Energetic particle effects on the atmosphere and climate

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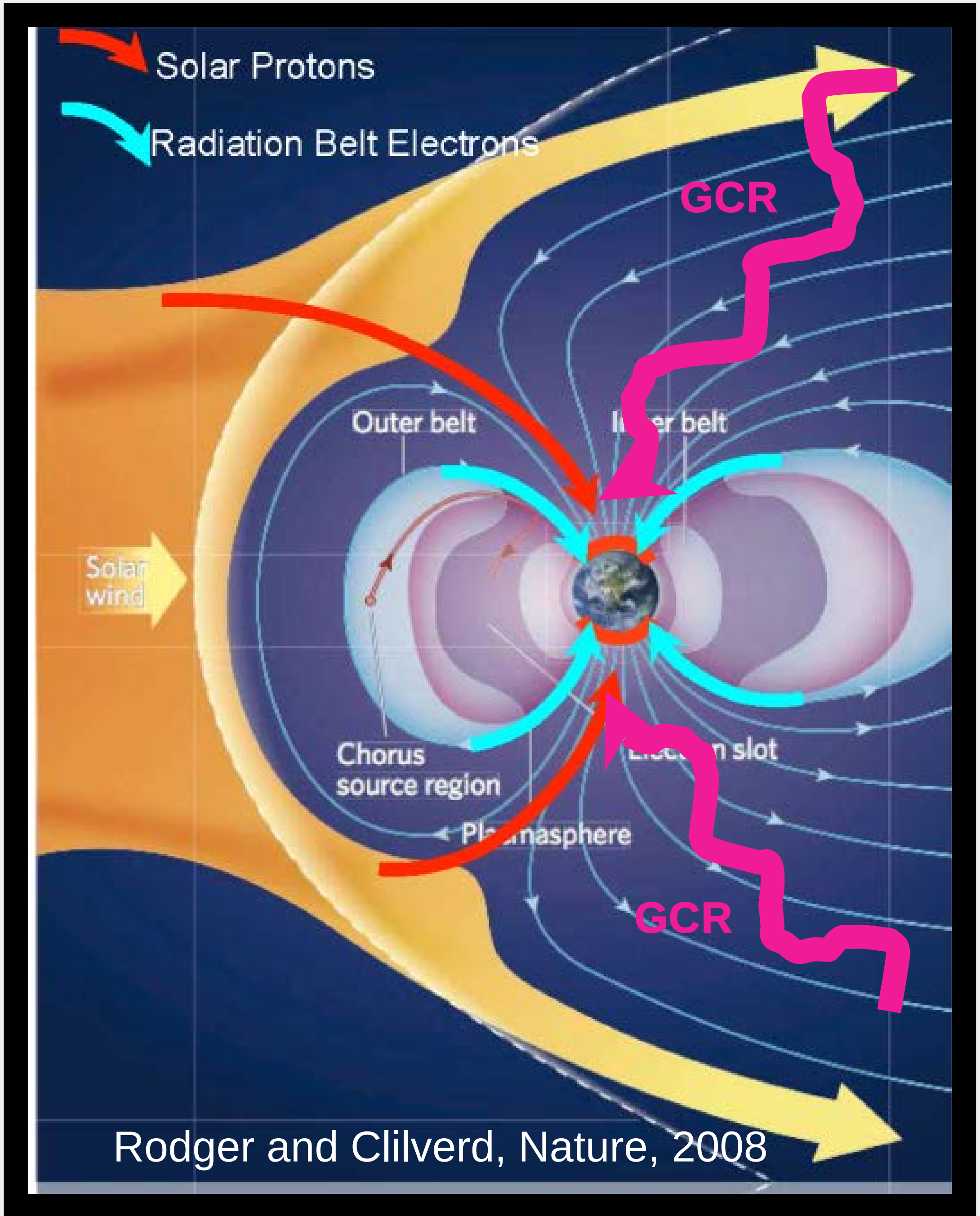
Precipitating energetic particles



Electrons

Low Energy (<30 KeV):
From plasma-sheat to auroral oval

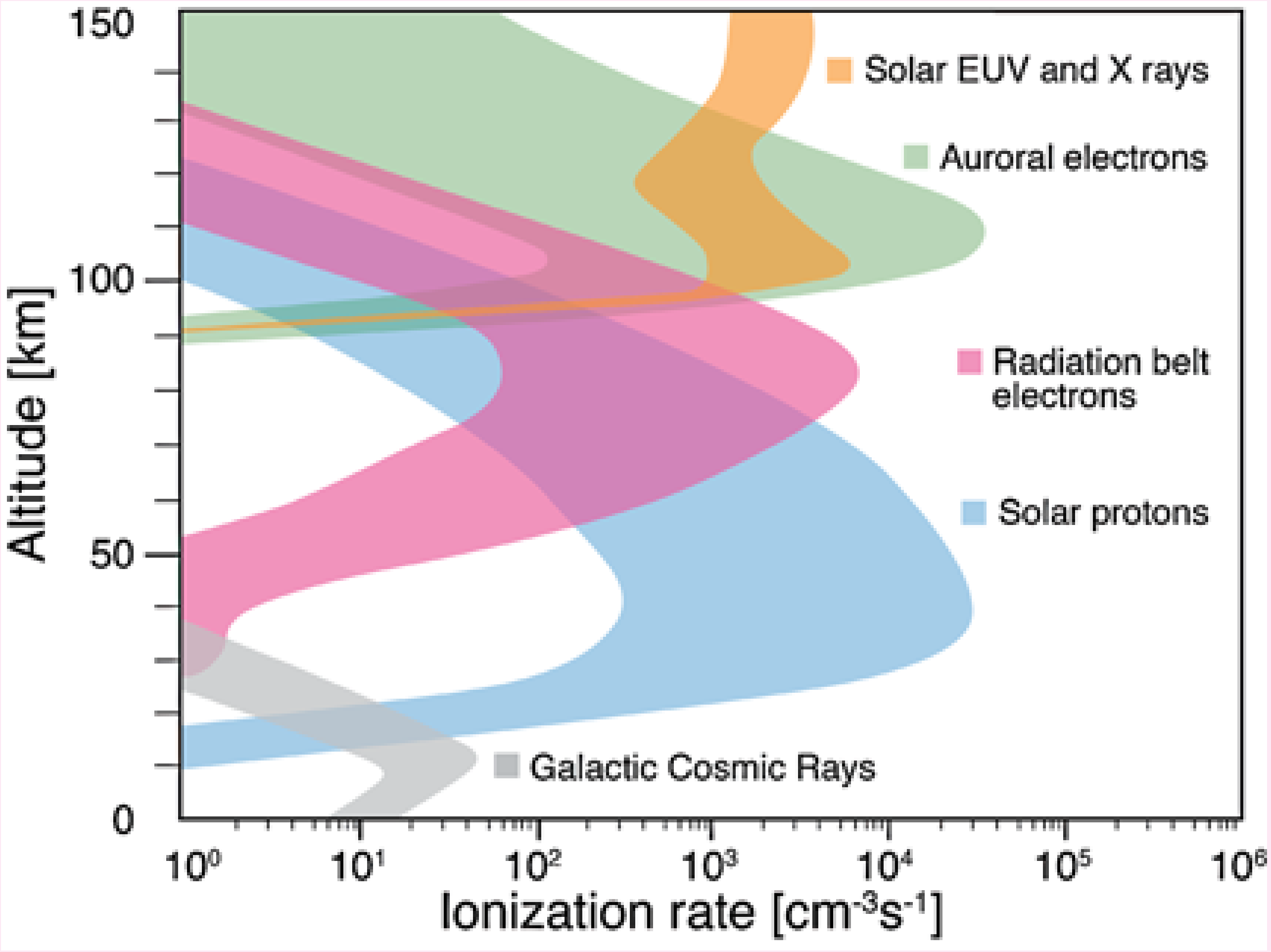
Medium to High Energy:
From the Radiation Belts to subauroral area

Solar Protons:
polar cap

Galactic cosmic rays:
From outside to everywhere

Vertical distribution depends on particle energy

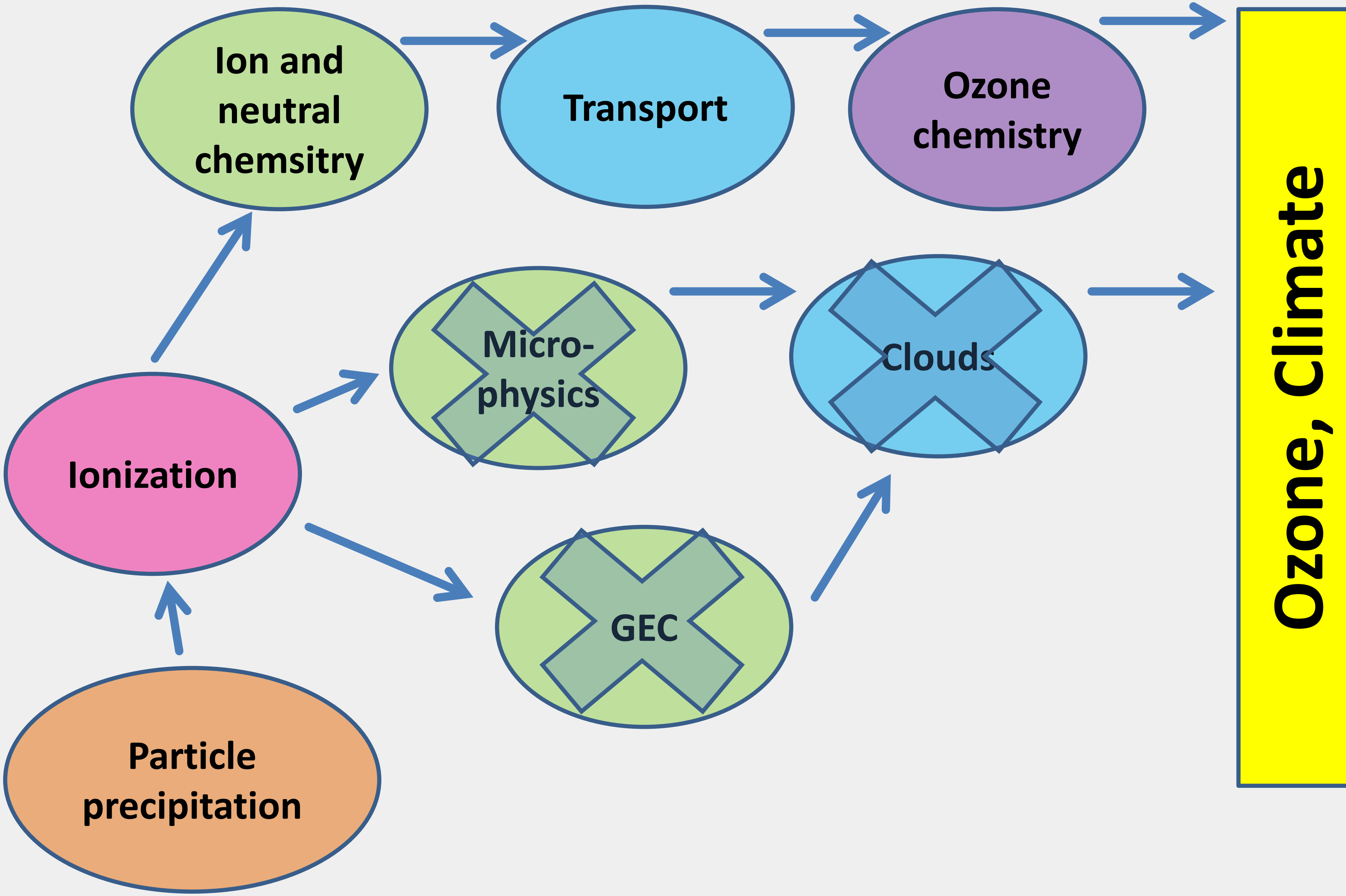
Types of precipitating energetic particles
based on energy deposition altitude



