pmod wrc

ISSI team meeting, Bern, 25 March, 2014

The treatment of the energetic particles in chemistry-climate models

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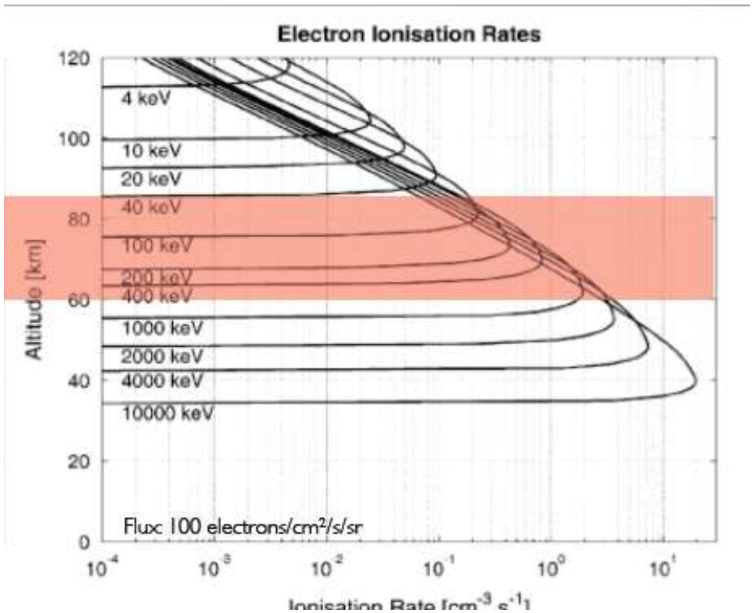
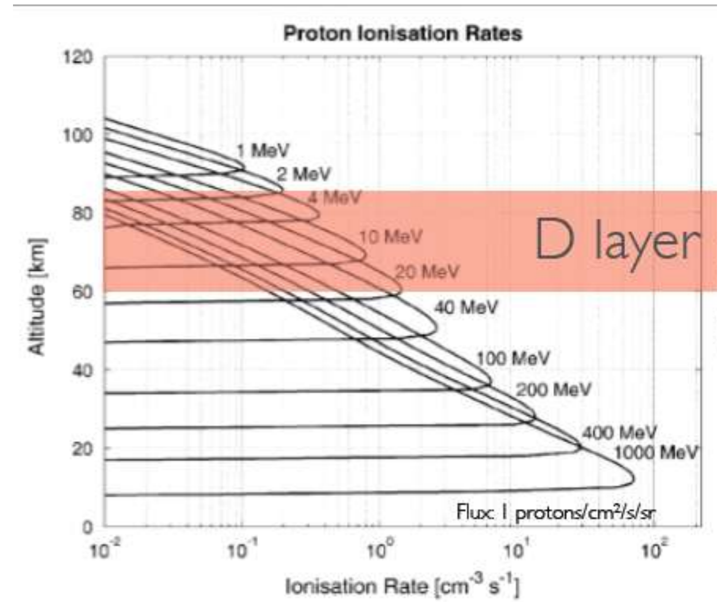
Particle classification

- Cosmic Rays
- Solar energetic particles (protons) up to 500 MeV
- Radiation belt electrons (~30 keV – several MeV)
- Discrete and diffuse auroral electrons (~ 0.1 – 30 keV)

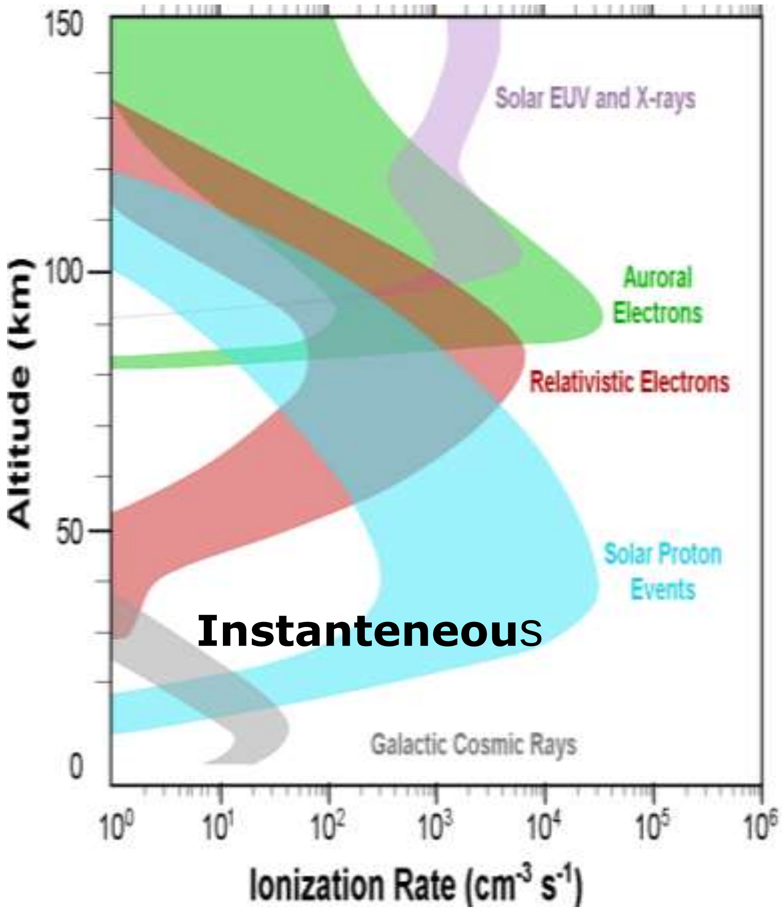
Particle classification



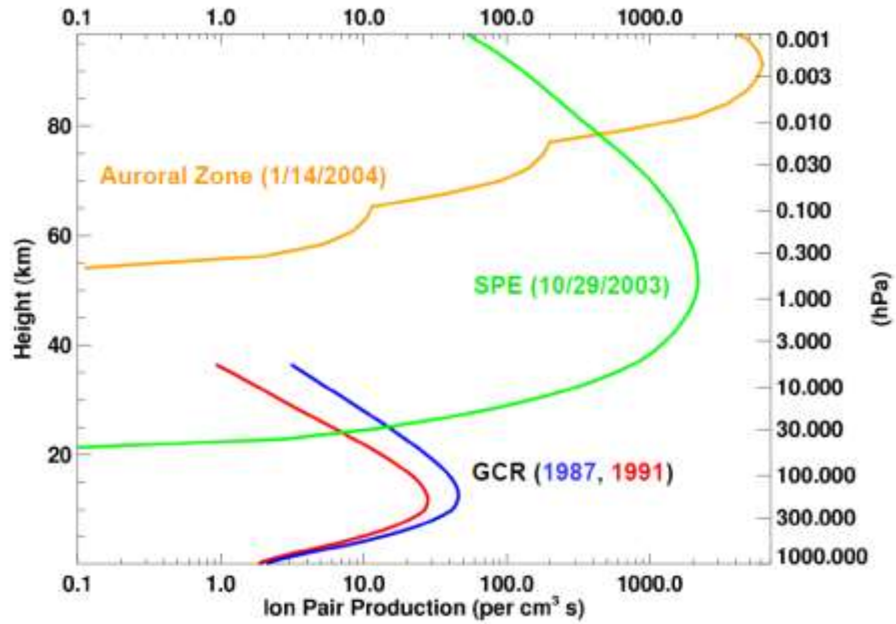


Turunen et al., 2009

Types of precipitating energetic particles
based on energy deposition altitude



Courtesy of Ch. Jackman



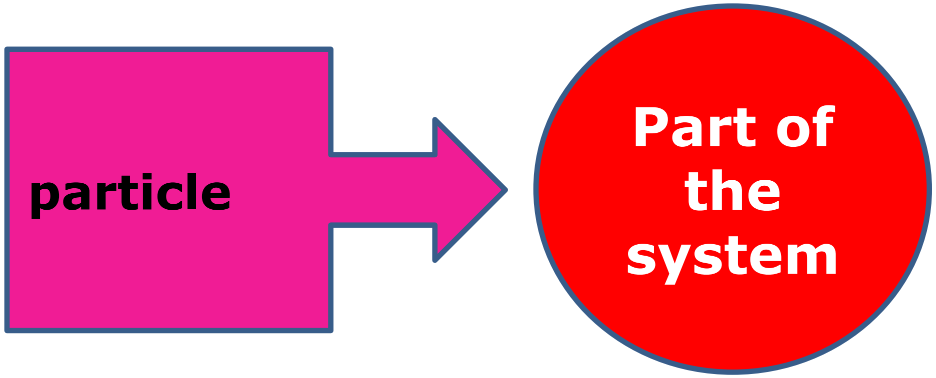
Semeniuk et al., 2011

The effects of energetic particles (chemical route!)

- **Primary effects**
- **Direct effects via chemistry**
- **Indirect effects via:**
  - transport
  - chemistry
  - temperature
  - circulation

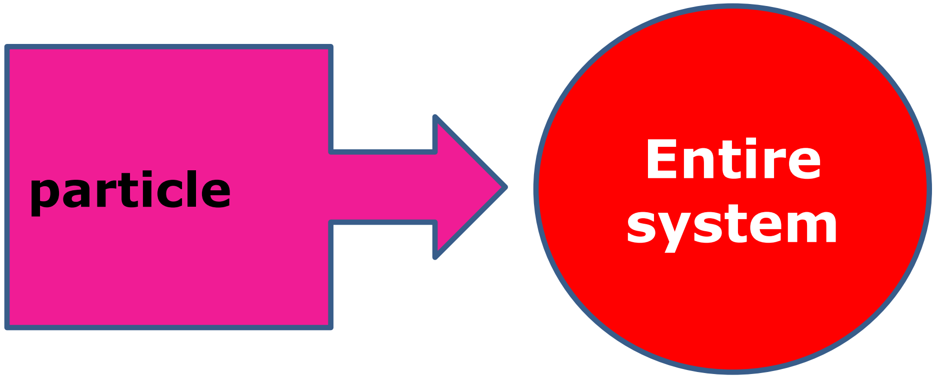
→ **Climate (temprature, presipitation, ozone, ..)**

Direct response



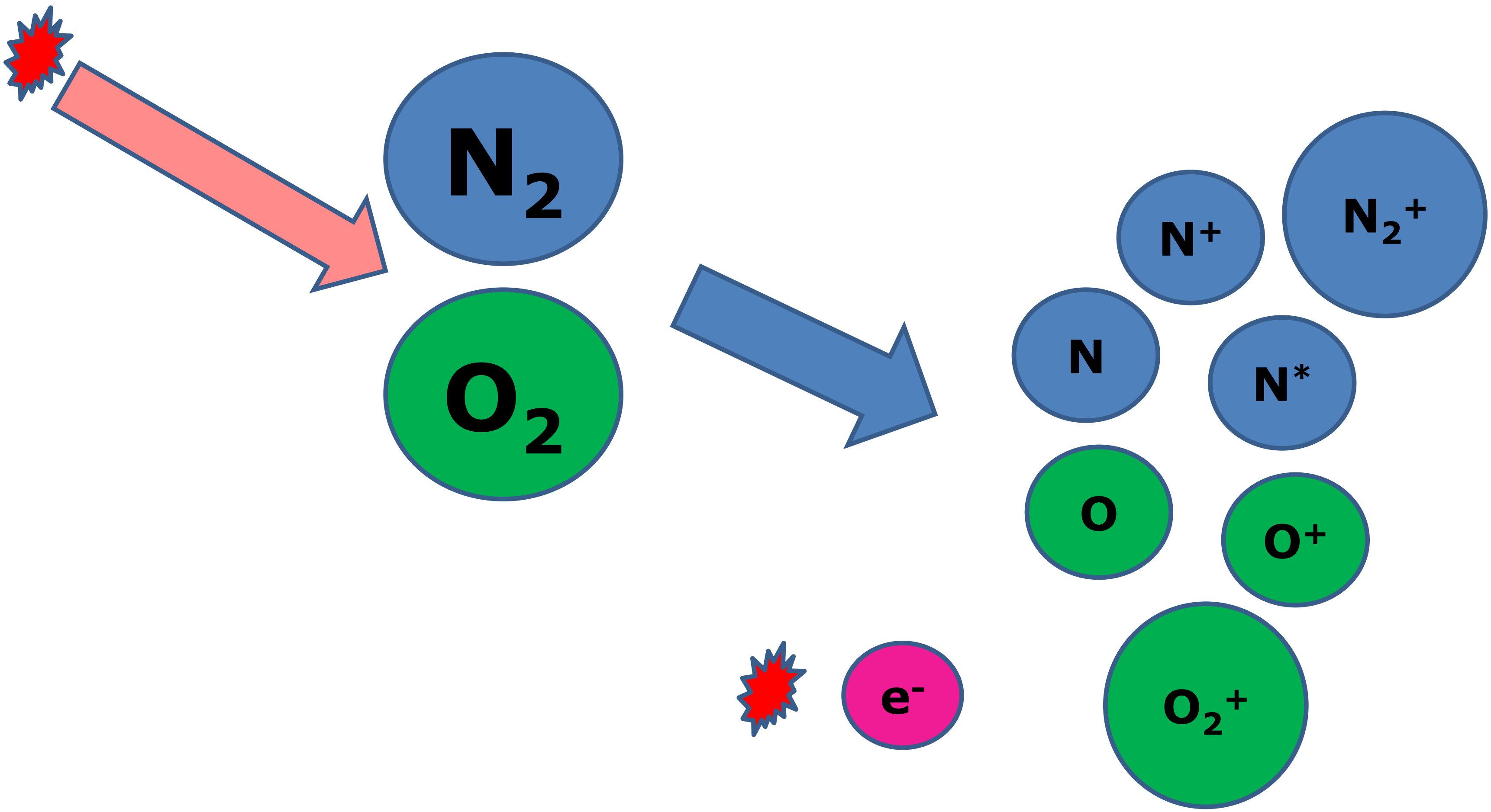
Short time scales
High signal/noise
Useful for model validation

