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Modeled Middle Atmosphere Chemical Response to Solar Proton Events 1989-2012

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Introduction

Among the most striking phenomena affecting ozone in the middle atmosphere are solar proton events (SPE). During SPEs, precipitation of energetic protons into the polar atmosphere results in production of odd hydrogen (HO_x) and odd nitrogen (NO_x) species. Enhancements of HO_x and NO_x lead to depletion of ozone in mesosphere and upper stratosphere, through catalytic reaction cycles. However, the complex ion chemistry reactions necessary to produce these changes have not previously been included in global chemistry-climate models.

In this presentation we use WACCM-D, a variant of Whole Atmosphere Community Climate Model which includes a selected set of D-region ion chemistry reactions that allows to analyse the statistical response of middle atmosphere neutral chemistry to SPEs. For comparison, an additional simulation using standard WACCM and covering the same period was performed. Simulations covered years 1989 - 2012, roughly two solar cycles. Introduction of ion chemistry is shown to improve the short-term response of the middle atmosphere neutral chemistry to SPEs, notably increasing the mesospheric production of NO_x and HNO_3 following the onset of SPE.

Description of the experiment

- Two simulations, both specified dynamics covering years 1989 – 2012
  1. SPE_STAT: Simulation with improved D-region chemistry (WACCM-D).
  2. REFERENCE: Reference run with standard WACCM ionization parametrization.
- Superimposed epoch analysis for 66 SPE:s chosen for analysis.
- Analysed contituents: O_3, HO_x, Cl_x, HNO_3, NO_x and H_2O.
- In addition to transient effects from SPEs, analysis shows some long-term effects due to solar cycle.

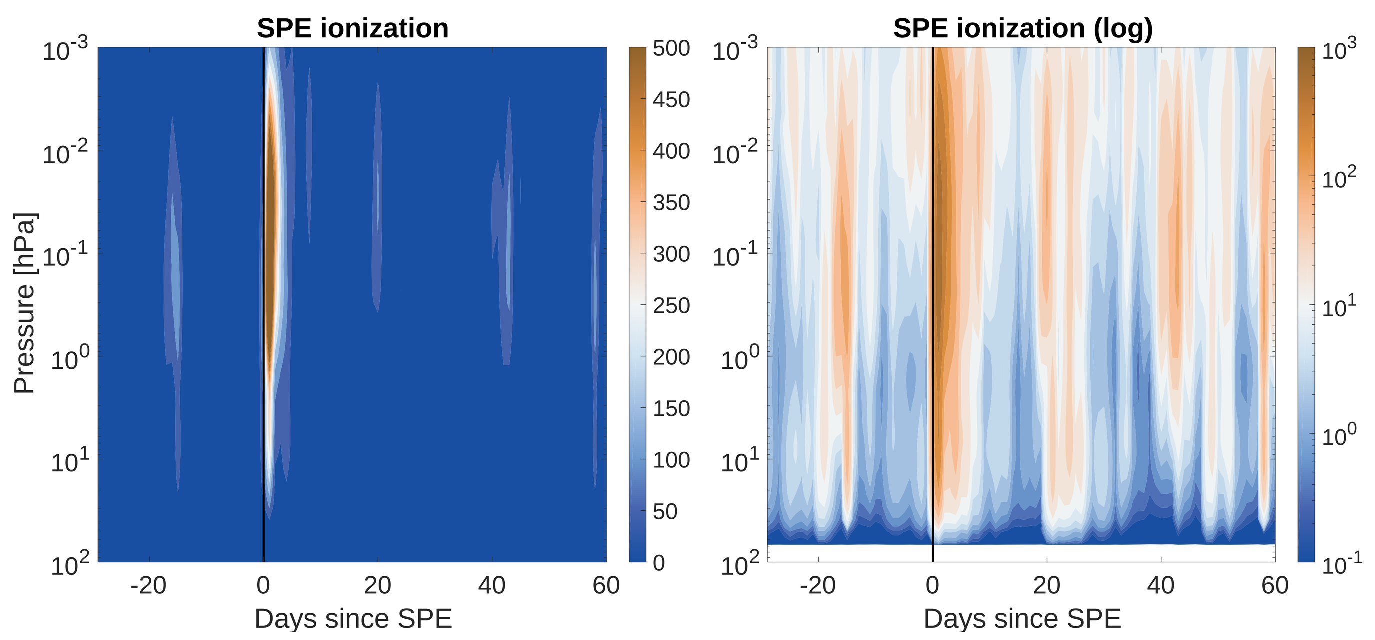

Figure 1: Composite mean SPE ionization for days [D_0-29, D_0+60]. Closely separated SPEs seen as secondary ionization peaks in figure.

