Middle-atmosphere chemical response to Solar Proton Events (SPEs) in 1989–2012 in WACCM-D simulations.

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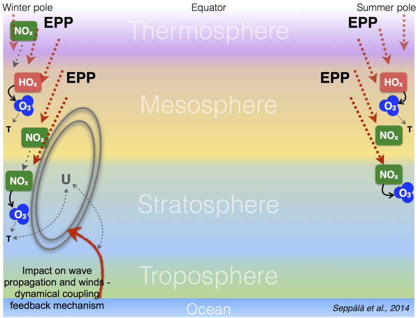
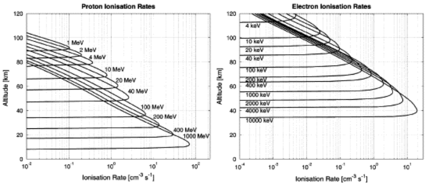
Solar Proton Events: an Introduction

- Bursts of high-energy solar particles
  - dominated by protons
  - tens or hundreds of MeVs/nucleon
  - from few hours to few days
  - most common during solar maximum (11-year cycle)
- Cause ionization and dissociation in the atmosphere
  - altitude range roughly 30-90 km, depending on energy
  - impact seen mostly in polar areas
- Impact O_3 chemistry via HO_x and NO_x reactions





Turunen et al., 2009

WACCM-D

- Whole Atmosphere Community Climate Model (WACCM)
- Component of Community Earth System Model (CESM)
  - Option for fully interactive Ocean, Land and Sea-Ice components
  - We generally run atmosphere only, other components included as input data
- WACCM-D adds an expanded lower ionosphere (D-region) ion chemistry scheme
  - Verronen et al., 2016
  - Included as out-of-the-box configuration in new version of CESM.

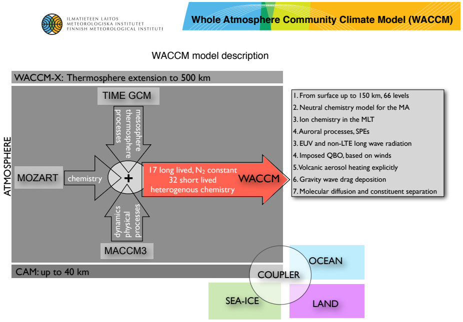
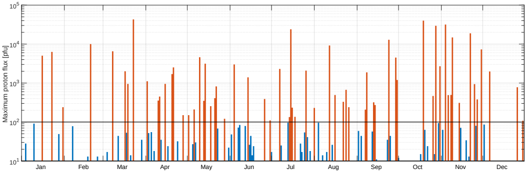