Indirect response



Long time scales
Lower signal/noise
Difficult to analyze
Important for the outcome

Primary effects of energetic particles



NO_x production/destruction

$$N_2^+ + O => NO^+ + N(^4S)$$
$$N_2 + N^+ => N_2^+ + N(^4S)$$
$$N_2^+ + e^- => N^* + N(^4S)$$
$$NO^+ + e^- => N(^4S) + O$$
$$N^+ + O => O^+ + N(^4S)$$
$$N^* + O_2 => NO + O$$

But

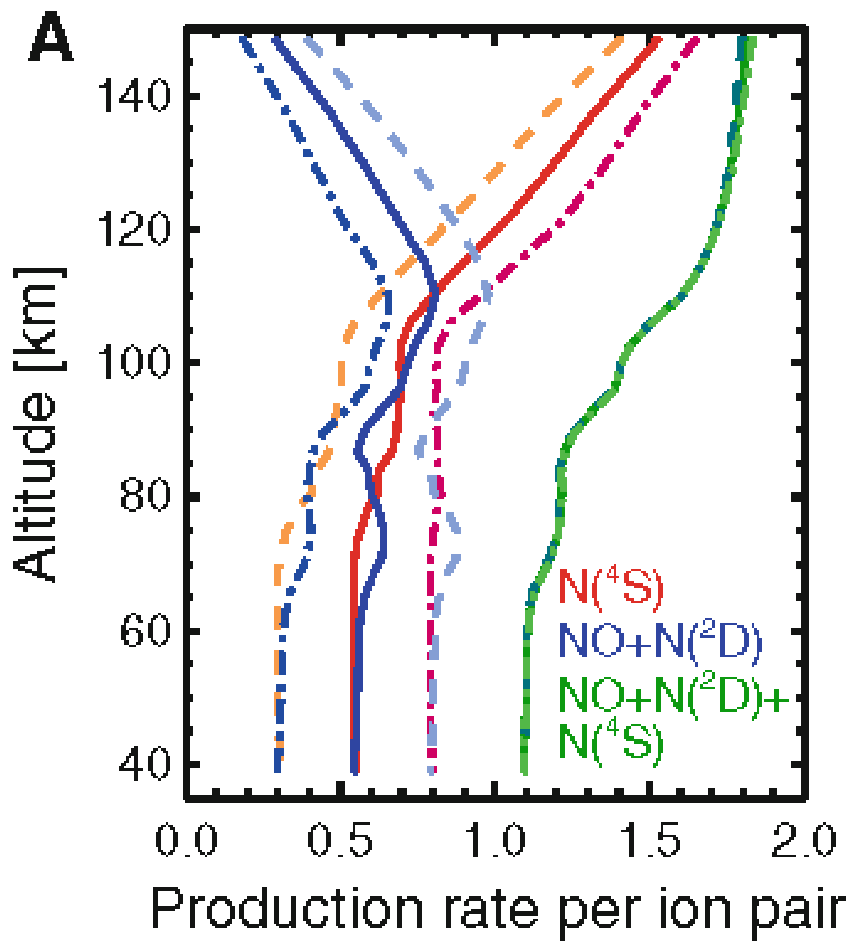
$$NO + h\nu => N(^4S) + O$$
$$N(^4S) + NO => N_2 + O$$

$N(^4S)/N^*$?!

Nicolet, 1965, 1975; Jones and Rees, 1973; Rusch et al., 1981

NOx production

Widely used parameterization:
Production by SP and RBE is 0.7 N^* and 0.55 $N(^4S)$ per Ion Pair



$N(^4S)/N^*$?!

From Sinnhuber, 2012
BIC model

HO_x production by energetic particles

Ionization by particles below 90 km leads to the enhancement of HOx via

$$O_2^+ + O_2 \rightarrow O_4^+ \qquad (R-13(a))$$

$$O_4^+ + H_2O \rightarrow O_2^+(H_2O) + O_2 \qquad (R-13(b))$$

Larger cluster ions can then be formed by reaction pathways like:

$$O_2^+(H_2O) + H_2O \rightarrow H_3O^+(OH) + O_2 \qquad (R-14(a))$$

$$O_2^+(H_2O) + H_2O \rightarrow H^+(H_2O) + OH + O_2 \qquad (R-14(b))$$

Those can then be followed by the formation of larger protonised water cluster ions, like

$$H_3O^+(OH) + H_2O \rightarrow H^+(H_2O)_2 + OH \qquad (R-15(a))$$

$$H^+(H_2O)_n + H_2O \rightarrow H^+(H_2O)_{n+1} \qquad (R-15(b))$$

During all these reaction chains, recombination reactions with electrons can take place:

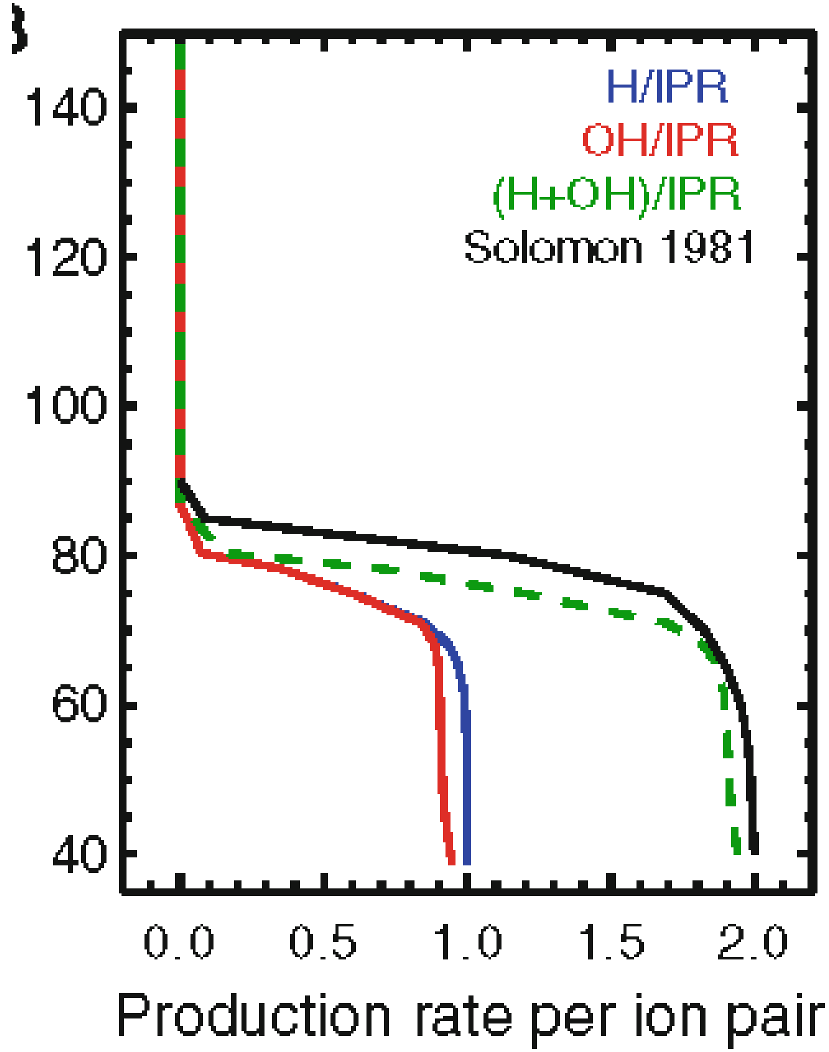
$$H_3O^+(OH) + e^- \rightarrow H_2O + H + OH \qquad (R-16(a))$$

$$H^+(H_2O)_n + e^- \rightarrow H + nH_2O \qquad (R-16(b))$$

From Sinnhuber et al., 2012

HOx production

Widely used parameterization:
Production by SP and RBE is up to 2 HOx per Ion Pair



From Sinnhuber, 2012
BIC model

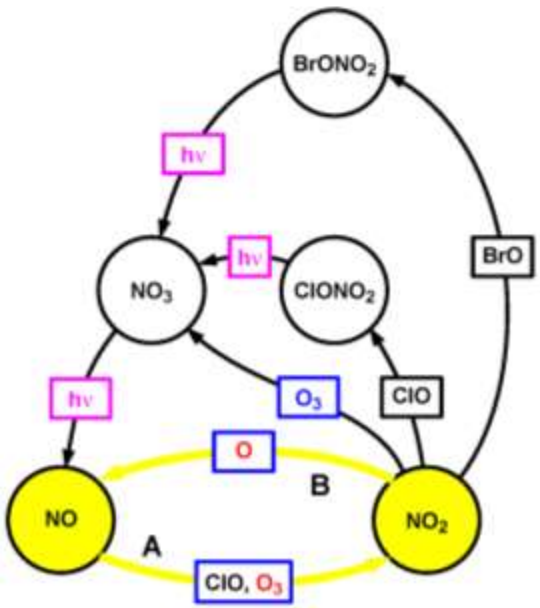
Ozone depletion by NOx and HOx

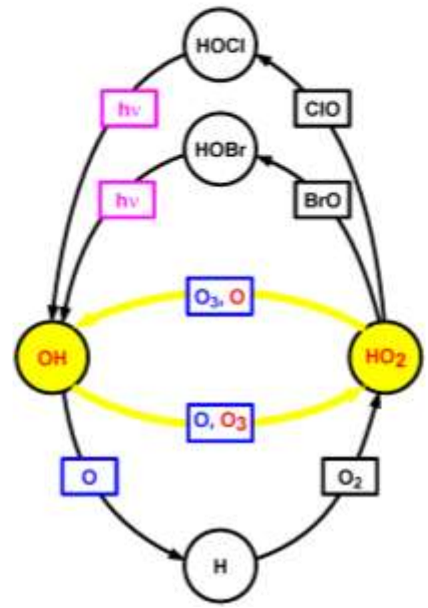
Nitrogen:

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

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

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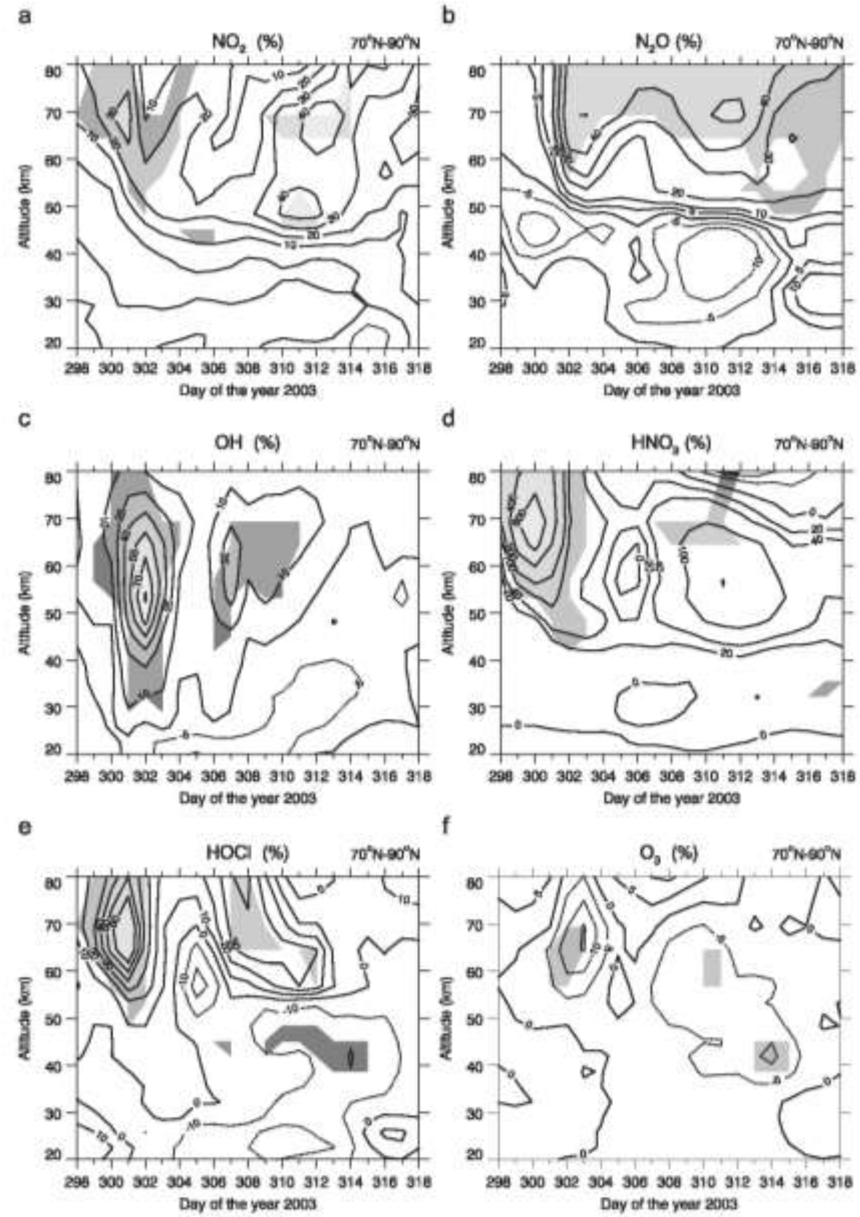
NOx and HOx production



e–altitude distribution of the difference (%) between experiments with complete and parameterized ion chemistry after October 2003 SPE for ... and HNO_3 (d), HOCl (e) and O_3 (f). The shades of gray show where the signal is statistically significant at more than 95% confidence level

