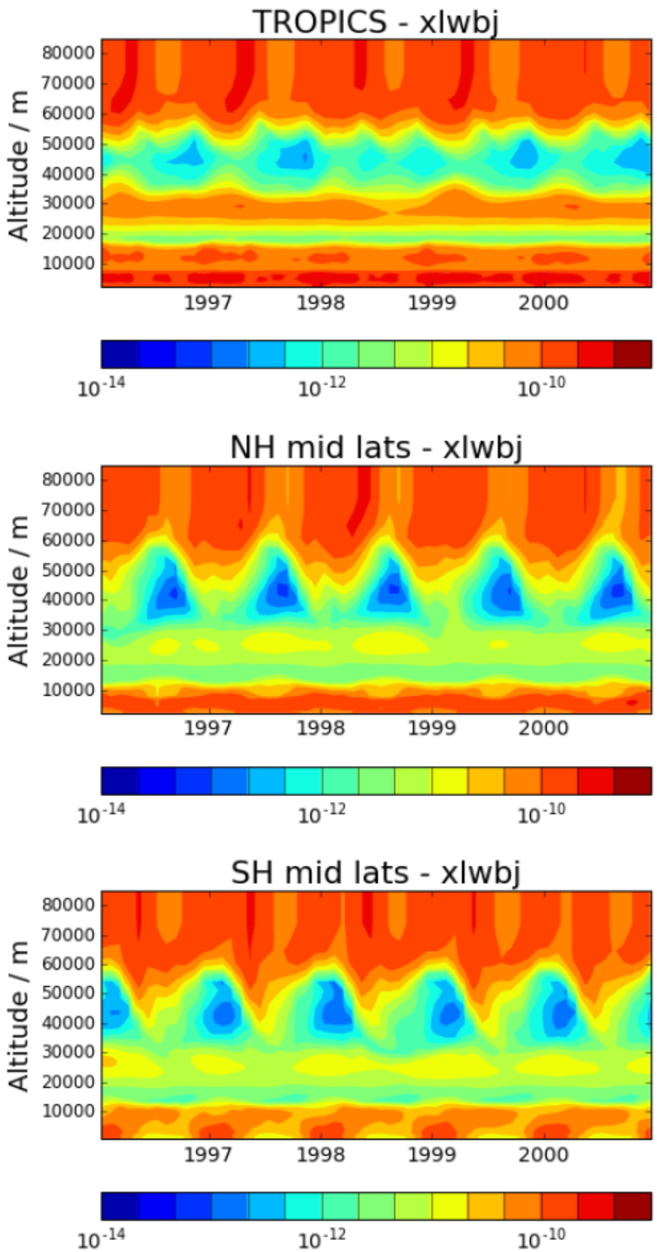
Fig 2b. Schematic of UM-UKCA stratospheric sulphur chemistry and coupling to GLOMAP-mode aerosol microphysics (see Dhomse et al., 2014)