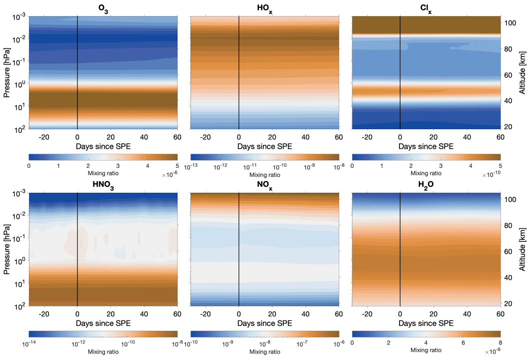
Figure: Monika Szelag

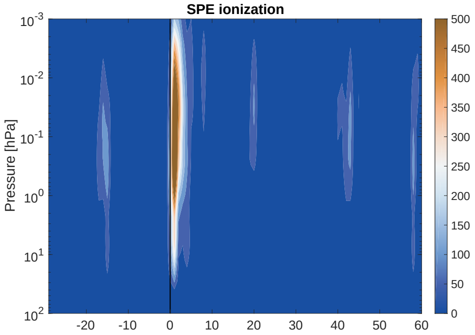
WACCM-D SPE superposed epoch analysis

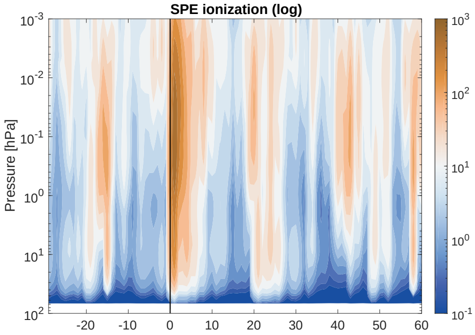
- Specified dynamics WACCM–D vs Standard WACCM–SD
- Superposed epoch analysis
  - Zero-epoch: first day GOES EPS proton flux exceeds 10 pfu [particles/(cm^2 s sr)]
  - Closely separated SPEs complicate interpretation
  - Solar maxima years overpresented ⇒ Solar cycle signals
- 1989–2012, Events larger than 100 pfu ⇒ 66 SPEs after some additional screening
- Difference between SPE epochs and same epochs from climatology ⇒ Effect of SPEs
- Difference between WACCM–D epochs and REF epochs ⇒ Effect of WACCM–D
- Considering polar caps (60-90 degrees geographical, area-weighted)
- ACPD: Kalakoski et al., Statistical response of middle atmosphere composition to solar proton events in WACCM-D simulations: importance of lower ionospheric chemistry