Effect of SPE in WACCM-D

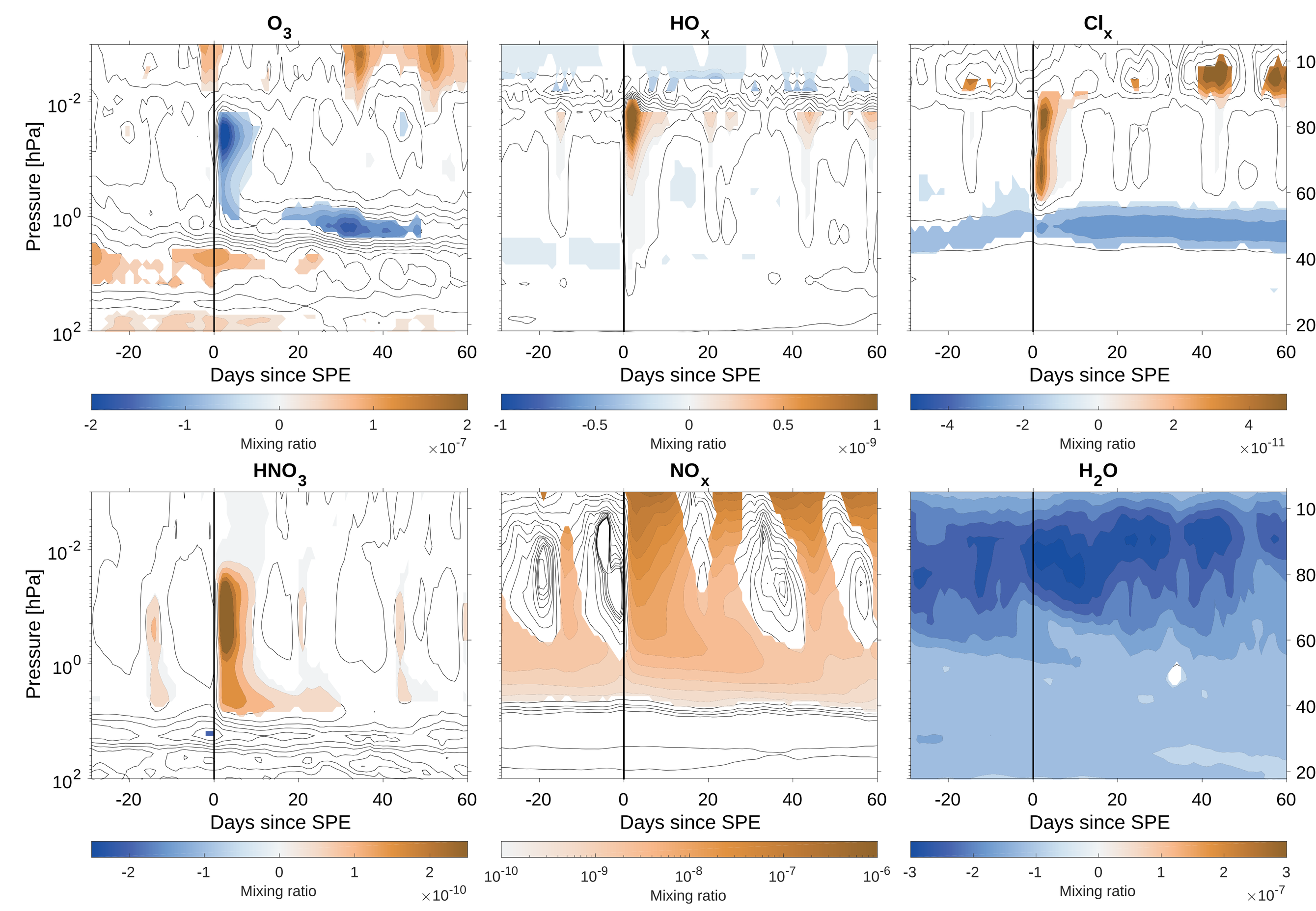

Figure 2: The mean difference of area-weighted northern polar cap epoch averages (latitude > 60°N) of O_3, HO_x, Cl_x, HNO_3, NO_x and H_2O mixing ratios and same epochs from daily climatology (1989-2012). X-axis shows the number of days before and after the event (day 0, solid black line) and y-axis pressure levels in model. Note the logarithmic color scale for NO_x.