$H_2SO_4(g)$: no MSP

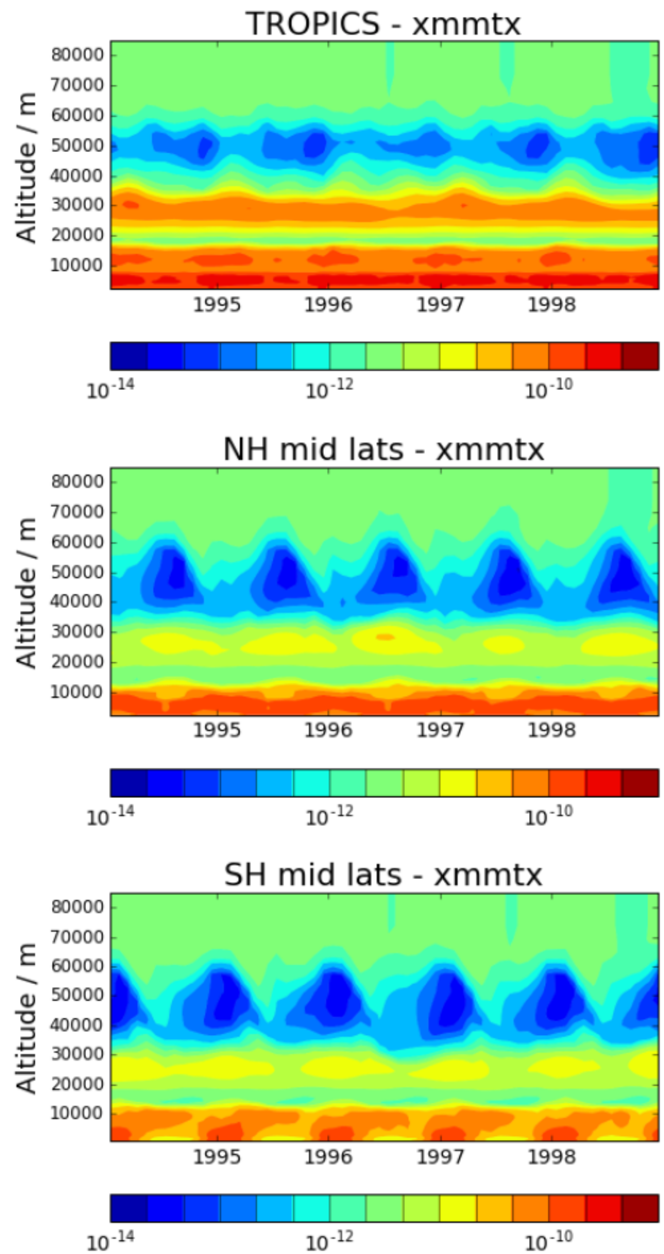
$H_2SO_4(g)$: withMSP



SO_2(g) : no MSP

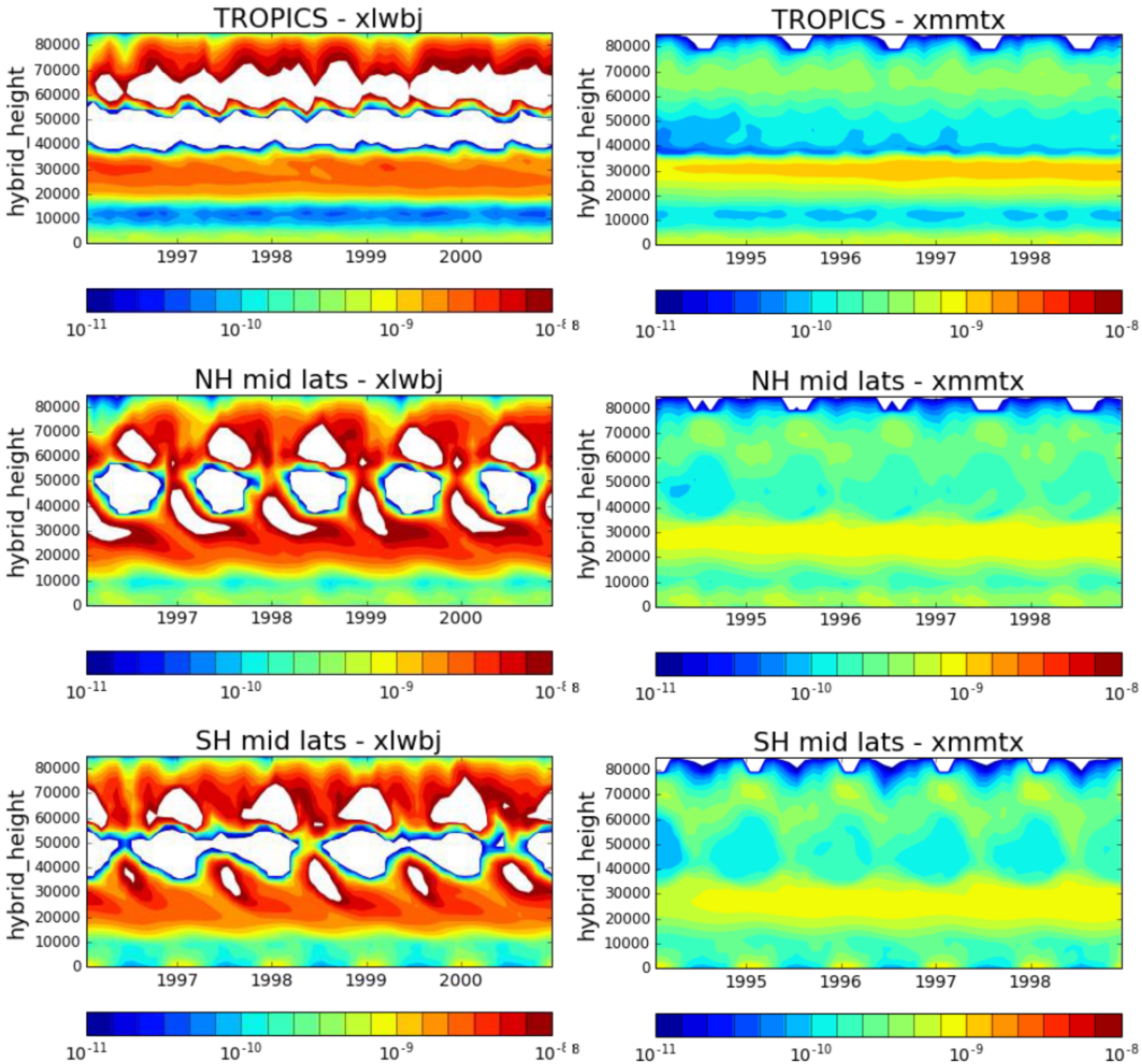


SO_2 (g) : withMSP

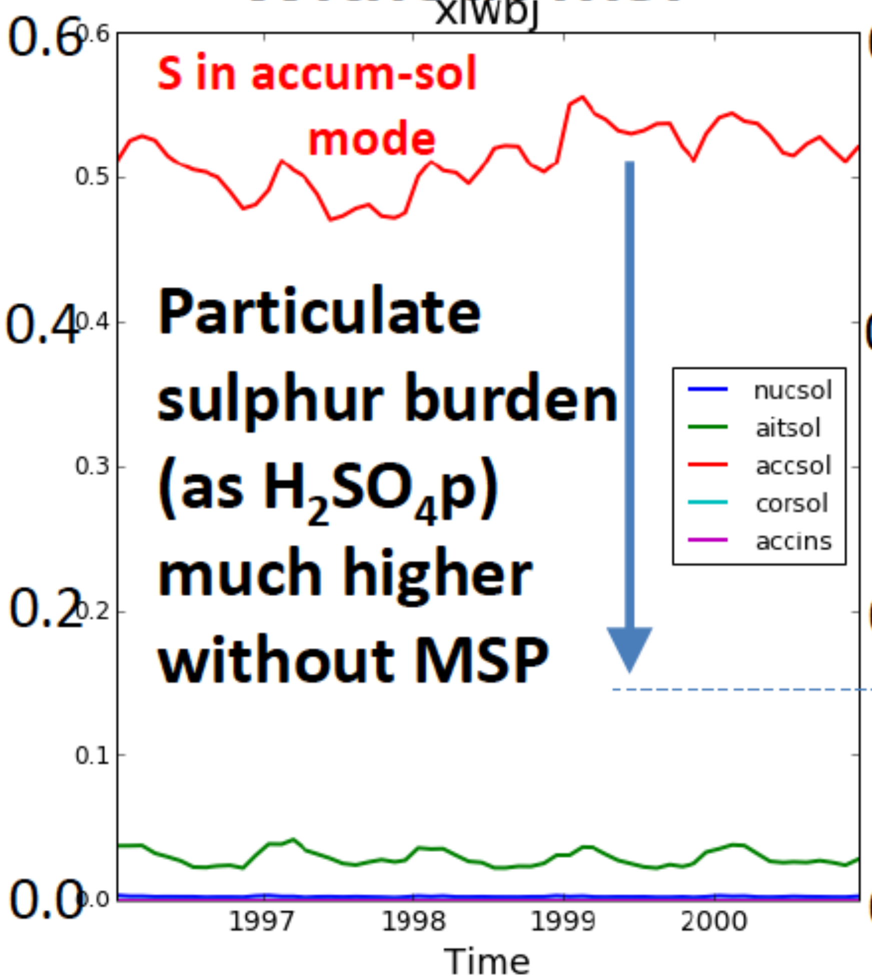


H_2SO_4(p) : no MSP

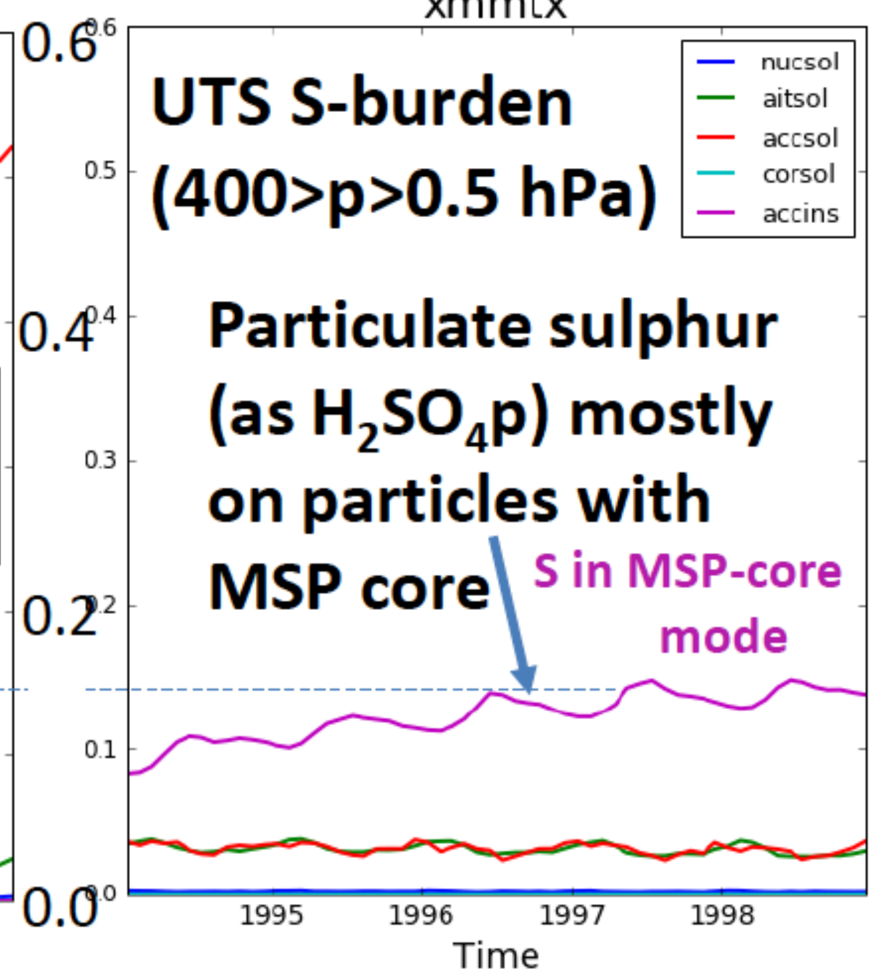
H_2SO_4 (p) : withMSP



Without MSP



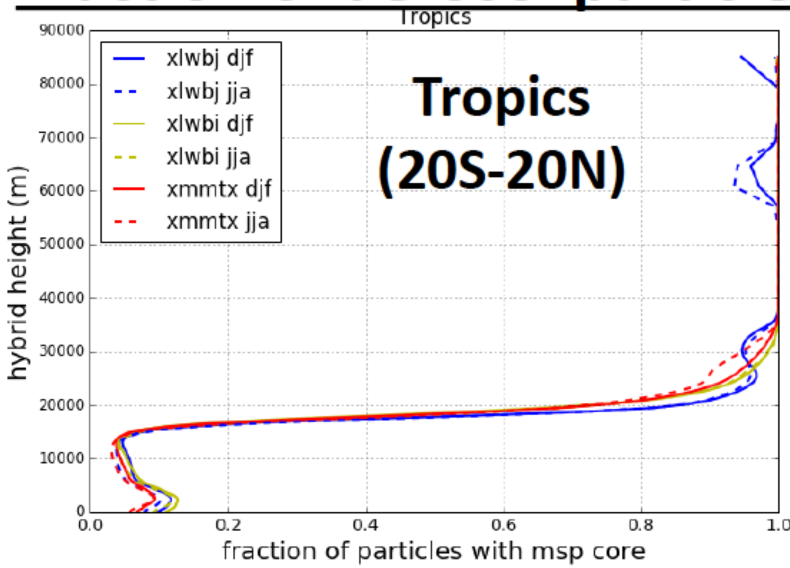
With MSP interaction

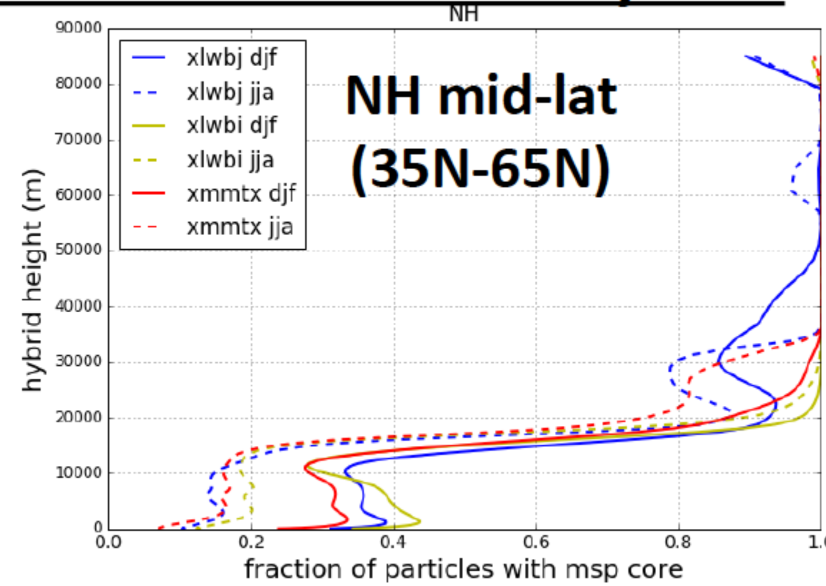


UTS particle sulphur burden decreases as vertical

SO4 distribution shifts towards tropopause

Fraction of aerosol particles which contain refractory core

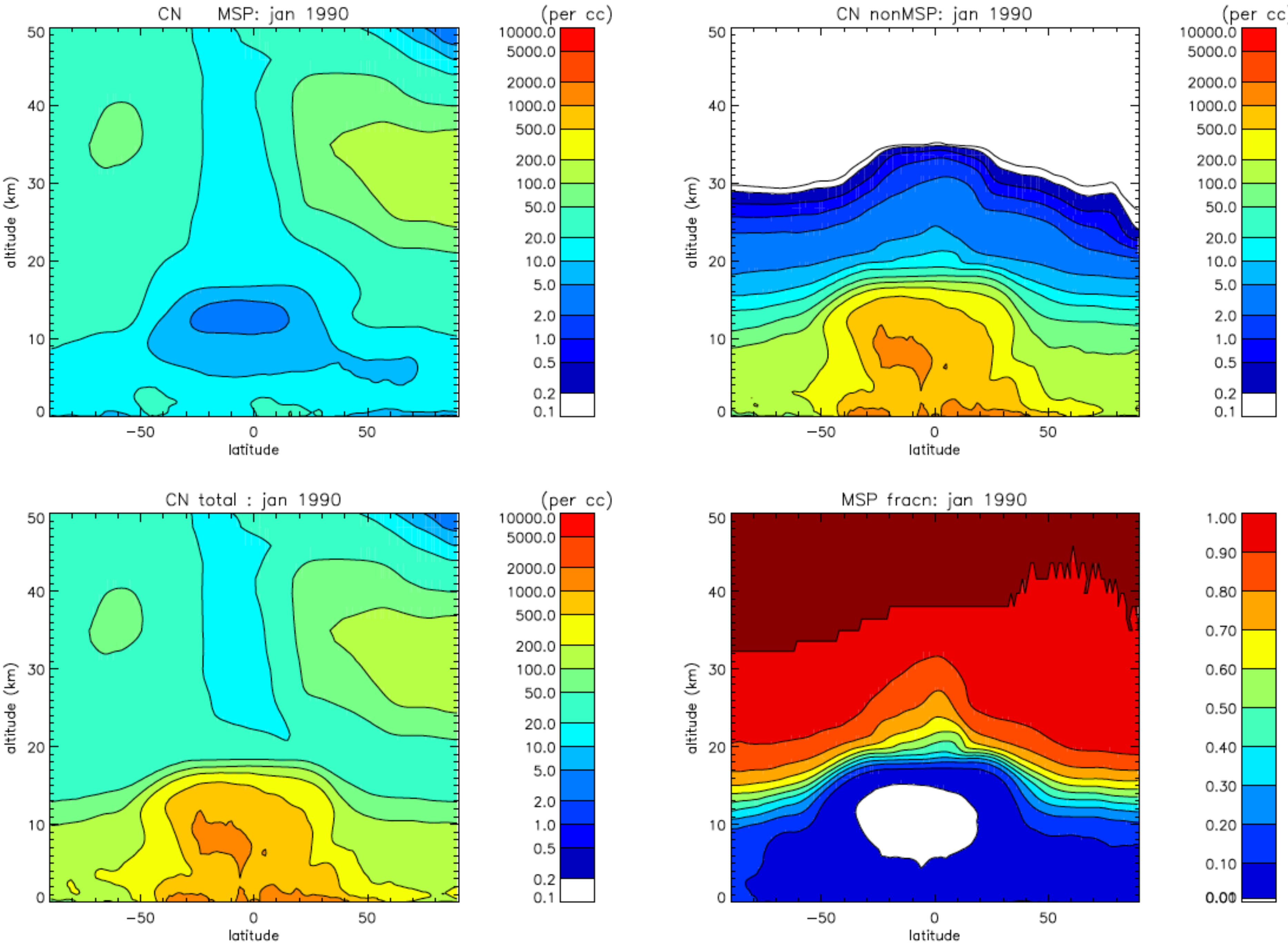




We find that, at least for this upper-limit MSP input flux, the stratospheric aerosol is dominated by MSP-core particles in all but the lowermost stratosphere. *(Note that terrestrial mineral dust is also tracked in this mode. In the troposphere the refractory –core particles will be mostly coated dust.)*

Summary

- Composition-climate model experiments with interactive tropospheric & stratospheric chemistry and aerosol to assess the influence of MSPs on stratospheric aerosol properties
- MSPs remove H_2SO_4 vapour from the gas phase even above the Junge layer since their surfaces are chemically reactive
- MSP reduces gas phase H_2SO_4 & SO_2 concentrations > 35km
- Sulphur burden reduced due to change in vertical distribution
- Results suggest MSP-core (heterogeneously nucleated) particles dominate aerosol particle population throughout the Junge layer
- Have used “upper-limit-estimate” of MSP input flux (40 kt/yr)
- Simulations using a new “best-estimate” input flux of 5 kt/yr being spun-up → initial results suggest a factor ~20 lower MSP number concentrations in lower stratosphere with reduced particle size.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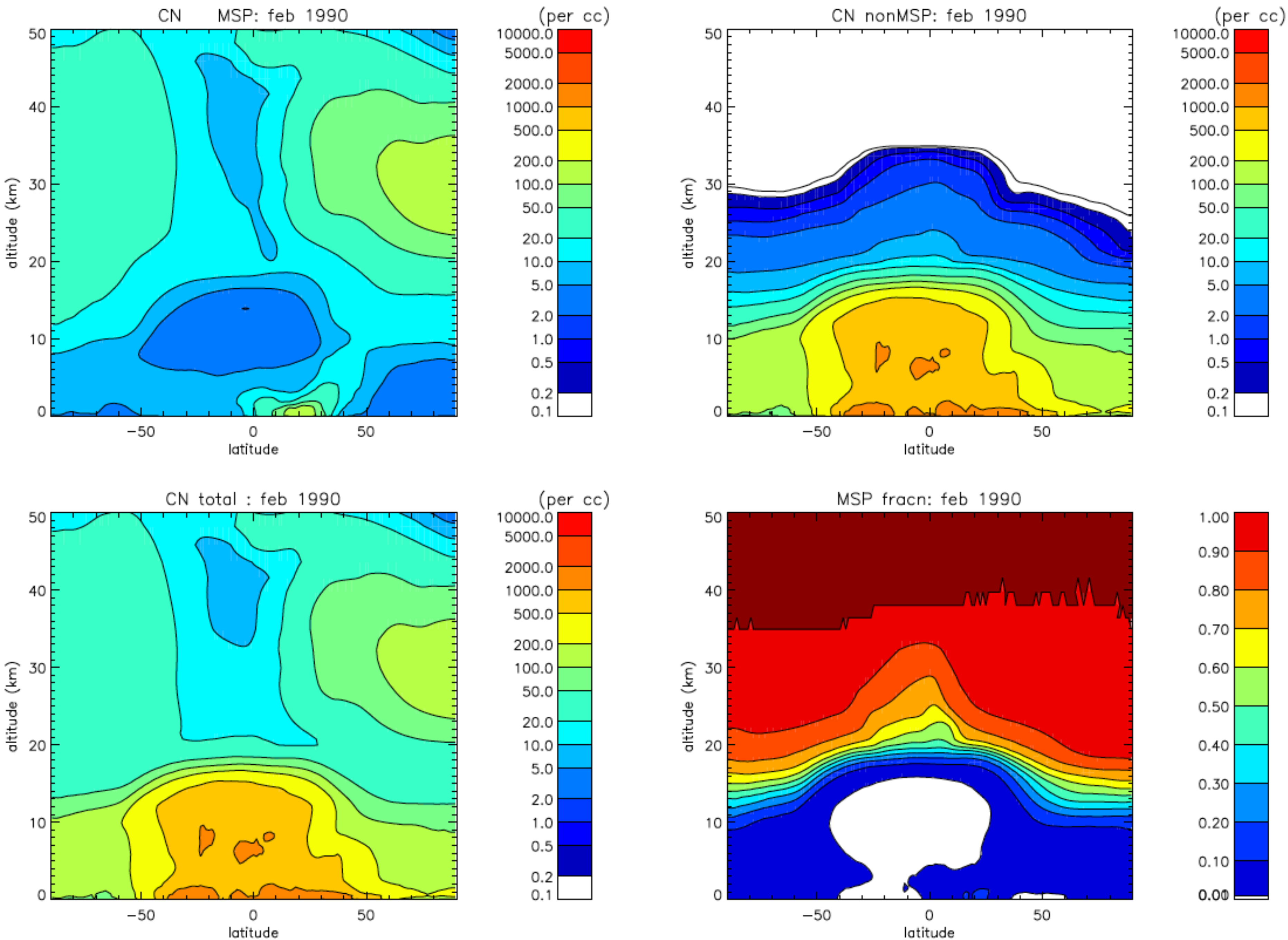
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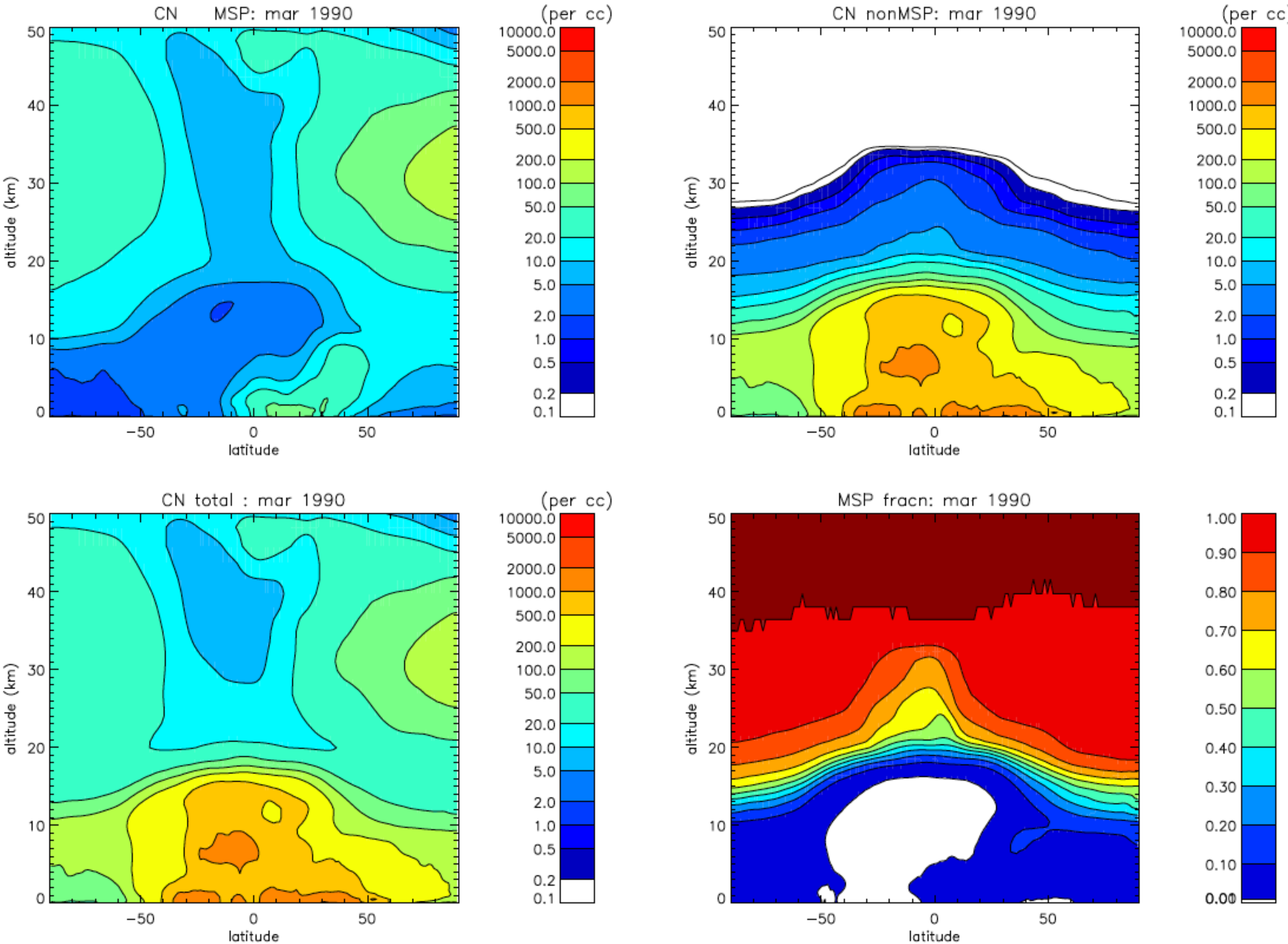

