Geoeffectiveness of precipitating auroral and ring current electrons in the Earth's upper and middle atmosphere

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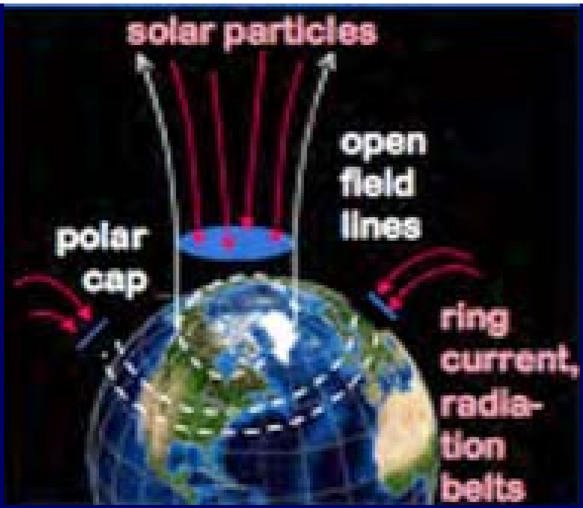
Outline

- Motivation;
- Introduction of a new parameterization method for electron impact ionization calculation;
- Geoeffectiveness of e^- precipitation on the atmosphere;
- Conclusion.

Direct Effect



Indirect Effect

energetic particle precipitation

↓

odd nitrogen (dissociation of N_2)
odd hydrogen (ion chemistry)

↓

catalytic destruction of O_3

$NO + O_3 \rightarrow NO_2 + O_2$

$NO_2 + O \rightarrow NO + O_2$

$HO + O_3 \rightarrow HO_2 + O_2$

$HO_2 + O_3 \rightarrow HO + 2O_2$

$HO + O \rightarrow H + O_2$

$H + O_3 \rightarrow HO + O_2$

$HO_2 + O \rightarrow HO + O_2$

↓

change of temperature gradients, circulation

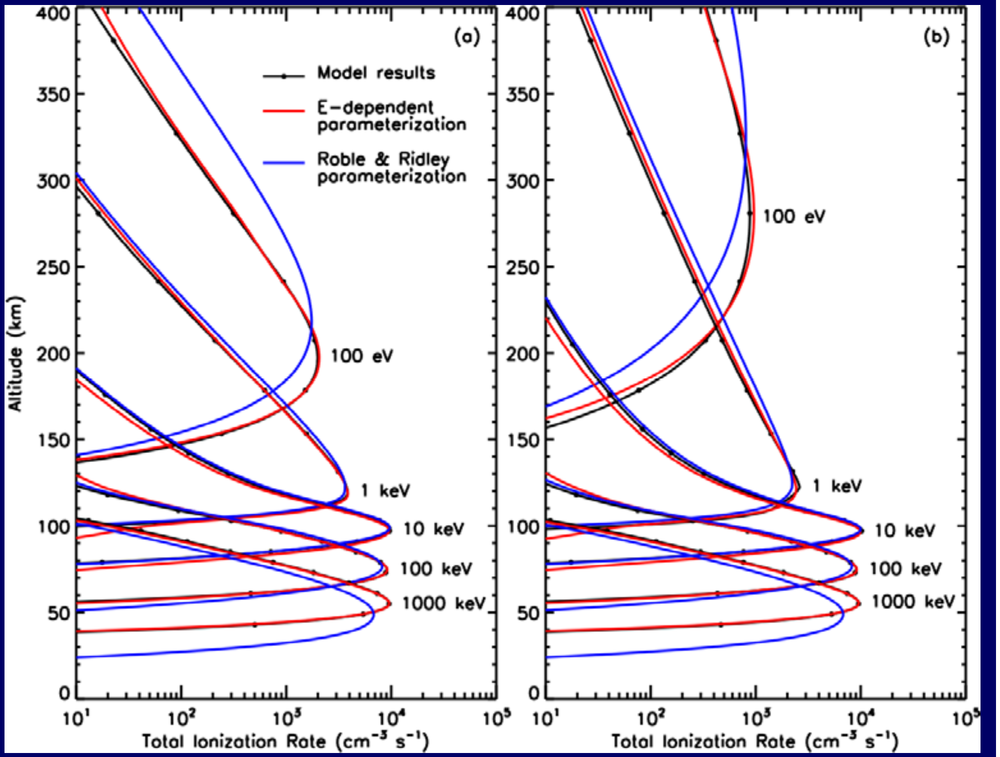
- NO_x ($NO + NO_2$) produced in the mesosphere and lower thermosphere can be transported into the stratosphere during polar night.
- Satellite measurements revealed that up to 40% of the NO_x in the stratospheric polar region might be derived from particle precipitation on an annual basis [*Randall et al*., 2007].

Parameterization of ionization

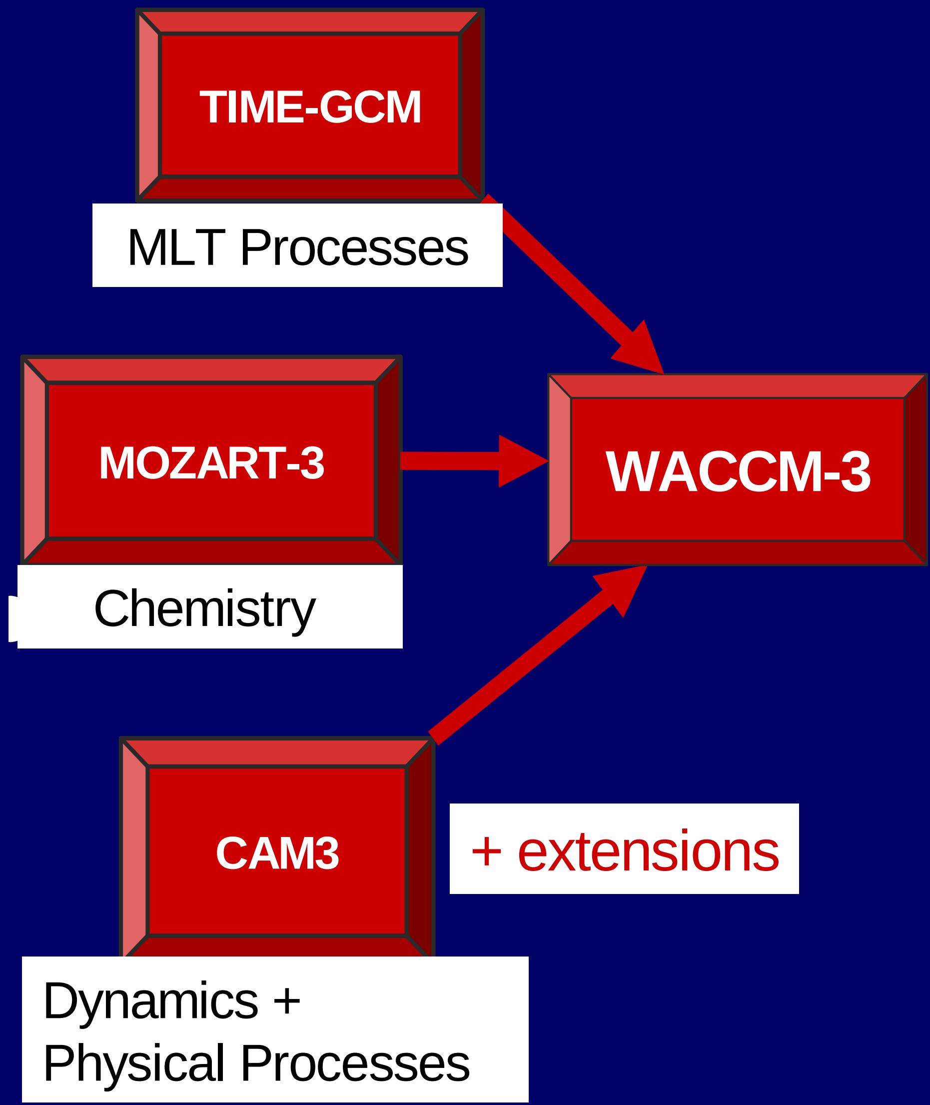
- Goal: derive simple functions to fit the altitude profile of the ionization rate from precipitating electrons and ions.