Events and Climatology

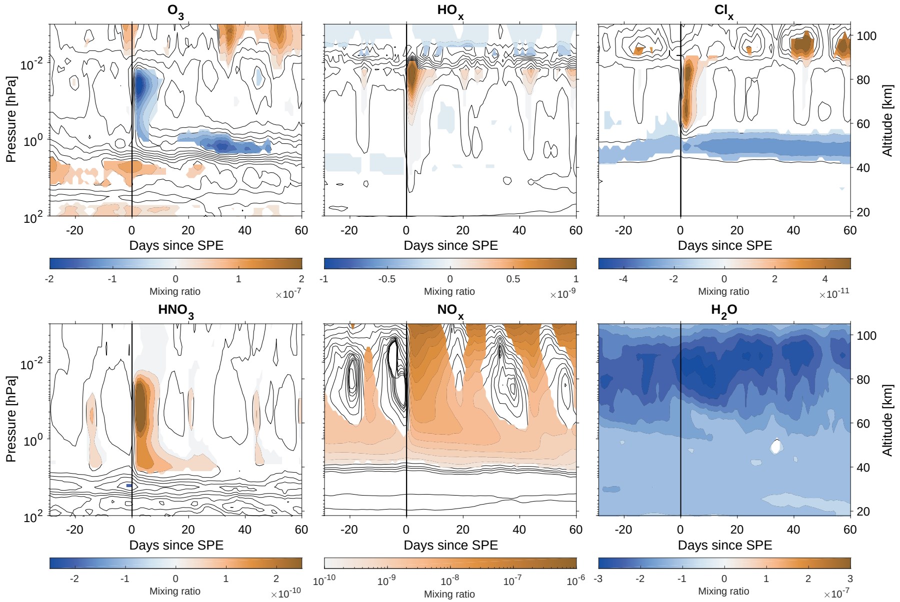








SPE – Climatology, Northern Polar Cap



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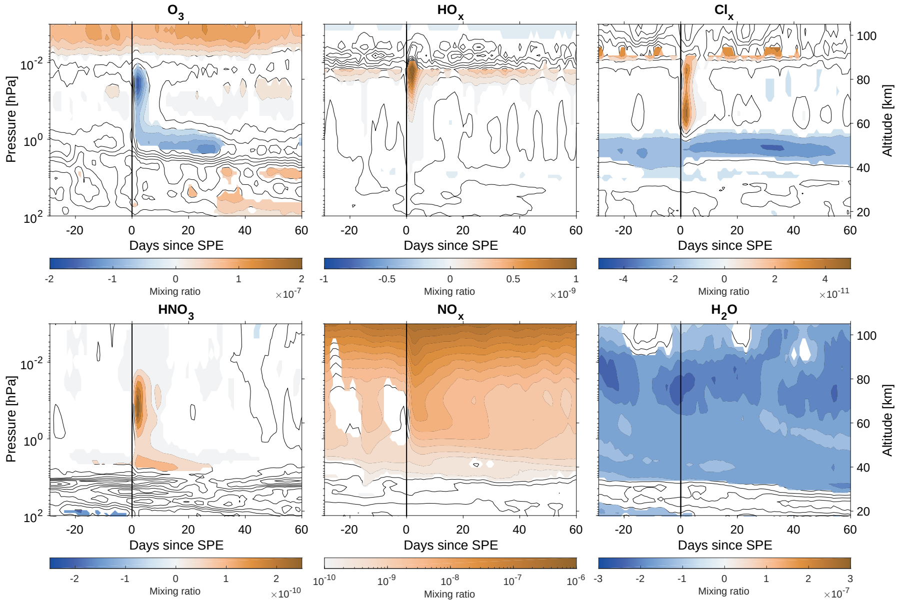
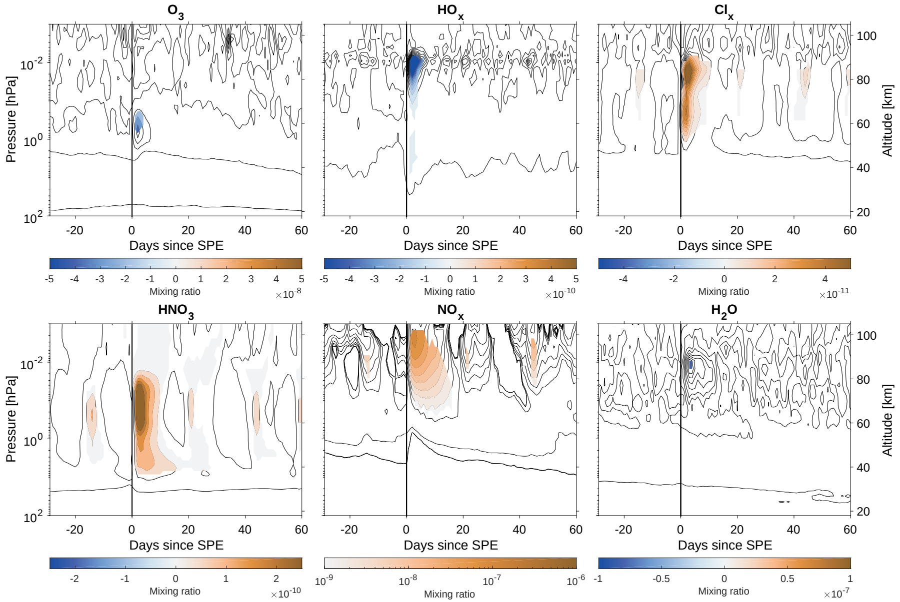
SPE – Climatology, Southern Polar Cap



WACCM-D – Reference, Northern Polar Cap



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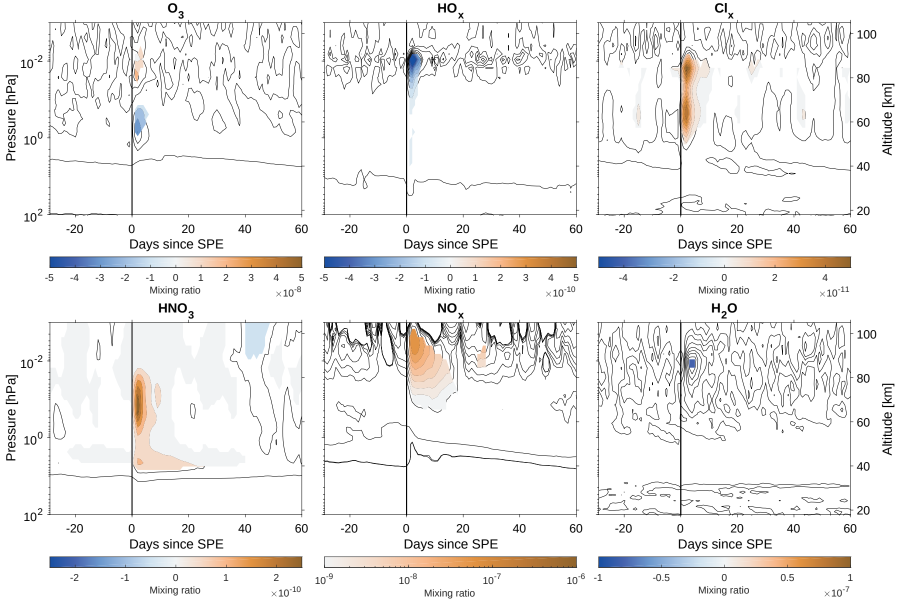
WACCM-D – Reference, Southern Polar Cap