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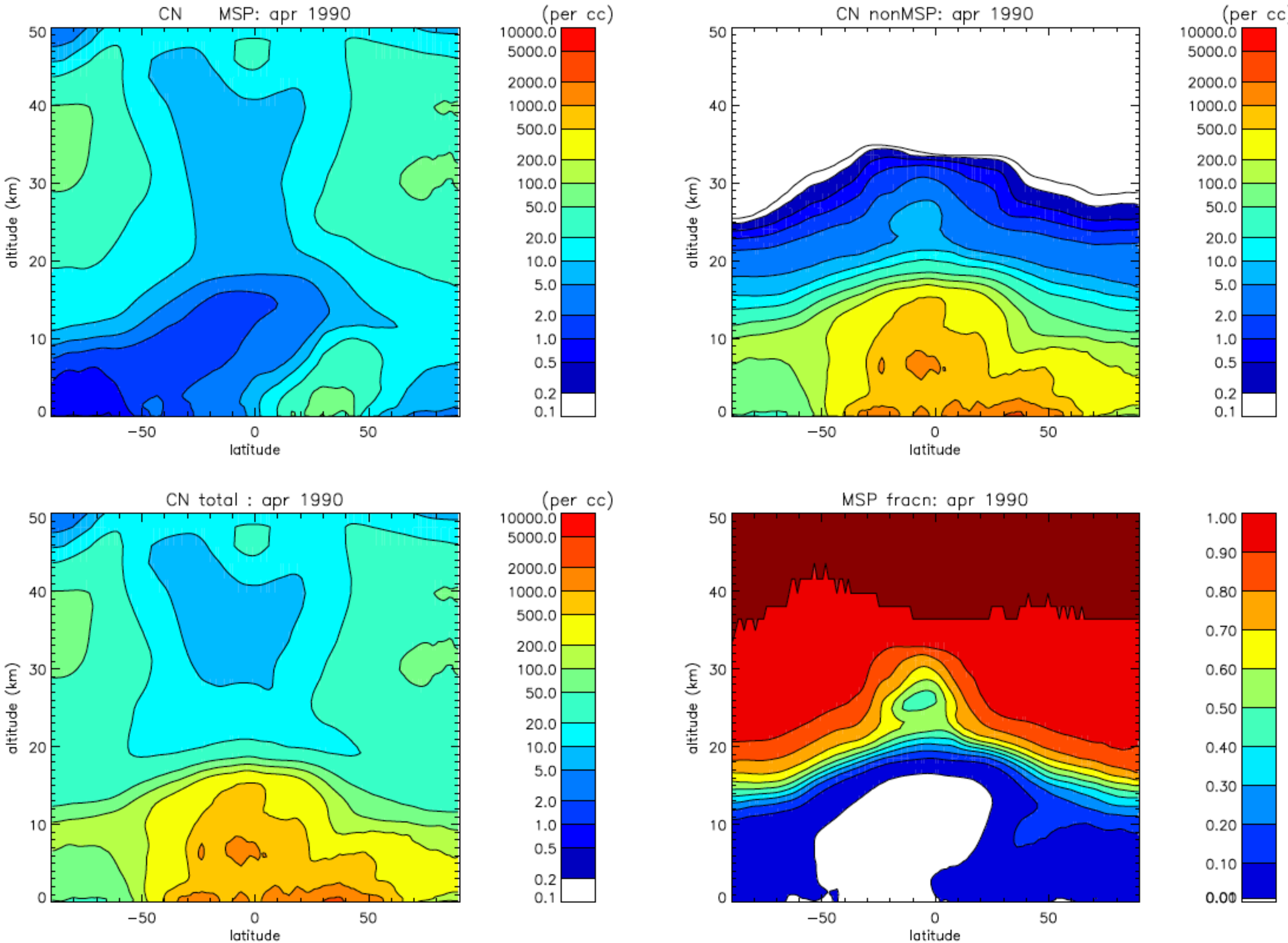
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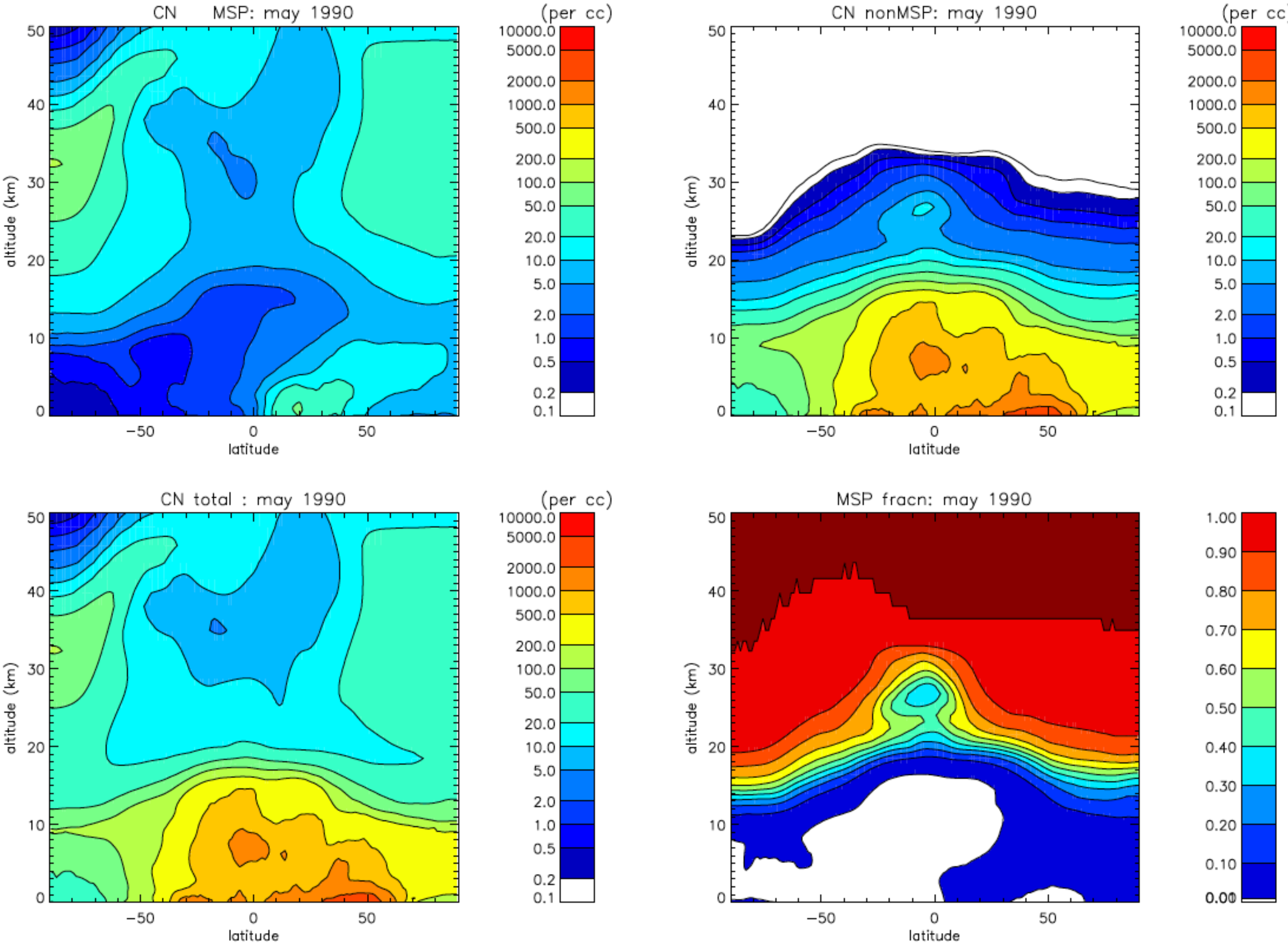
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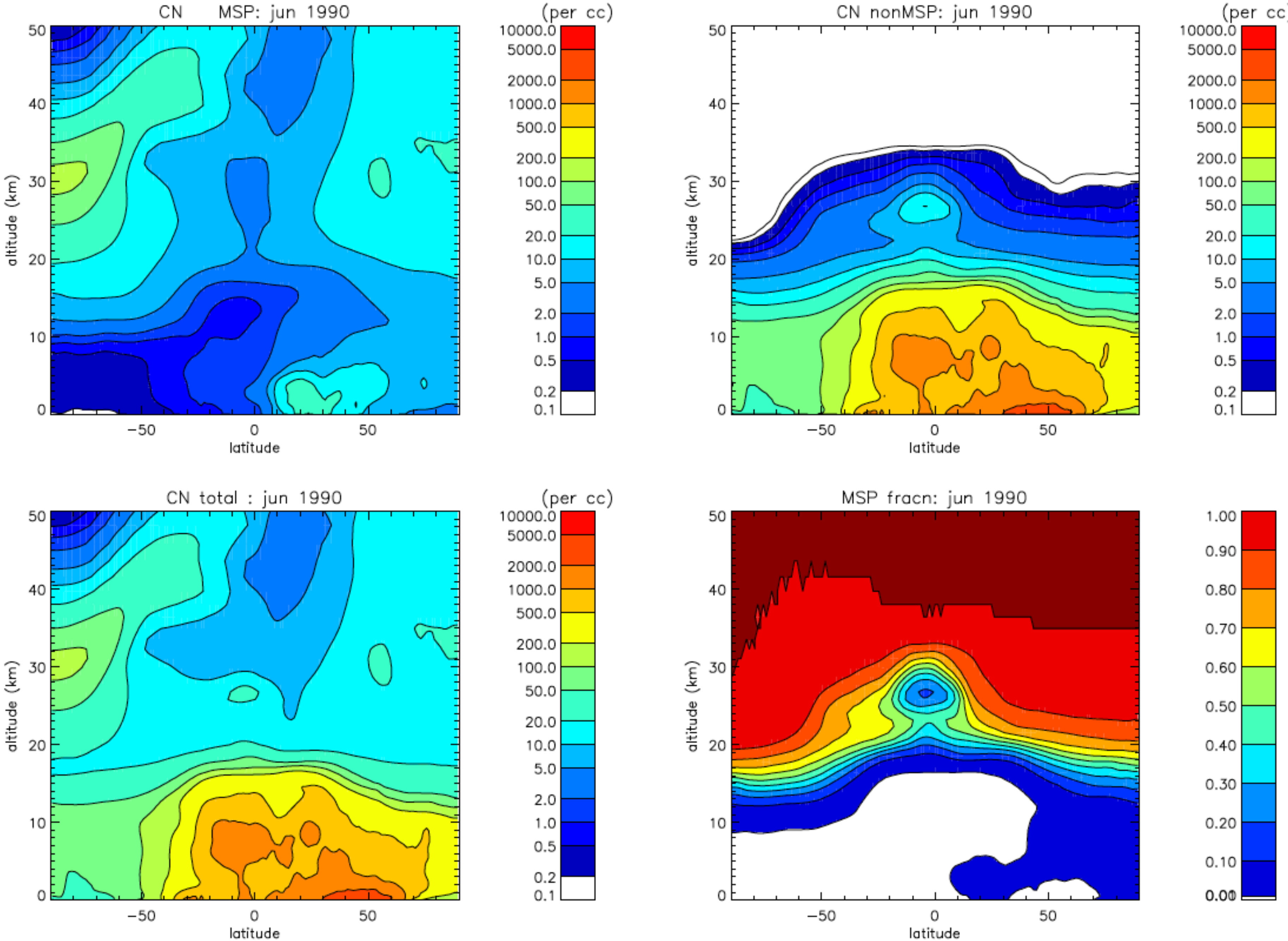
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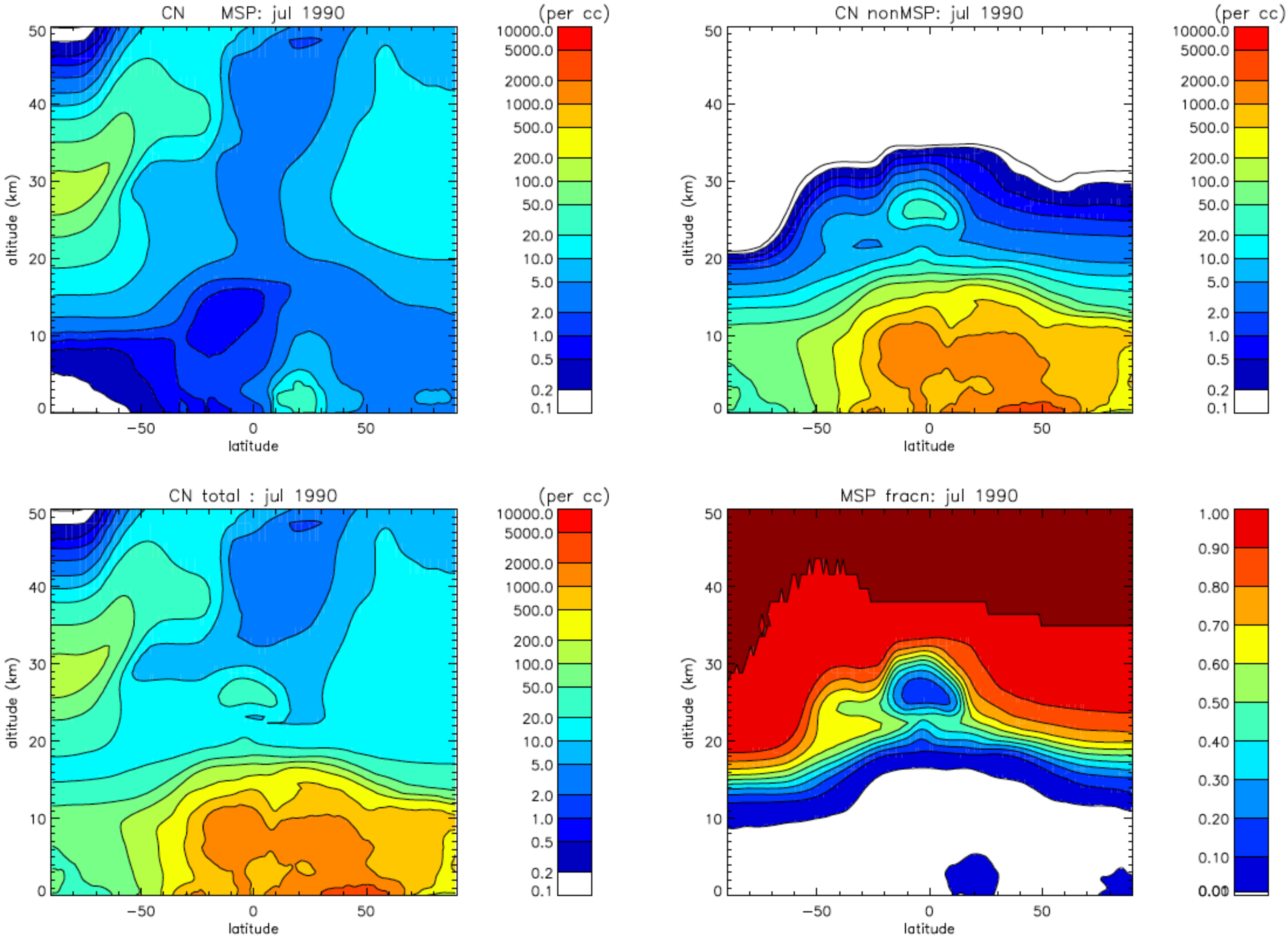
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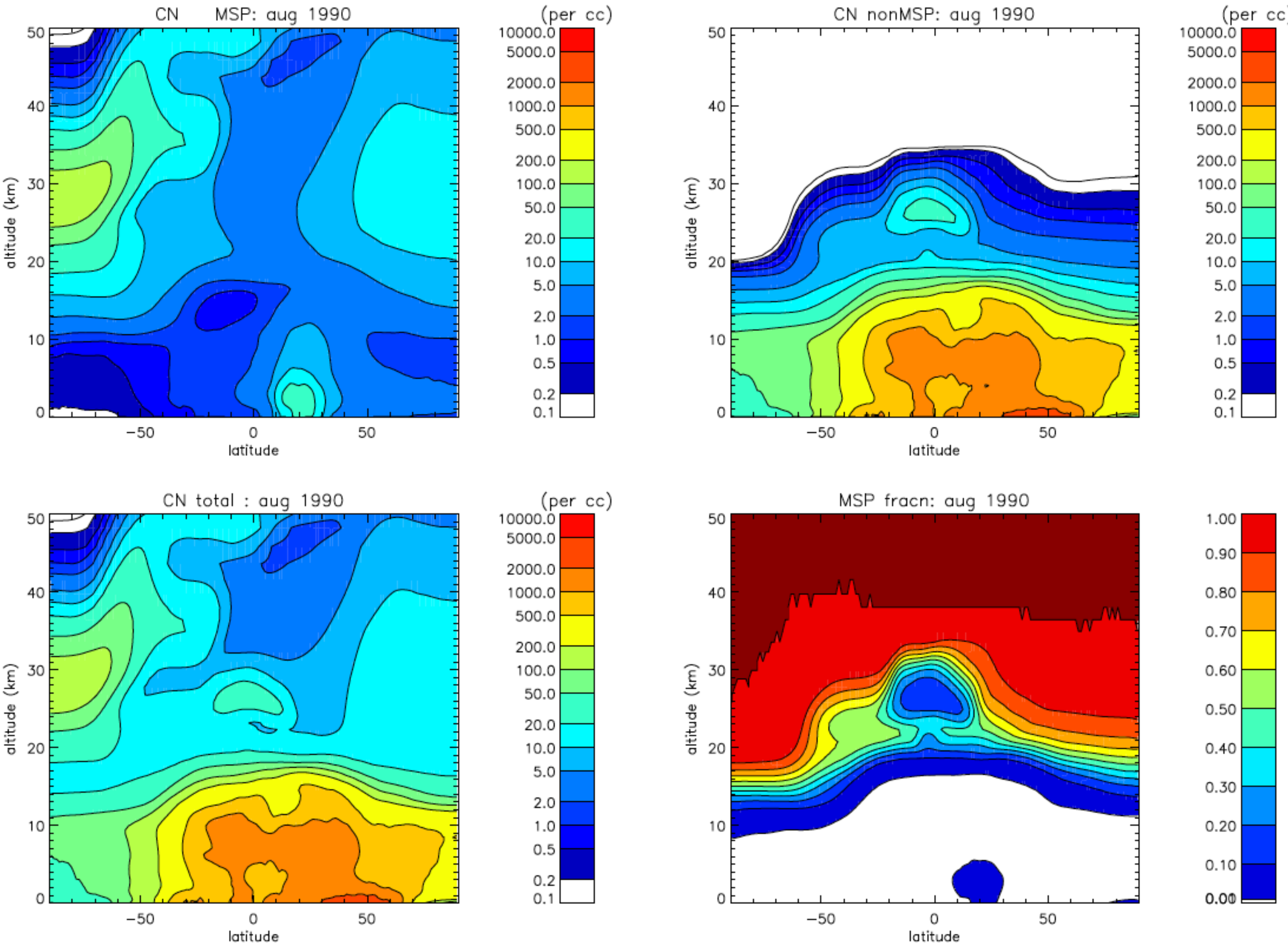
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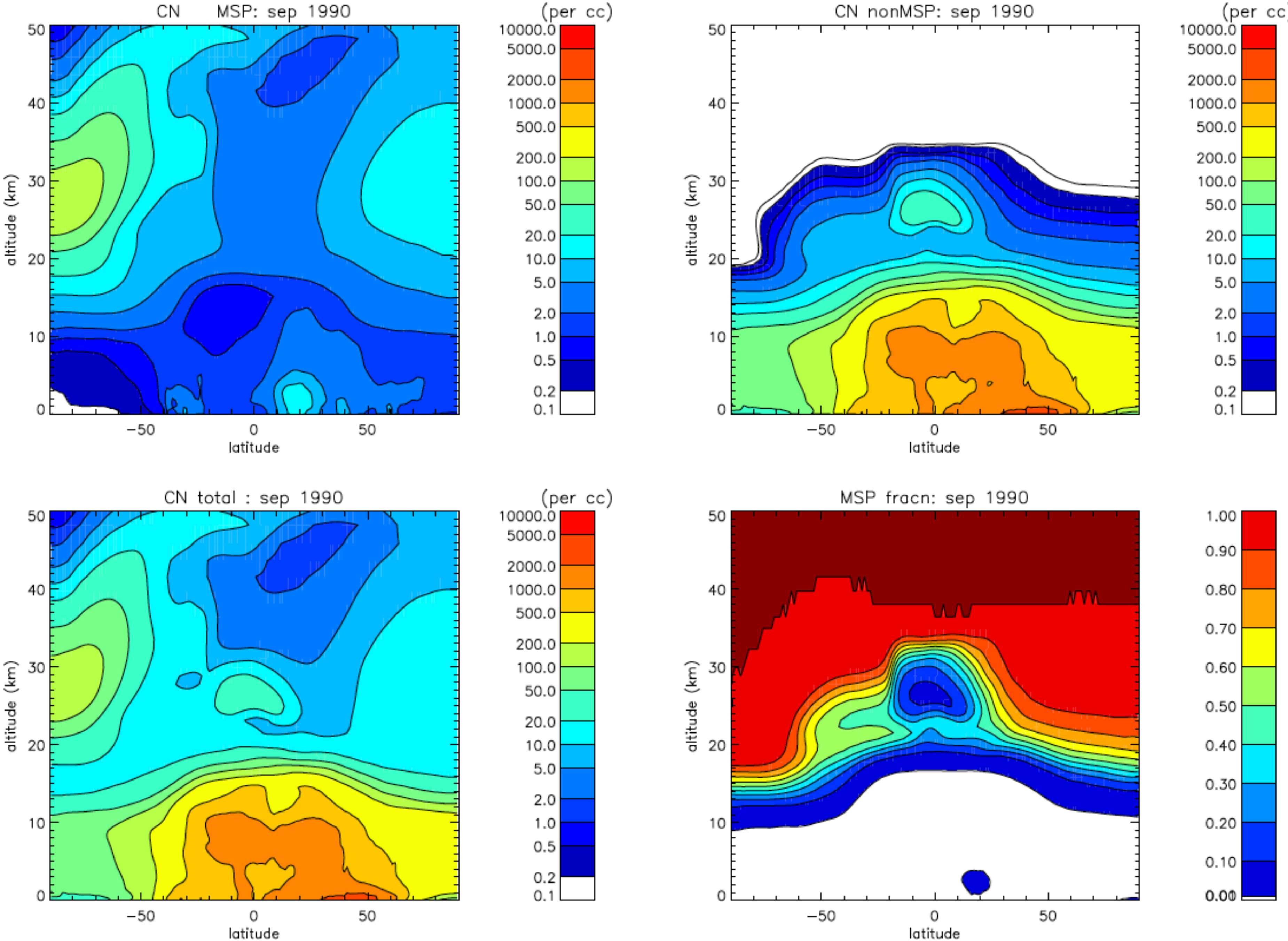
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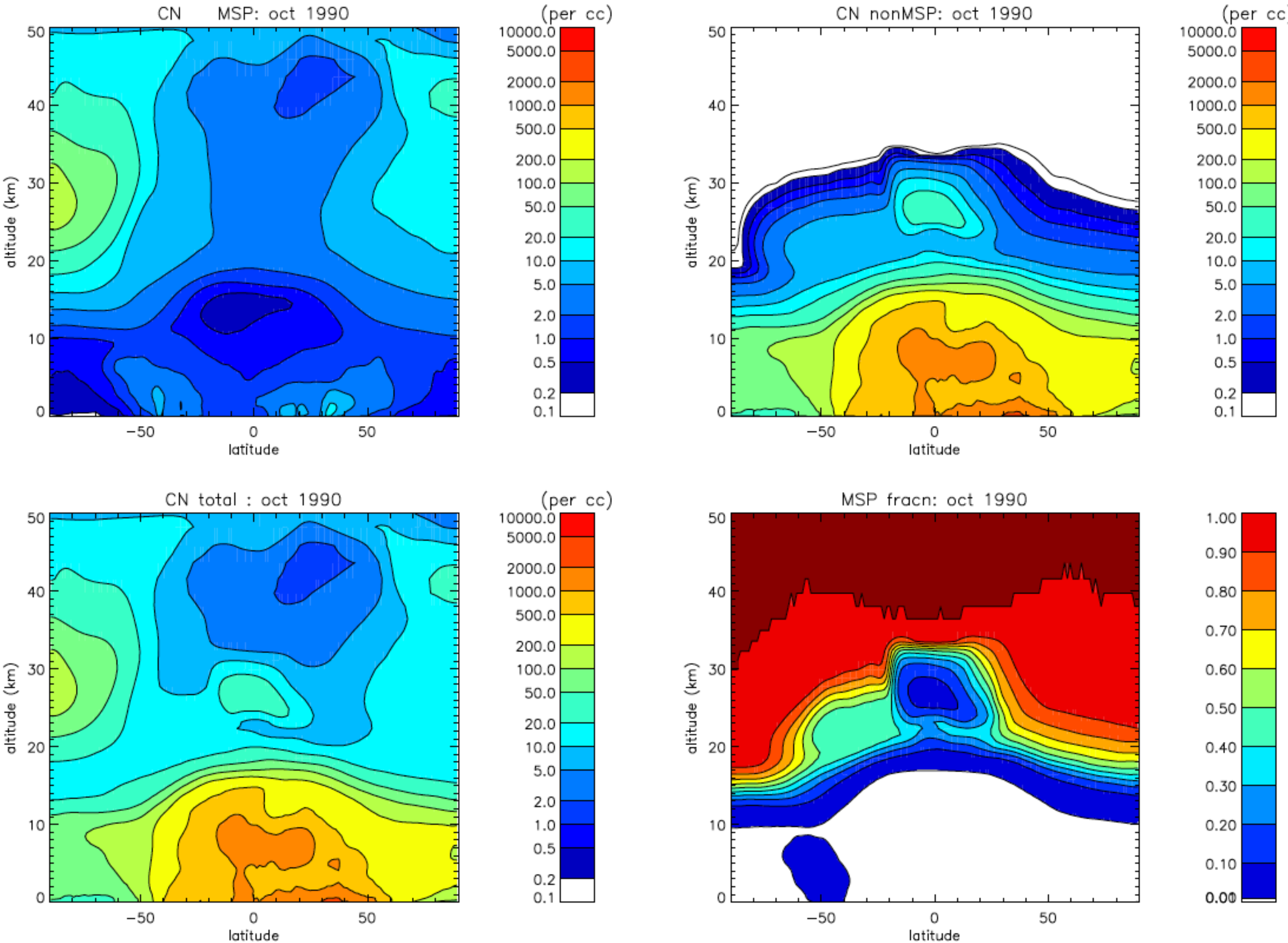