- A newly created parameterization method [*Fang et al*., 2008]

  - Fit to model results (Two-stream and multi-stream electron transport models);
  - Works for E_0=100 eV to 1 MeV precipitating electrons;
  - Energy dependent;
  - Atmospheric independent;



Whole Atmosphere Community Climate Model (WACCM)



(Adapted from Rolando Garcia)

WACCM Parameterization of Precipitation Effects

Aurora

- Input = Kp
- Distribution = Auroral Oval
- Roble and Ridley [1987]

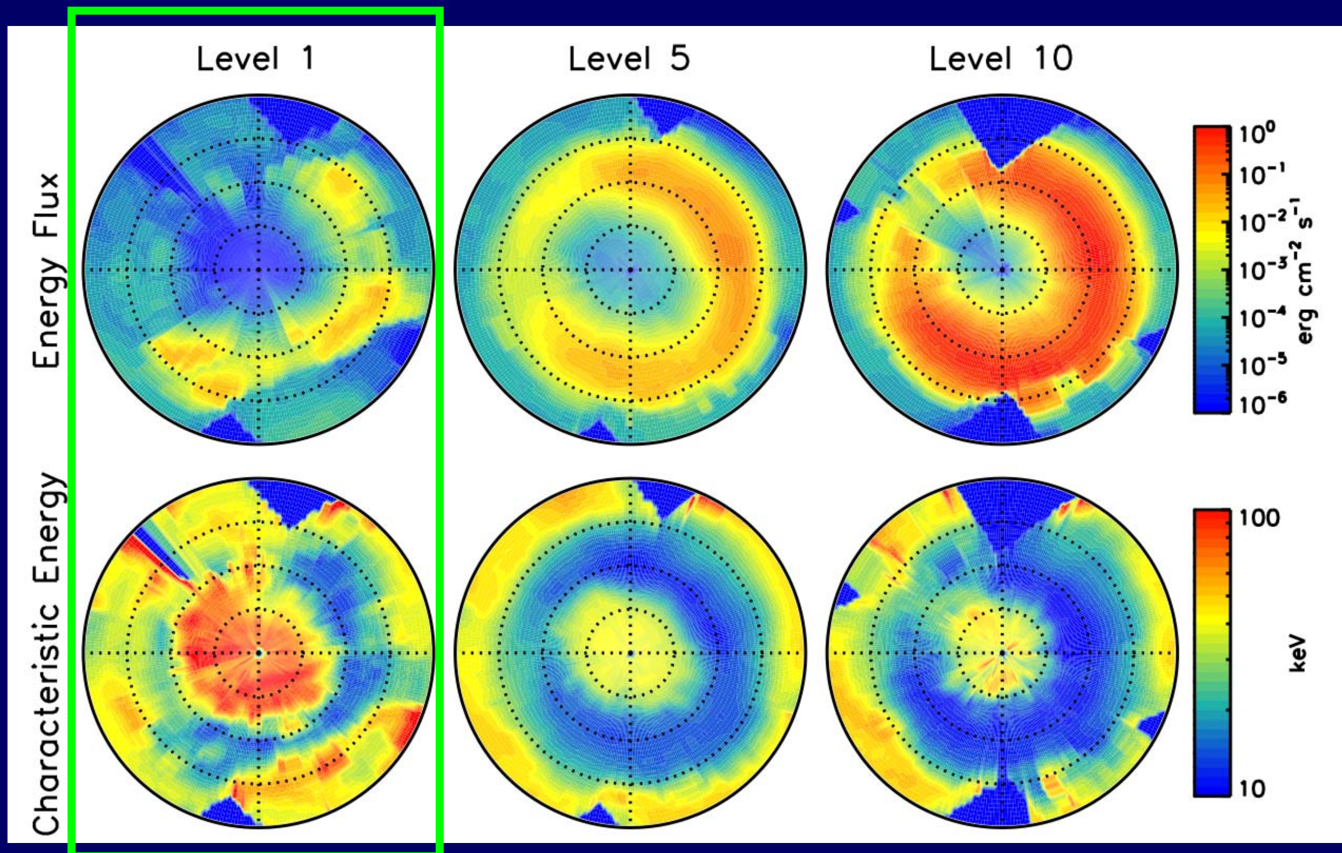
Medium Energy Electrons

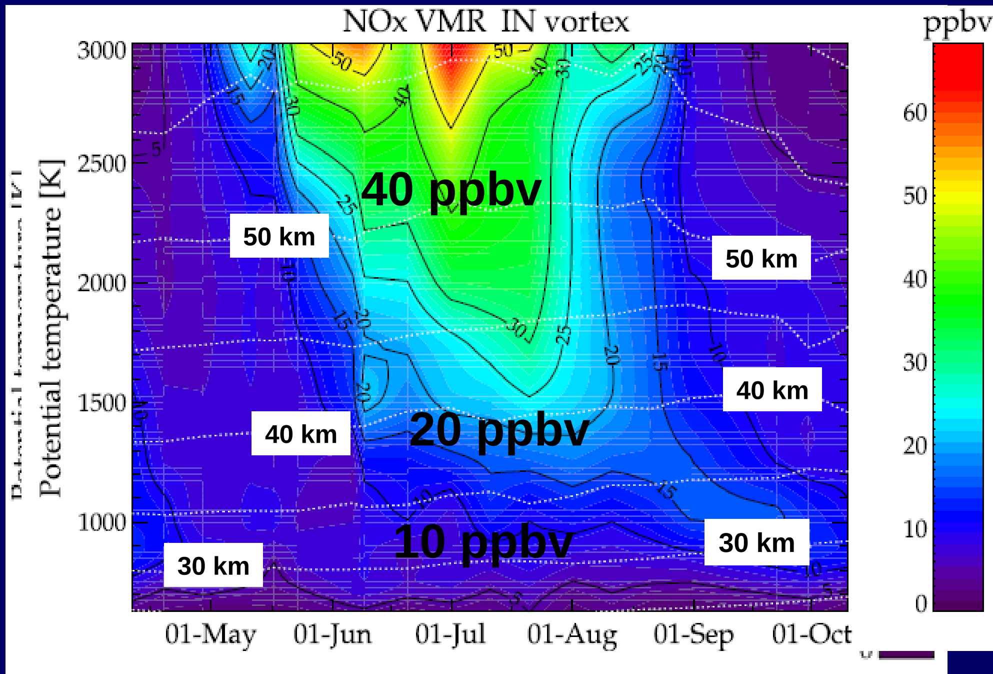
(30 keV – 2.5 MeV)

- Input = NOAA/MEPED activity level (or hemispheric power)
- Distribution = statistical patterns by Codrescu et al. [1997]
- Fang et al. [2008]

Compare 3 cases:

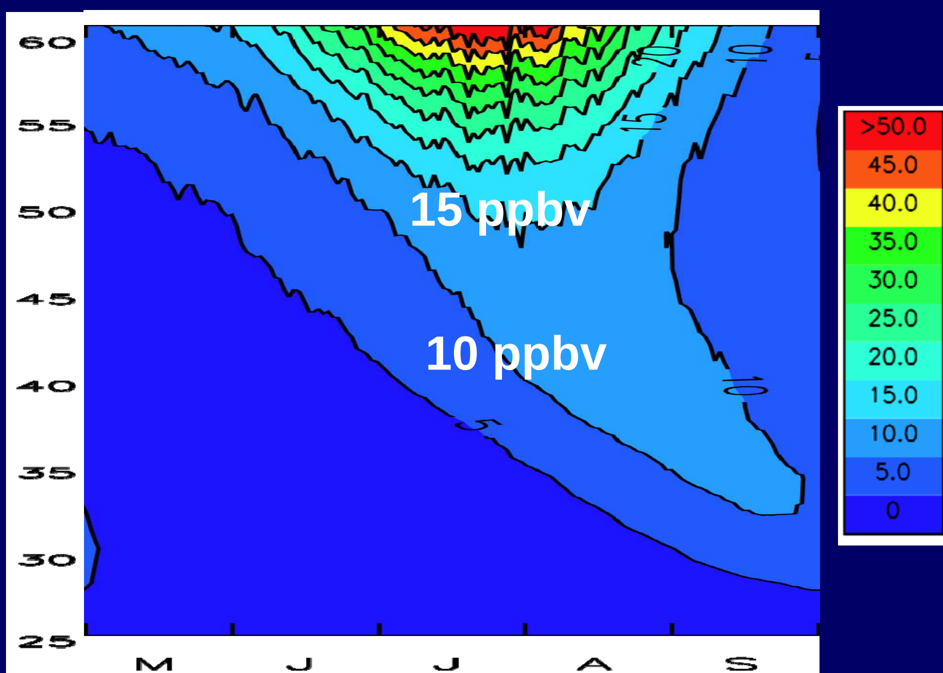
- Case 1: essentially no particle precipitation, Kp=2/3 (Ap=3)
- Case 2: includes moderate auroral electrons, Kp=4 (Ap=27)
- Case 3: includes auroral electrons plus NOAA/MEPED >30 keV electrons (level 1)





MIPAS, Funke et al. [2005]

SH Winter



WACCM3 NO_X

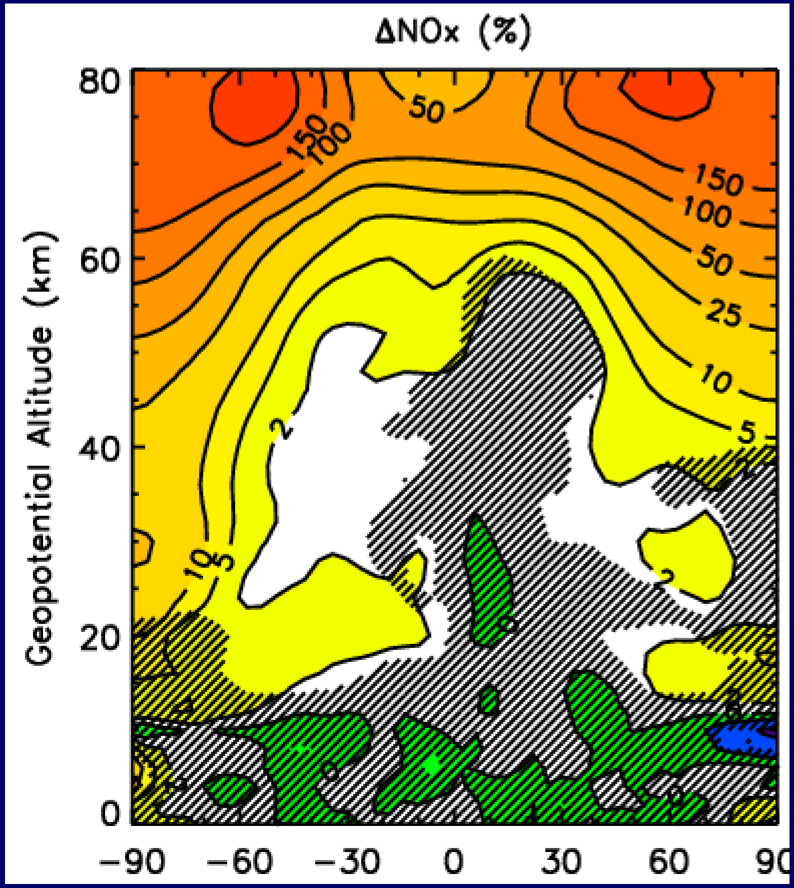
- 70º-90º SH
- Aurora + low-level MEE

(case 3, close to realistic 2003 geomagnetic activity)

WACCM simulation similar to MIPAS, but WACCM underestimates EPP-NO_x by about a factor of 2.

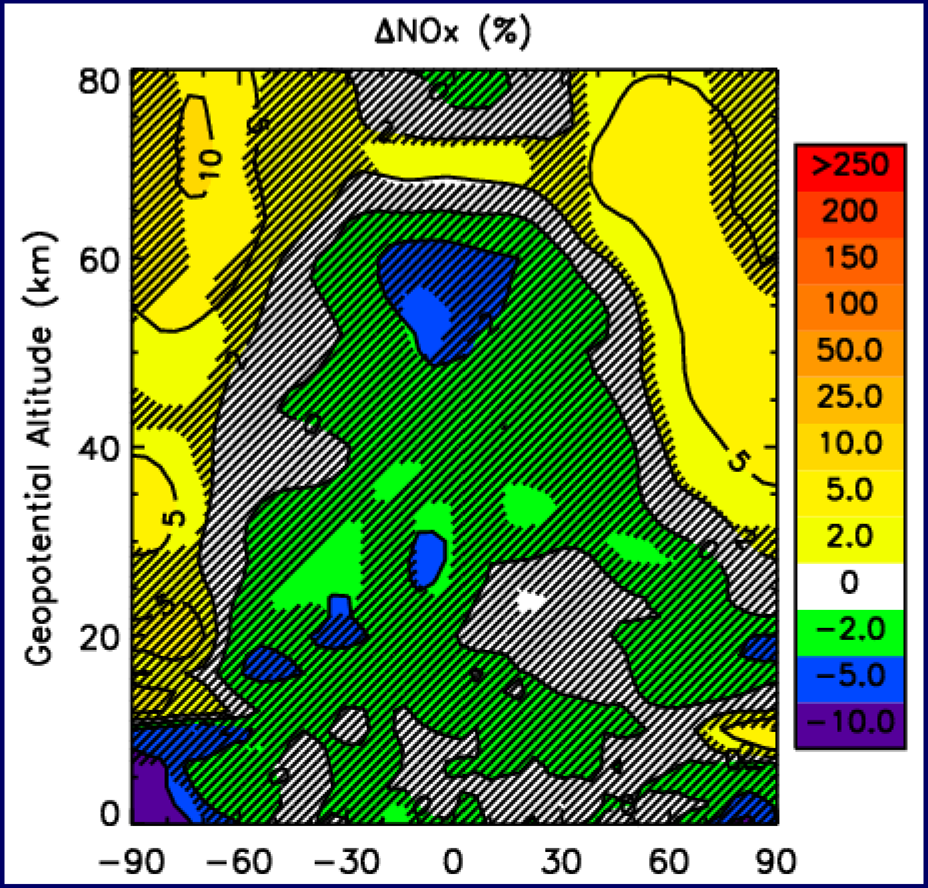
Change in NO_x due to EPP Annual Averages