Instanteneous

Mironova et al., 2015

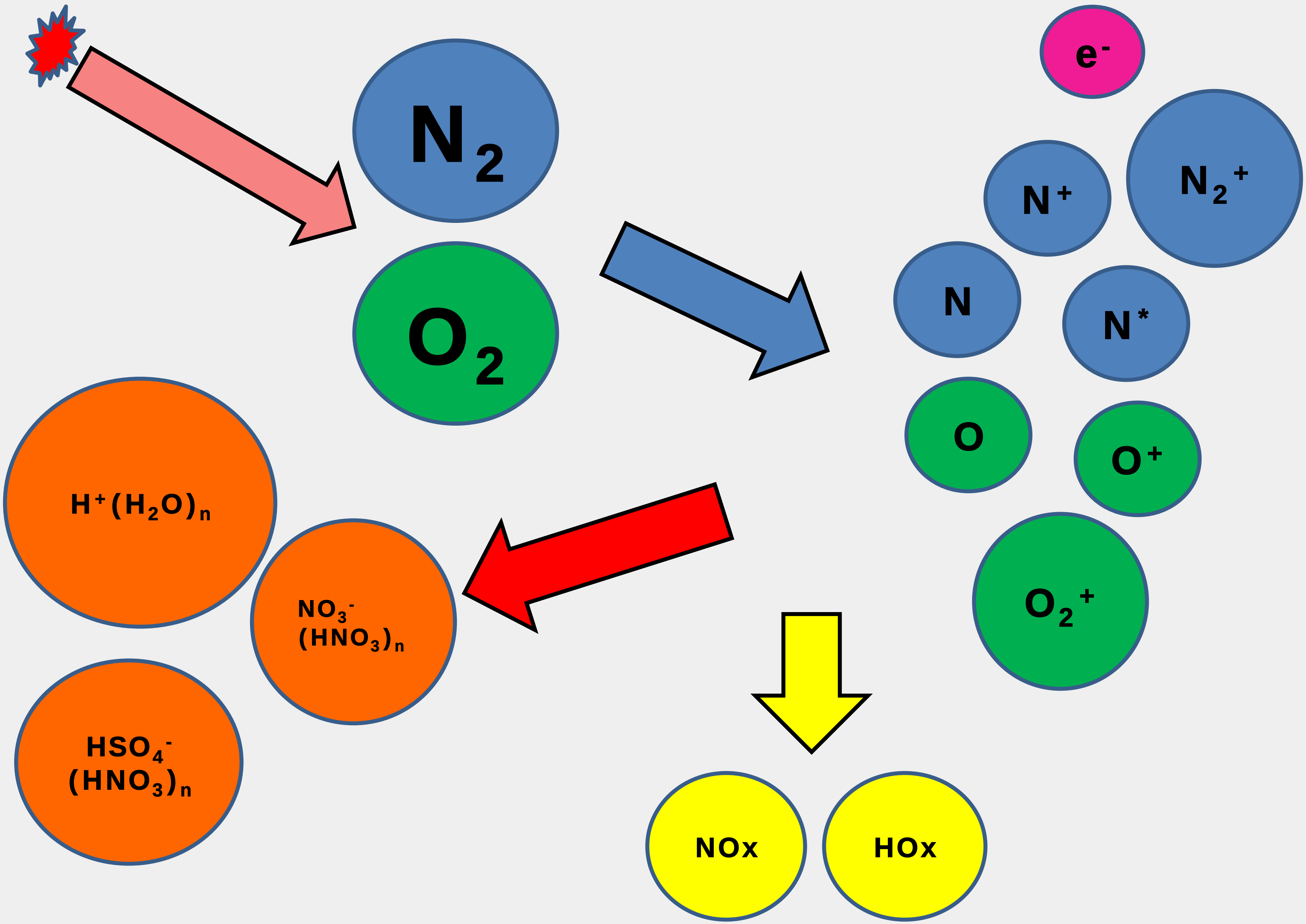
Processes



Ion and neutral chemsitry
Transport
Ozone chemistry
Micro-physics
Clouds
Ionization
GEC
Particle precipitation
Ozone, Climate

Processes

Ionization products



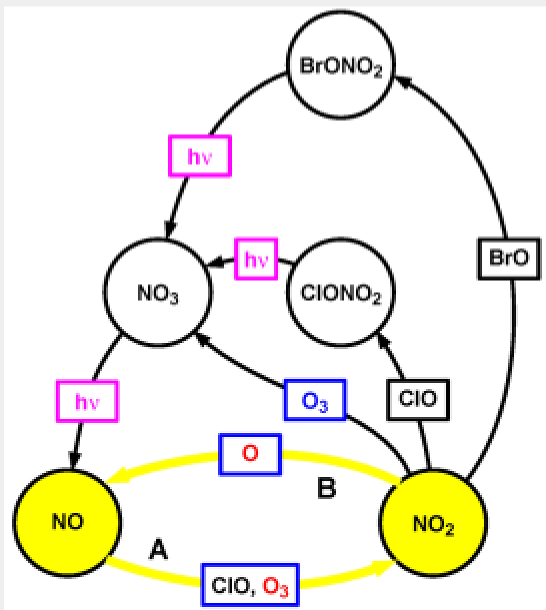
Stratospheric ozone depletion by NO_x and HO_x

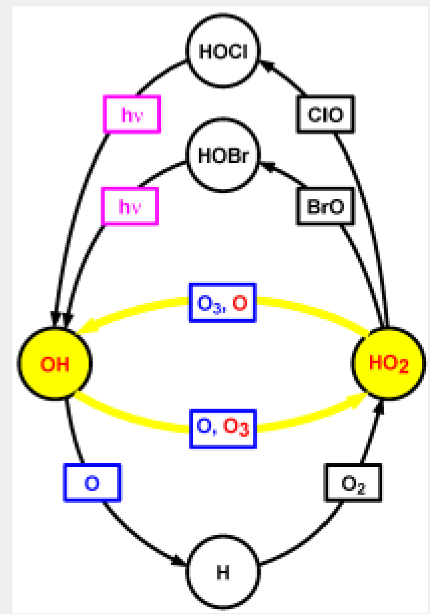
Nitrogen:

$NO + O_3 \rightarrow NO_2 + O_2$
$NO_2 + O \rightarrow NO + O_2$
========================
$O_3 + O \rightarrow 2O_2$

Hydrogen:

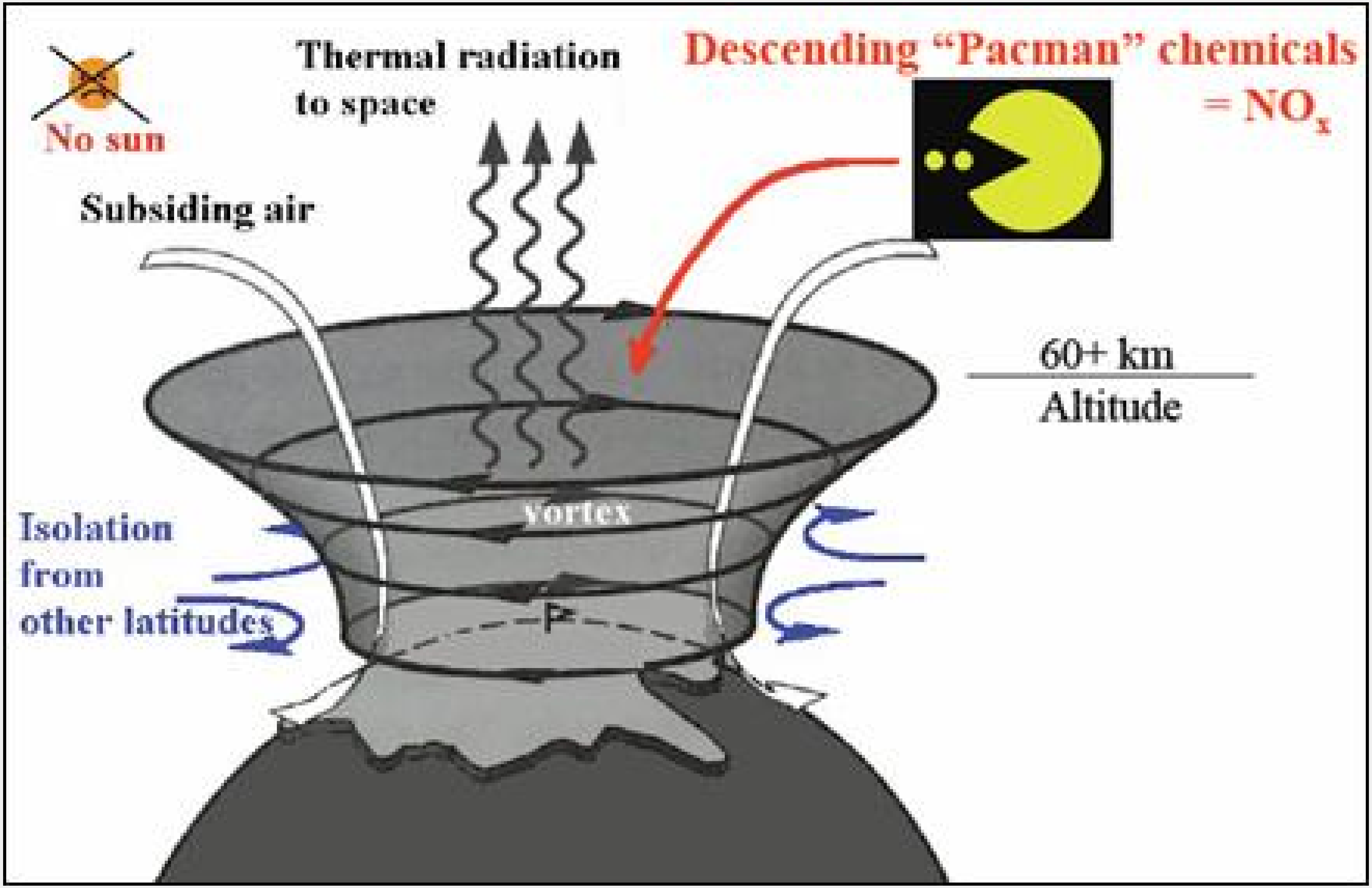
$OH + O_3 \rightarrow HO_2 + O_2$
$HO_2 + O \rightarrow OH + O_2$
========================
$O_3 + O \rightarrow 2O_2$





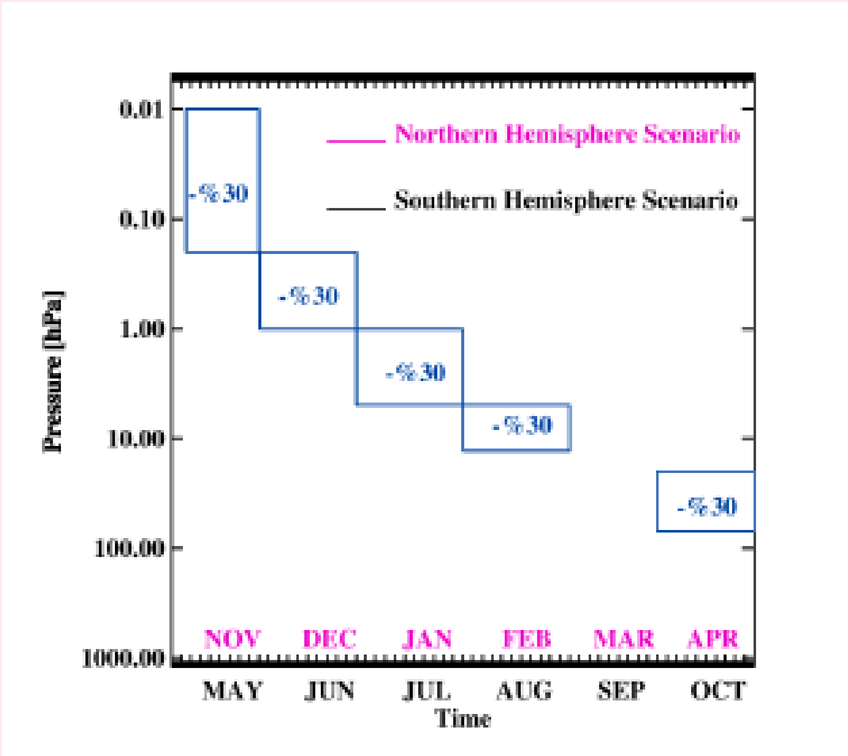
From D. Lary

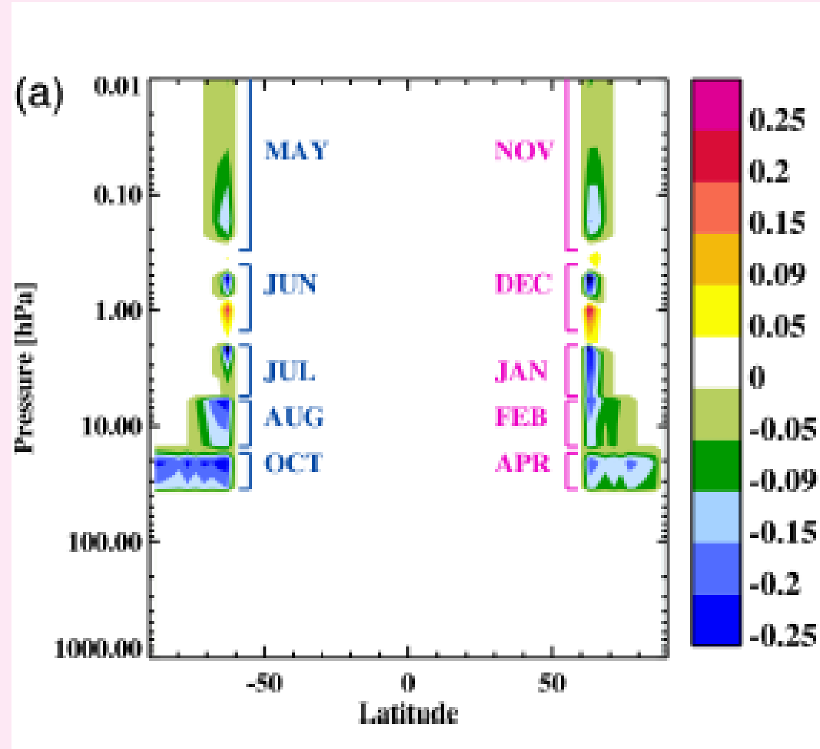
Downward transport of thermospheric NO_x