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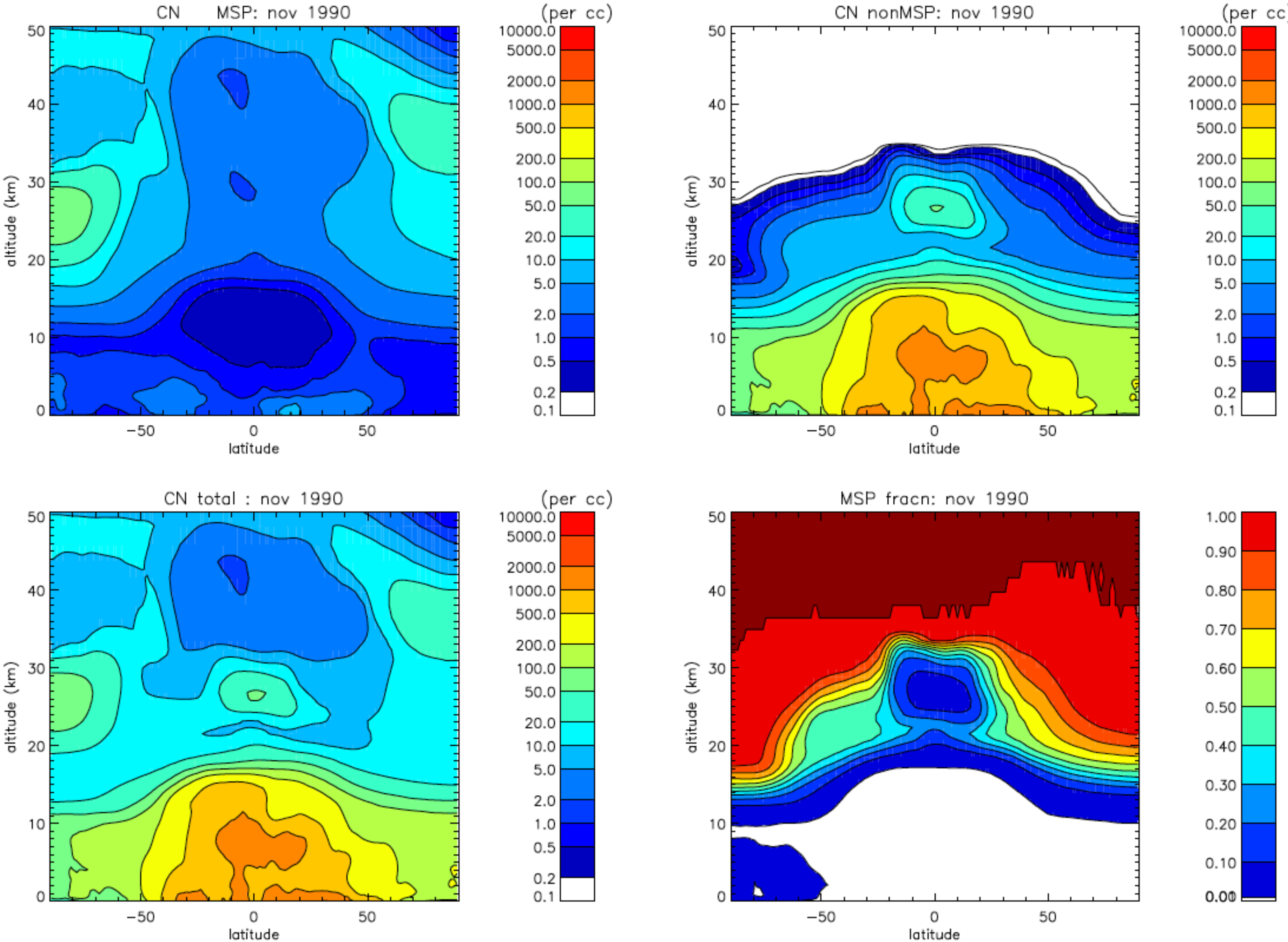
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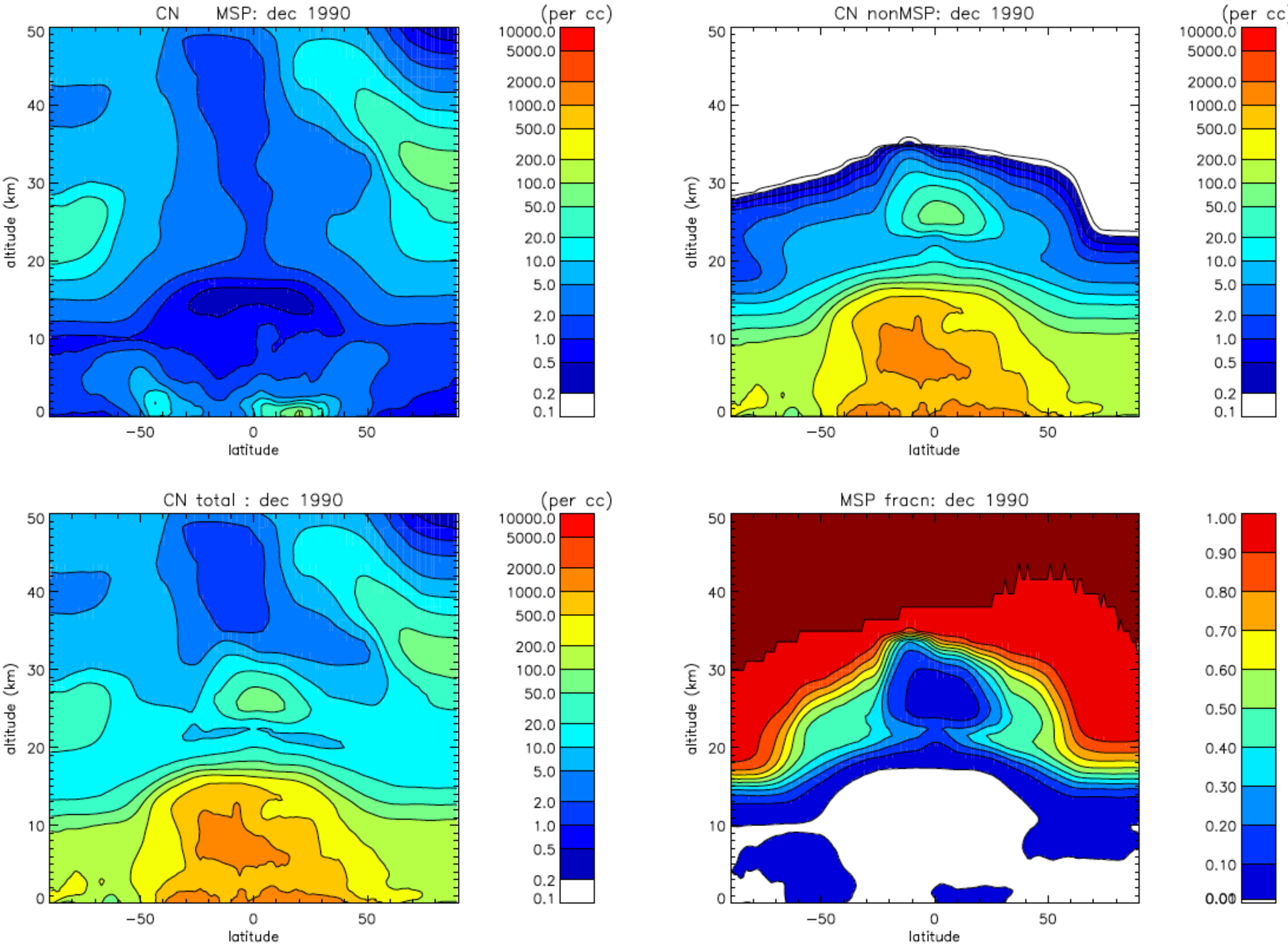
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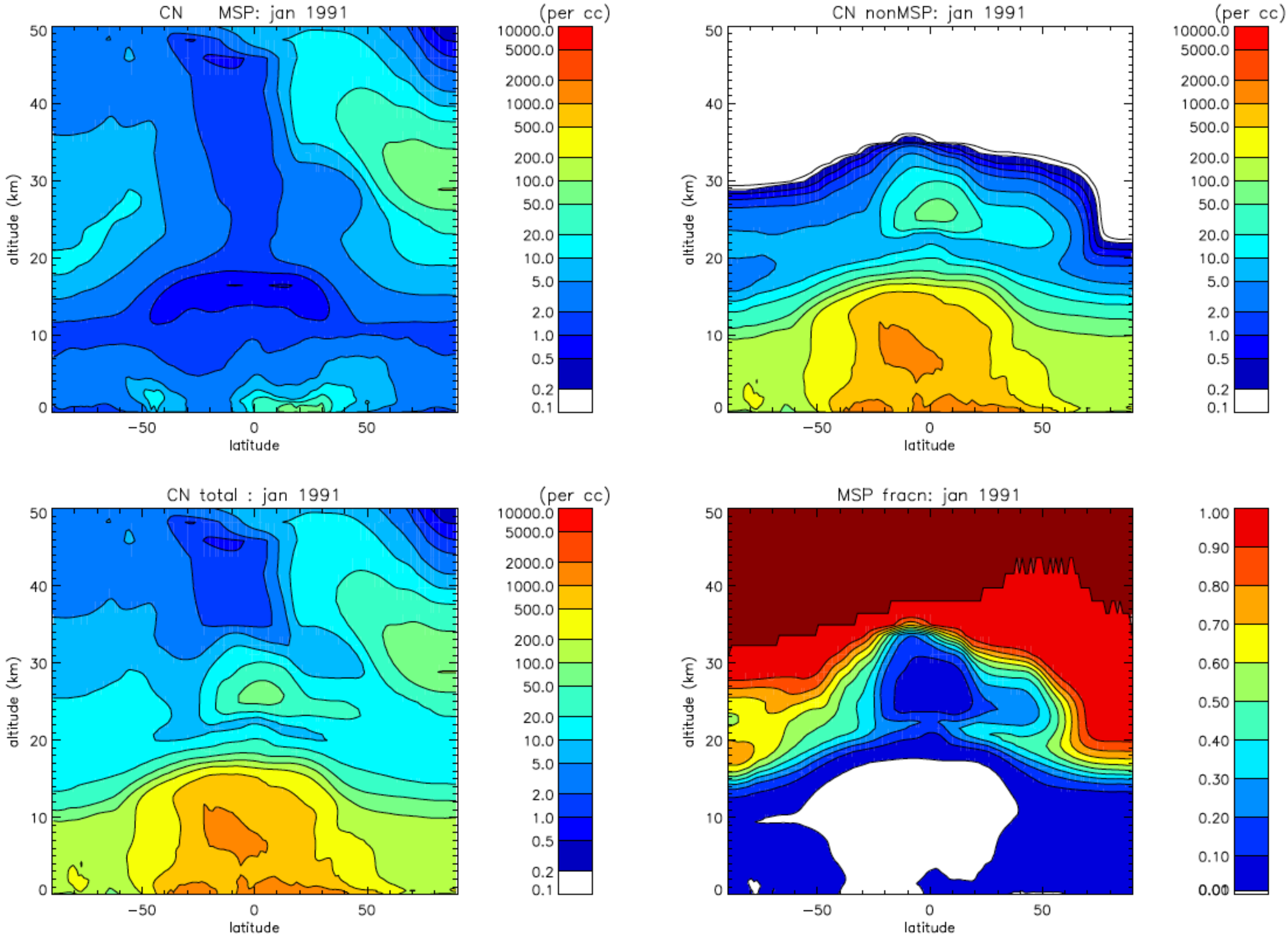
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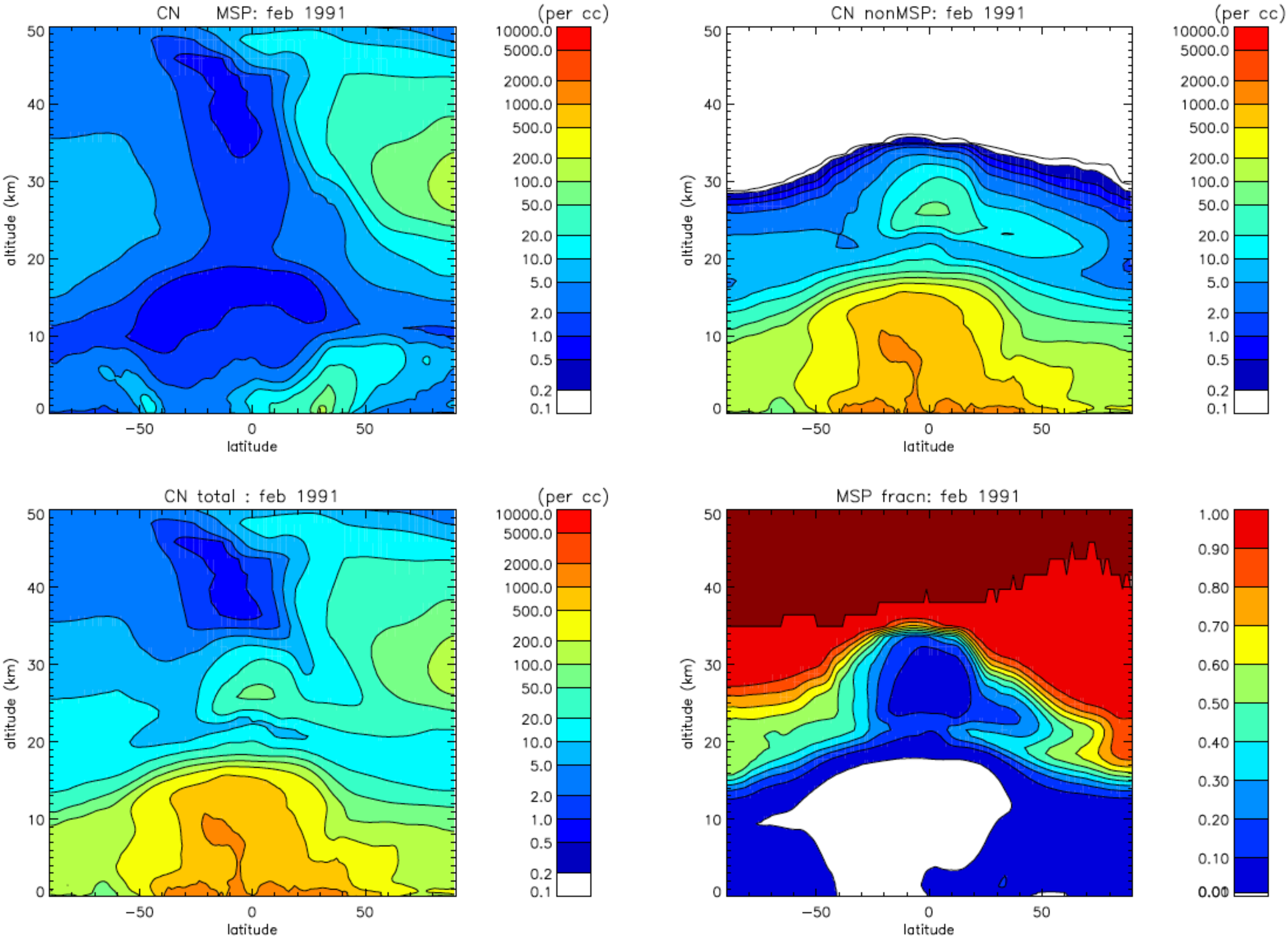
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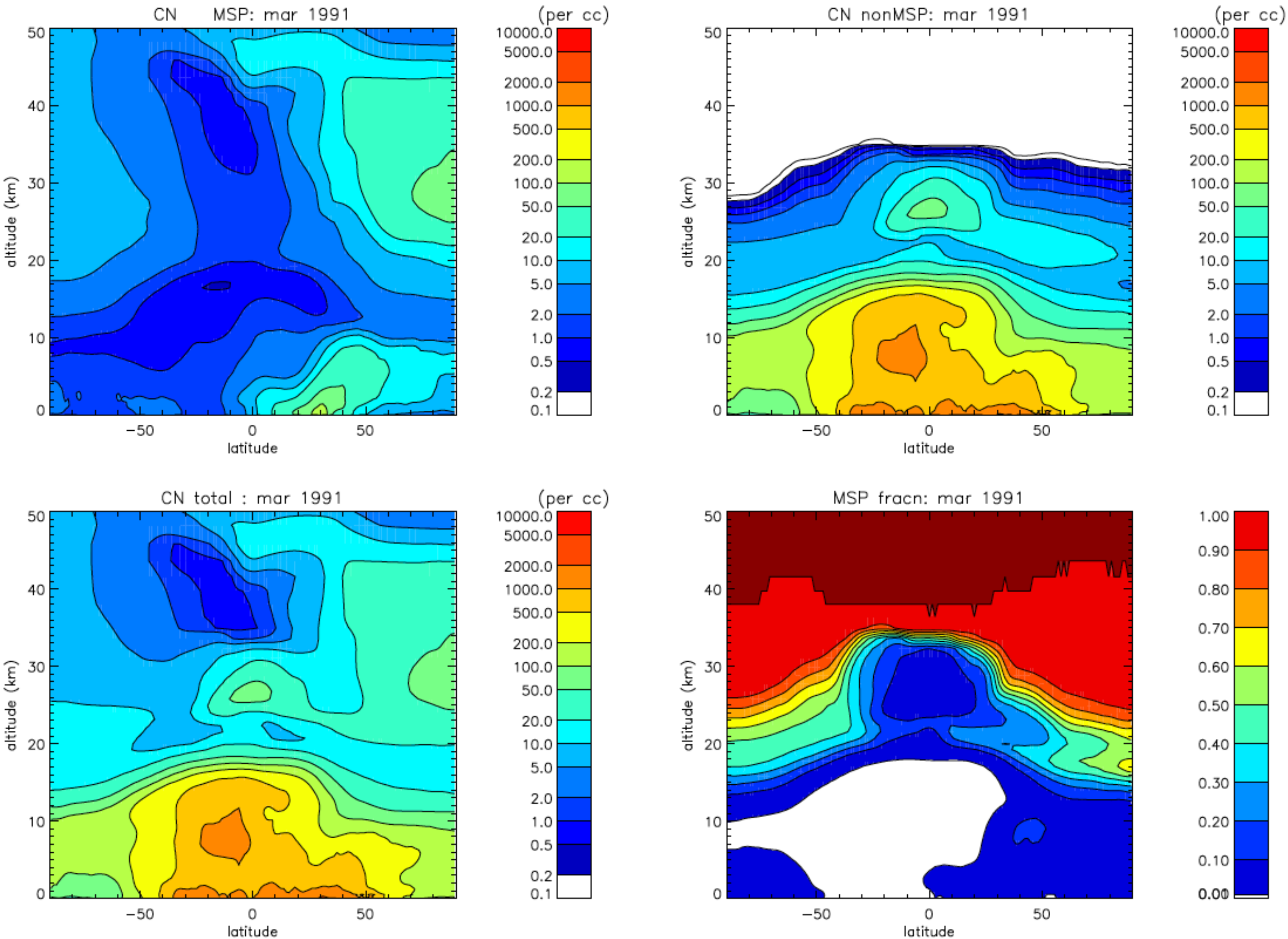