Aurora Effect



Latitude

MEE Effect

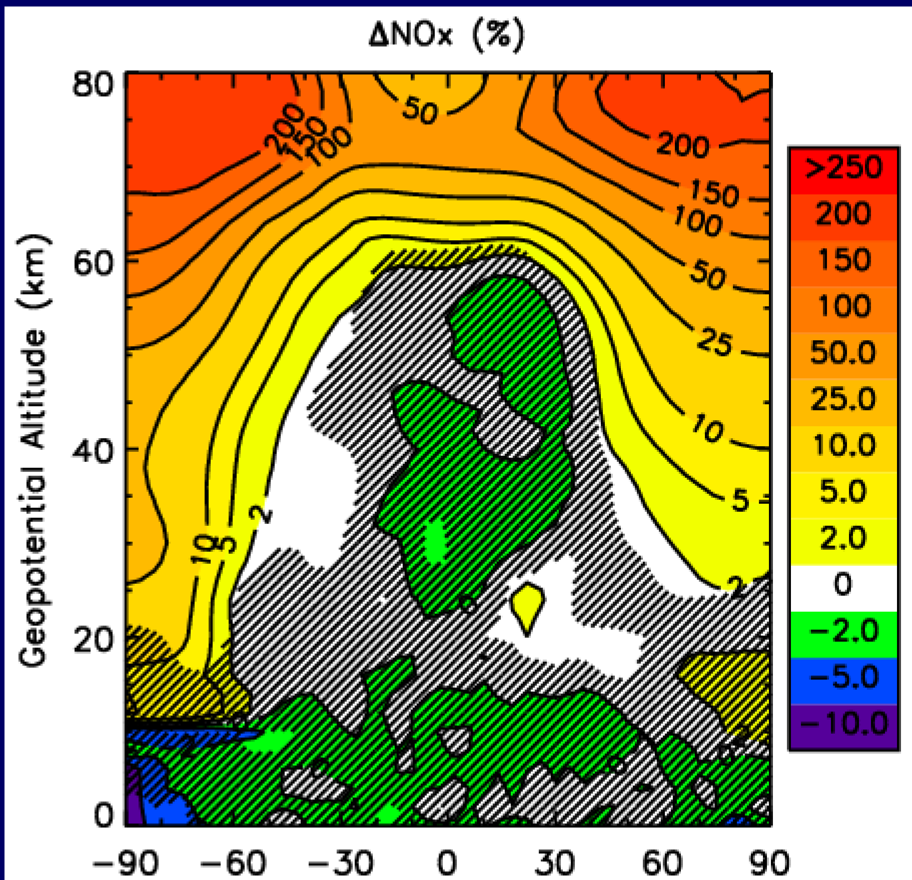


Latitude

Regions without cross-hatching significant at 95% confidence level

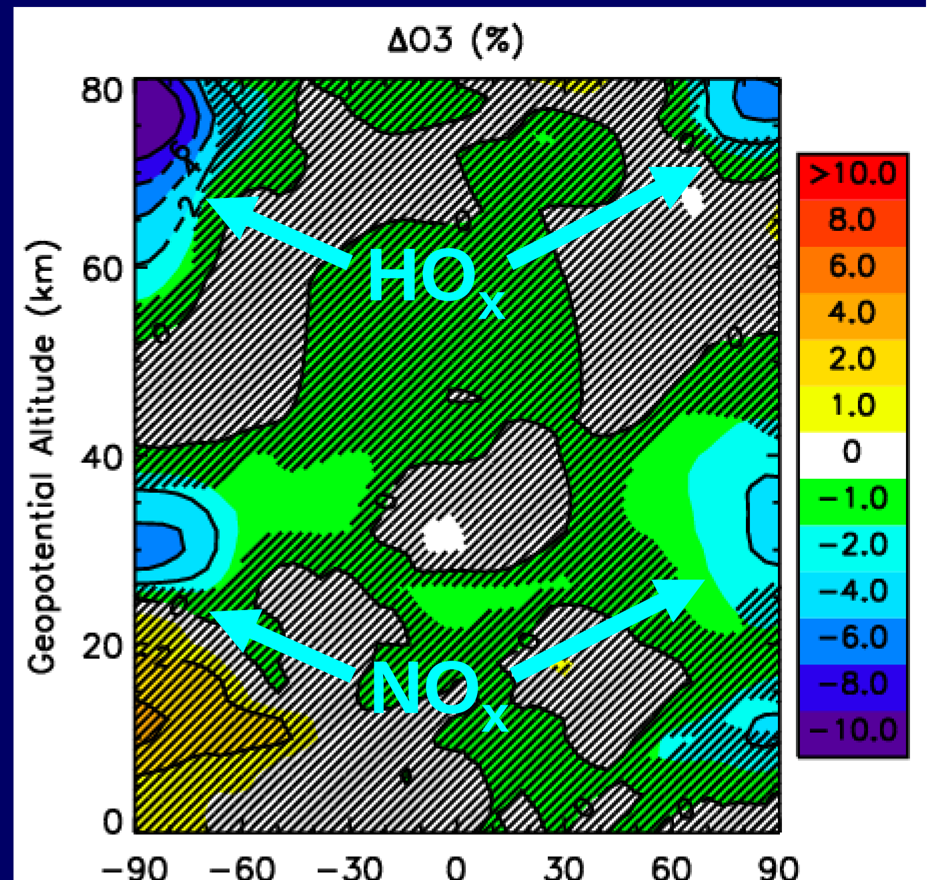
Change in NO_x and O_3 due to EPP Annual Averages: Aurora + MEE

