Energetic particle effects on the atmosphere and climate

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Precipitating energetic particles

Electrons

*Low Energy (<30 KeV)*: From plasma-sheath 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

![Graph showing types of precipitating energetic particles based on energy deposition altitude.](image-url)

Instantaneous

Mironova et al., 2015
Processes

Ion and neutral chemistry
Transport
Ozone chemistry
Micro-physics
Clouds
GEC
Particles precipitation

Ozone, Climate

VarSITI, Albena, Bulgaria, 9 June, 2016
Processes
Ionization products

- $N_2$
- $O_2$
- $H^+(H_2O)_n$
- $NO_3^-(HNO_3)_n$
- $HSO_4^-(HNO_3)_n$
- $e^-$
- $N^+$
- $N_2^+$
- $N^*$
- $O$
- $O^+$
- $O_2^+$
- $NO_x$
- $HO_x$
Stratospheric ozone depletion by $\text{NO}_x$ and $\text{HO}_x$

Nitrogen:

$\text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2$

$\text{NO}_2 + \text{O} \rightarrow \text{NO} + \text{O}_2$

$\text{O}_3 + \text{O} \rightarrow 2\text{O}_2$

Hydrogen:

$\text{OH} + \text{O}_3 \rightarrow \text{HO}_2 + \text{O}_2$

$\text{HO}_2 + \text{O} \rightarrow \text{OH} + \text{O}_2$

$\text{O}_3 + \text{O} \rightarrow 2\text{O}_2$

From D. Lary
Downward transport of thermospheric NO$_x$
Polar ozone depletion and SW heating rates

Karami et al., 2015, APCD
Polar ozone depletion and LW cooling rates

Karami et al., 2015, APCD

January
Polar
10% O₃ depletion
AER LBL code
Downward propagating response or ‘top-down’ mechanism

Solar UV heating and O₃ increase

EPP cooling and O₃ decrease


Thomson & Wallace (1998)

Hadley sell shift and ... (J.Haigh)
SPE effects
SPE effects on the atmosphere
SPE effects on the atmosphere

Temporal evolution of relative O3 changes with respect to 26 October 2003 in MIPAS observations averaged over 70°–90° 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


Up to -20% in August at 8 hPa
Effects of electrons

Up to -20% in July at 3 hPa

Effects of electrons

Up to -10% in August at 8 hPa

EPP - noEPP, 60°S-90°S, Rozanov et al. (2012)
No MEE
Effects of electrons
Missing MEE

MEE effects, Arsenovich et al. (2016)
Effects of electrons
Weak thermospheric source

\[ \text{NO}_y \ (\text{ppbv}) \text{ at } 60 \text{ km (70}^\circ\text{S-90}^\circ\text{S). Red (standard run), blue (new boundary conditions) and green (standard run with MEE). MIPAS data are shown in black. Rozanov et al., (2016)} \]
Effects of electrons
Thermospheric source from MIPAS

Up to -10% in July at 2 hPa

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

Solar (aa index)

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\textsubscript{x} and HO\textsubscript{x}

From Volz-Thomas et al. 1990
Effects of GCR

NOx

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

O3

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