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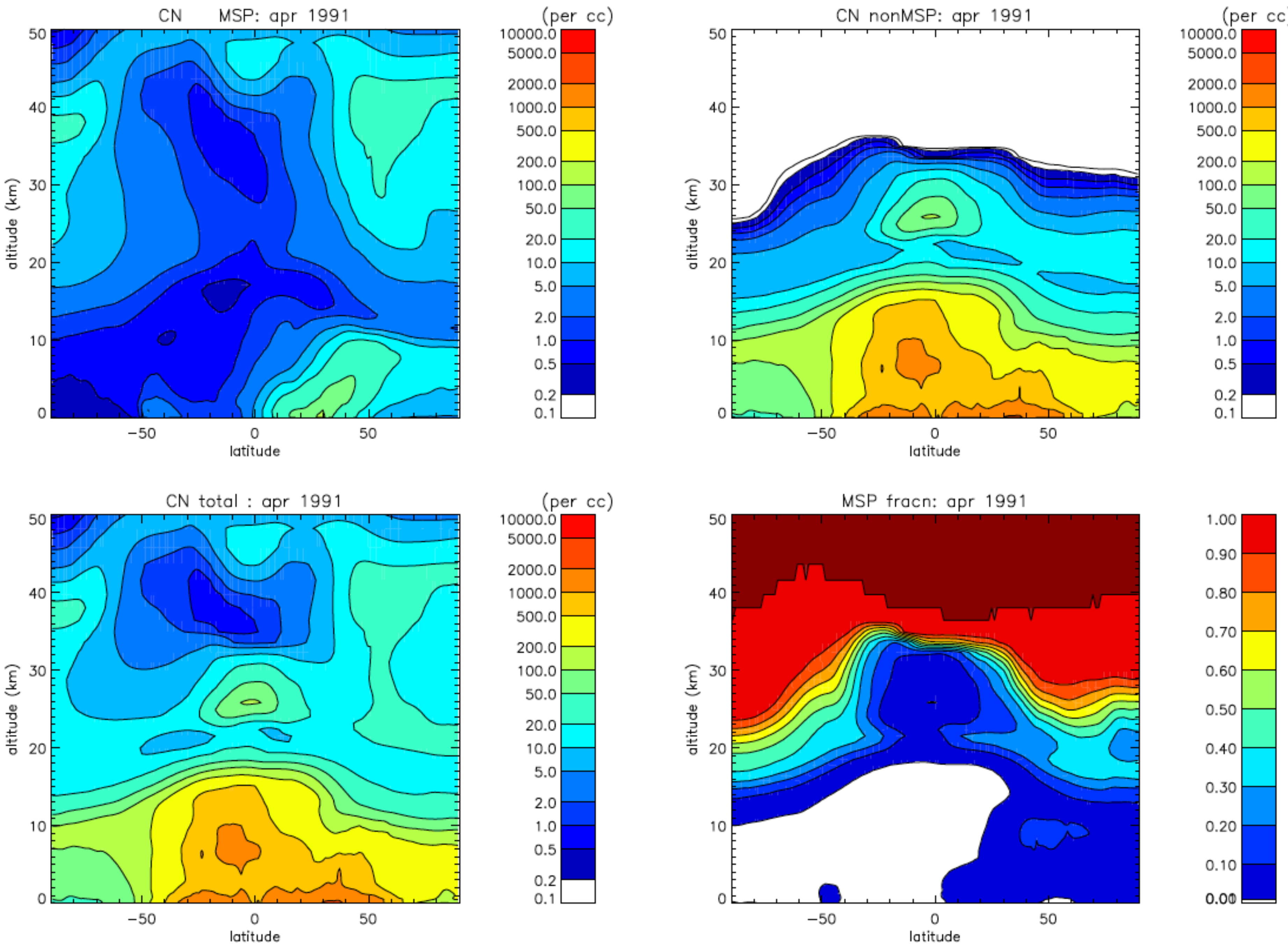
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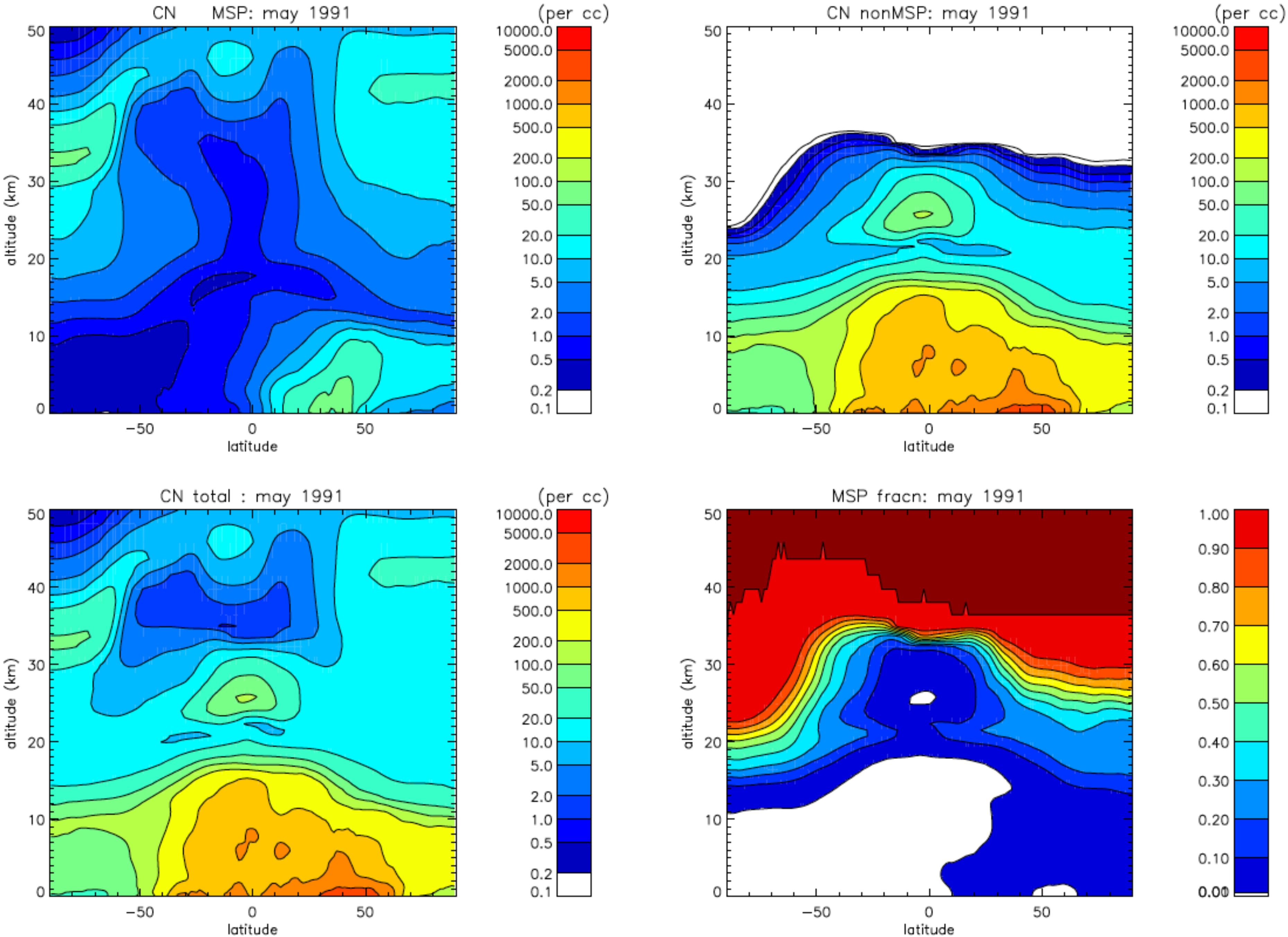
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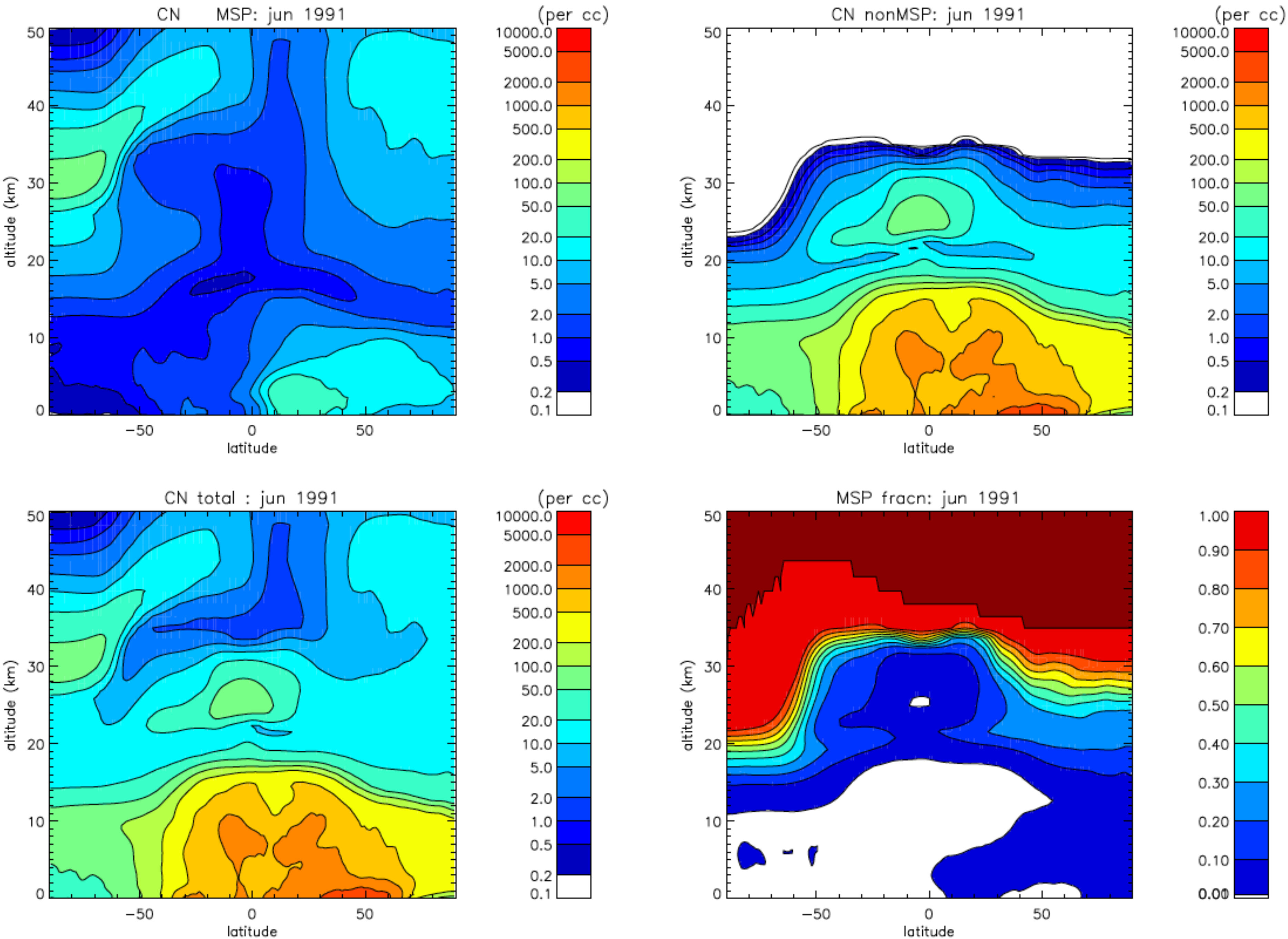
latitude
CN nonMSP: may 1991
(per cc)
altitude (km)
latitude
CN total : may 1991
(per cc)
altitude (km)
latitude
MSP fracn: may 1991
altitude (km)
latitude
10000.0
5000.0
2000.0
1000.0
500.0
200.0
100.0
50.0
20.0
10.0
5.0
2.0
1.0
0.5
0.2
0.1
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00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CN total : jun 1991
MSP fracn: jun 1991
(per cc)
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200.0
100.0
50.0
20.0
10.0
5.0
2.0
1.0
0.5
0.2
0.1
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
altitude (km)
latitude
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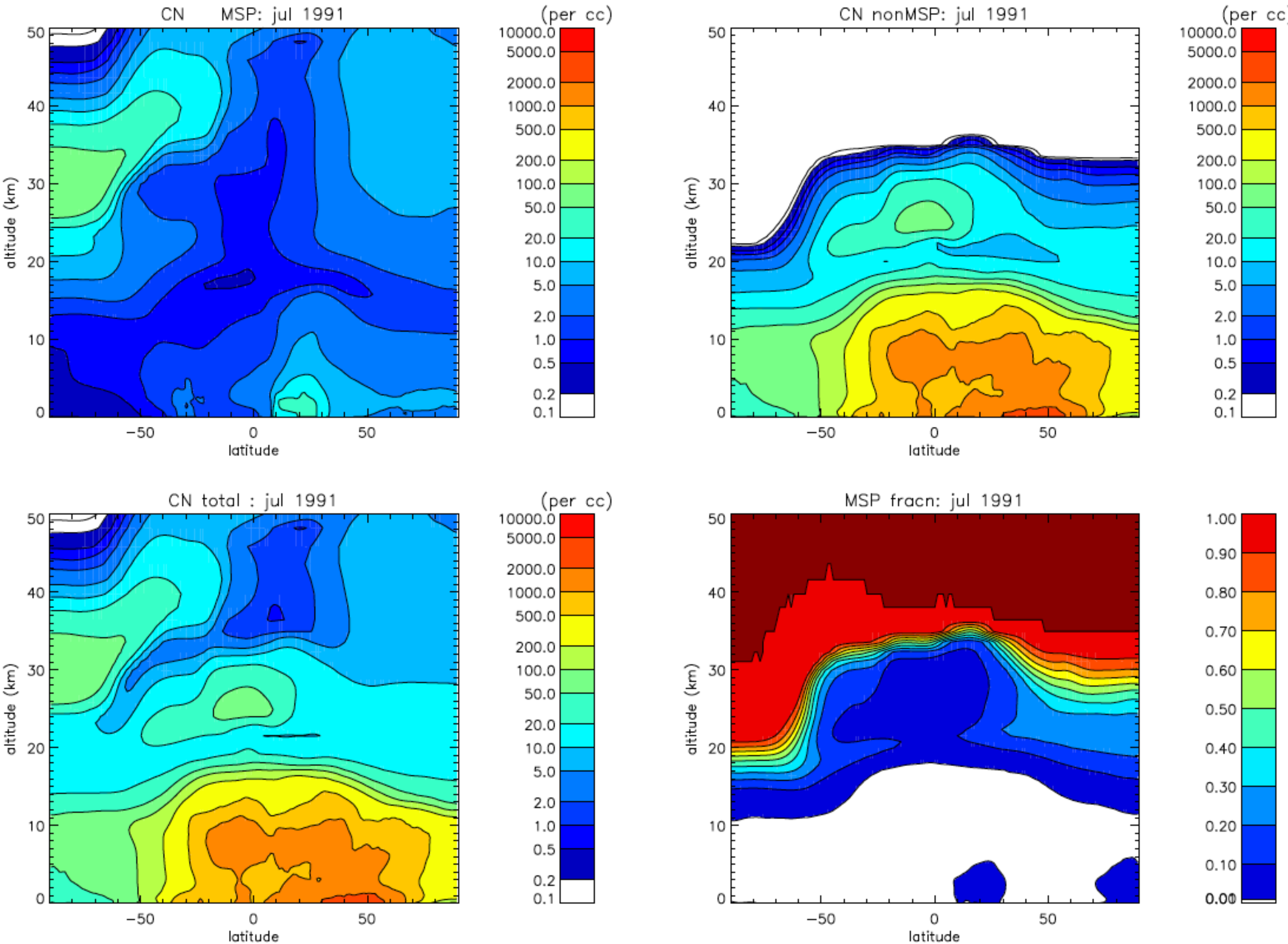
0
50
0
10
20
30
40
50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(per cc)
altitude (km)
latitude
CN nonMSP: jul 1991
(per cc)
altitude (km)
latitude
CN total : jul 1991
(per cc)
altitude (km)
latitude
MSP fracn: jul 1991
altitude (km)
latitude
10000.0
5000.0
2000.0
1000.0
500.0
200.0
100.0
50.0
20.0
10.0
5.0
2.0
1.0
0.5
0.2
0.1
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
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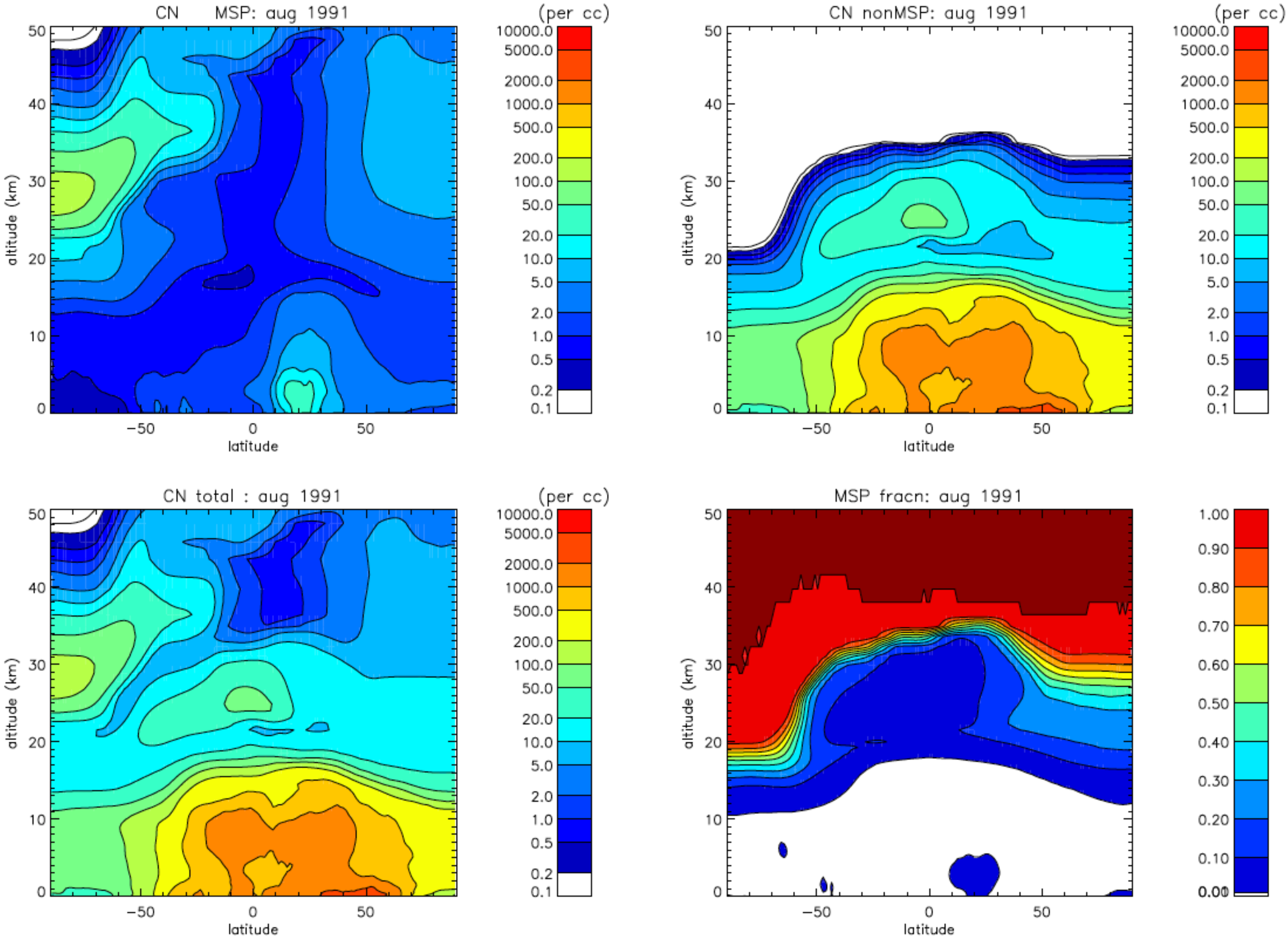
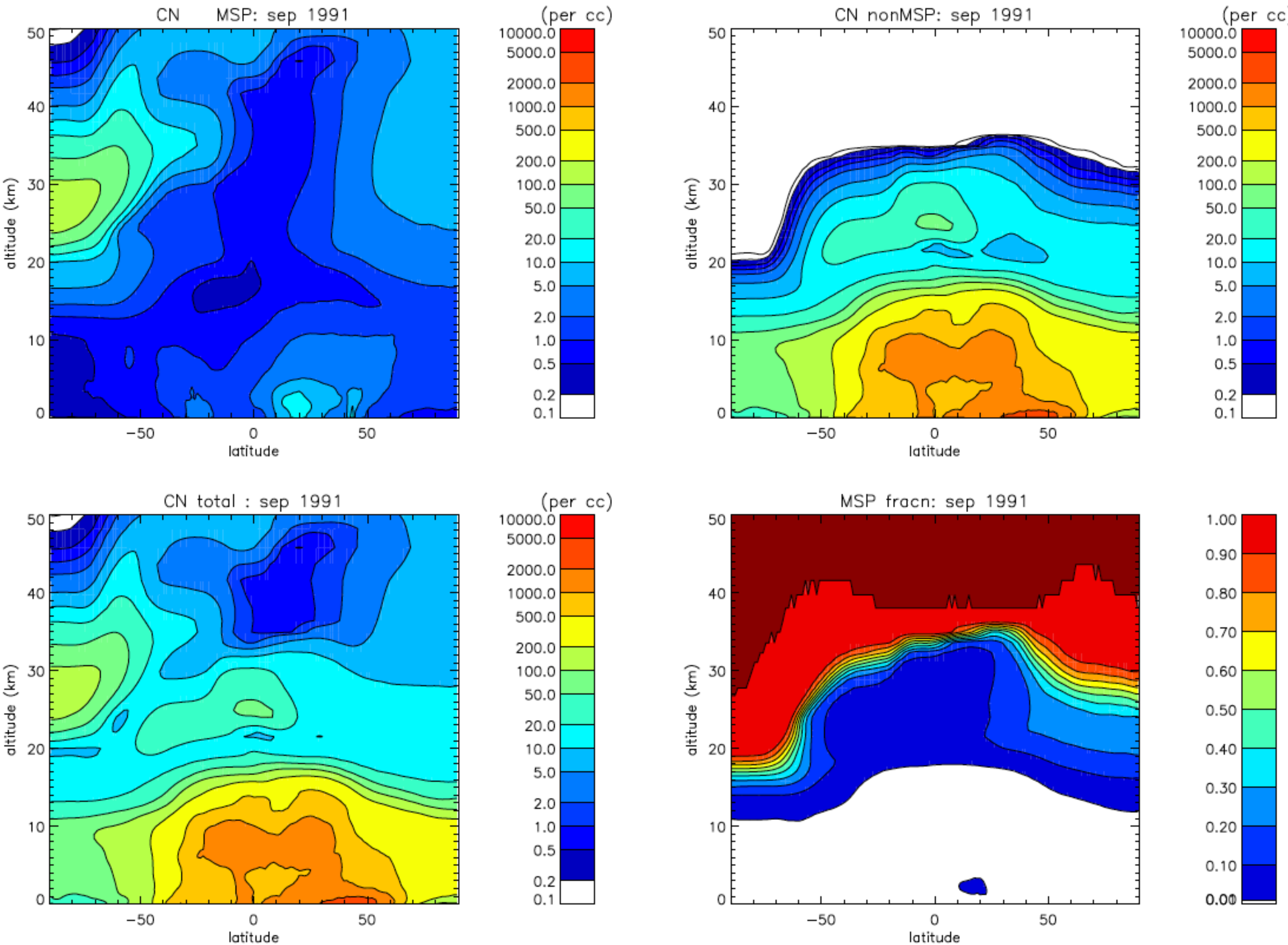
0.10
0.00