NO_x



Latitude

Ozone



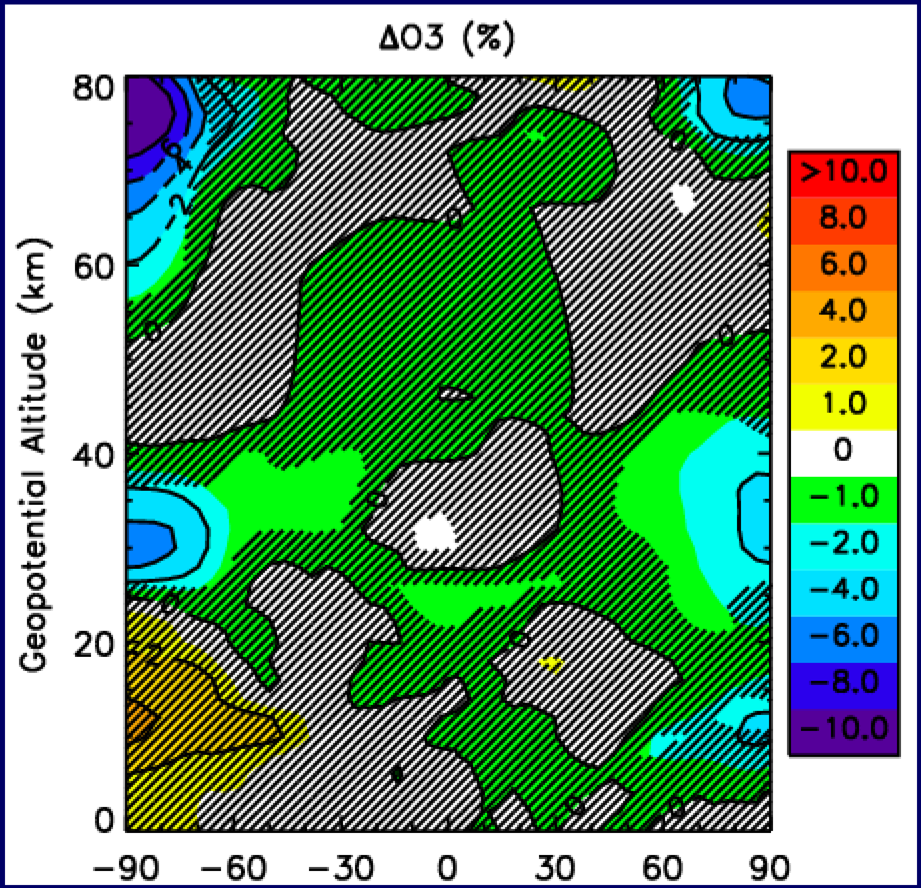
Latitude

Regions without cross-hatching significant at 95% confidence level

Xiaohua Fang, HEPPA meeting, October 8, 2009

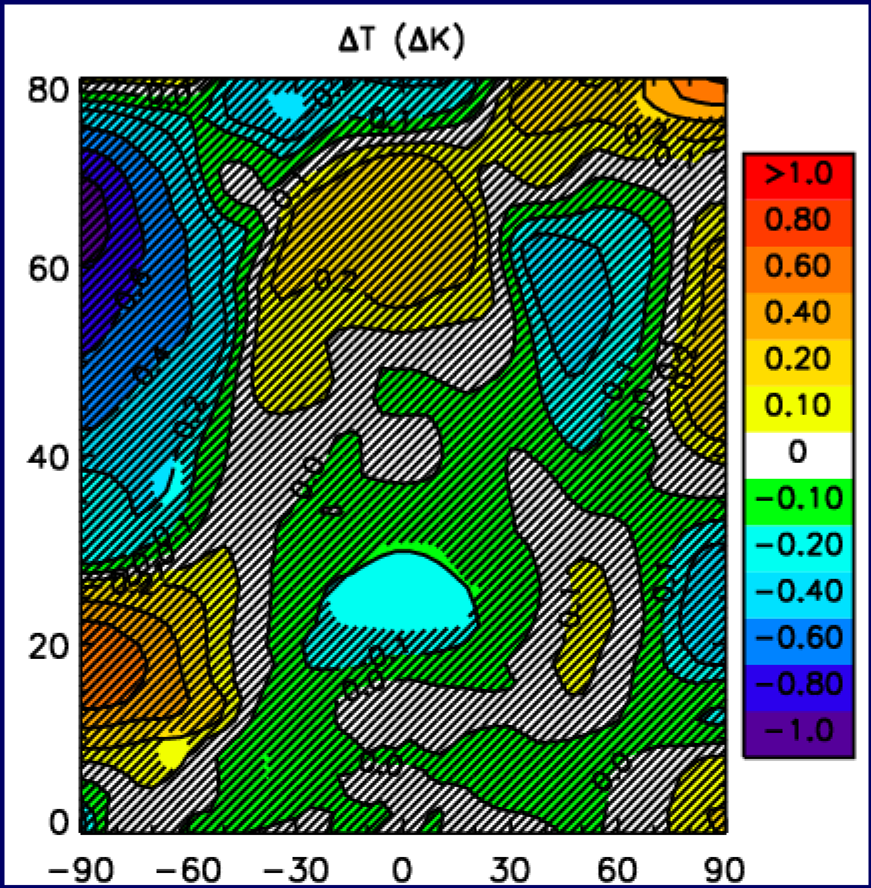
Change in O_3 and Temp due to EPP Annual Averages: Aurora + MEE