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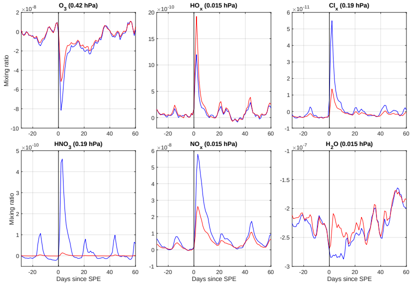
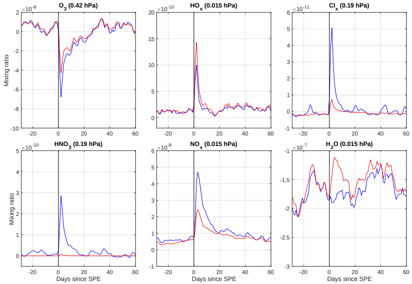
Details



O3 (0.42 hPa)
HOx (0.015 hPa)
Clx (0.19 hPa)
HNO3 (0.19 hPa)
NOx (0.015 hPa)
H2O (0.015 hPa)
Mixing ratio
Days since SPE



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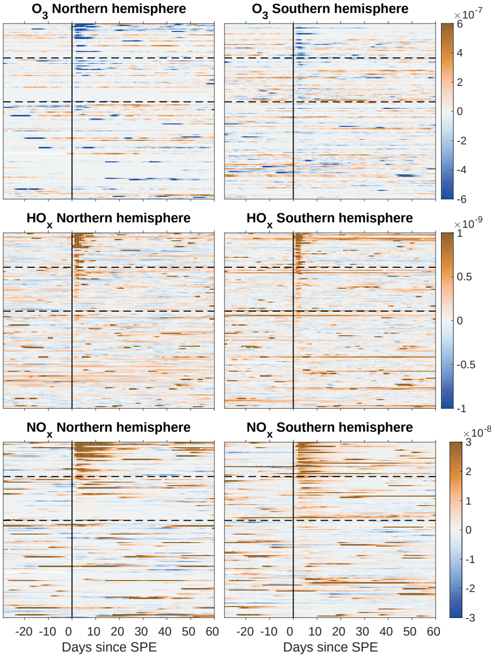

O3 Northern hemisphere
O3 Southern hemisphere
HOx Northern hemisphere
HOx Southern hemisphere
NOx Northern hemisphere
NOx Southern hemisphere
Days since SPE
Days since SPE

WD_SPE_STAT: Conclusions

- Response from WACCM-D to SPE:s looks reasonable
- WACCM-D makes a difference
  - Reduced HO_x around 0.01 hPa $\Rightarrow$ Ozone loss reduced around 0.01 hPa (SH)
  - Increased Cl_x above 1 hPa $\Rightarrow$ Ozone loss increased around 1 hPa
  - Dramatically increased HNO_3
  - Increased NO_x in mesosphere, change in downward transport not robust.
  - H_2O loss at 0.01 hPa?
- Response dominated by larger events, SPEs smaller than 100 pfu only add noise.