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

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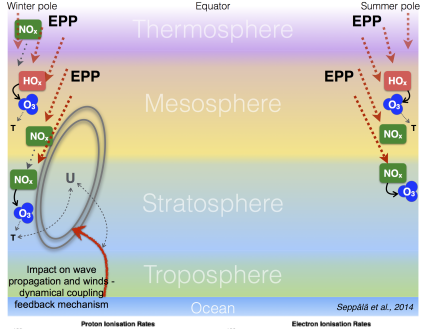
Solar Proton Events: an Introduction

- 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.

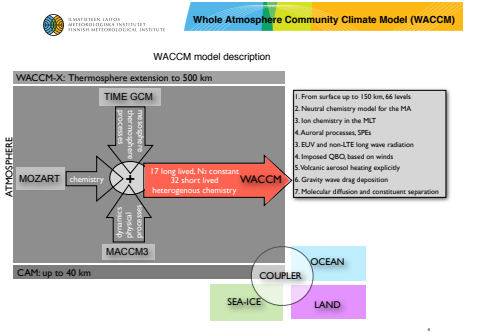
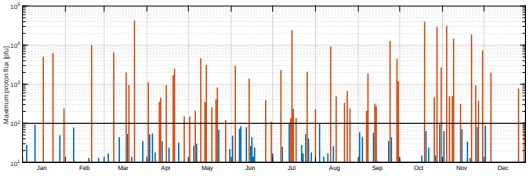


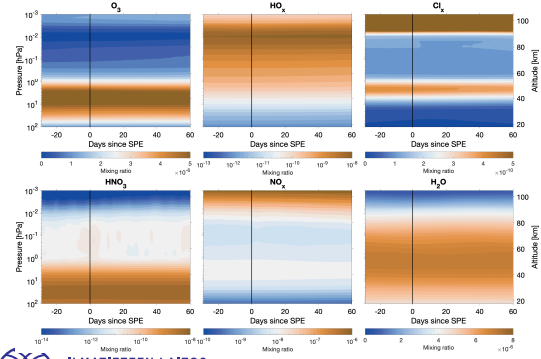
Figure: Monika Szelag

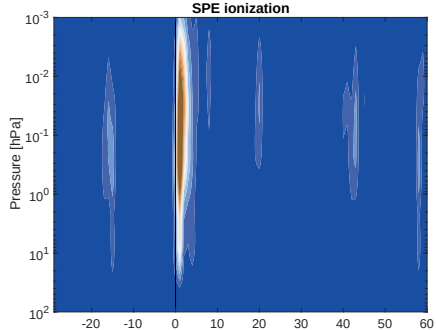
WACCM-D SPE superposed epoch analysis

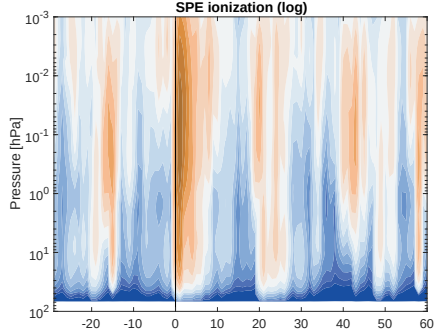
- Specified dynamics WACCM–D vs Standard WACCM–SD
- Superposed epoch analysis
  - Zero-epoch: first day GOES EPS proton flux exceeds 10 pfu [particles/(cm^2 s sr)]
  - Closely separated SPEs complicate interpretation
  - Solar maxima years overpresented $\Rightarrow$ Solar cycle signals
- 1989–2012, Events larger than 100 pfu $\Rightarrow$ 66 SPEs after some additional screening
- Difference between SPE epochs and same epochs from climatology $\Rightarrow$ Effect of SPEs
- Difference between WACCM–D epochs and REF epochs $\Rightarrow$ Effect of WACCM–D
- Considering polar caps (60-90 degrees geographical, area-weighted)
- ACP: 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