Rodger, 2008

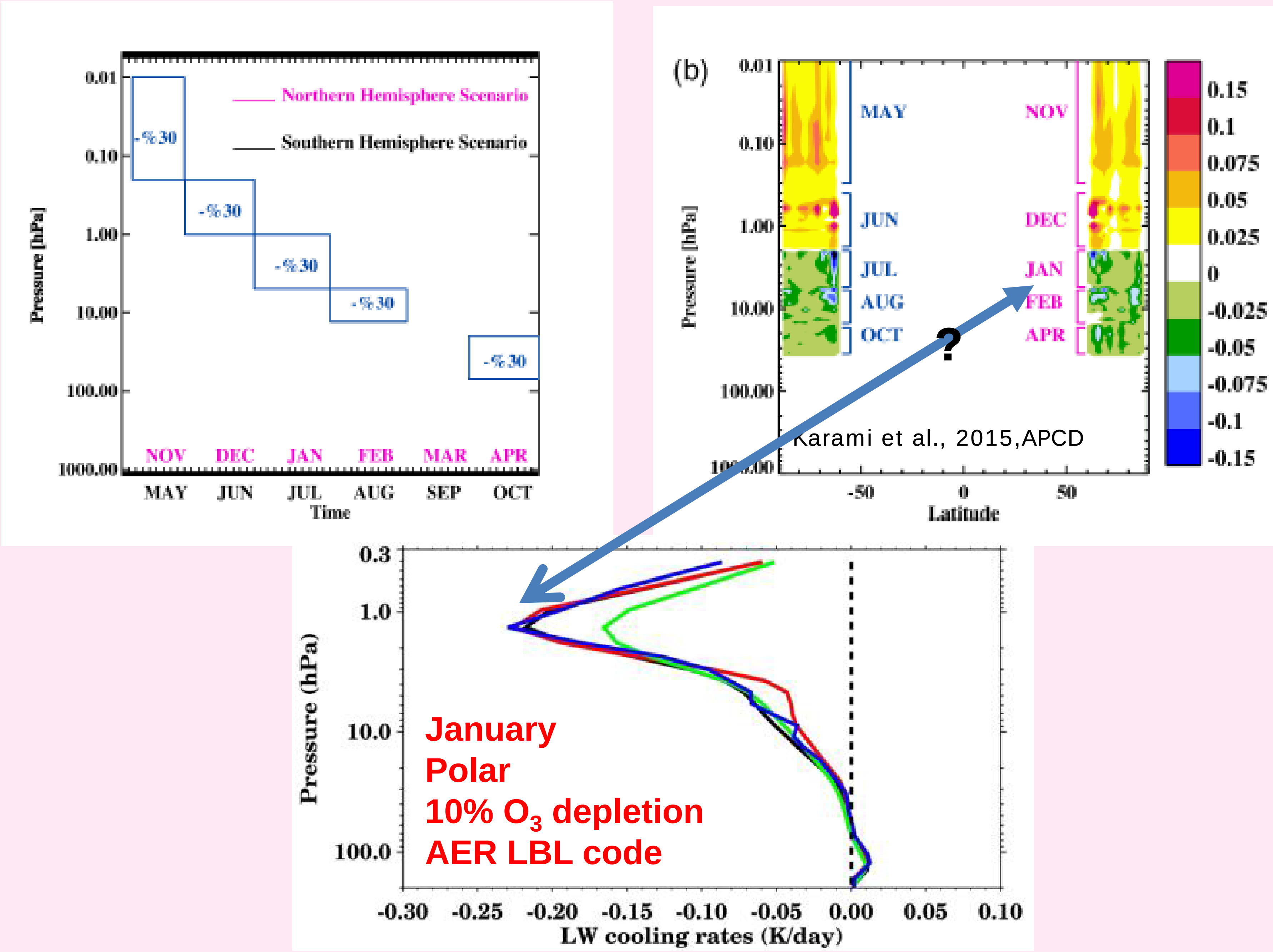
Polar ozone depletion and SW heating rates



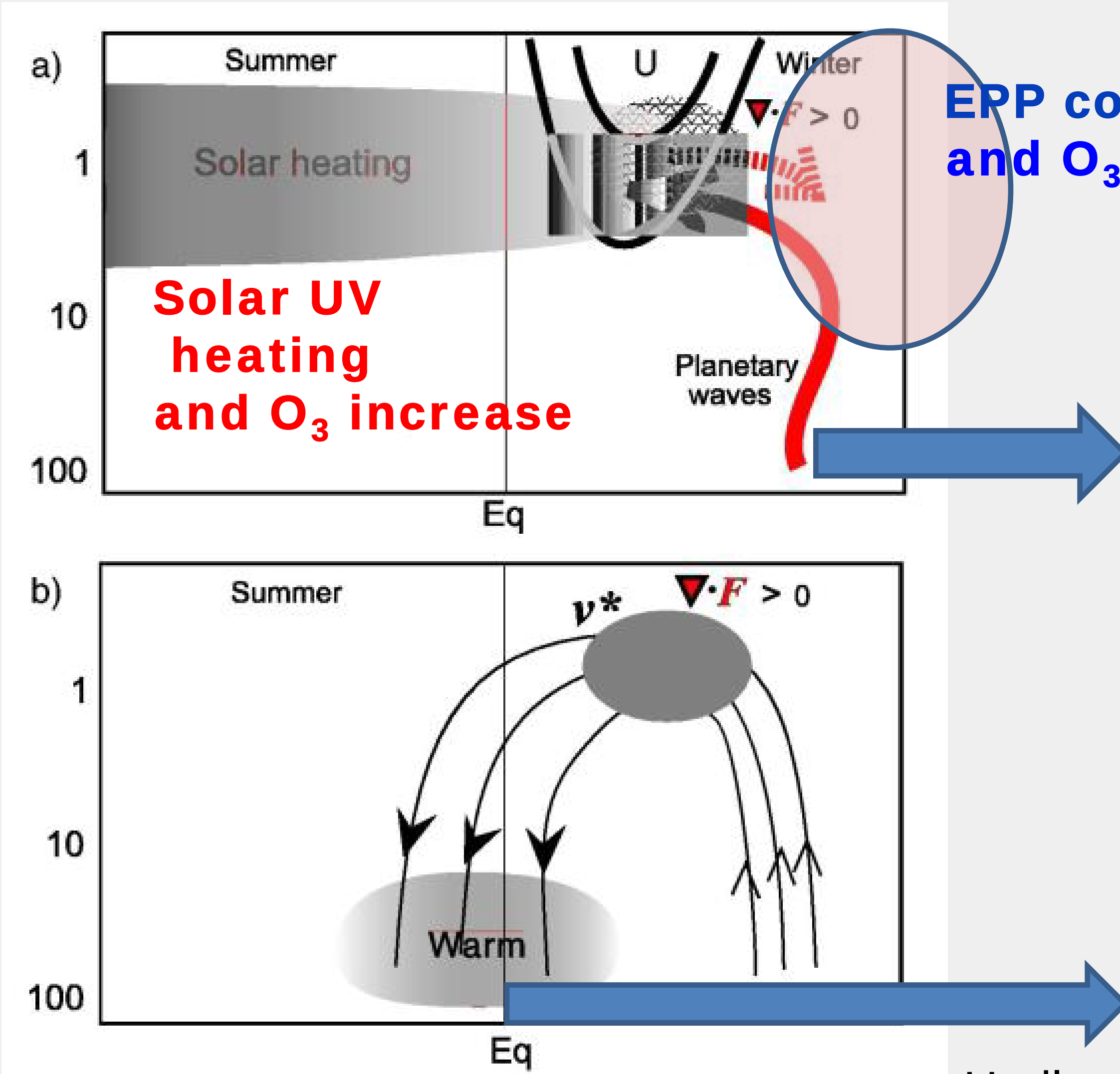


Karami et al., 2015,APCD

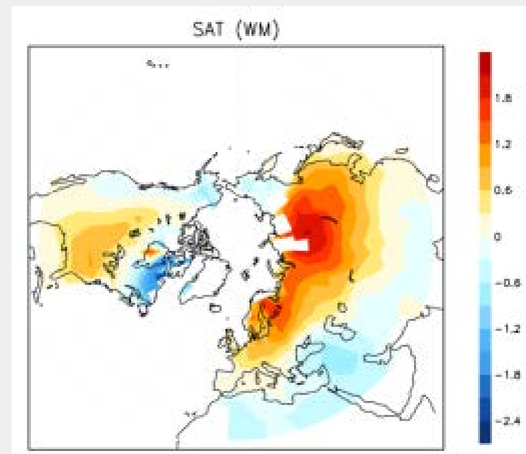
Polar ozone depletion and LW cooling rates



Downward propagating response or ‘top-down’ mechanism



Kodera and Kuroda, (2002)

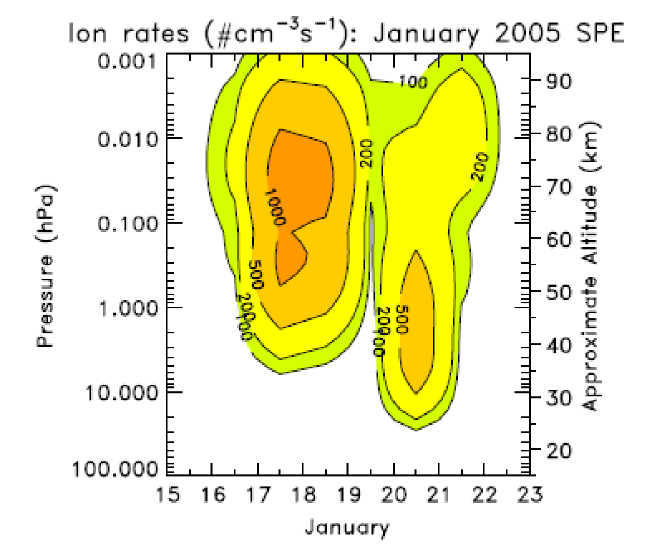


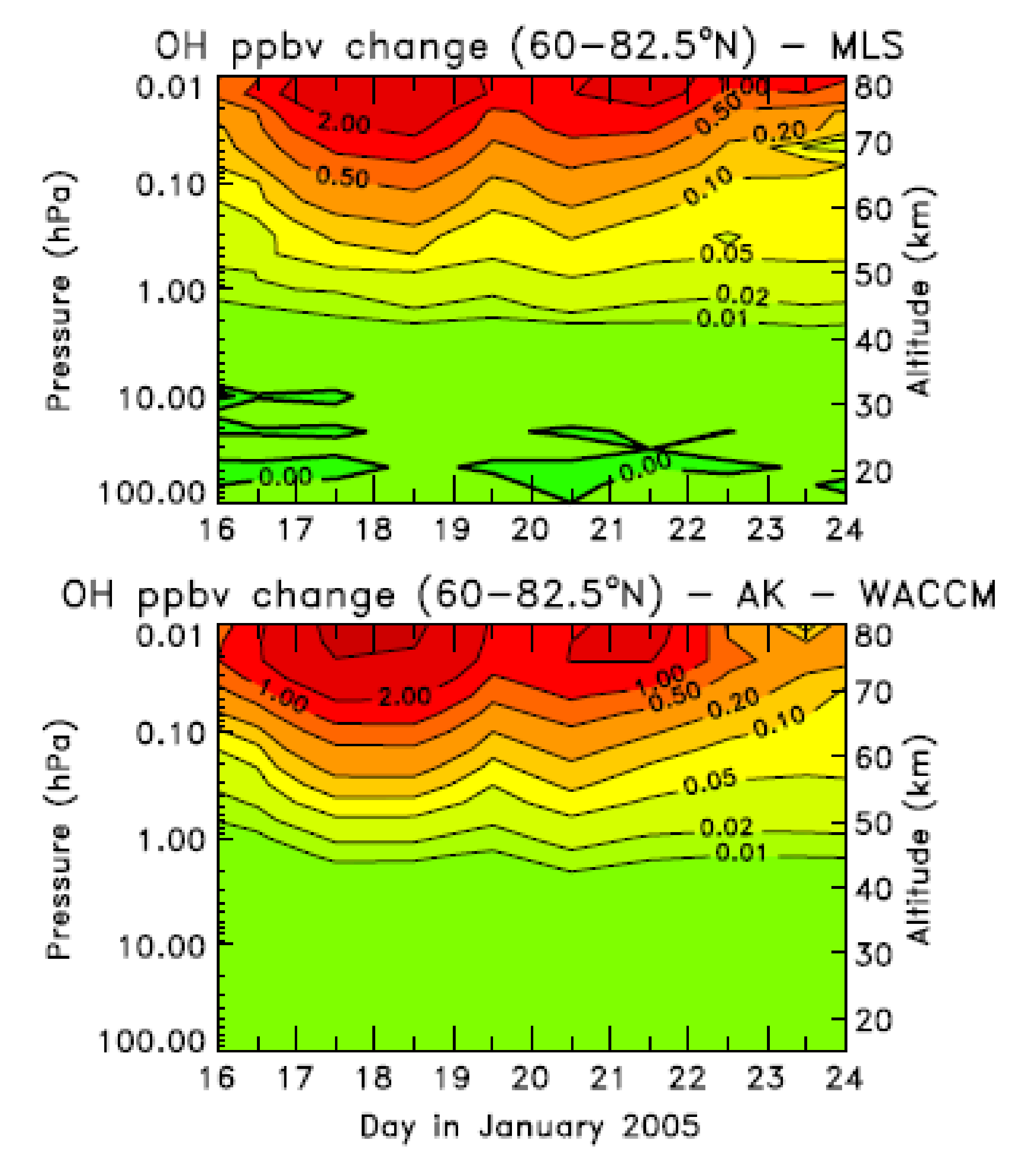
Thomson & Wallace (1998)

Hadley sell shift and ... (J.Haigh)