CN MSP: aug 1991
CN nonMSP: aug 1991
CN total : aug 1991
MSP fracn: aug 1991
(per cc)
altitude (km)
latitude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CN nonMSP: sep 1991
CN total : sep 1991
MSP fracn: sep 1991
(per cc)
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2000.0
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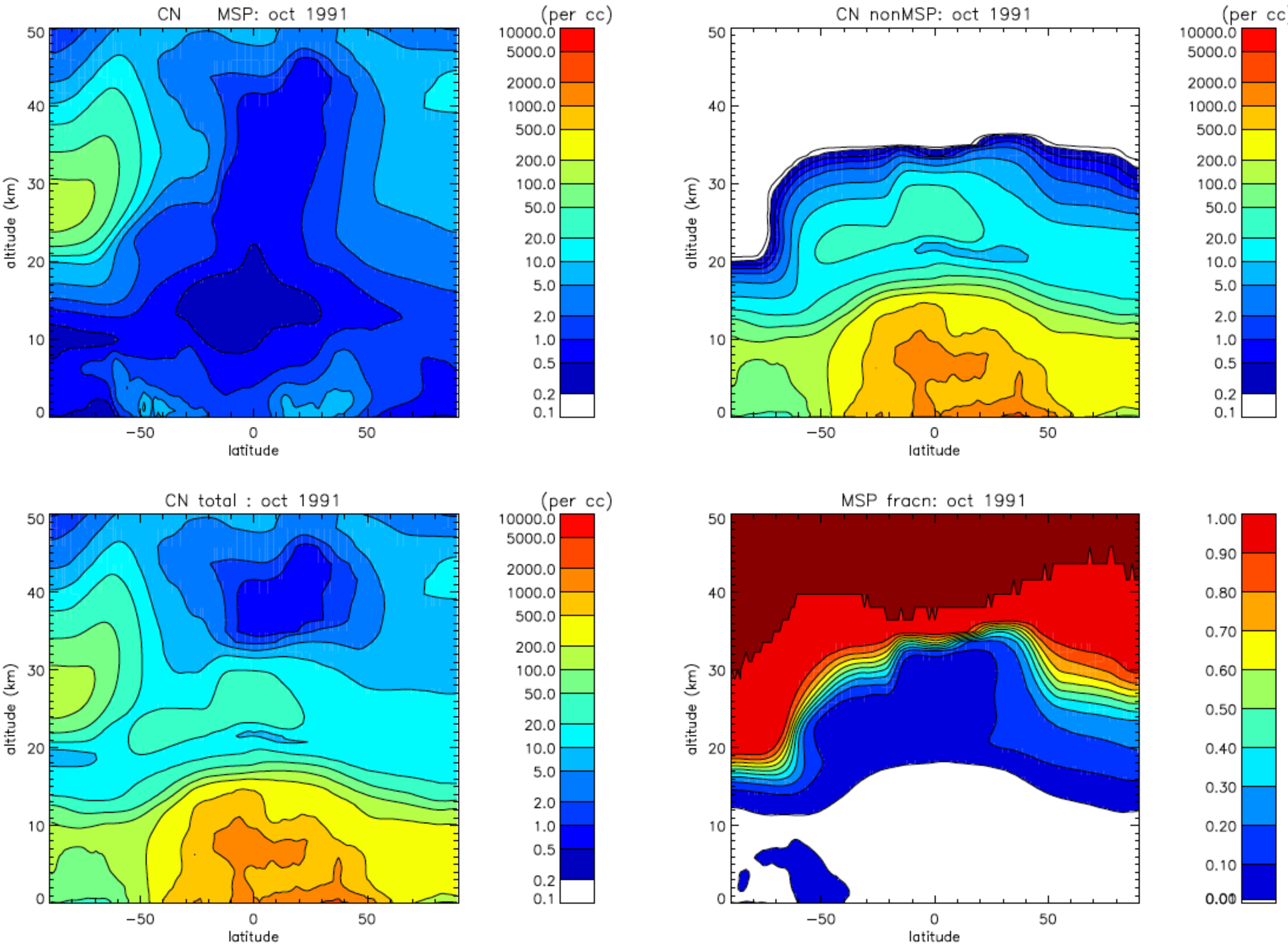
500.0
200.0
100.0
50.0
20.0
10.0
5.0
2.0
1.0
0.5
0.2
0.1
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
altitude (km)
latitude