Widely used parameterization ($0.7\ N^* + 0.55\ N(^4S)$ + up to 2 HOx per Ion Pair)

against

complete ion chemistry CCM SOCOL (Egorova et al., 2011)

Ozone enhancement by NOx

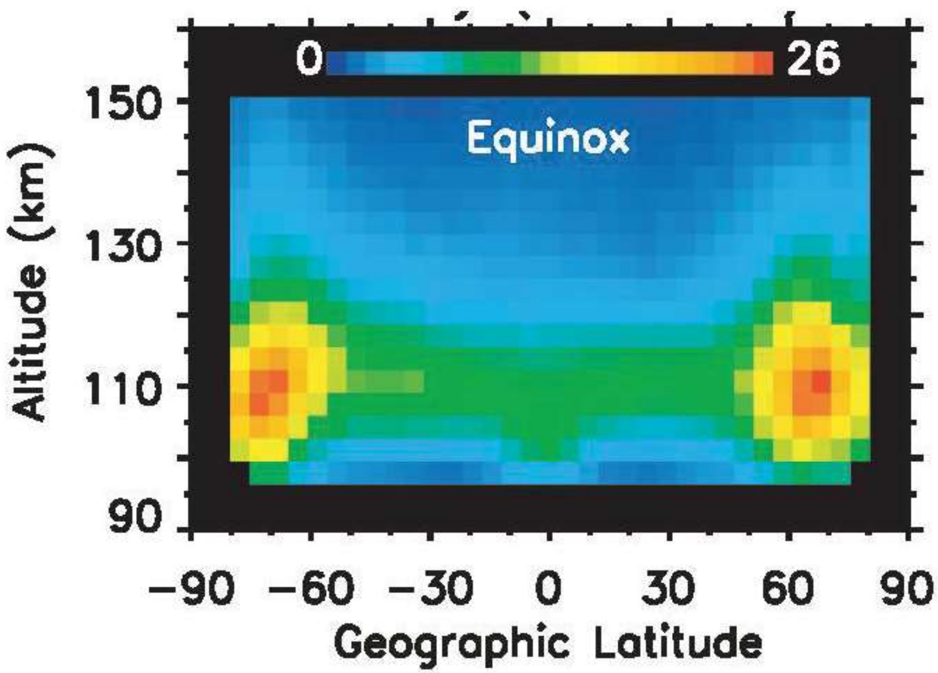
$NO_2 + h\nu \rightarrow NO + O$
$O + O_2 + M \rightarrow O_3 + M$
$NO + RO_x \rightarrow$ products

Works in the troposphere where NOx are avilable and NO_x are limited.

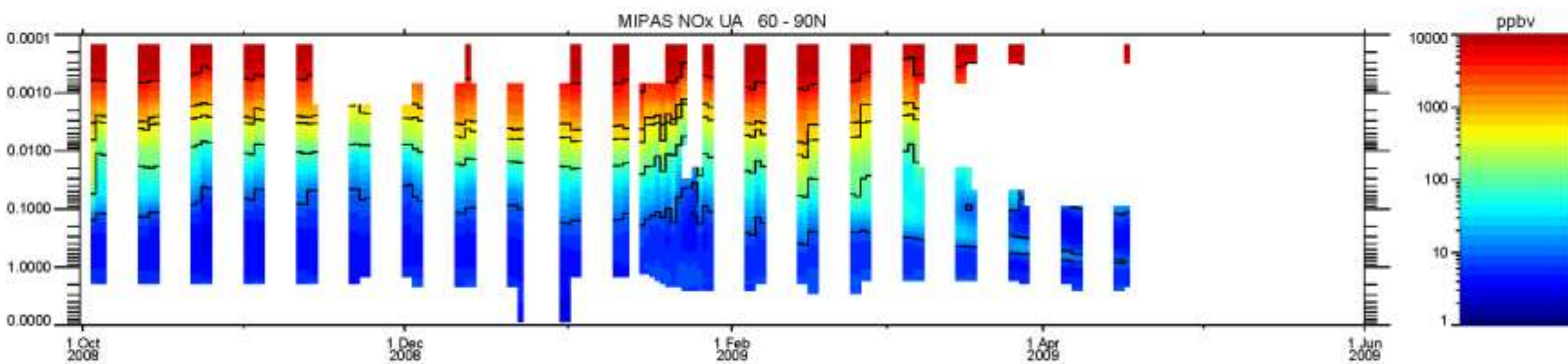
Relevant to GCR

From D. Wang

Observations of the auroral electrons direct effects

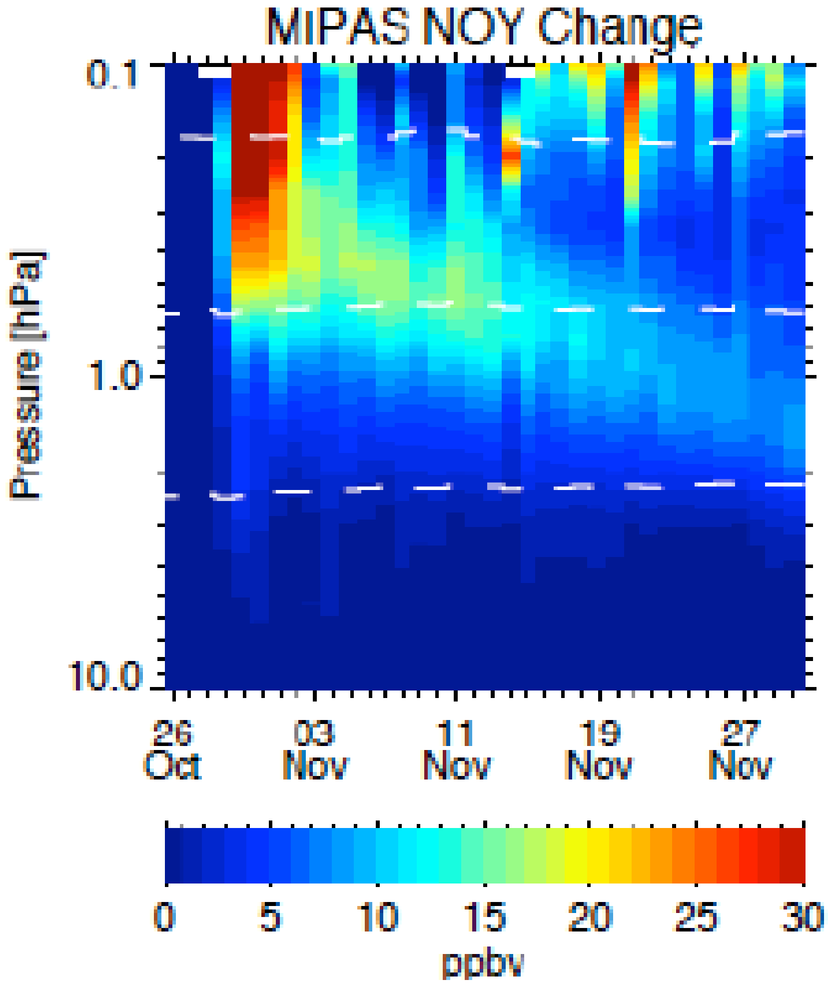


NO (10^7 cm^3) measured by SNOE instrument. From Barth et al. (2003).

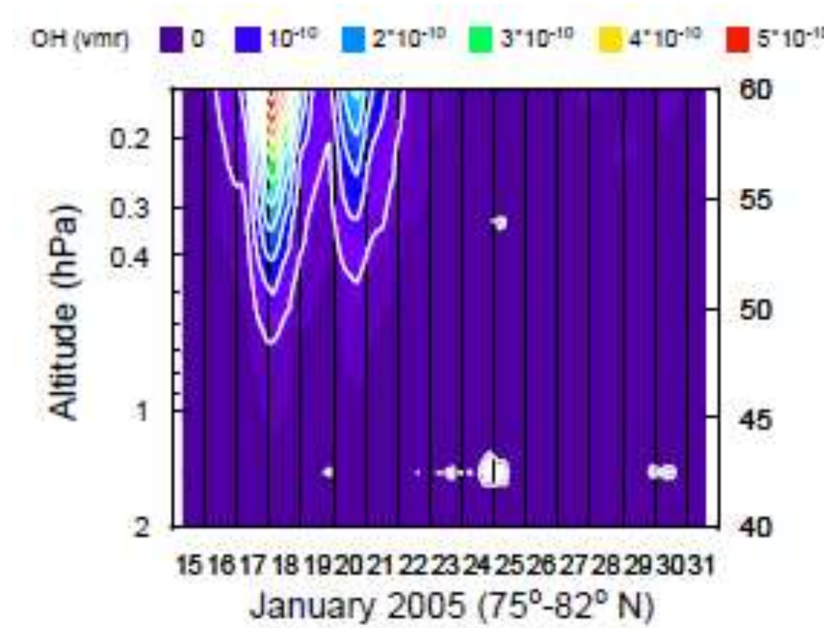


NO_x (ppbv) from MIPAS. HEPPA-2, Courtesy of B. Funke

Observations of the solar protons direct effects

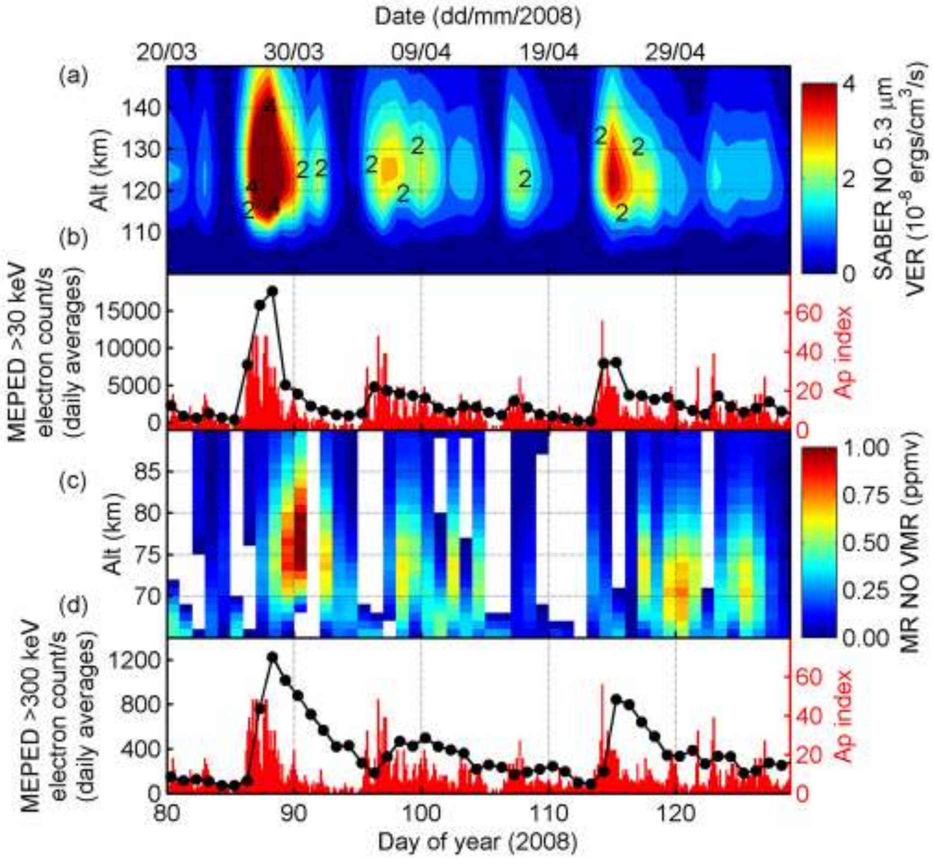


From Funke et al., 2011
October 2003 SPE

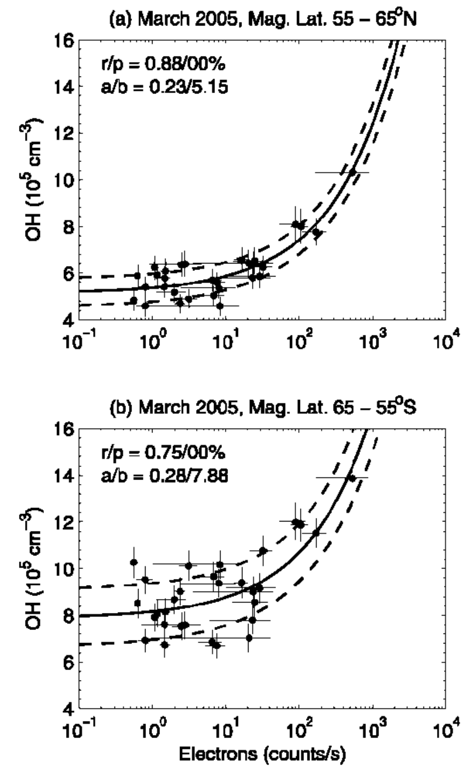


From Damiani et al., 2008
January 2005 SPE

Observations of the RBE direct effects



From Newnham et al., 2011



From Verronen et al., 2011

Treatment of the direct EP effects in CCMs (WACCM/HAMMONIA)