SPE effects

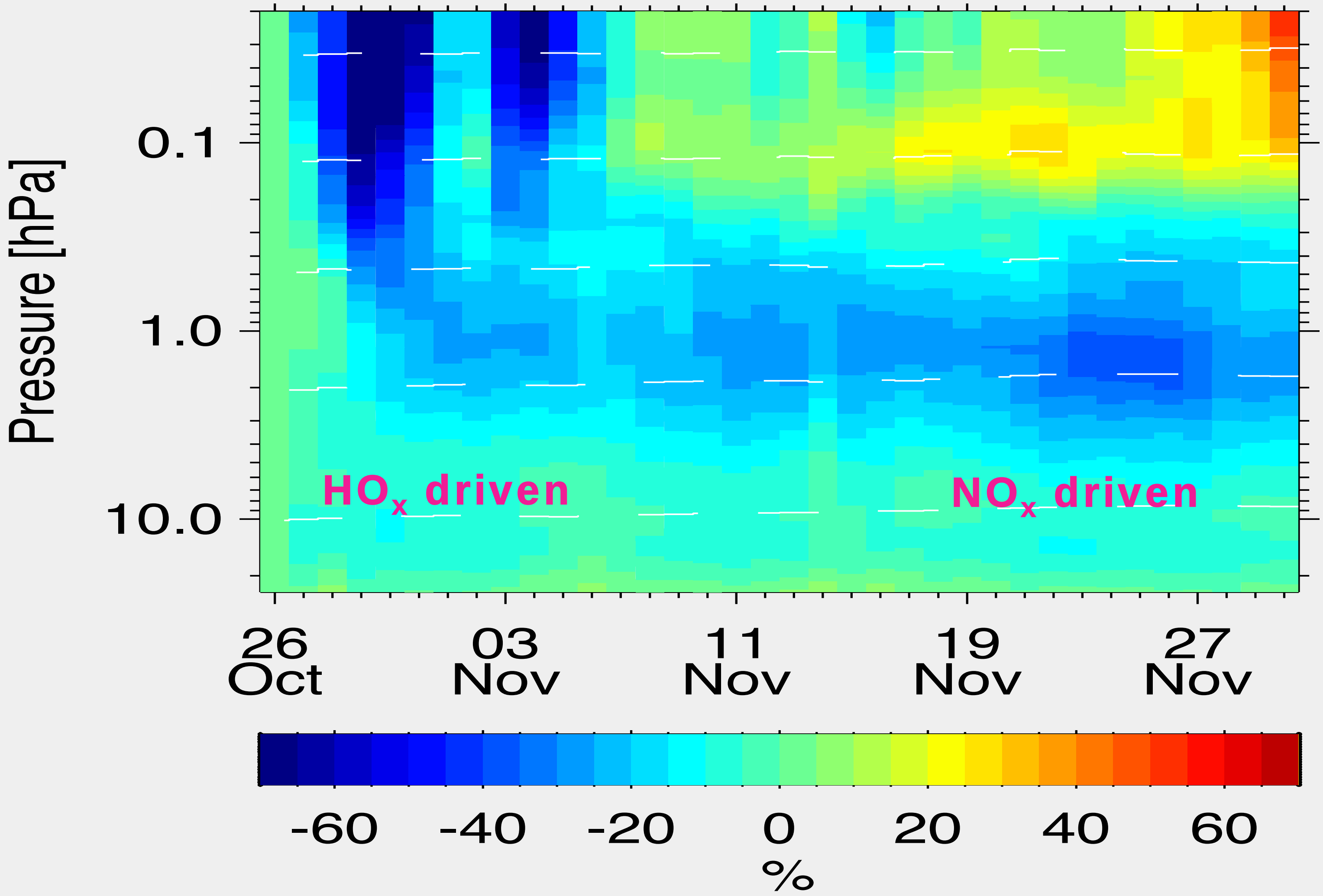
SPE effects on the atmosphere





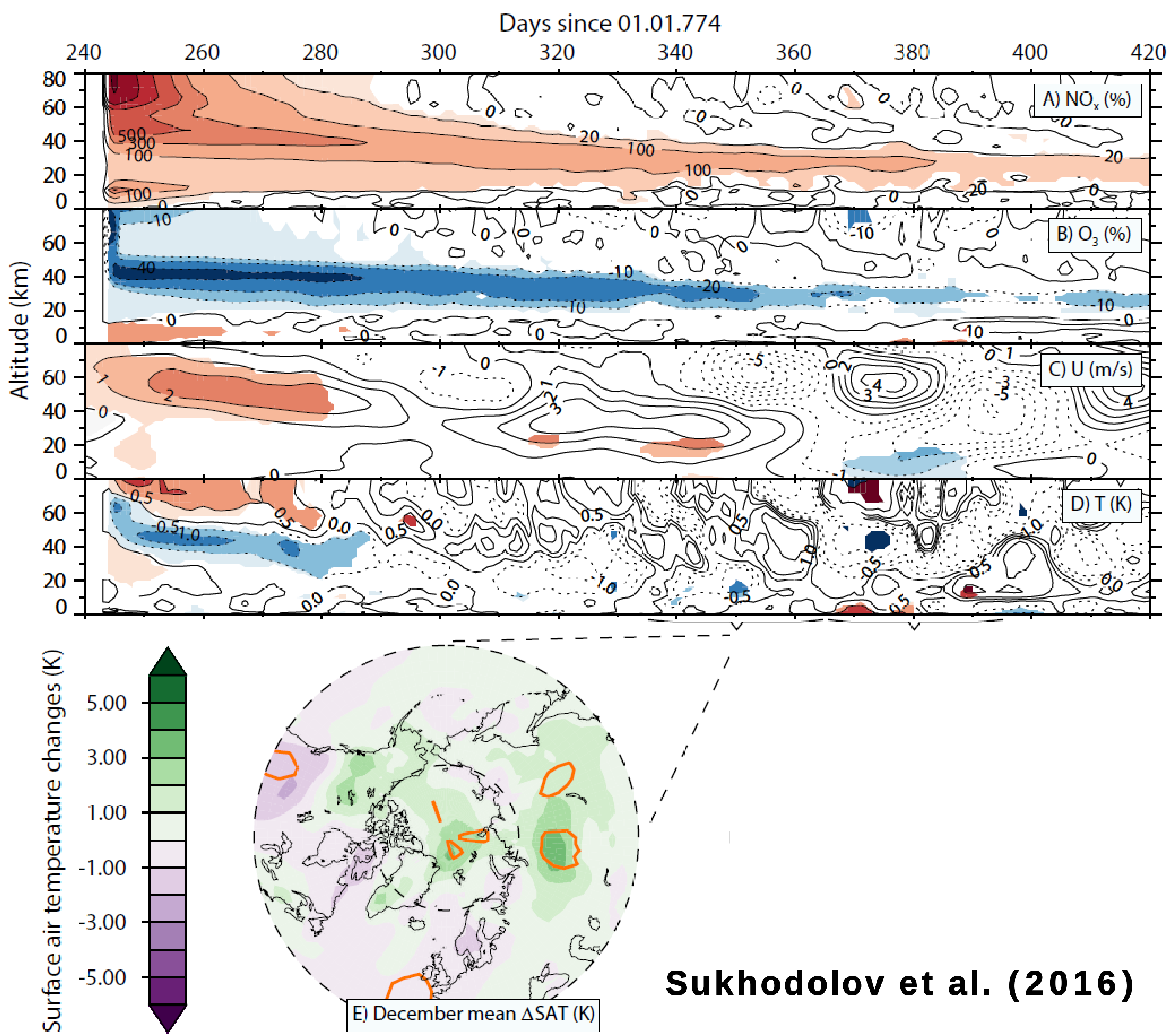
Jackman et al., 2011

SPE effects on the atmosphere



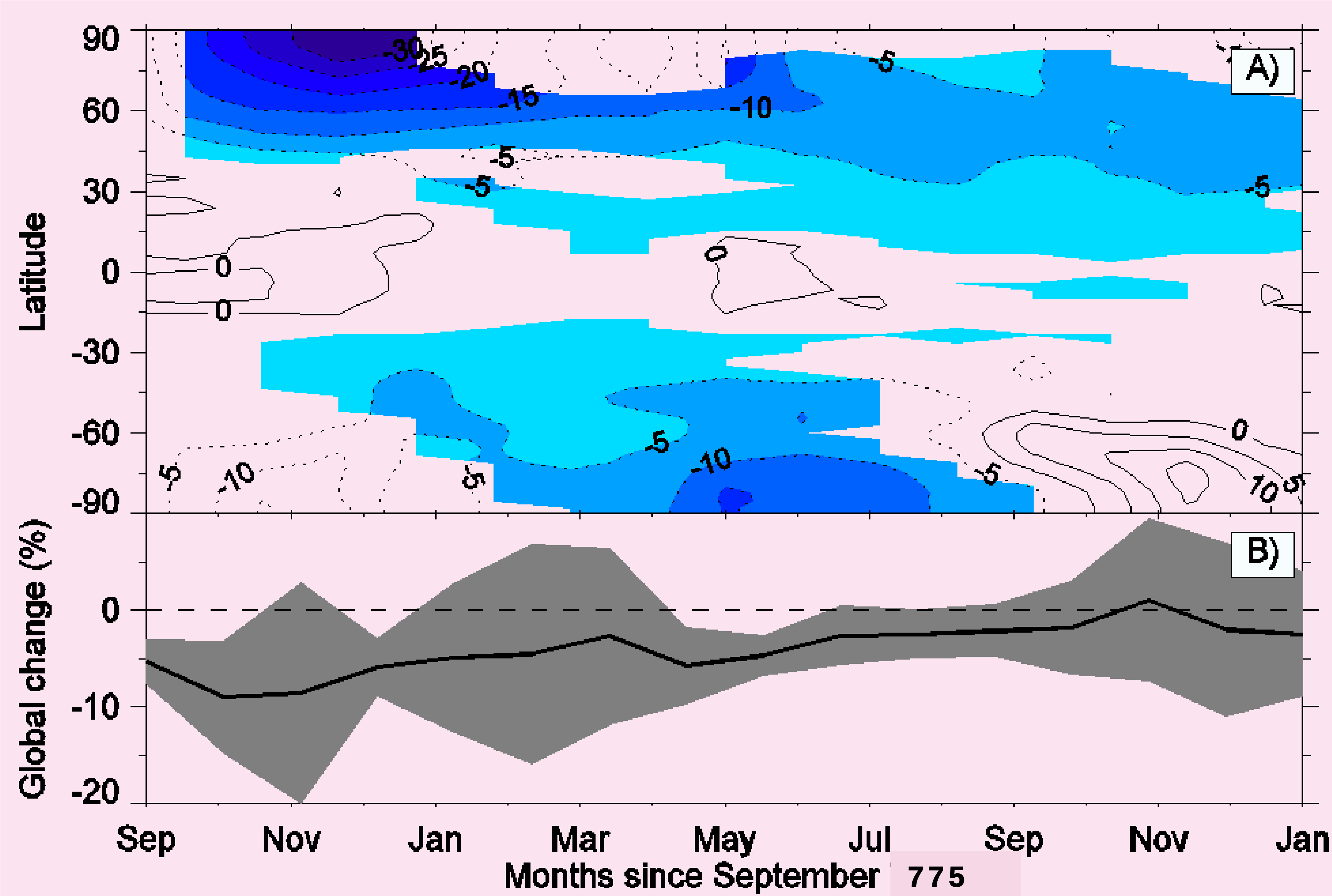
Temporal evolution of relative O3 changes with respect to 26 October 2003 in MIPAS observations averaged over 70º–90º N. Figure is reproduced from **Funke et al. (2011).**

775 AD SPE effects on the atmosphere



Sukhodolov et al. (2016)

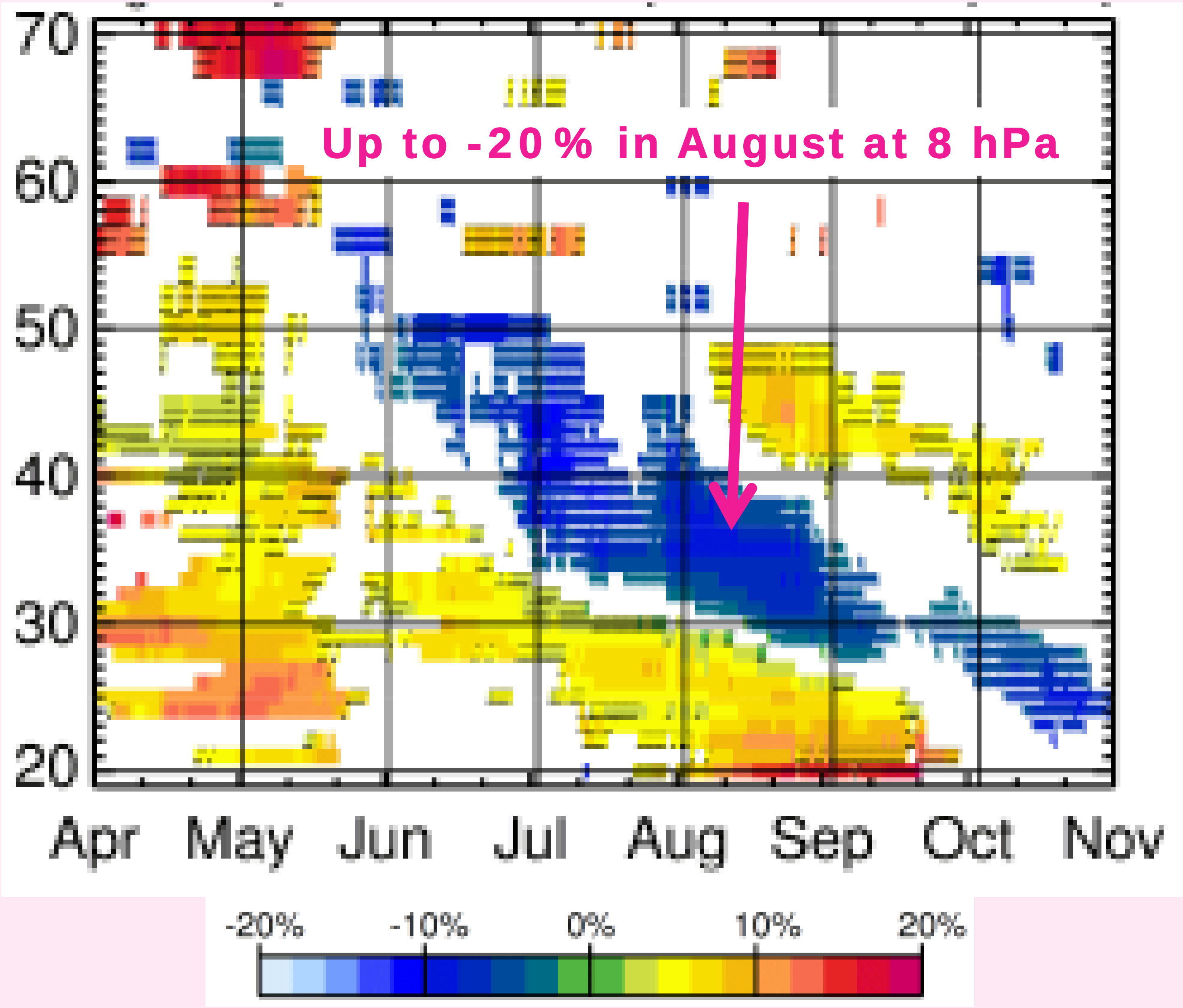
775 AD SPE effects on Total Ozone



Sukhodolov et al. (2016)