O_3



Latitude

Temperature

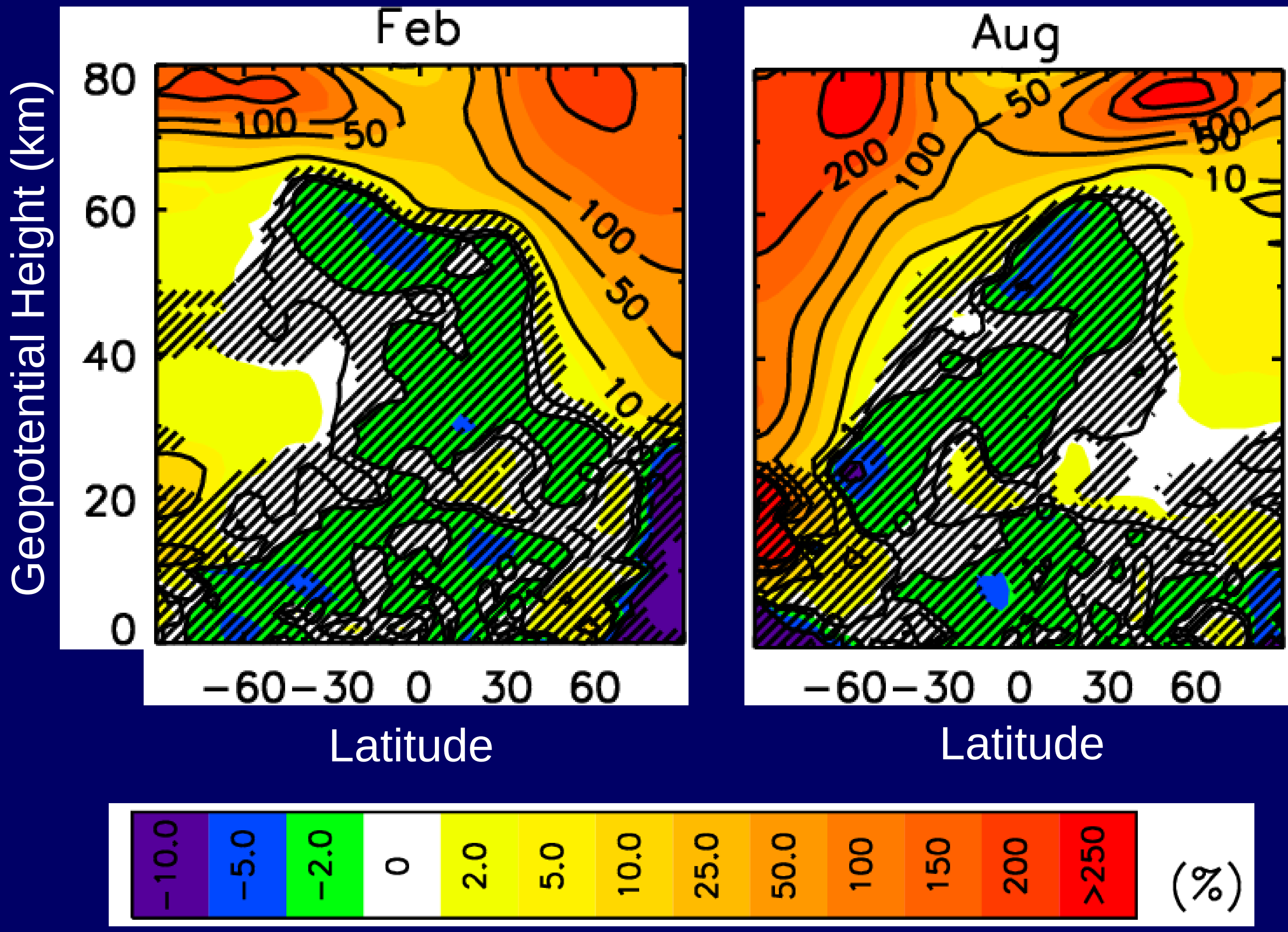


Latitude

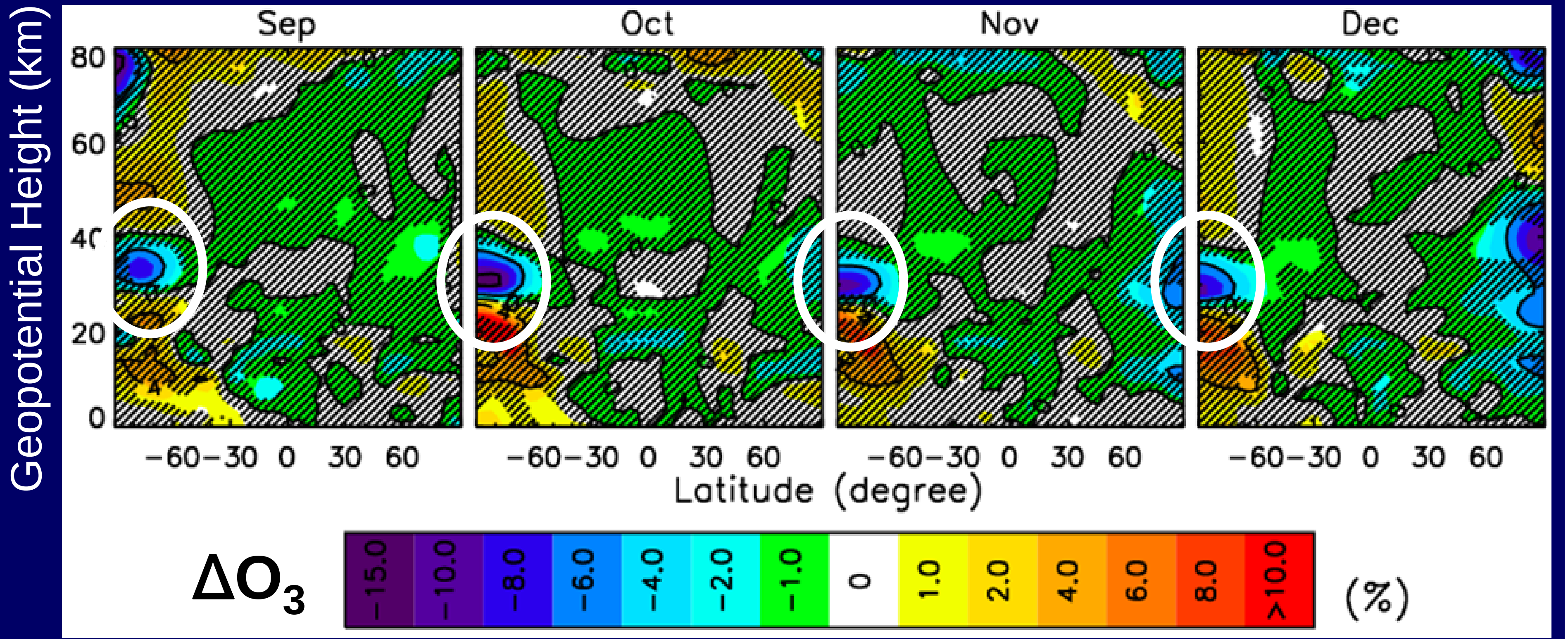
Regions without cross-hatching significant at 95% confidence level

Xiaohua Fang, HEPPA meeting, October 8, 2009

NO_x change in Feb and Aug: Aurora + MEE



Monthly average ozone depletion of up to 15% at high southern latitudes, 30-35 km



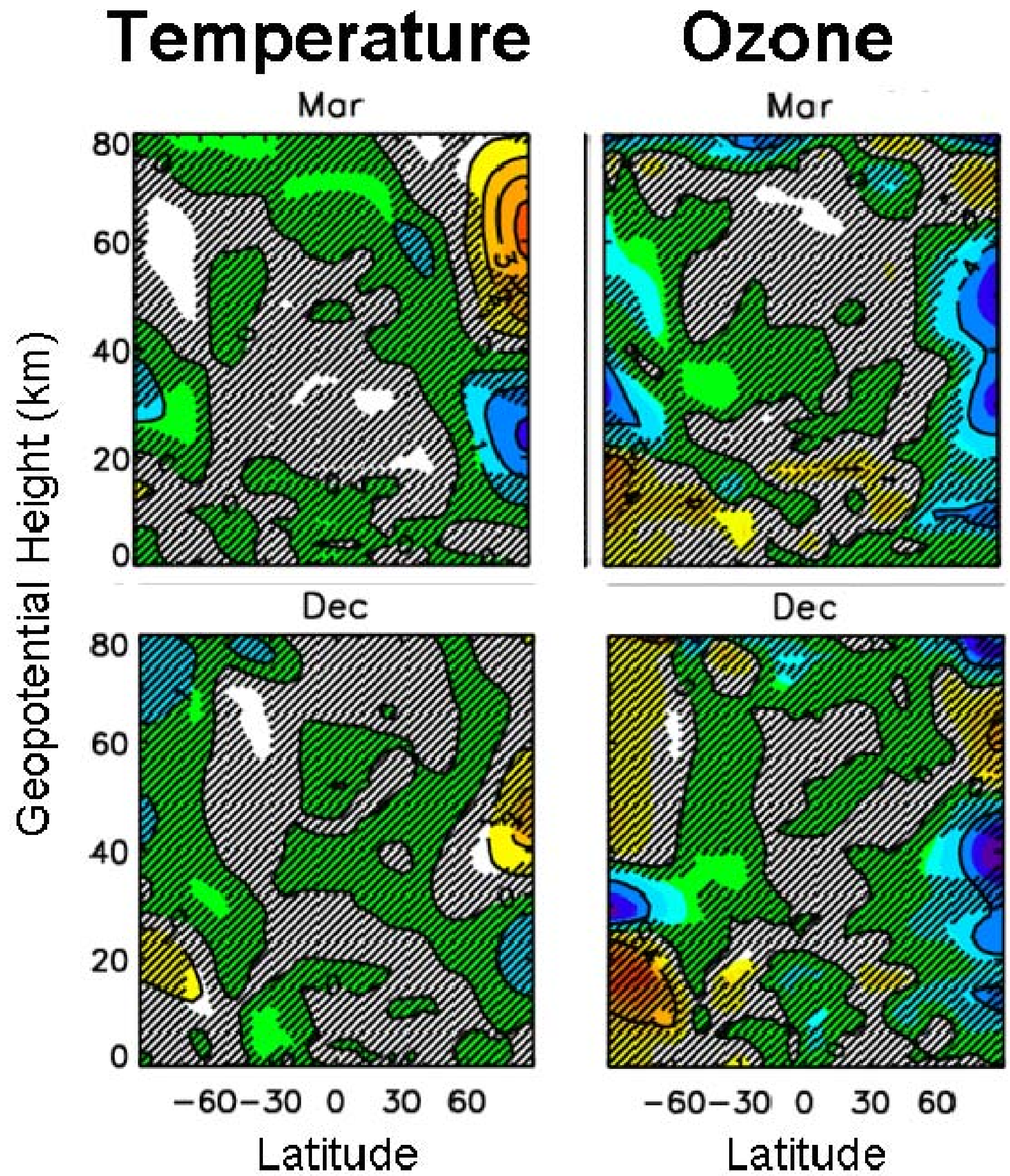
Corresponds to catalytic NO_x destruction

Largest NH Ozone depletion occurs in March from 20-60 km and in Dec near 40 km.

March temperature differences could suggest SSW effects.

Similar behavior in Dec, but low significance & lower altitudes.

Cause/effect not clear.