- Model top at 130/250 km
- Simplified ion chemsitry, e^- and major ions (N_2^+, N^+, O_2^+ and O^+) => works only above 90 km
- Ionization rates are based on Kp index/AIMOS
- Production by SP and RBE is 0.7 N^*, 0.55 $N(^4S)$ and 2xHO_x per ion pair; valid below mesopause

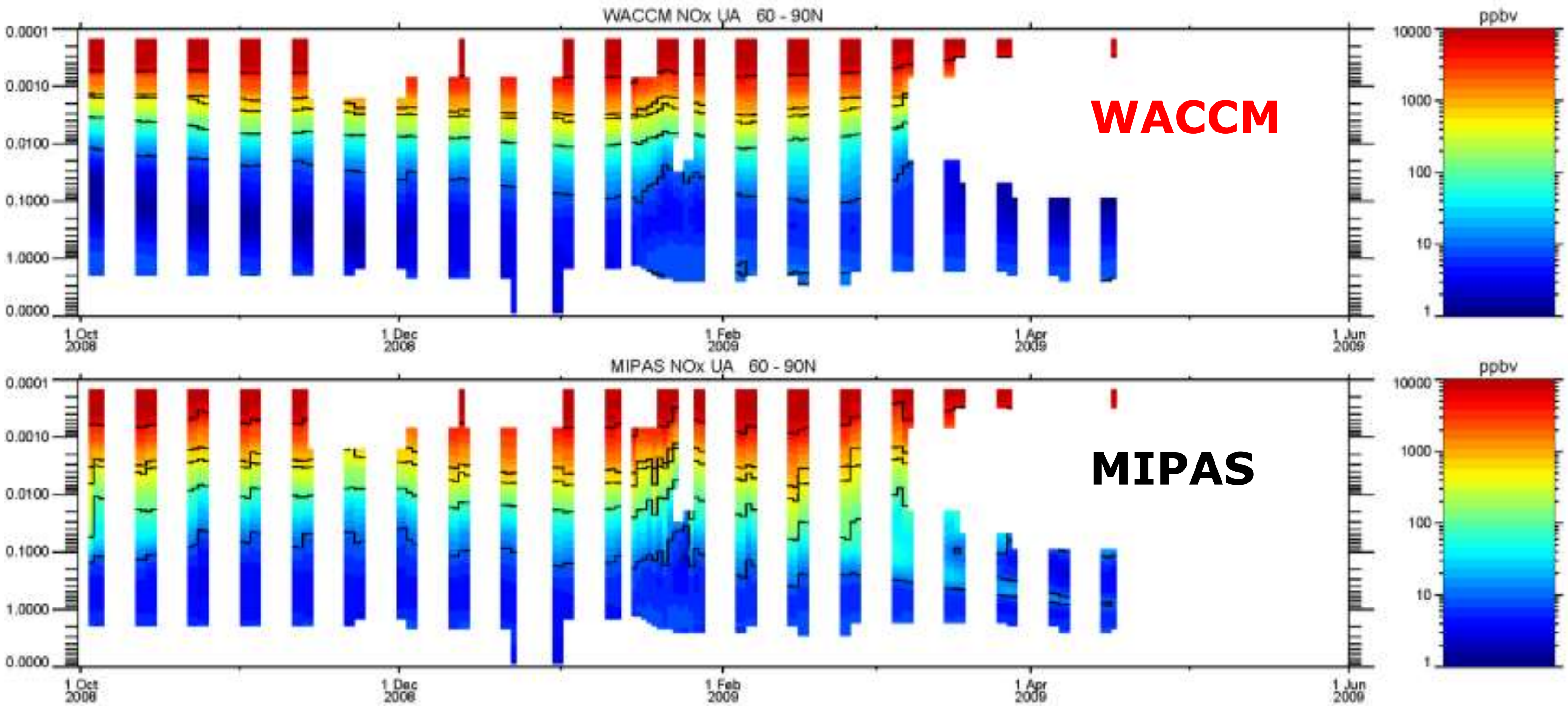
Treatment of the direct EP effects in CCMs (CMAM)

- Model top at 90 km
- Production by SP and RBE is 0.7 N^*, 0.55 $N(^4S)$ and $2xHO_x$ per ion pair; valid below mesopause
- Ionization rates from electrons (>30 KeV) are based on satellite data and energy deposition code
- No thermospheric NO_x production by auroral electrons (< 30 KeV)

Treatment of the direct EP effects in CCMs (EMAC, SOCOL)

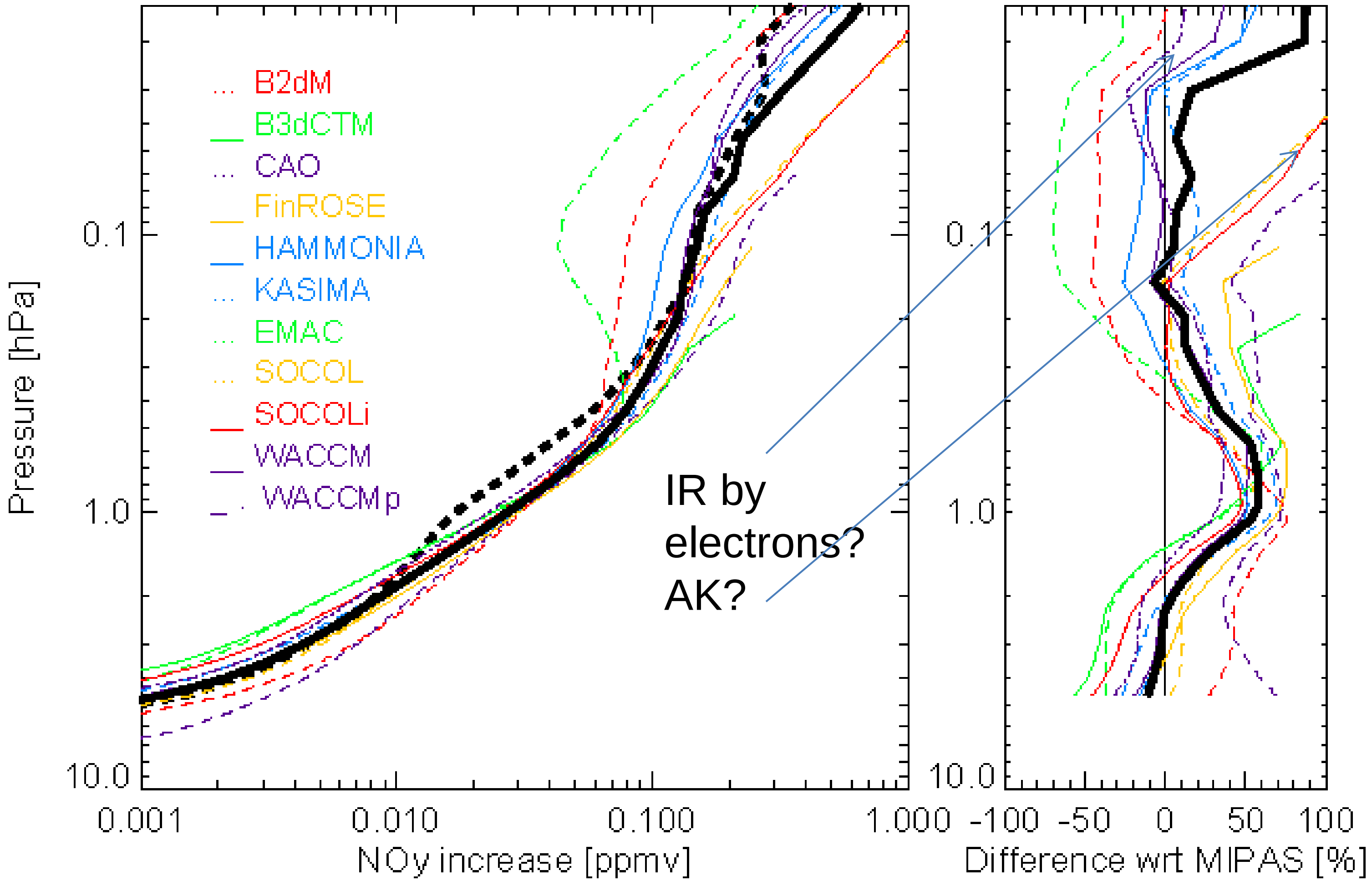
- Model top at 80 km
- Production by SP and RBE is 0.7 N^*, 0.55 $N(^4S)$ and $2xHO_x$ per ion pair; valid below mesopause
- Ionization by electrons (> 30 KeV) is absent

Modeling of the auroral electrons direct effects



NO_x (ppbv) from MIPAS. HEPPA-2, Courtesy of B. Funke

Modeling of the solar protons direct effects



Observed and modeled NO_y enhancement during October 2003 SPE, 70–90ºN, Funke et al., 2011

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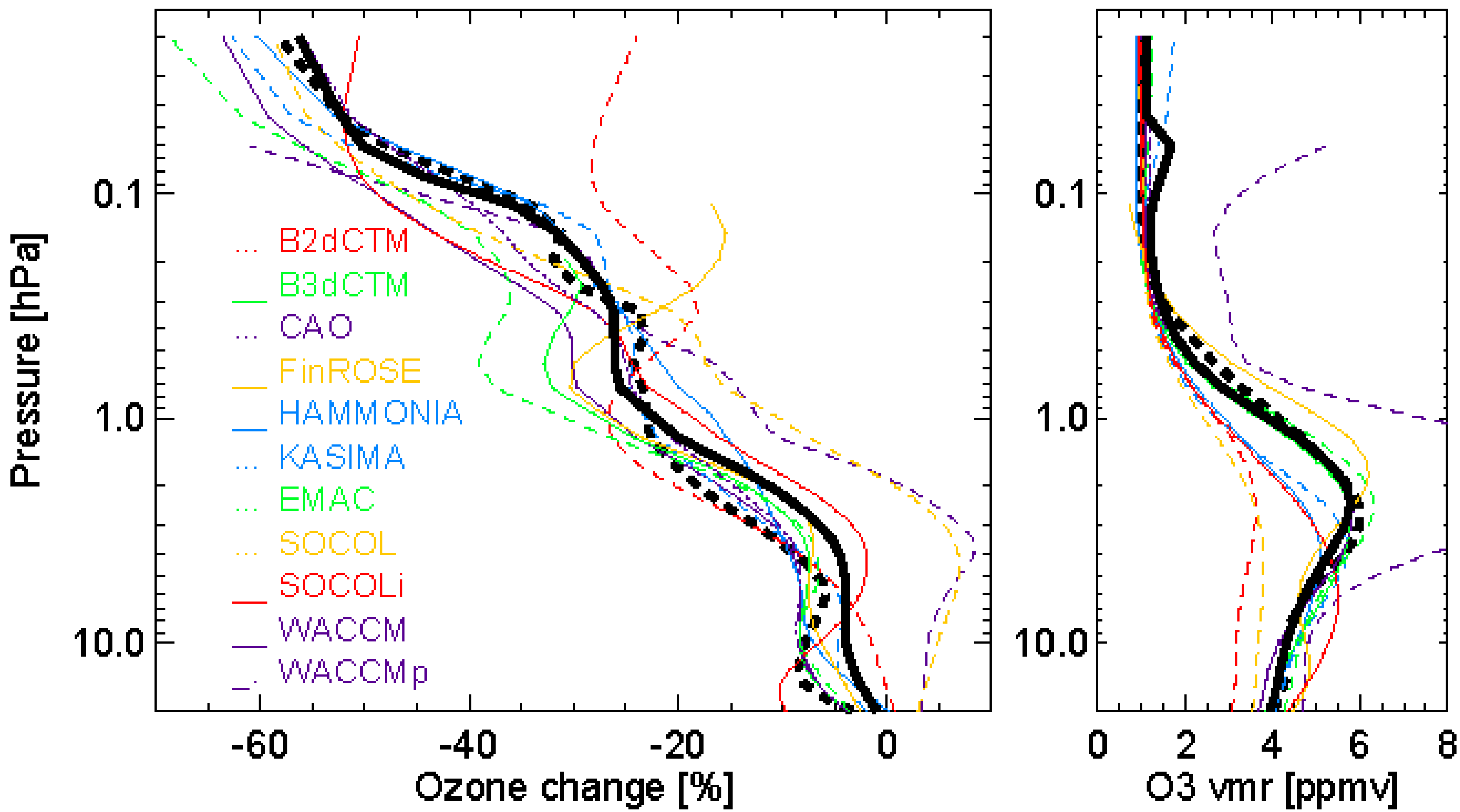
Modeling of the solar protons direct effects



Observed and modeled O_3 depletion during October 2003 SPE, 70–90ºN, Funke et al., 2011