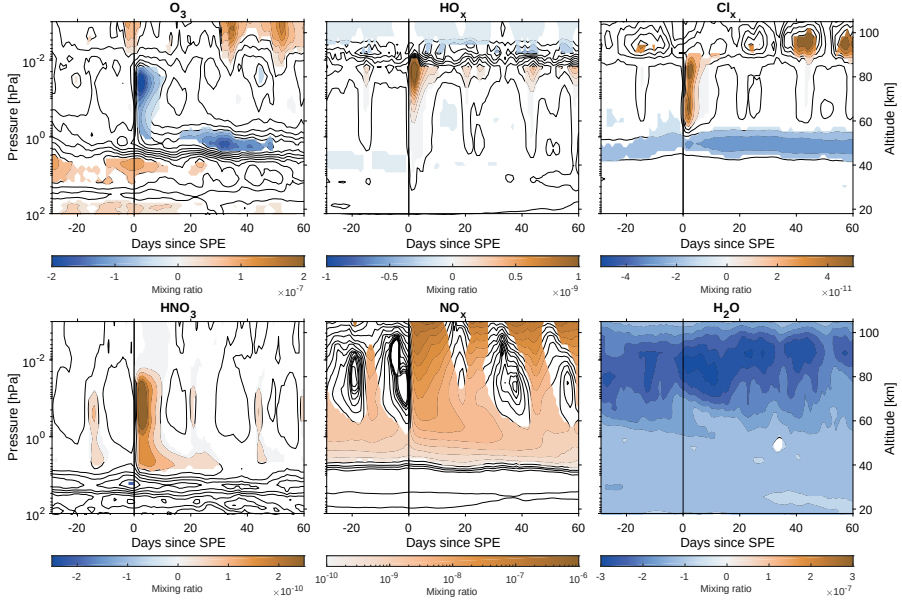




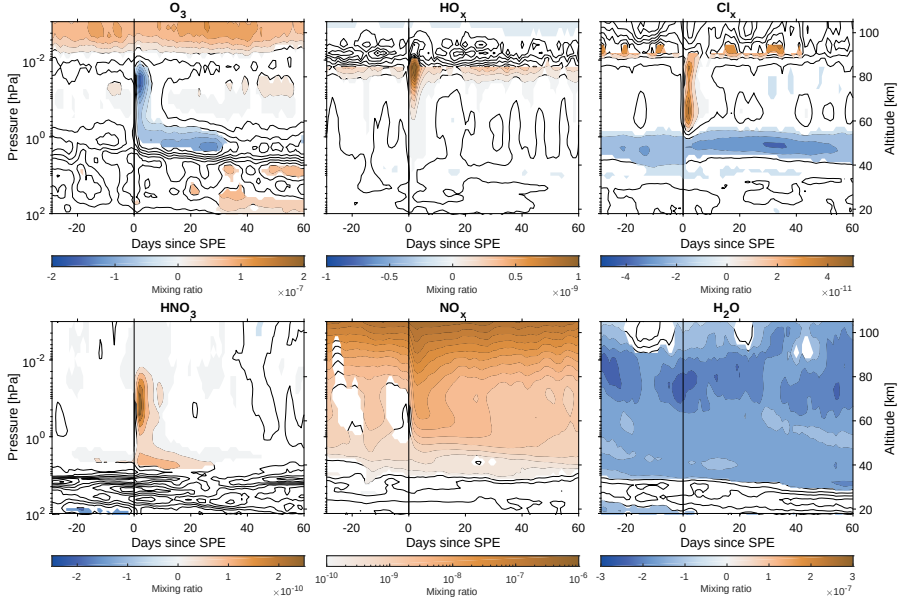




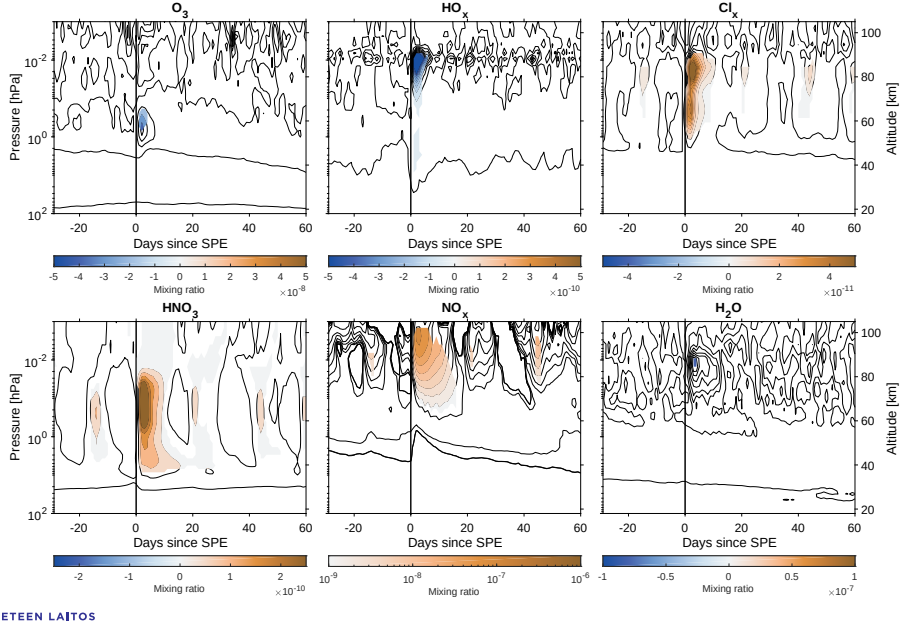
SPE – Climatology, Northern Polar Cap



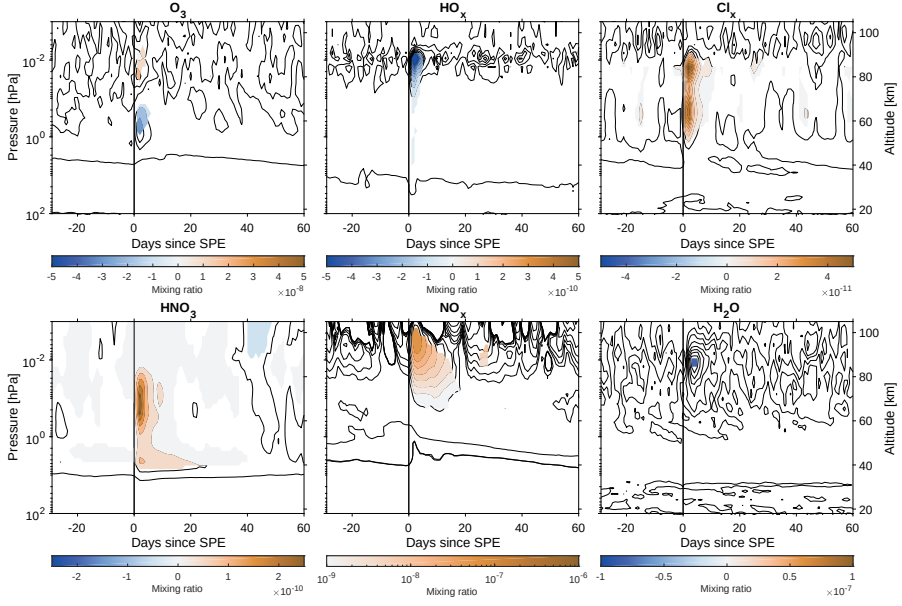
SPE – Climatology, Southern Polar Cap



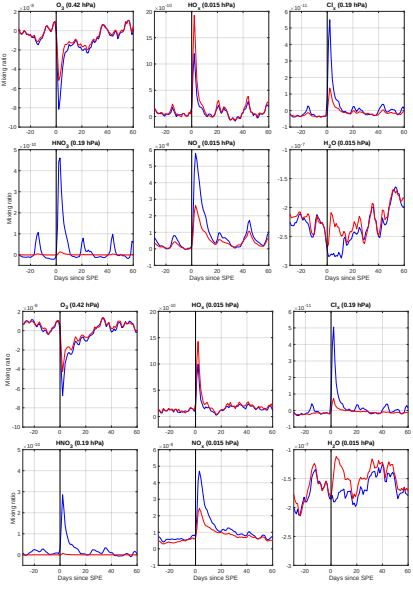
WACCM-D – Reference, Northern Polar Cap