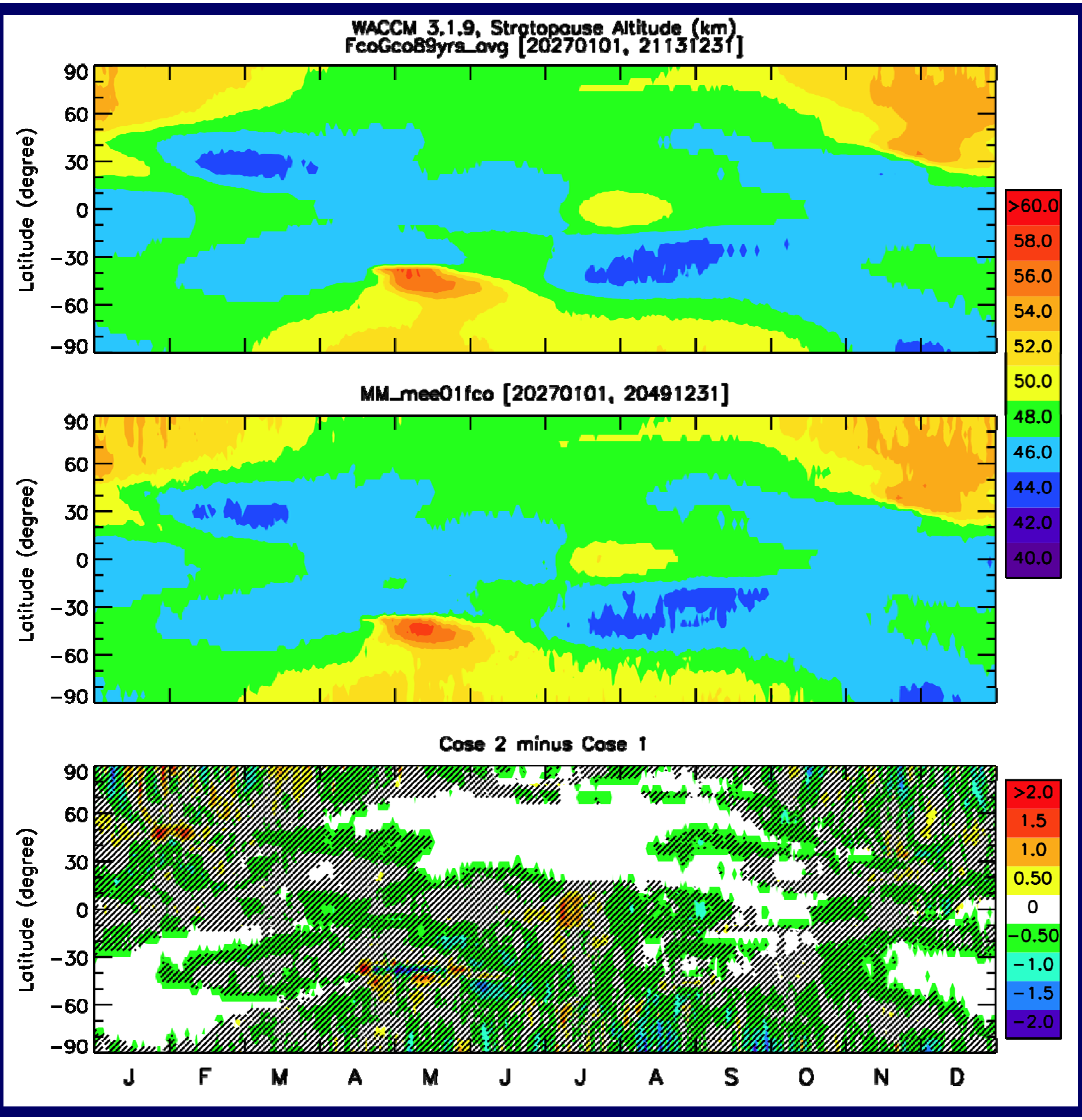
Summary:

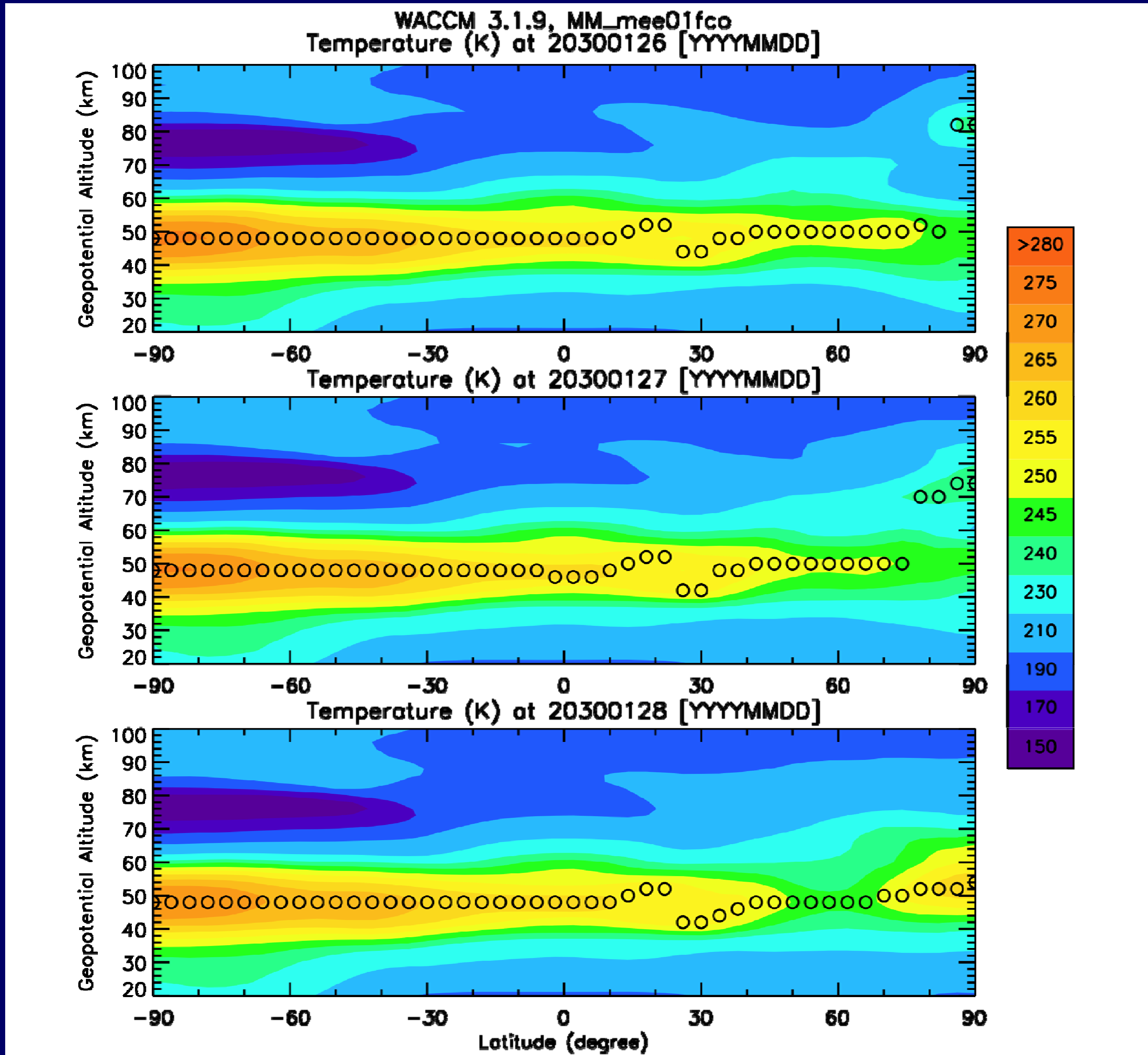
• WACCM captures the indirect effect of energetic particle precipitation.
• WACCM underestimates the EPP-NOx, by about a factor of 2.
• Change in annual averages: NO_X (~20 %), O3 (~5%), T (insignificant).
• Change in monthly averages:
  O3 (~15%, SH, 30-35 km),
  T (stratospheric warming, but unclear).