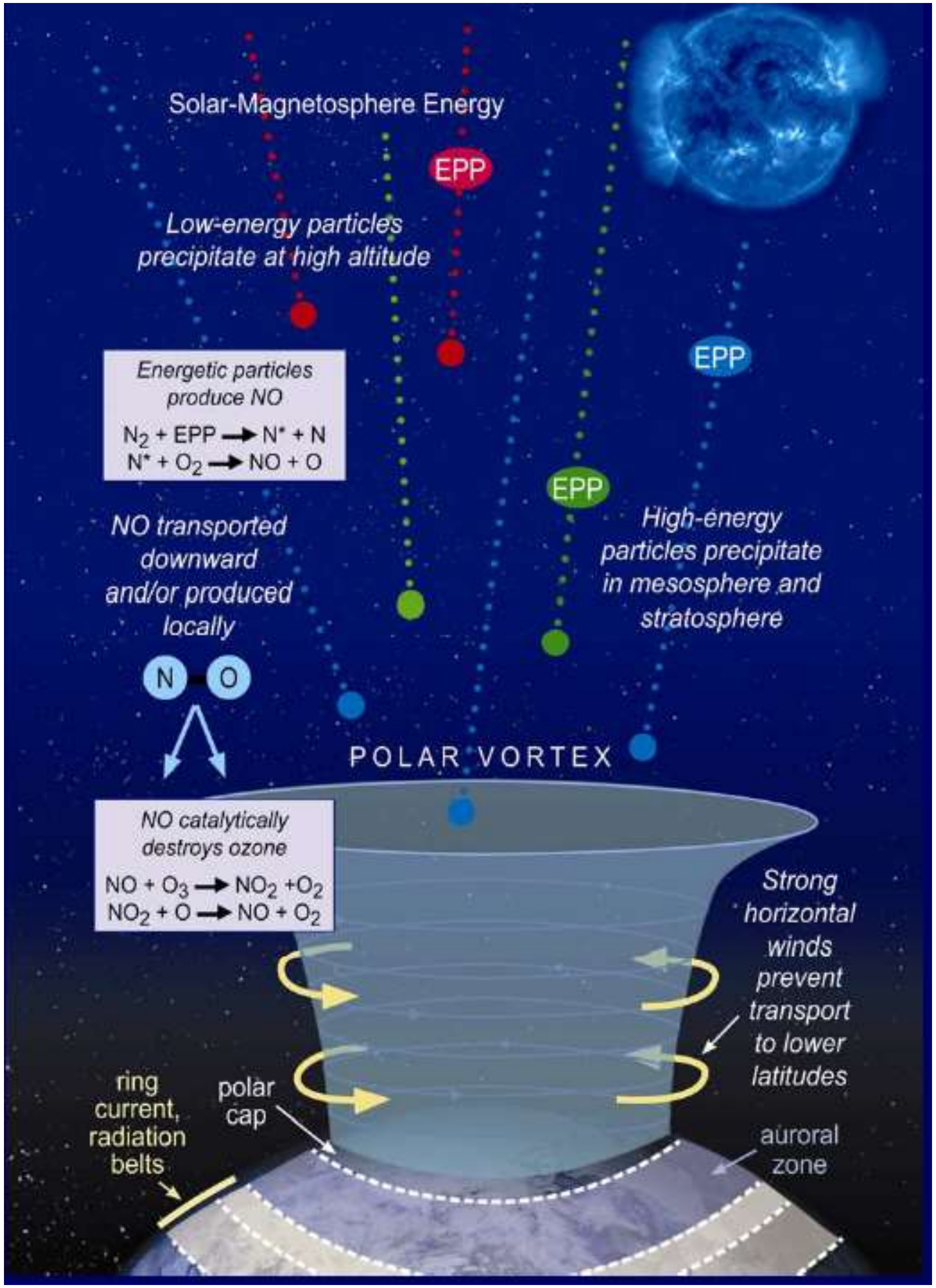
Modeling of the RE direct effects

I could not find proper observation vis CCMs comparison. Possible but difficult due to poor knowledge of electron fluxes and IR.

Modeling of the GCR direct effects

I could not find proper observation vis CCMs comparison. Could be possible to look at NOx in the polar UTLS after FD or GLE?

Indirect effects via transport/chemistry



Baily et al., 2009

Treatment of the auroral electrons in low top CCMs (EMAC, SOCOL)

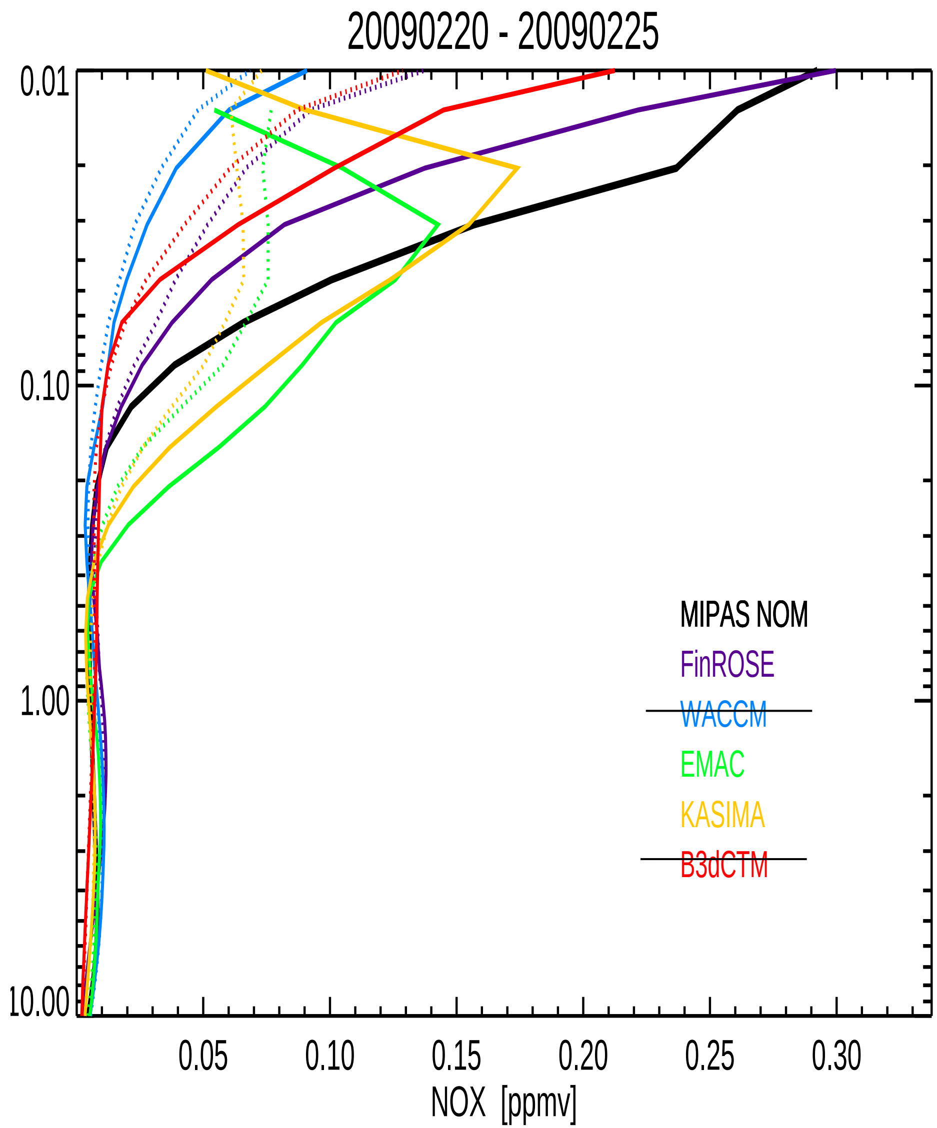
following time dependency was chosen:

$$F = {A_p}^{2.5} \cdot c \cdot 2.20 \times 10^5 \mathrm{cm}^{-2} \mathrm{s}^{-1} \cdot \max\left(0.1, \cos(\pi / 182.625 \cdot (d - 172.625))\right), \qquad (4)$$

where d is day of year. This sinusoidal variation centered around solstice represents the minimum requirement of a seasonal variation with maximum in winter. The 10% flux

Baumgartner et al, 2009

Modeling of the auroral electrons indirect effects



High top models

NO_x (ppbv) from MIPAS. HEPPA-2, Courtesy of B. Funke

Modeling of the auroral electrons indirect effects

Circulation effect

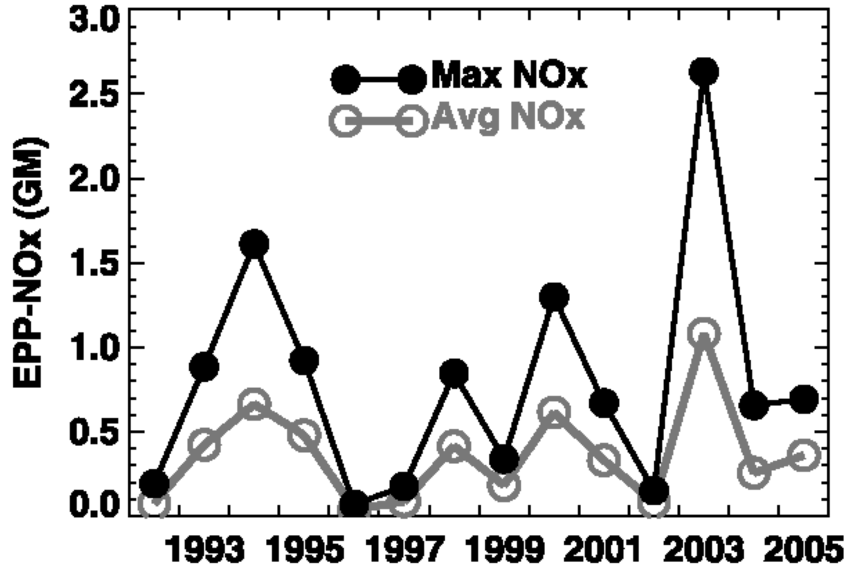
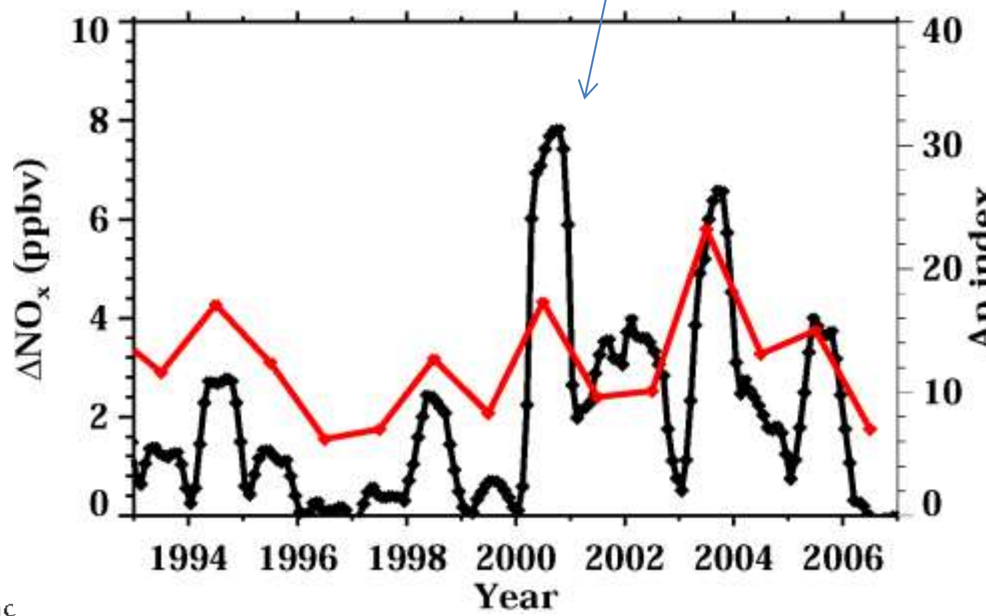