CN MSP: oct 1991
CN nonMSP: oct 1991
CN total : oct 1991
MSP fracn: oct 1991
(per cc)
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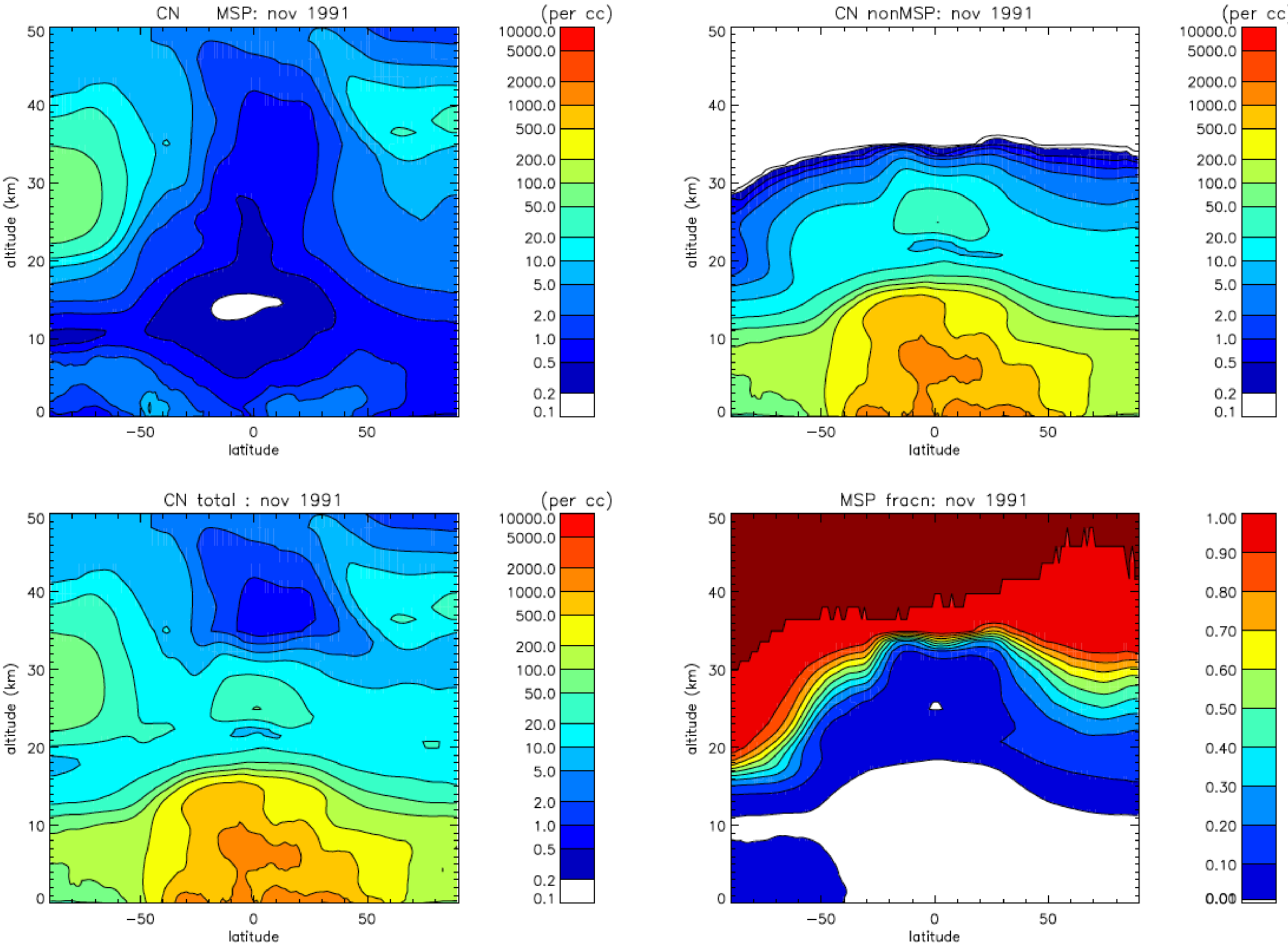
5000.0
2000.0
1000.0
500.0
200.0
100.0
50.0
20.0
10.0
5.0
2.0
1.0
0.5
0.2
0.1
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
altitude (km)
latitude