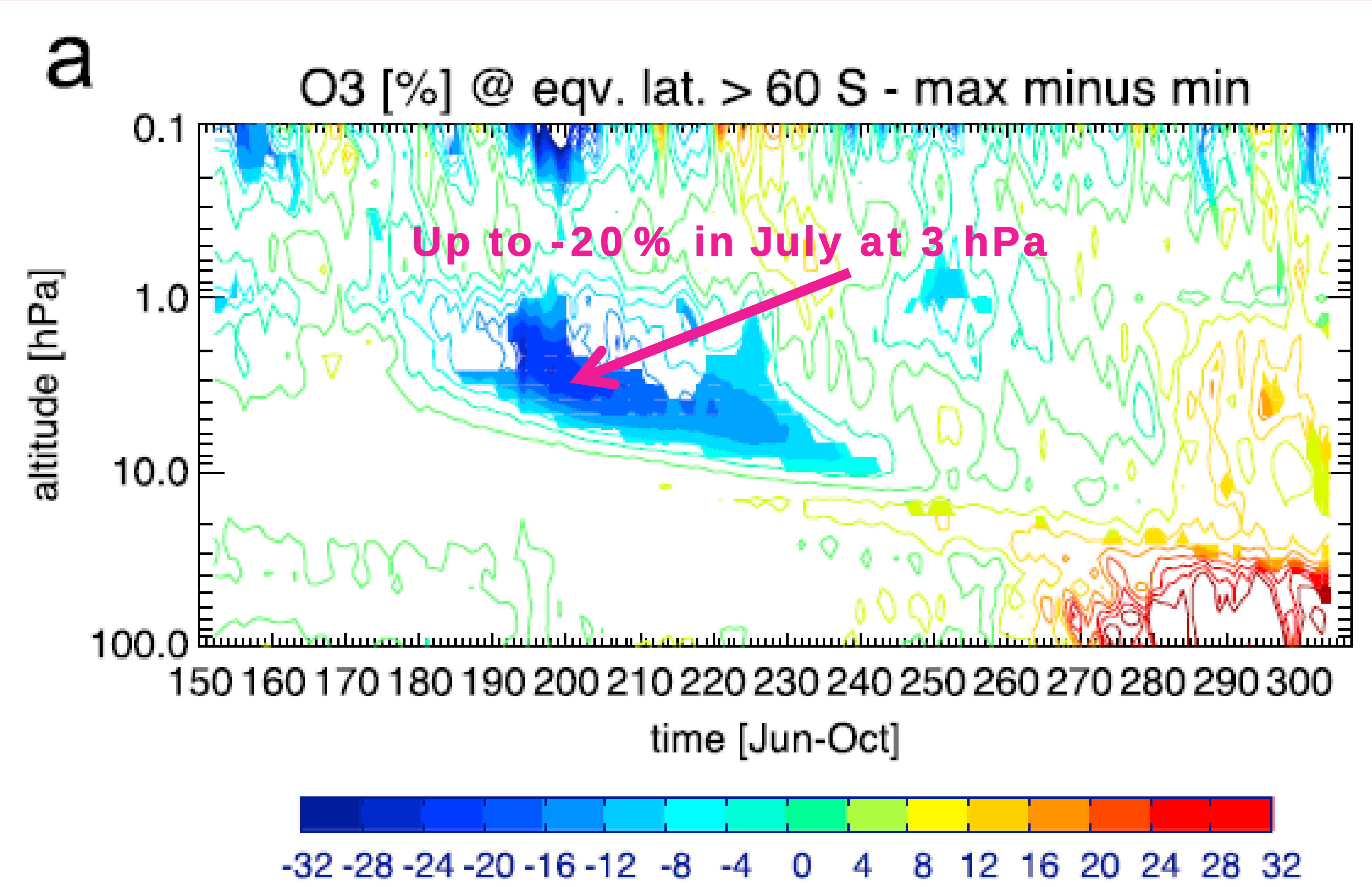
Electron effects

Effects of electrons



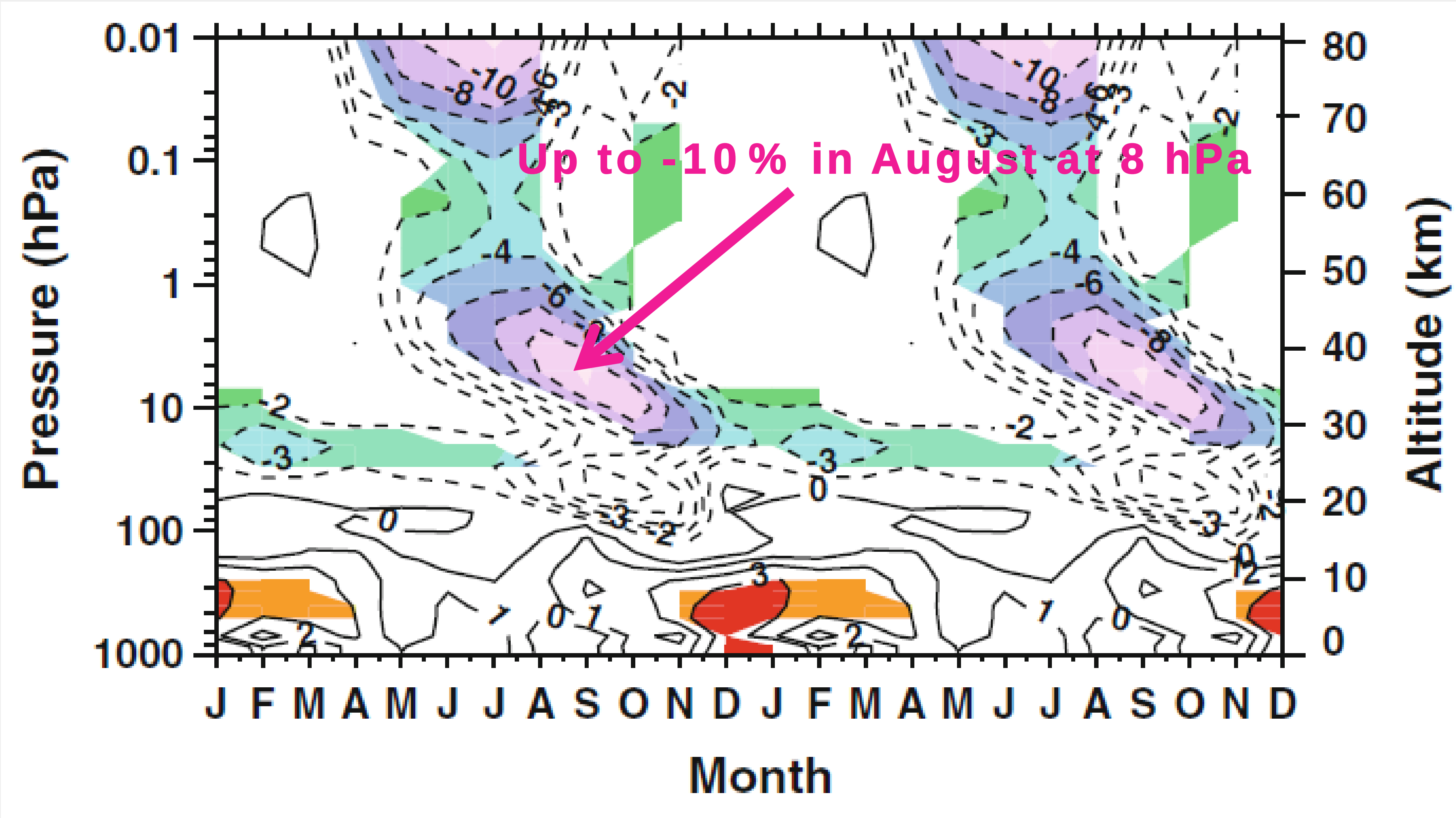
High Ap – Low Ap composite, Fytterer et al. (2015)

Effects of electrons



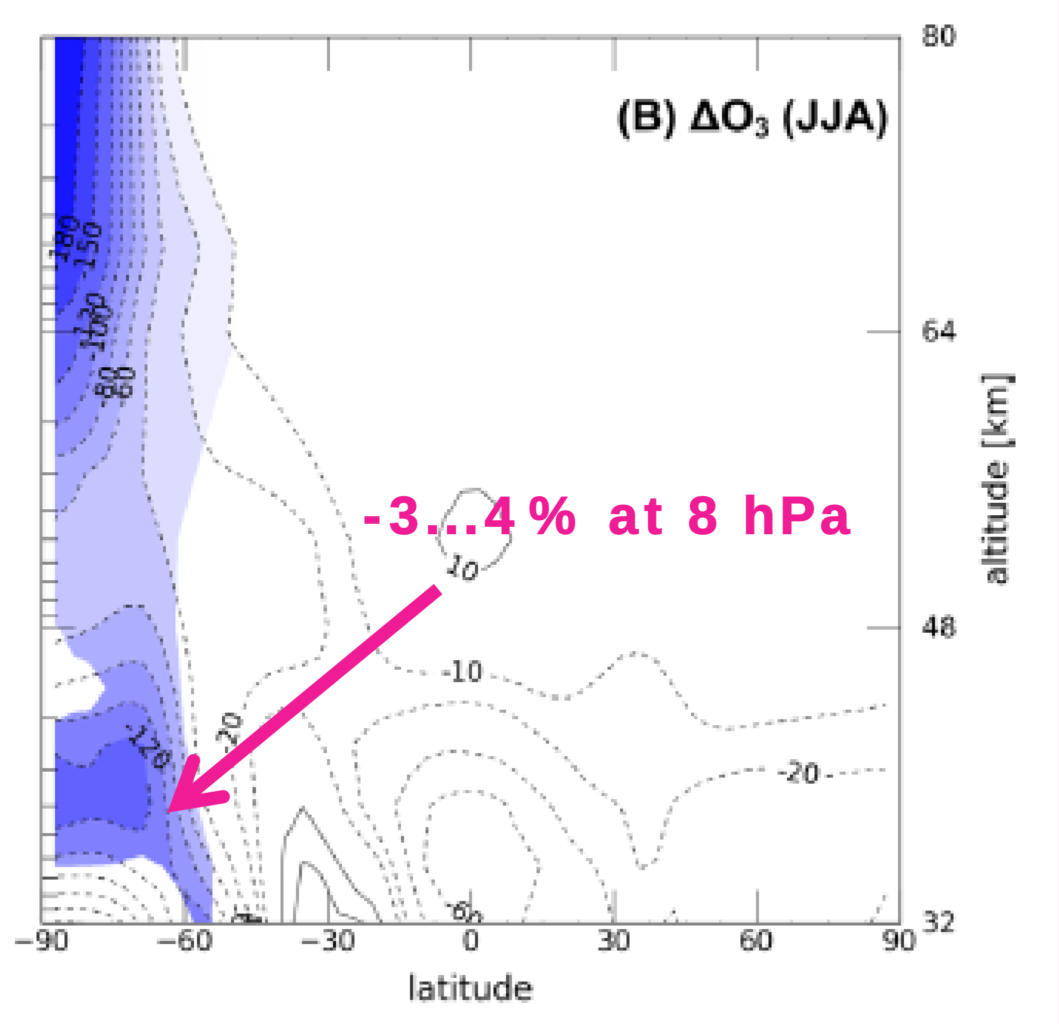
High Ap – Low Ap composite, Damiani et al. (2016)