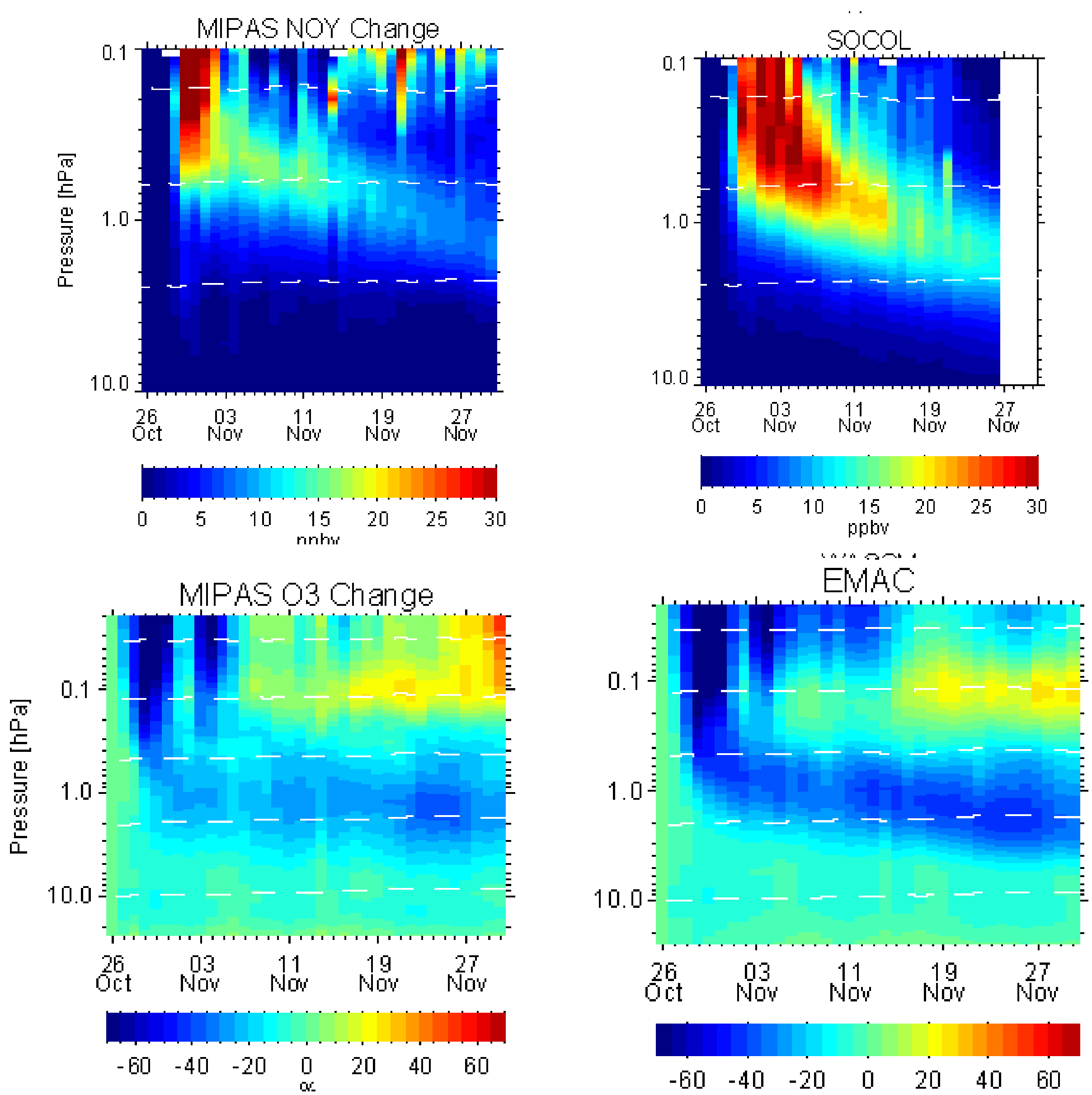
Figure 9. Annual EPP-NO_x at 45 km in the SH arising from the EPP IE, calculated from the average NO_x residuals corresponding to CH_4 < 0.27 ppmv (open circles, gray) or the maximum NO_x residuals (dots, black).



Randall et al., 2007

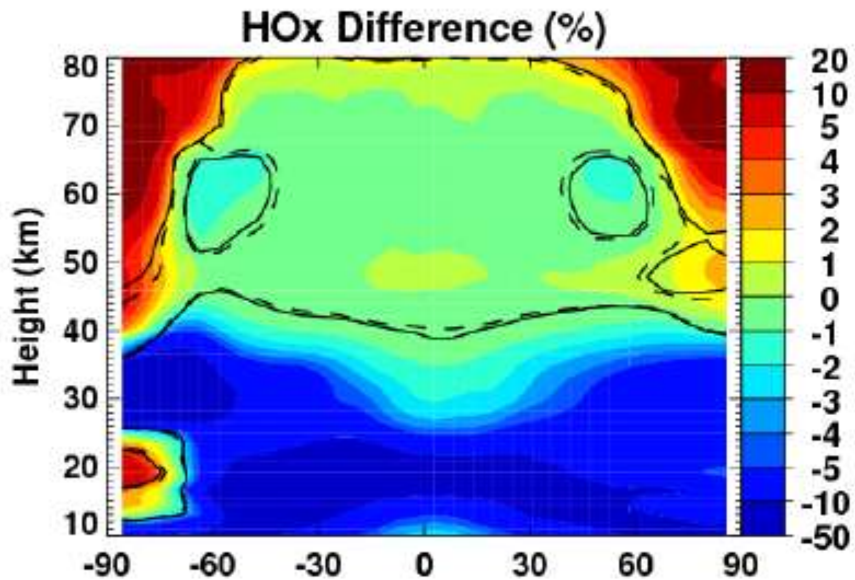
Rozanov et al., 2012

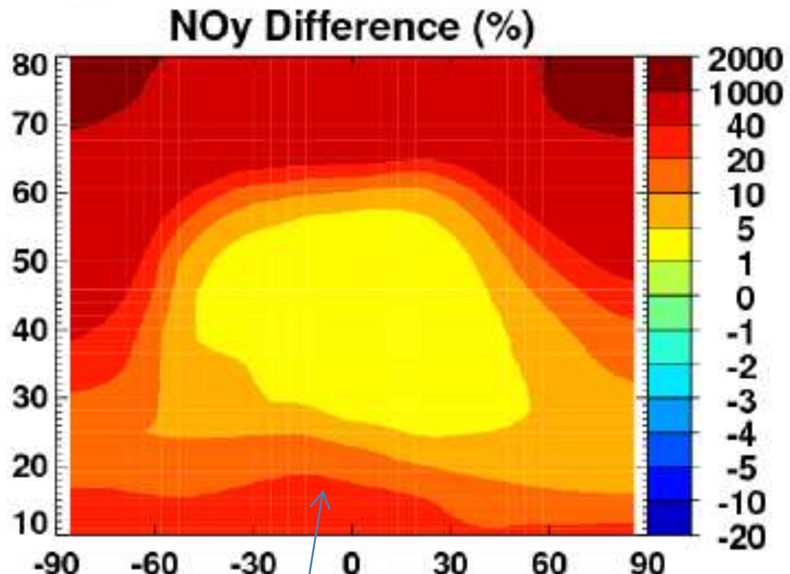
Modeling of the solar protons indirect effects



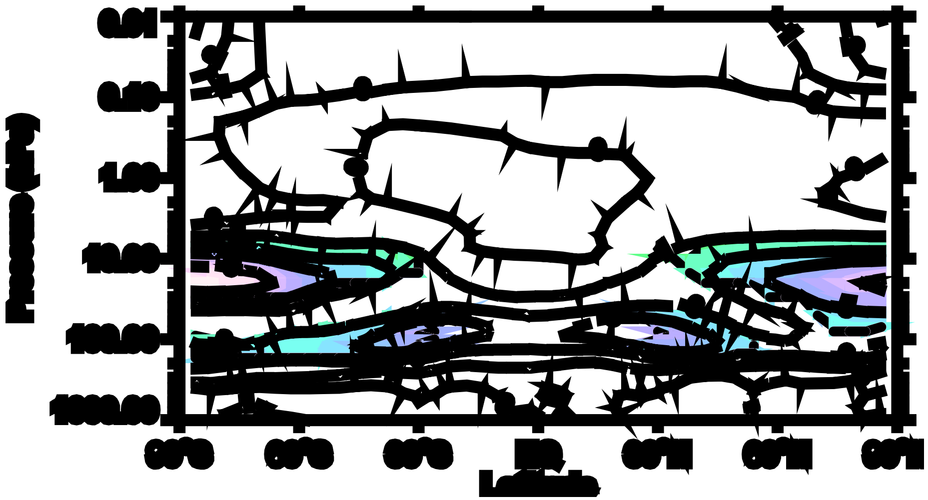
, Funke et al., 2011

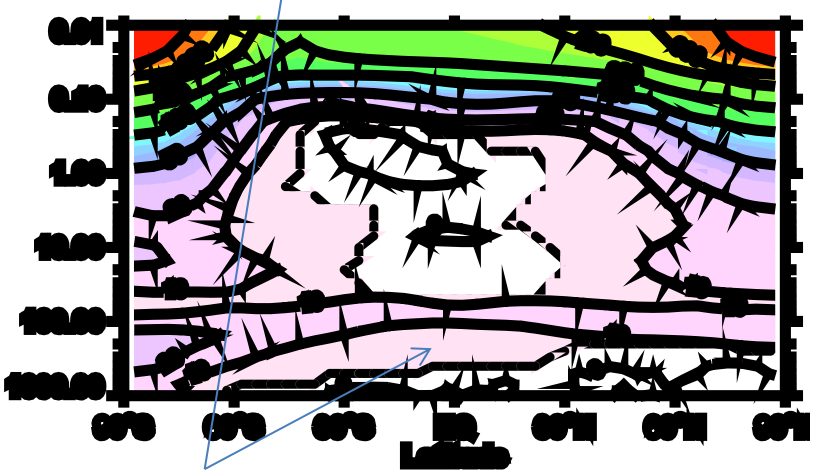
EP influence on model climatology





CMAM, Semeniuk et al., 2011

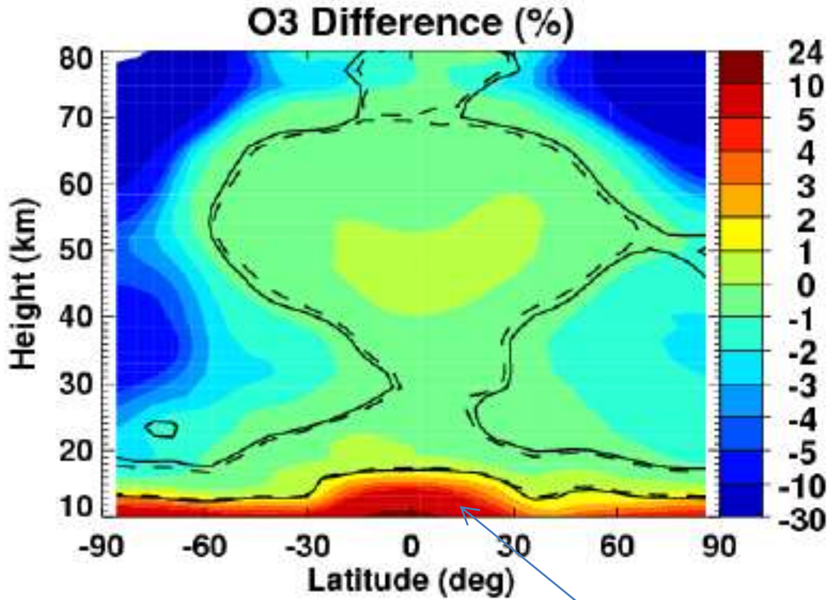




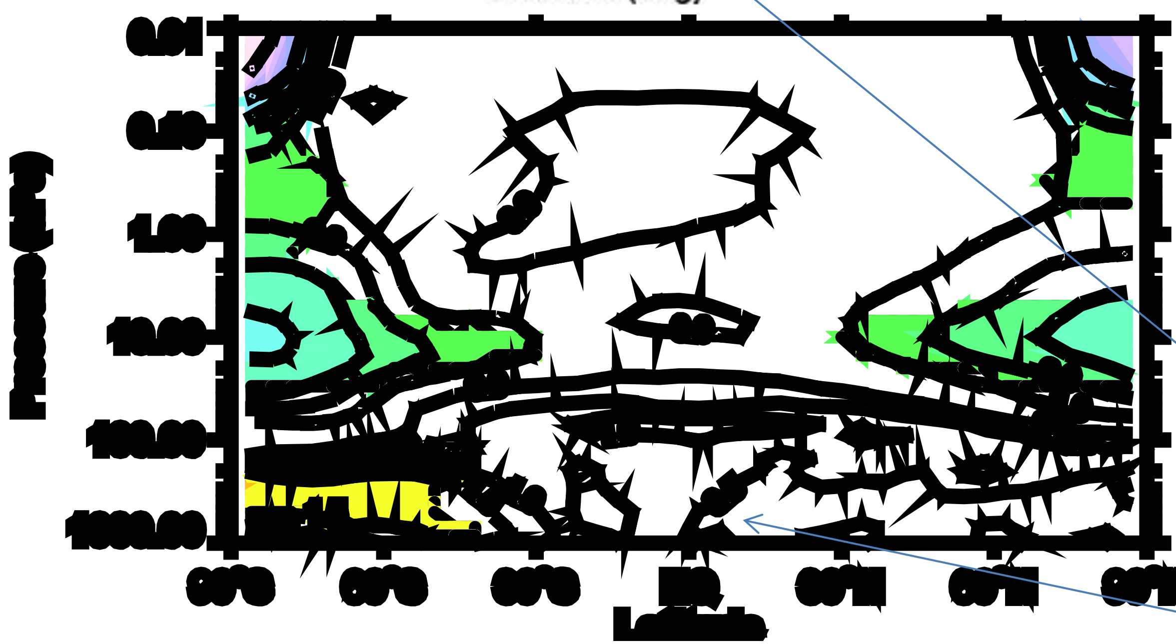
SOCOL v2.0, Rozanov et al., 2012

GCR !!!