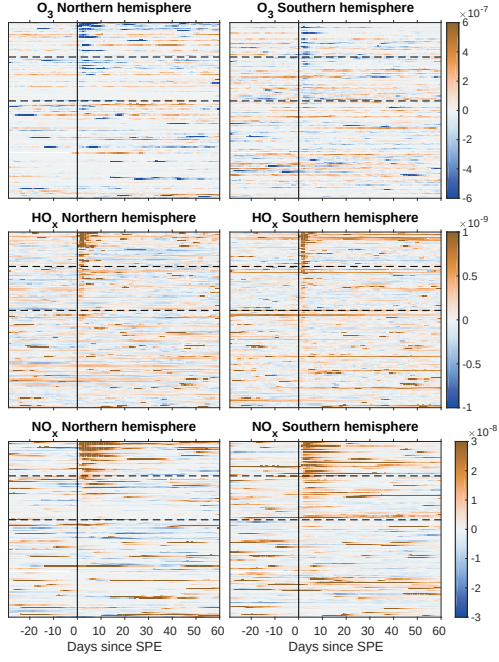


WACCM-D – Reference, Southern Polar Cap



Details


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


O3 Northern hemisphere
O3 Southern hemisphere
HOx Northern hemisphere
HOx Southern hemisphere
NOx Northern hemisphere
NOx Southern hemisphere
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.