Effects of electrons



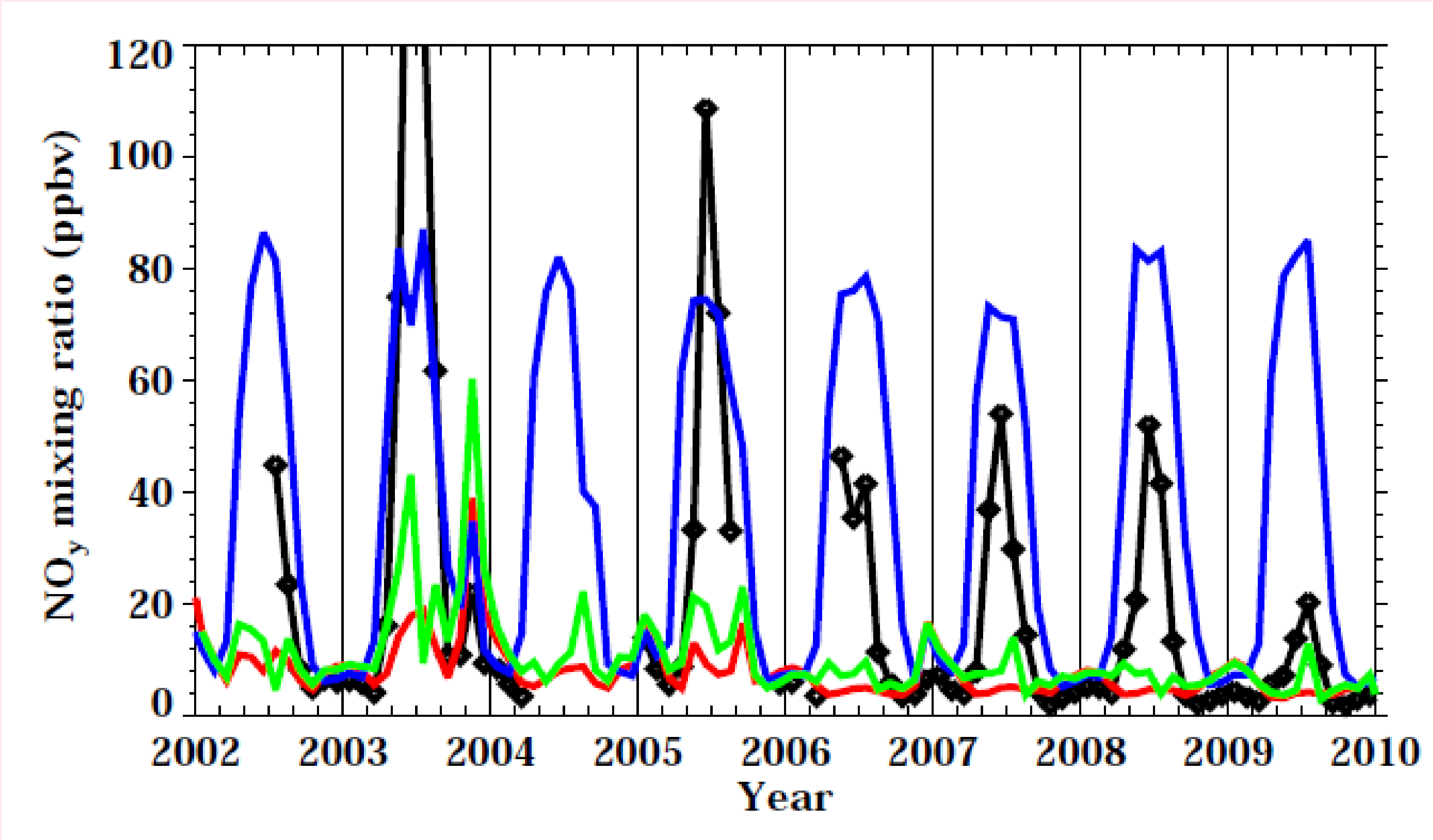
EPP - noEPP, 60ºS-90ºS, Rozanov et al. (2012)
No MEE

Effects of electrons
Missing MEE



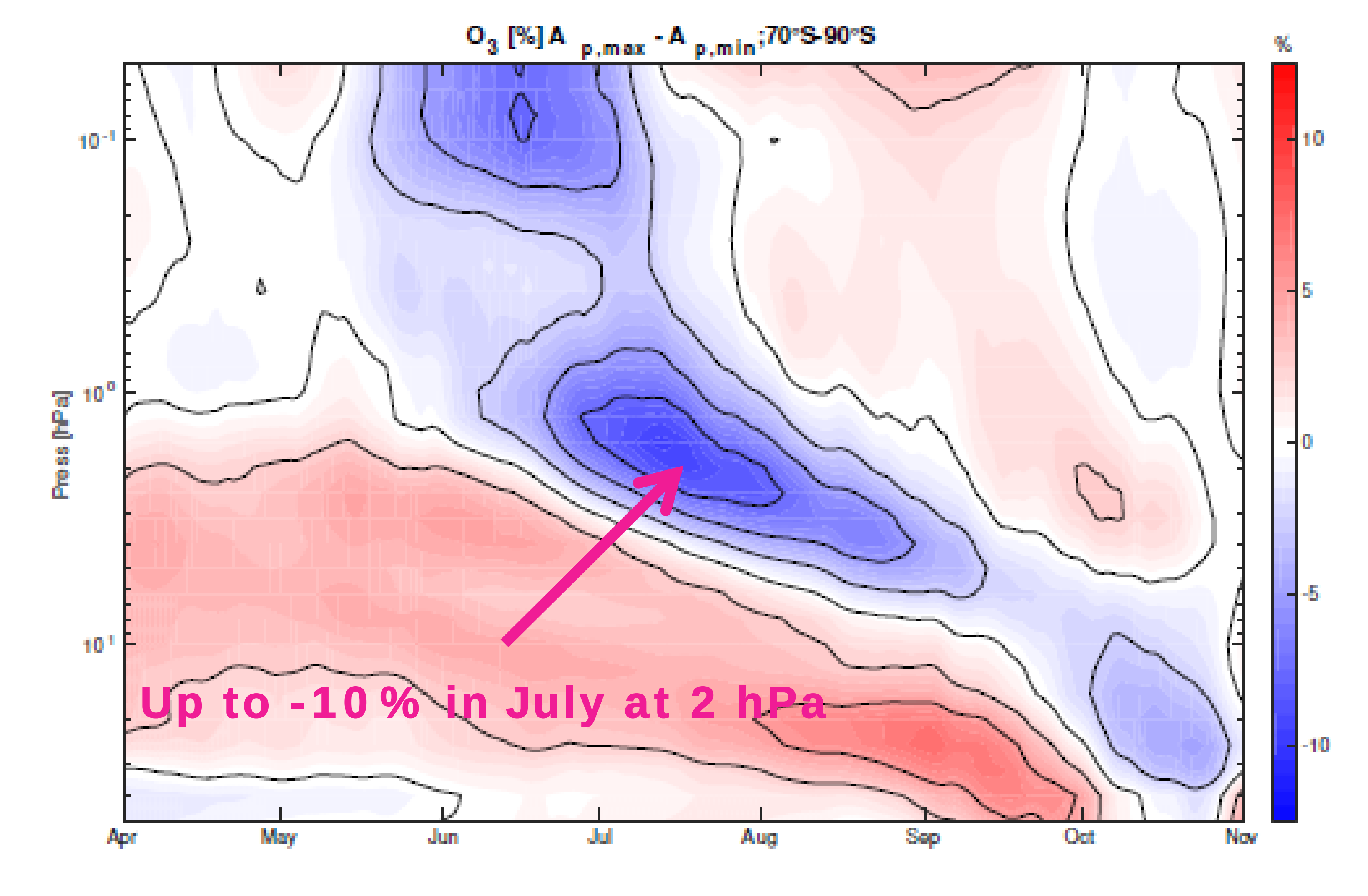
MEE effects, Arsenovich et al. (2016)

Effects of electrons
Weak thermospheric source



NO$_y$ (ppbv) at 60 km (70^{o}S-90^{o}S). Red (standard run), blue (new boundary conditions) and green (standard run with MEE). MIPAS data are shown in black. Rozanov et al., (2016)

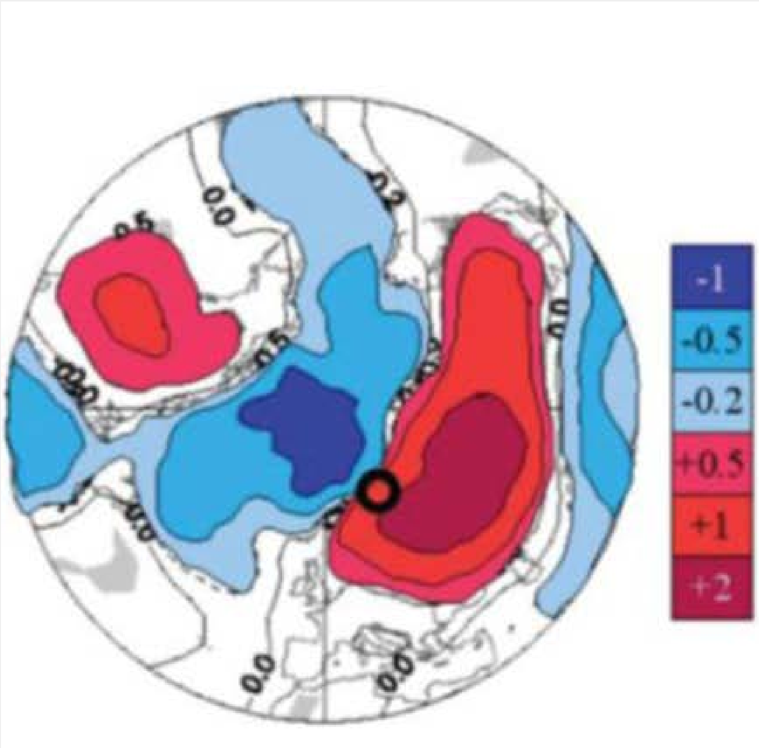
Effects of electrons
Thermospheric source from MIPAS



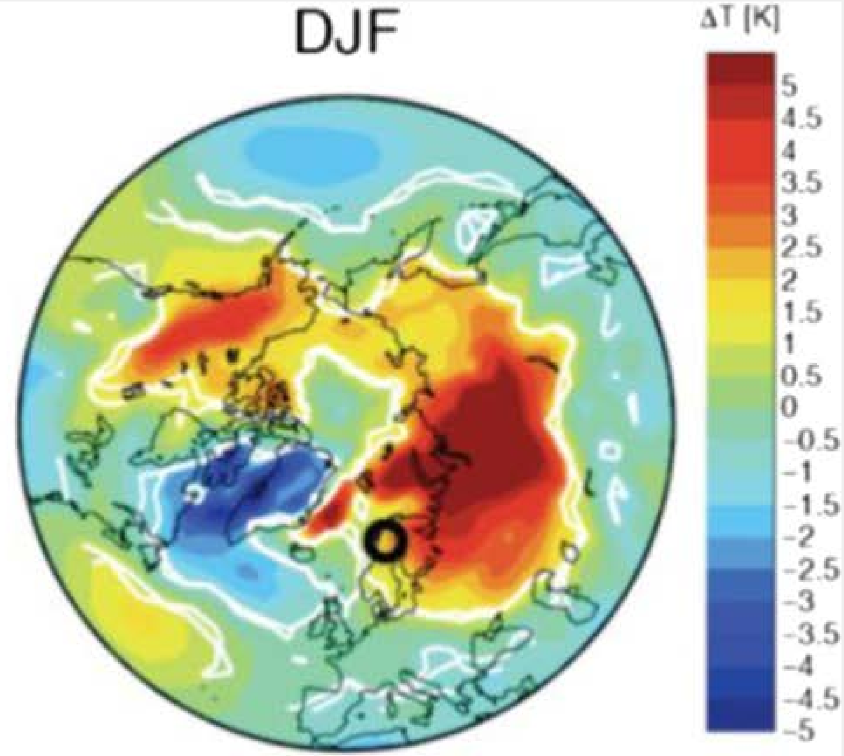
Auroral electron effects, EMAC, Matthes et al. (2016)

Surface climate response

EPP and surface climate



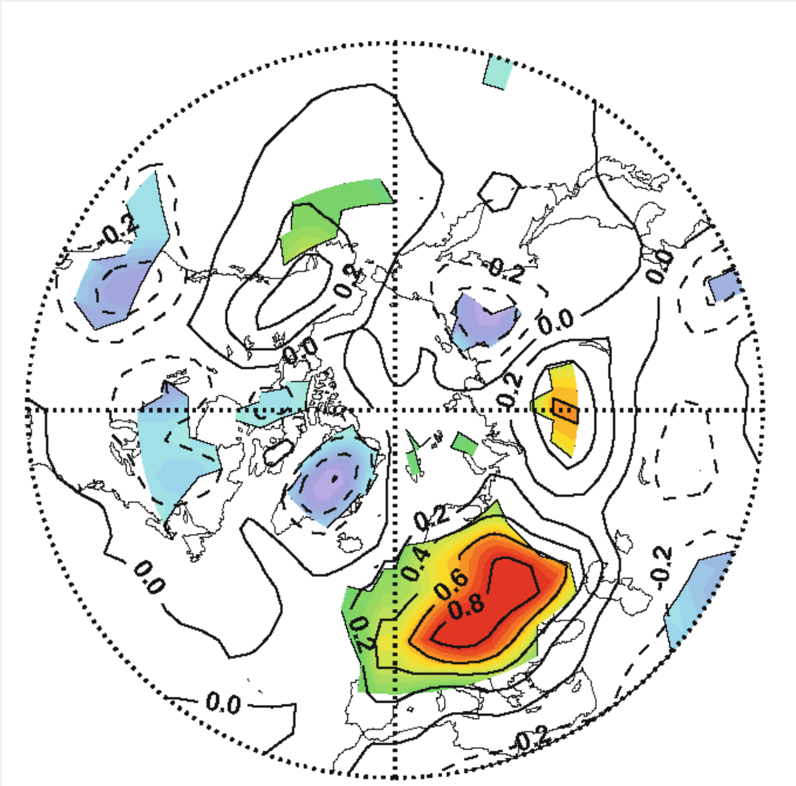
Surface air temperature changes in the northern winter hemisphere from model calculation including energetic electron precipitation (Rozanov et al. 2005).