EP influence on model climatology



CMAM,
Semeniuk et al., 2011

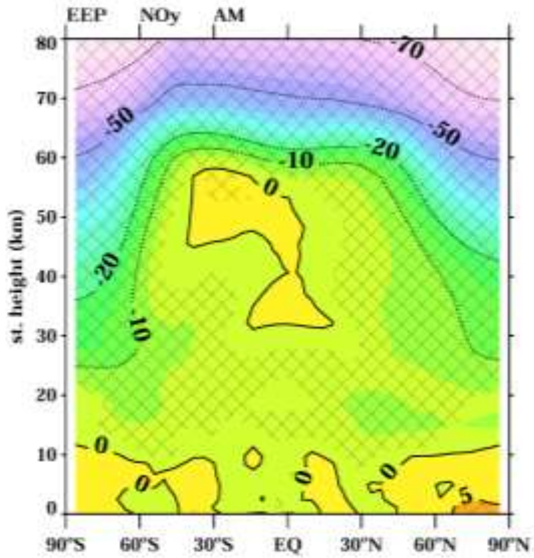


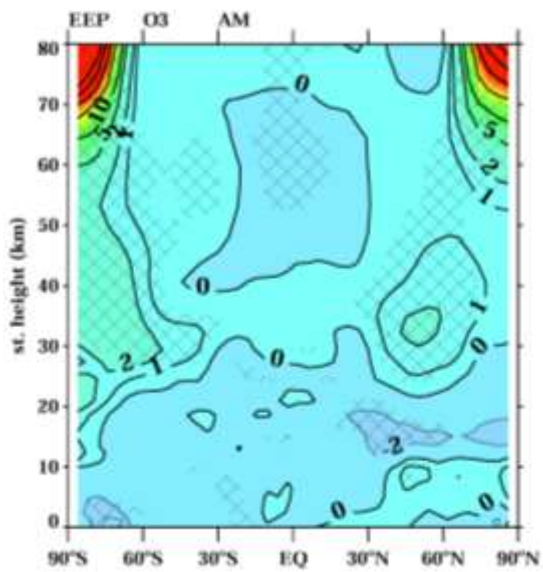
SOCOL v2.0,
Rozanov et al., 2012

GCR !!!

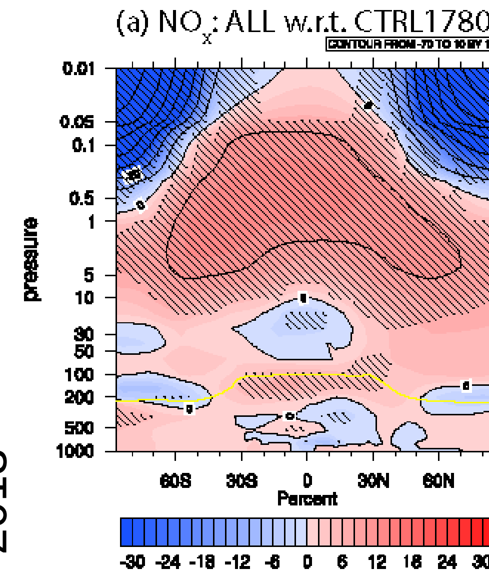
The effects of solar activity decline in SOCOL 2.0 (left) and 3.0 (right)

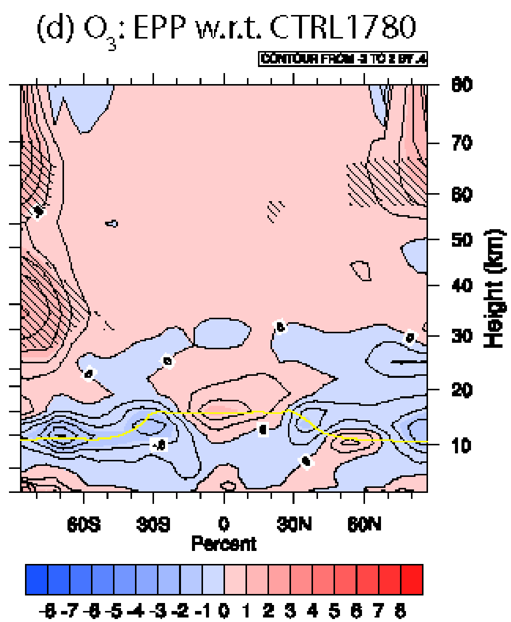
Rozanov et al., 2012





Anet et al., 2013





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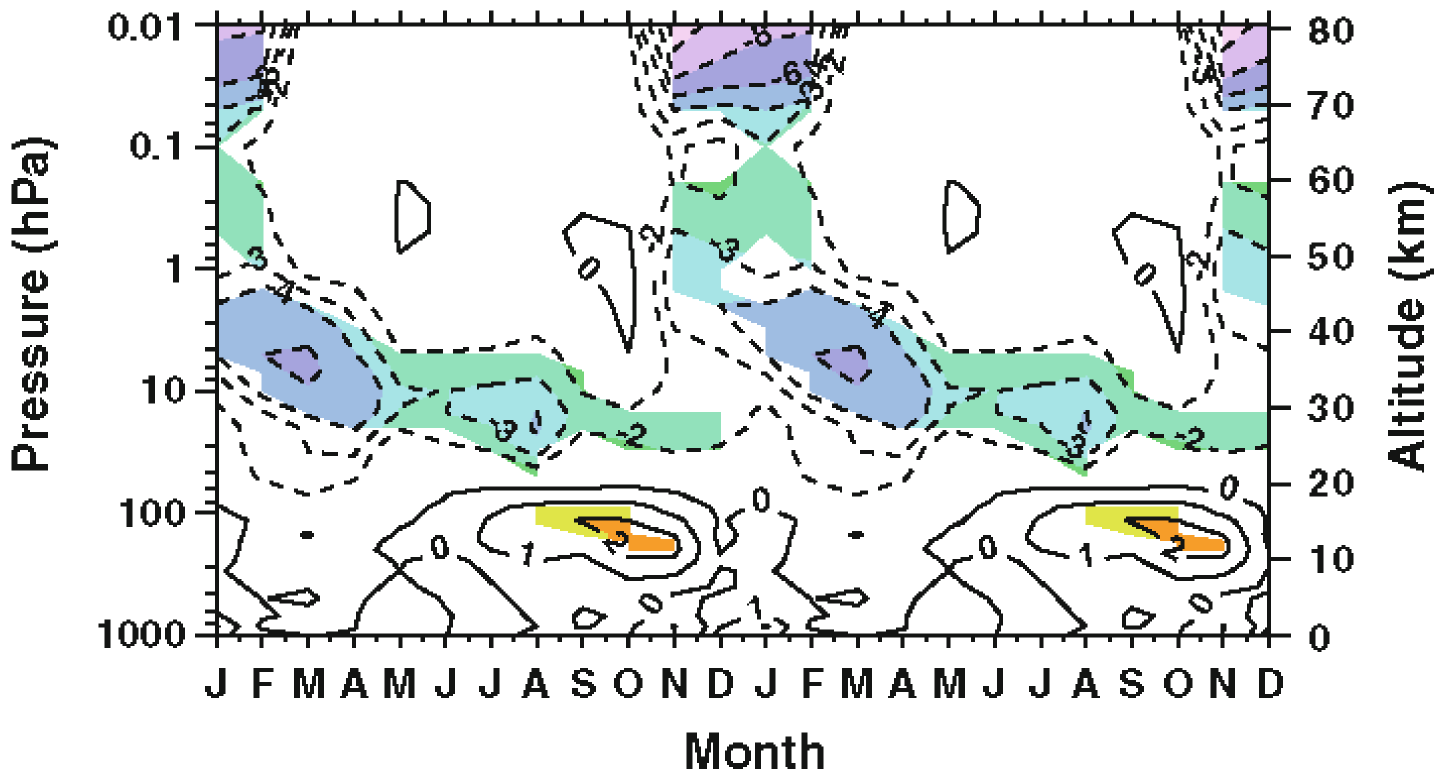
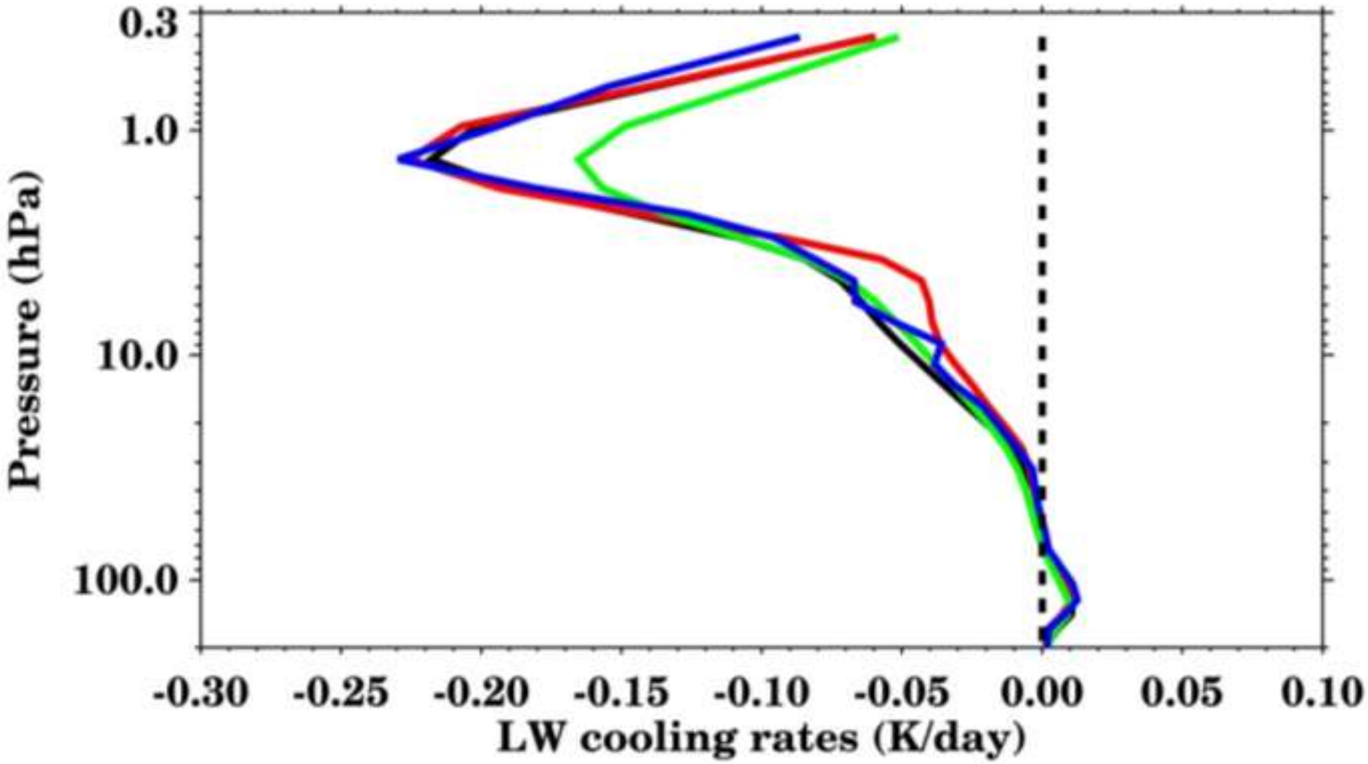
EP influence on model ozone climatology



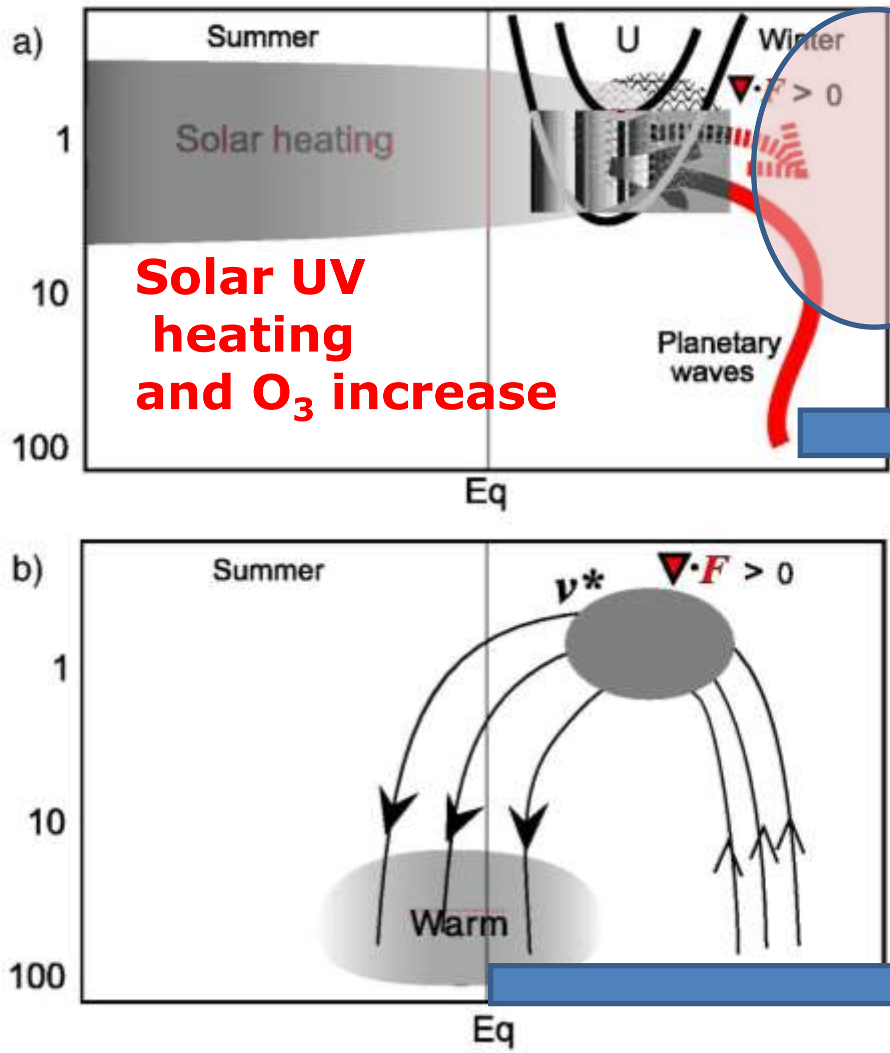
Ozone change by EPP, 70-90^{o}N, CCM SOCOL v2.0, Rozanov et al., 2012