CN MSP: nov 1991
(per cc)
CN nonMSP: nov 1991
(per cc)
CN total : nov 1991
(per cc)
MSP fracn: nov 1991
altitude (km)
latitude
10000.0
5000.0
2000.0
1000.0
500.0
200.0
100.0
50.0
20.0
10.0
5.0
2.0
1.0
0.5
0.2
0.1
1.00
0.90
0.80
0.70
0.60
0.50
0.40
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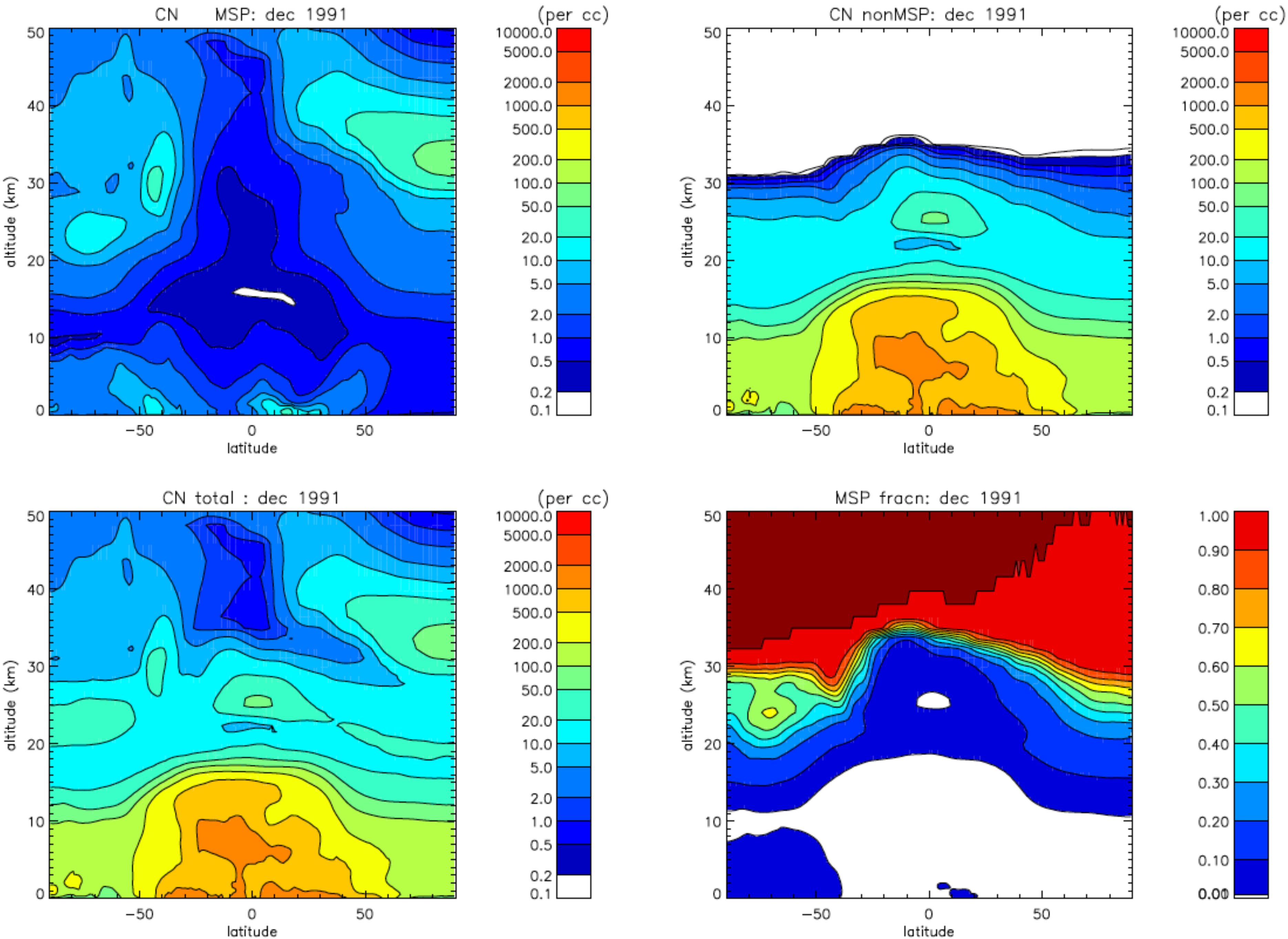
0.00


CN MSP: dec 1991
(per cc)
CN nonMSP: dec 1991
(per cc)
CN total : dec 1991
(per cc)
MSP fracn: dec 1991
altitude (km)
latitude
10000.0
5000.0
2000.0
1000.0
500.0
200.0
100.0
50.0
20.0
10.0
5.0
2.0
1.0
0.5
0.2
0.1
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-50
0
50