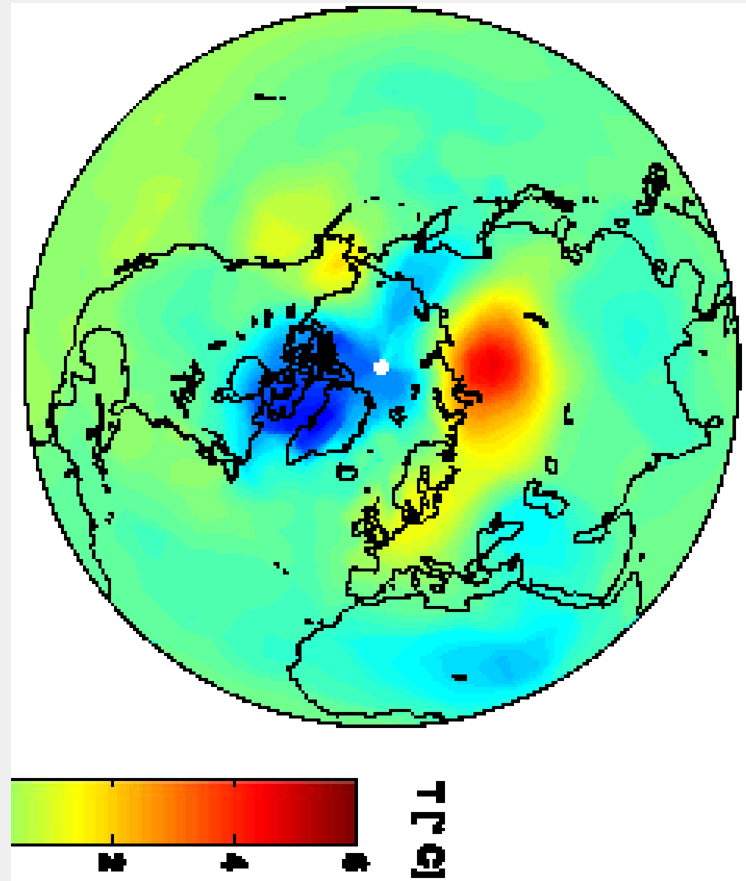


Difference between surface air temperatures for the high Ap (geomagnetic activity index) minus low Ap years from 1957 to 2006 (Seppälä et al. 2009).

Adapted from McCrea et al. (2015).

EPP and surface climate

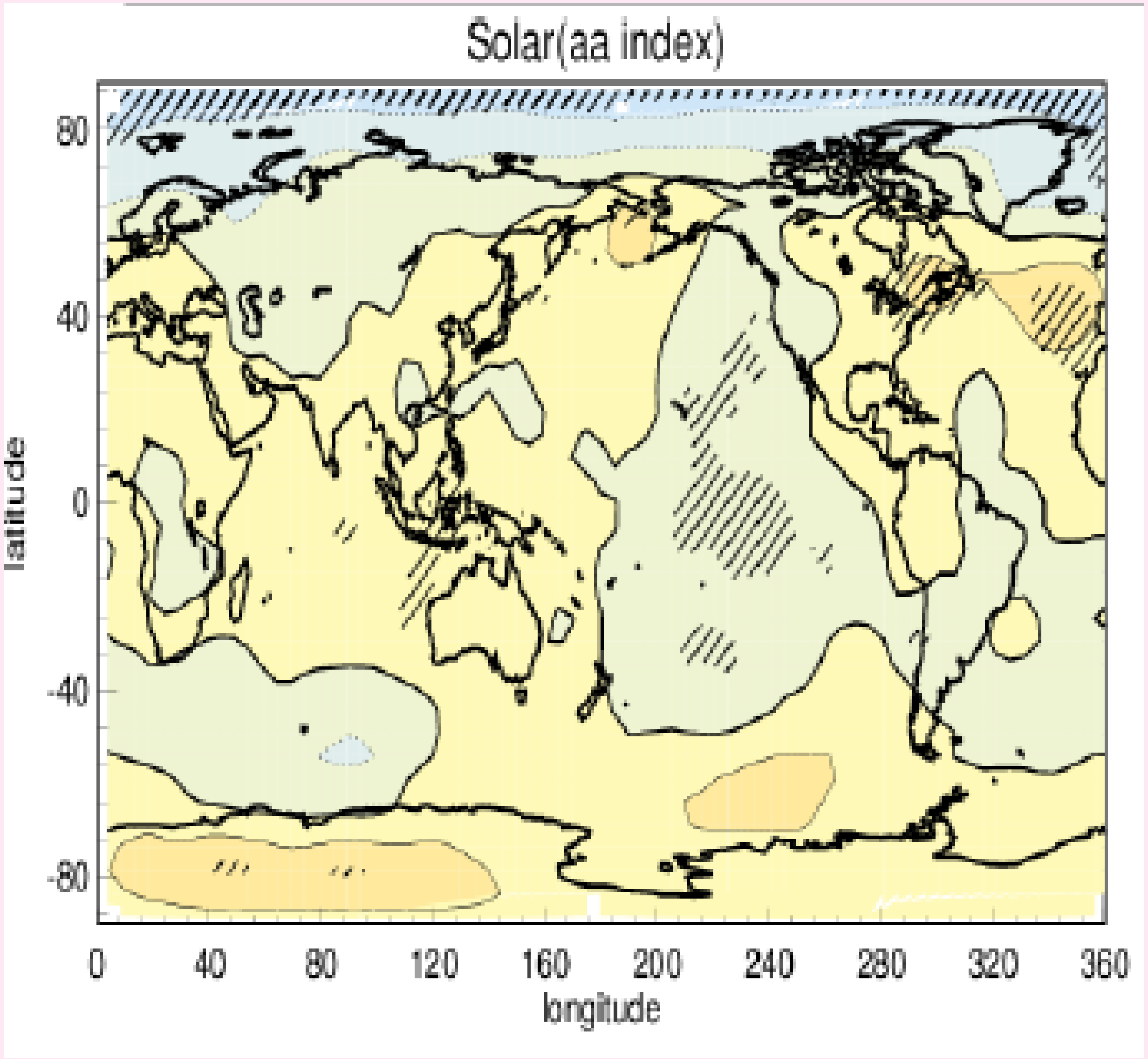




DJF, SOCOL v2.0, all EP
Rozanov et al., 2012

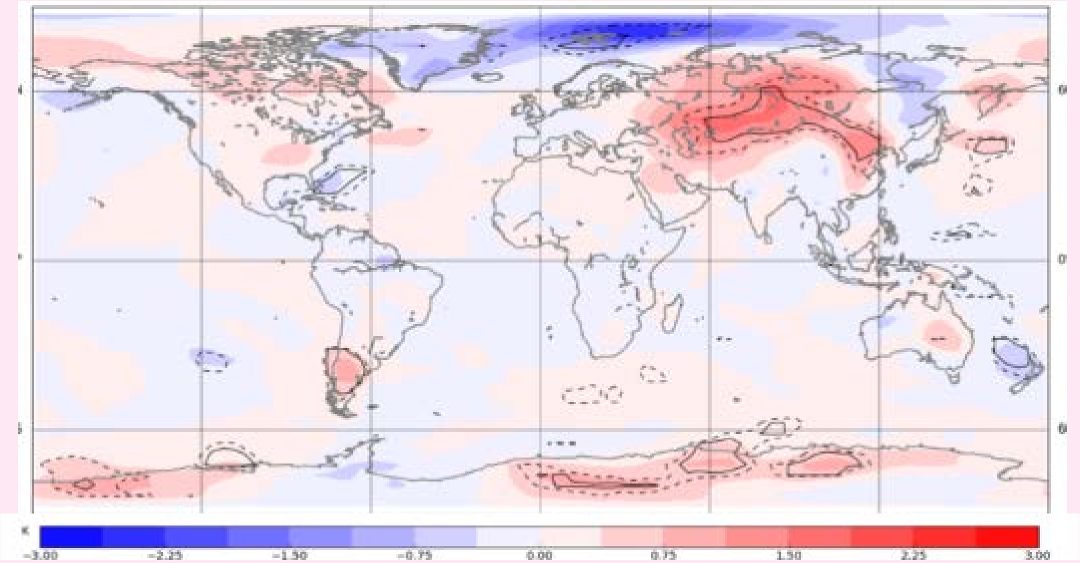
NDJ composite High D1 - Low D1 from GISS
Maliniemi et al., 2013

EPP and surface climate

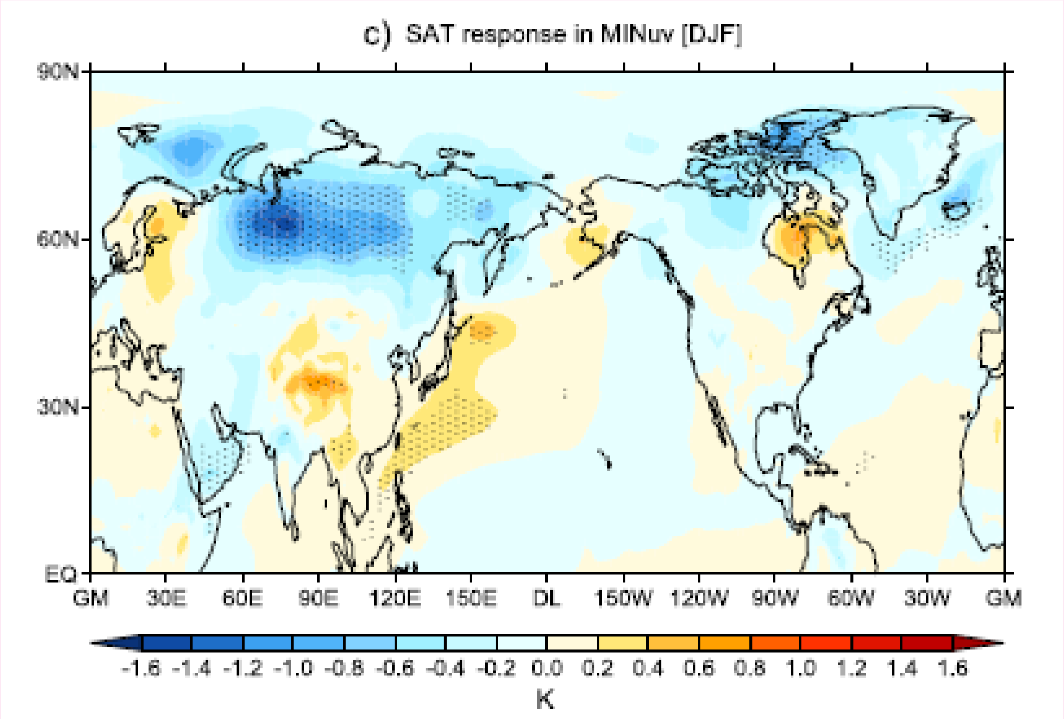


AA index, Roy et al. (2016)