Effects of the auroral electrons



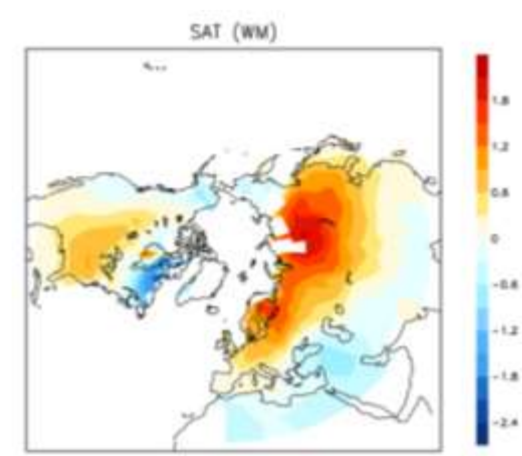
January
Polar
AER LBL code

Downward propagating response or 'top-down' route



Solar UV heating and O_3 increase

EPP cooling and O_3 decrease

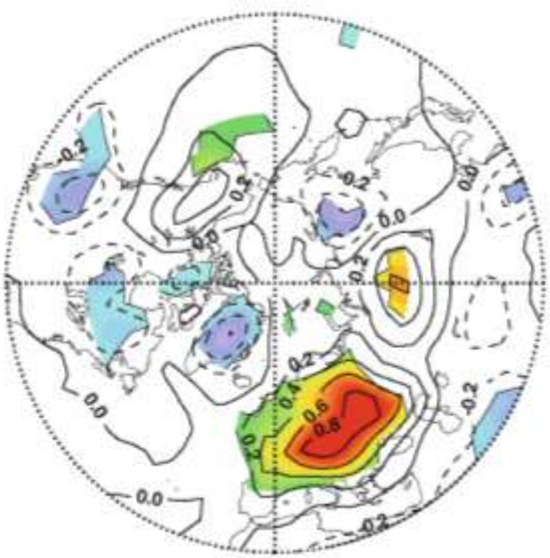


Thomson & Wallace (1998)

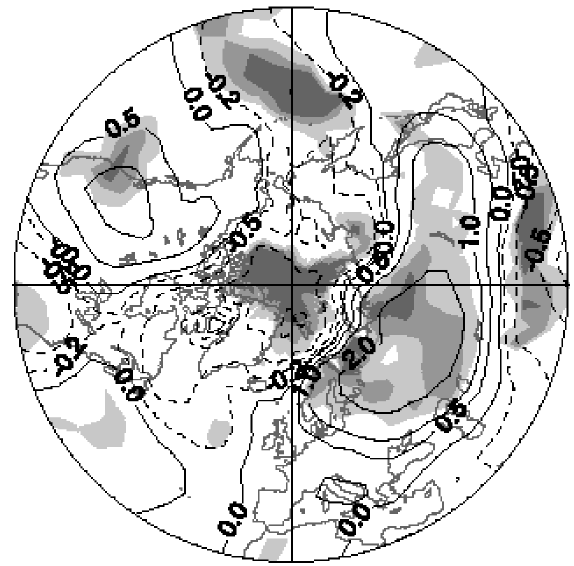
Kodera and Kuroda, (2002)

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

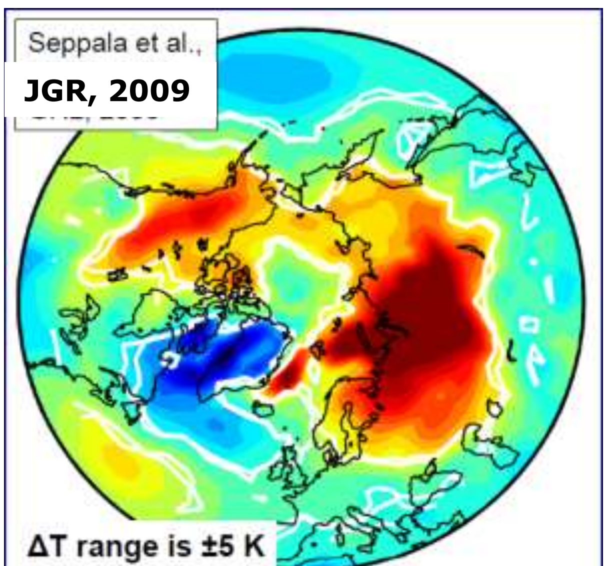
EP influence on surface air temperature



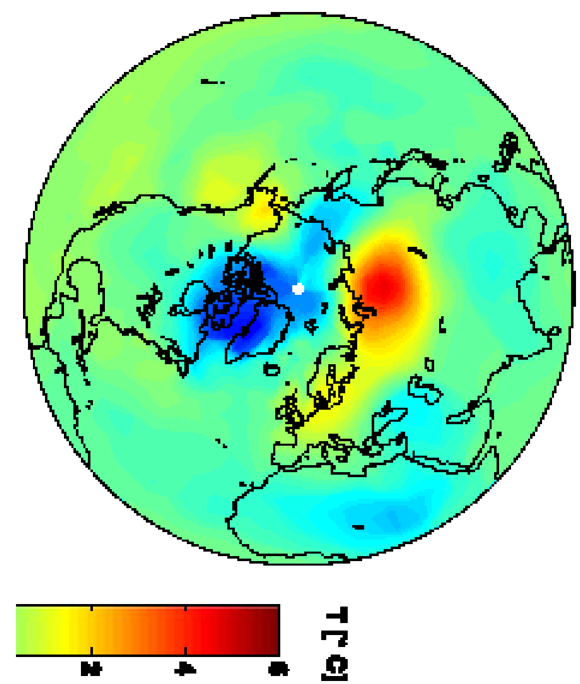
DJF, SOCOL v2.0, all EP Rozanov et al., 2012



DJF, UIUC CCM, RE Rozanov et al., 2005



DJF composite High Ap-Low Ap SAT from ERA-40



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

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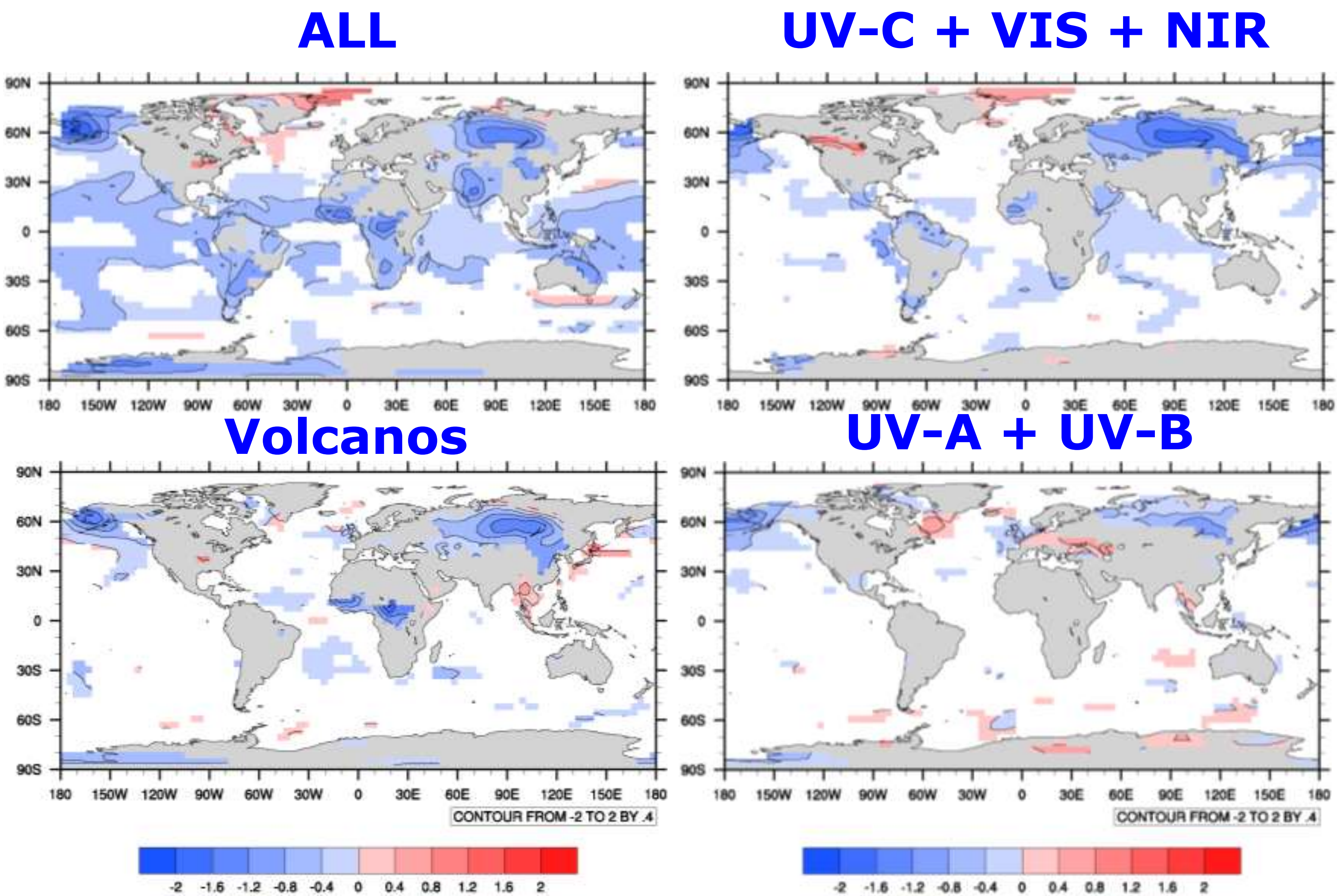
DJF mean surface air temperature change (K) during DM due to different forcing



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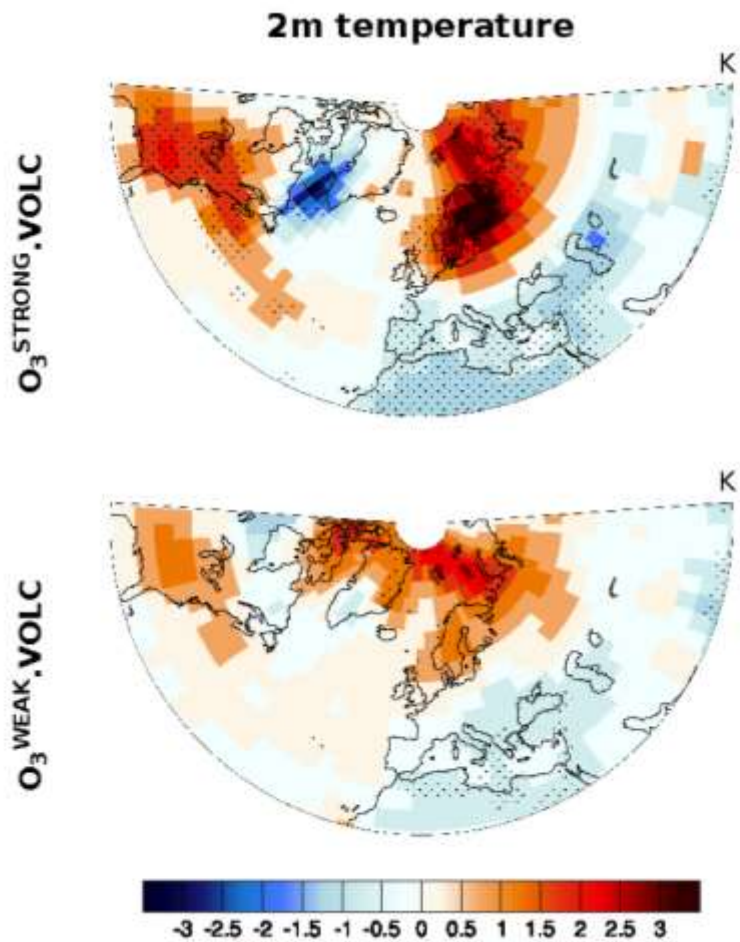
Model response to volcanic eruption



Muthers et al., 2014

Conclusions

The progress in the understanding and characterization of the EP effects on ozone and climate is substantial (First time ever EP is defined as a forcing for CCMI)

There are still many problems to address:

1. Ionization rates by RBE
2. Downward propagation of NOx from lower thermosphere (HEPPA-2)
3. Climate response, top-down mechanism efficiency
4. More careful model evaluation to understand why the particle effects heavily depends on model state
5. Resolving the disagreement between the magnitude of GCR effects in the troposphere (more models are needed)
6. Projection of EP fluxes and spectrum behavior for future grand minimum of the solar activity