Future studies:

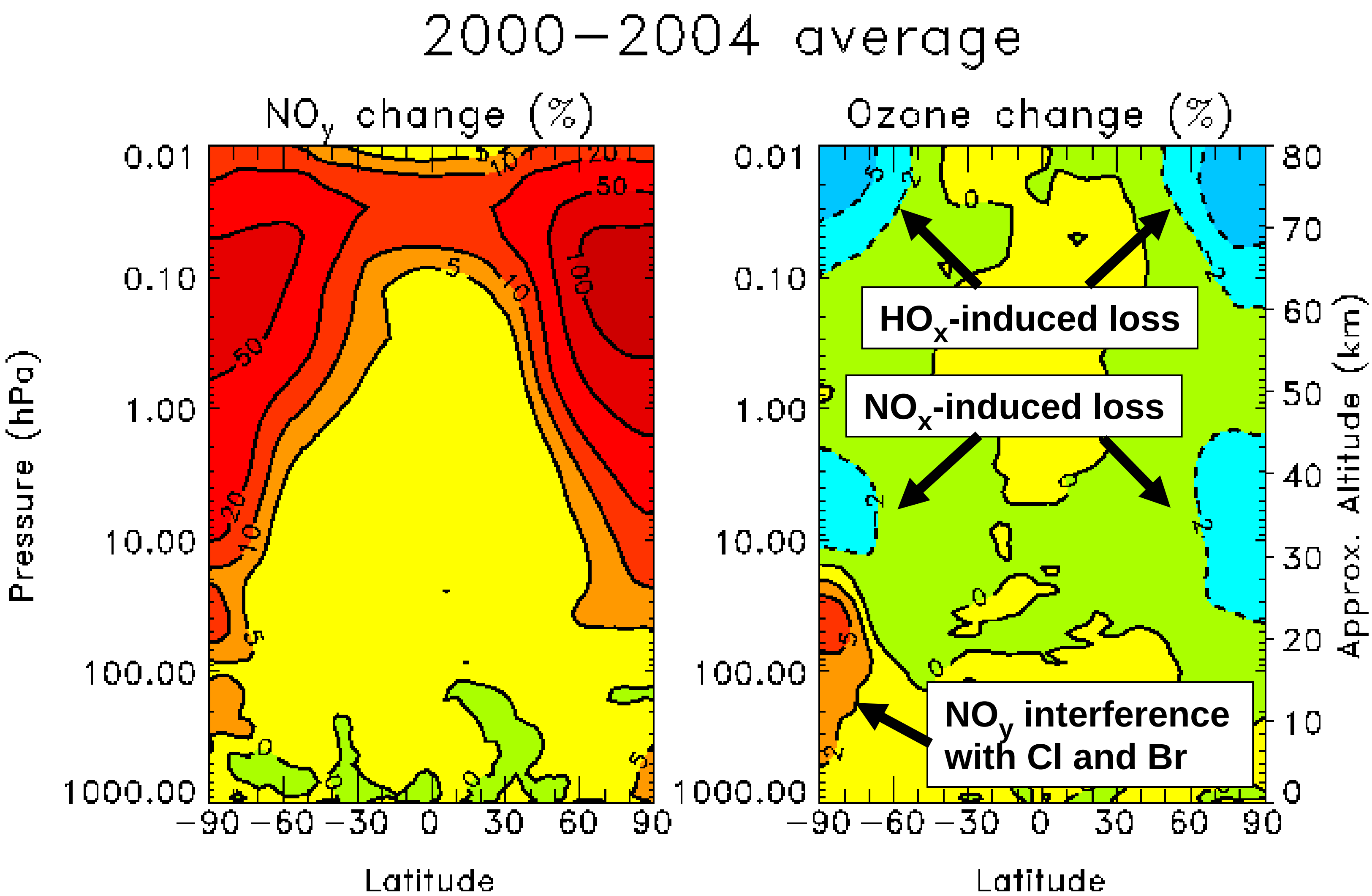
• Zonal average is taken in our current analyses. But this may cause problems, as polar vortex is not symmetric in NH.
• Include time-varying, more realistic particle precipitation.
• Include more types of particle precipitation: auroral protons, SPE, REP.
• Study dynamics in WACCM.

EXTRA SLIDES


WACCM 3.1.9, Stratopause Altitude (km)
FcoGco89yrs_avg [20270101, 21131231]
MM_mee01fco [20270101, 20491231]
Case 2 minus Case 1
Latitude (degree)
90 60 30 0 −30 −60 −90
J F M A M J J A S O N D
>60.0 58.0 56.0 54.0 52.0 50.0 48.0 46.0 44.0 42.0 40.0
>2.0 1.5 1.0 0.50 0 −0.50 −1.0 −1.5 −2.0

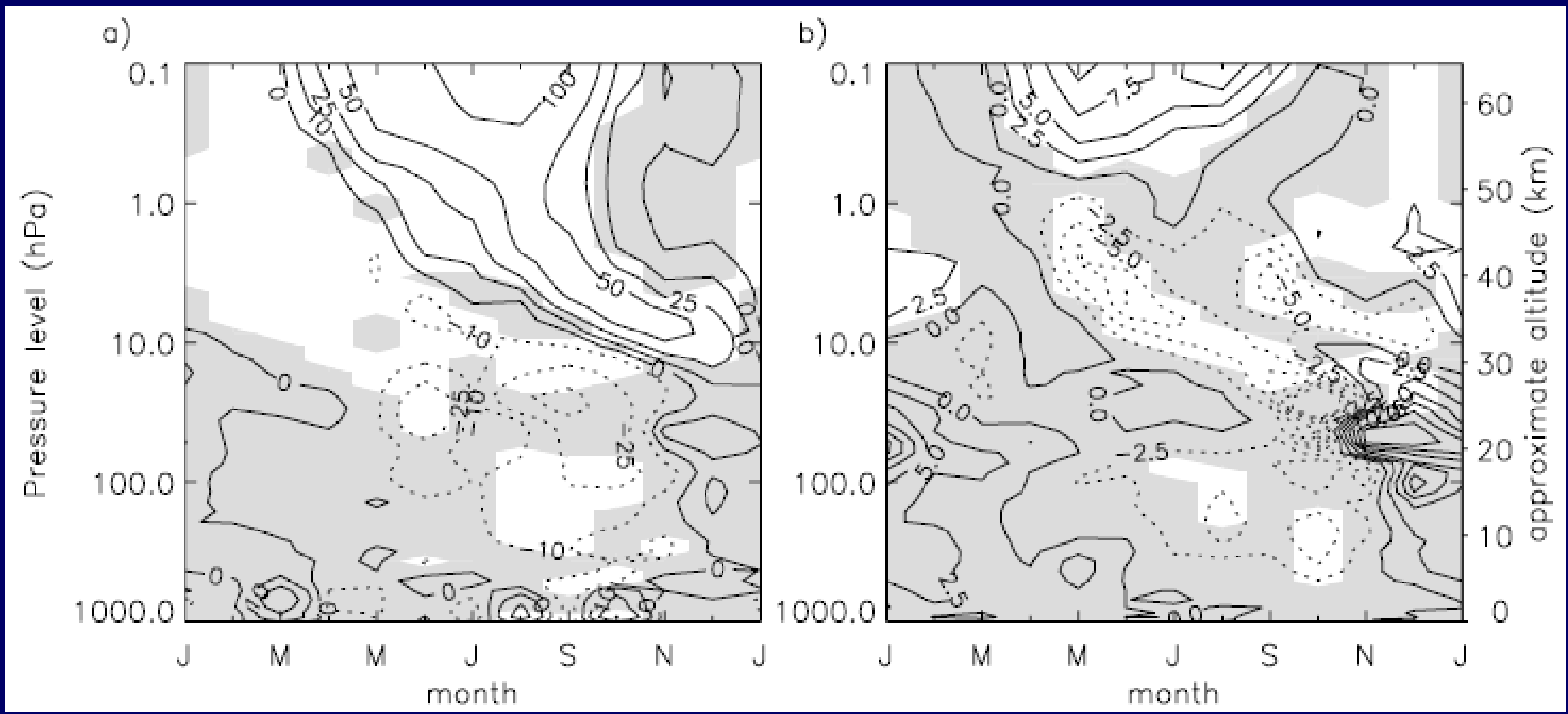


WACCM 3.1.9, MM_mee01fco
Temperature (K) at 20300126 [YYYYMMDD]
Temperature (K) at 20300127 [YYYYMMDD]
Temperature (K) at 20300128 [YYYYMMDD]
Geopotential Altitude (km)
Latitude (degree)
100
90
80
70
60
50
40
30
20
−90
−60
−30
0
30
60
90
>280
275
270
265
260
255
250
245
240
230
210
190
170
150



Very Large SPEs in 2000, 2001, & 2003

Jackman, COSPAR 2008



From Marsh et al., 2007