EPP vs UV effects on surface climate



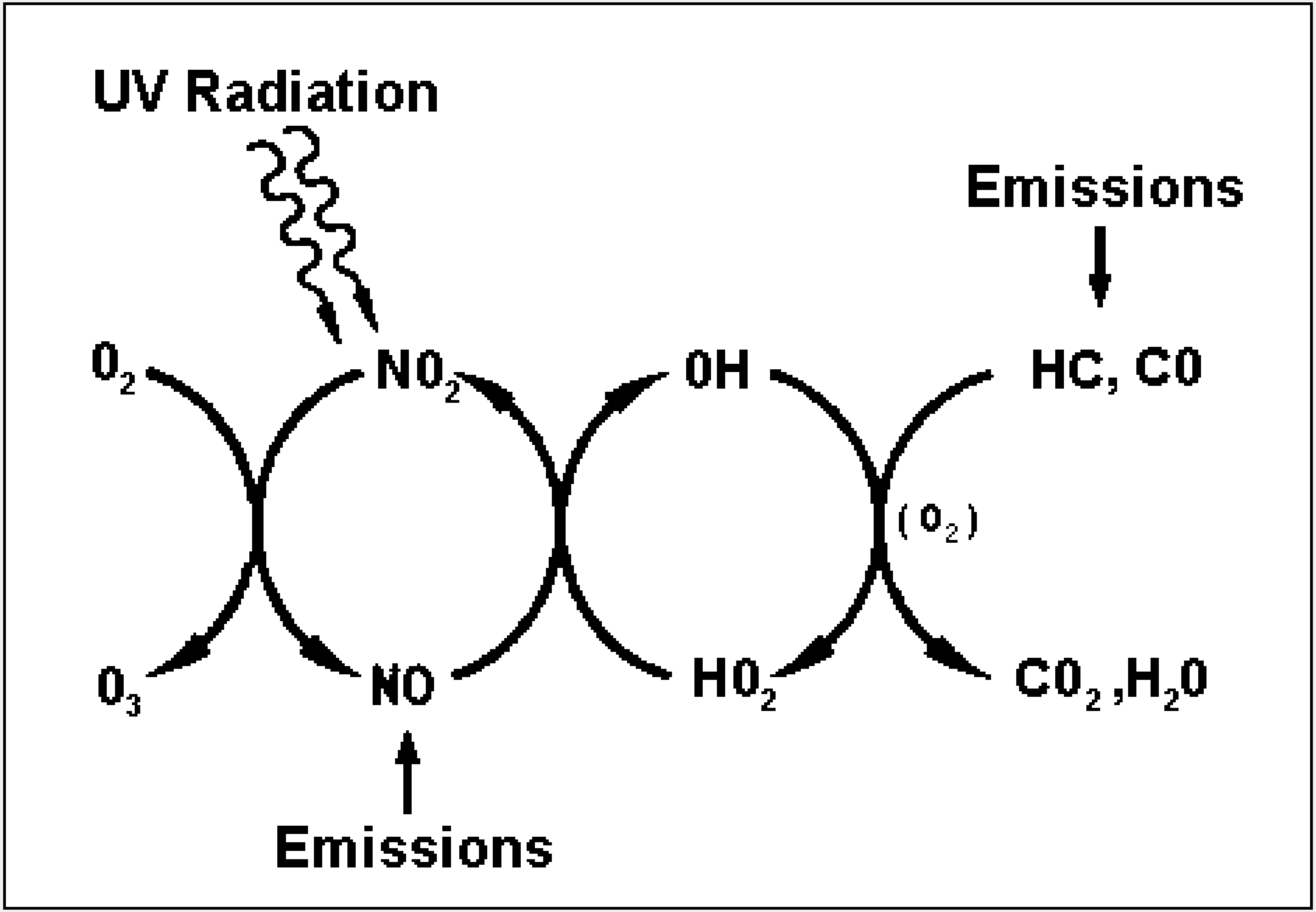
MEE
Arsenovic et al., 2016



UV
Chiodo et al., 2016

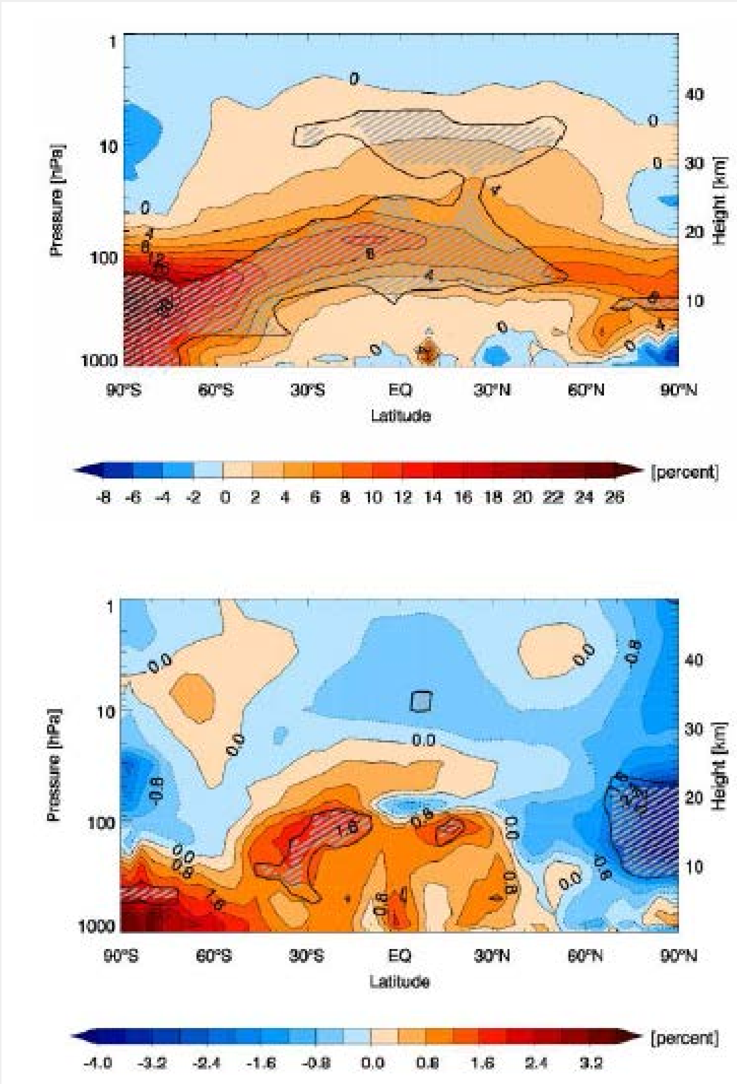
GCR effects

Tropospheric ozone production by NO_x and HO_x



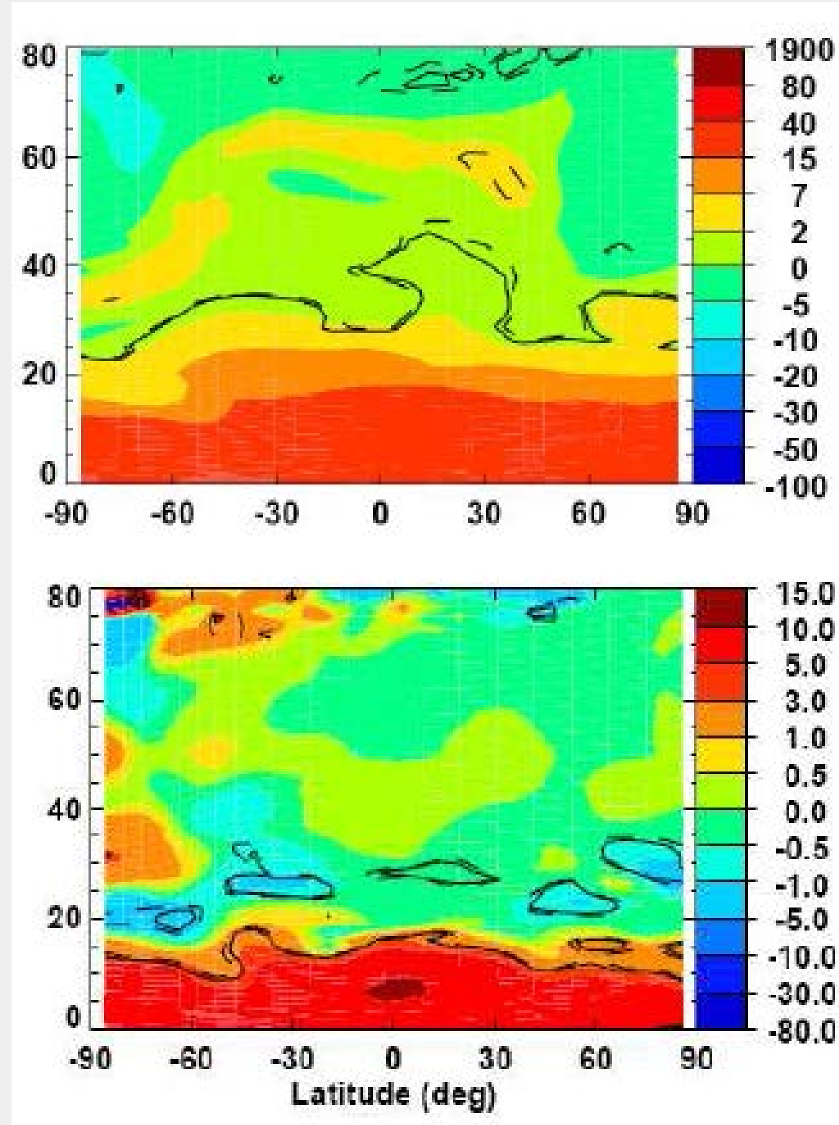
From Volz-Thomas et al. 1990

Effects of GCR



NOx

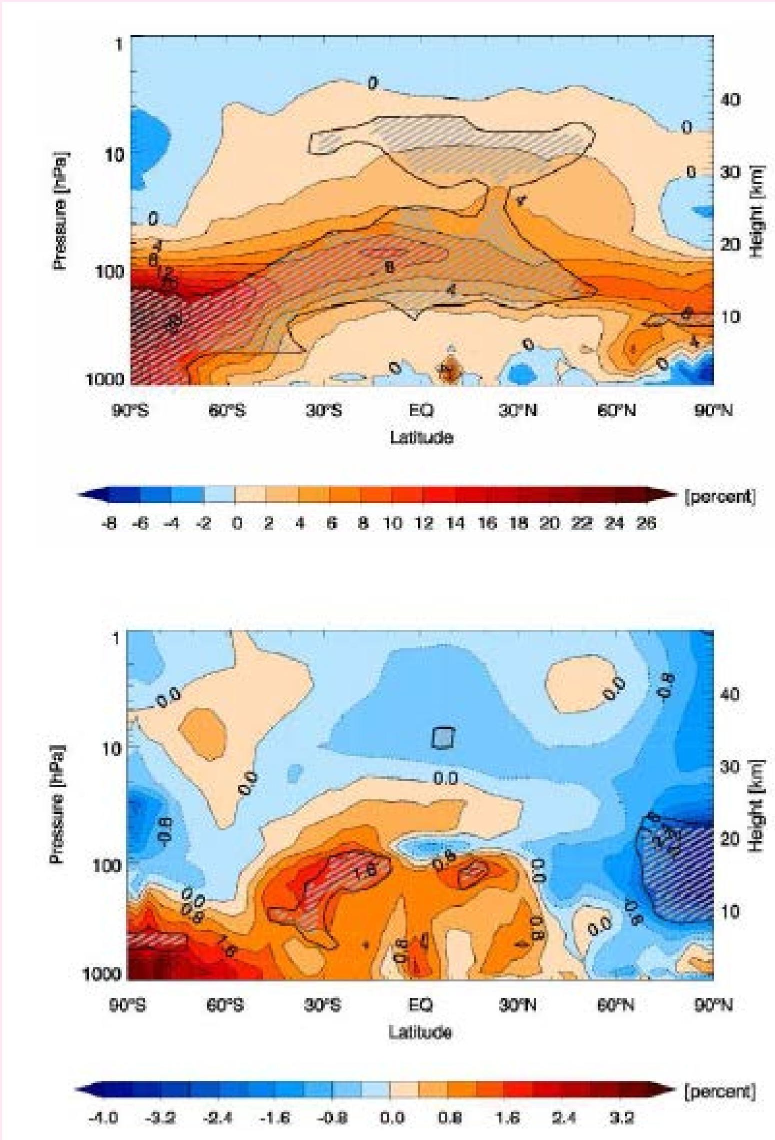
O_3



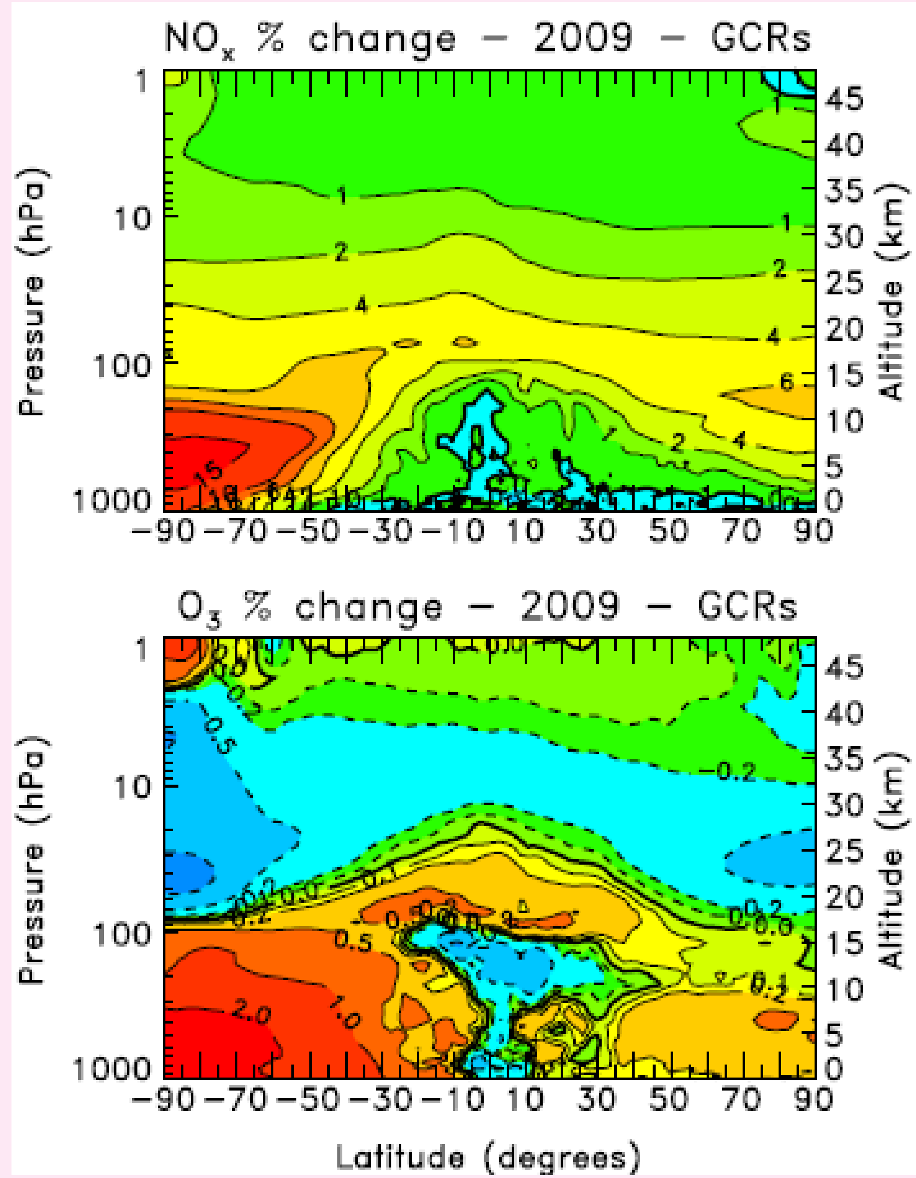
SOCOL, Calisto et al., (2011: ASP)

CMAM, Semeniuk et al., (2011: ASP)

Effects of GCR



SOCOL, Calisto et al., (2011: ASP)



WACCM, Jackman et al., (2016)

Conclusions

Achievements during VarSITI period

- ✓ Recent observations and modelling studies showed that the understanding of energetic particle influence on the ozone layer and surface climate is growing
- ✓ Characterization of the energetic electron effects on the atmospheric chemistry;
- ✓ Robust estimate of GCR influence on tropospheric ozone;
- ✓ Finding more indications of surface climate and ozone layer response to energetic particles.

Main challenges

- Understand the processes behind downward propagation of the perturbations from the middle atmosphere;
- Study of the energetic particle contribution to the past and future climate and ozone layer changes;
- Convince climate community to consider energetic particles as climate forcing;
- Intensify work on the GEC role in climate change.

END