Effect of improved D-region chemistry

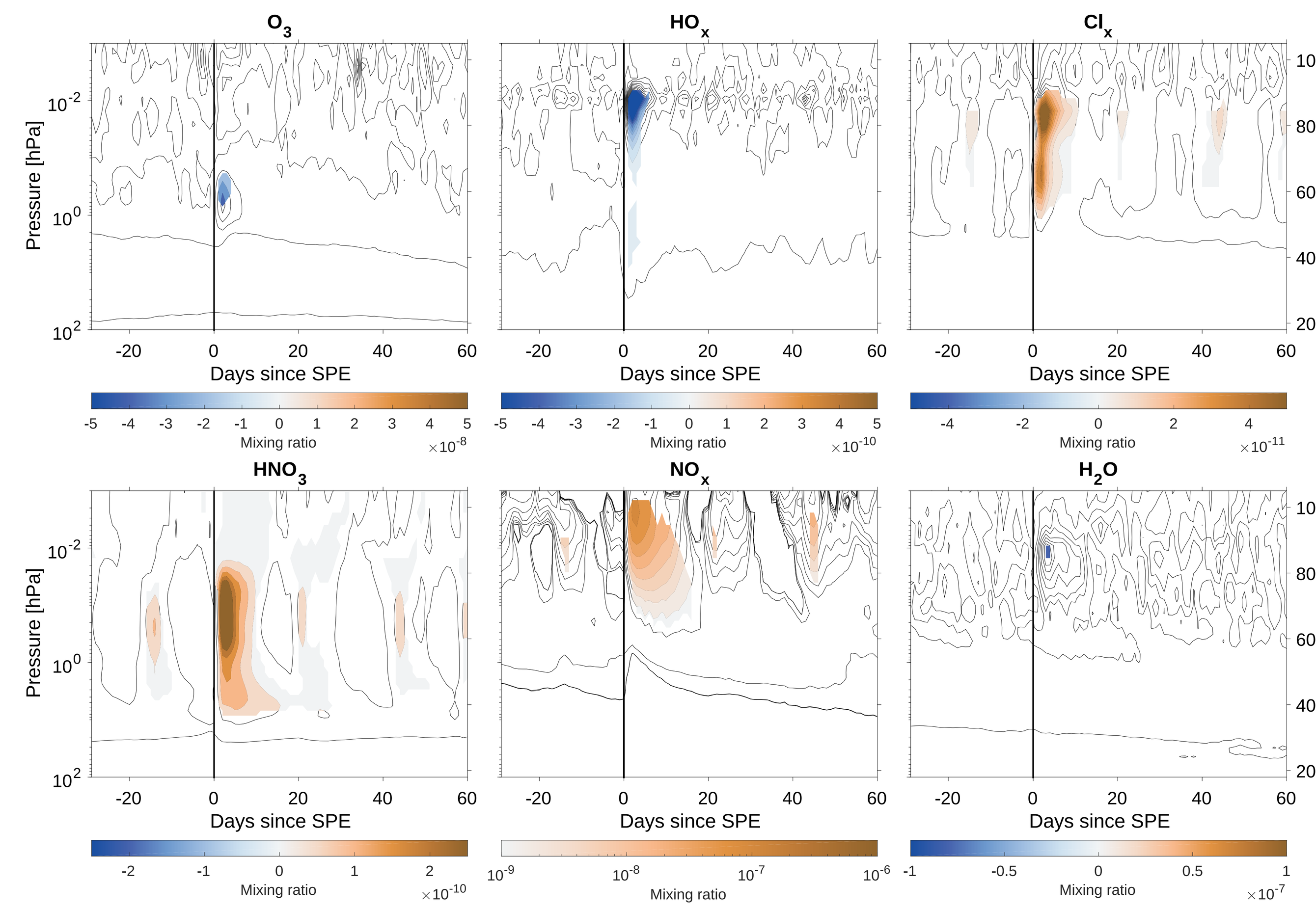

Figure 3: Difference of epoch differences between WACCM-D and standard WACCM for northern polar cap (latitude > 60°N). X-axis shows the number of days before and after the event (day 0, solid black line) and y-axis pressure levels in model. Note the logarithmic color scale for NO_x.

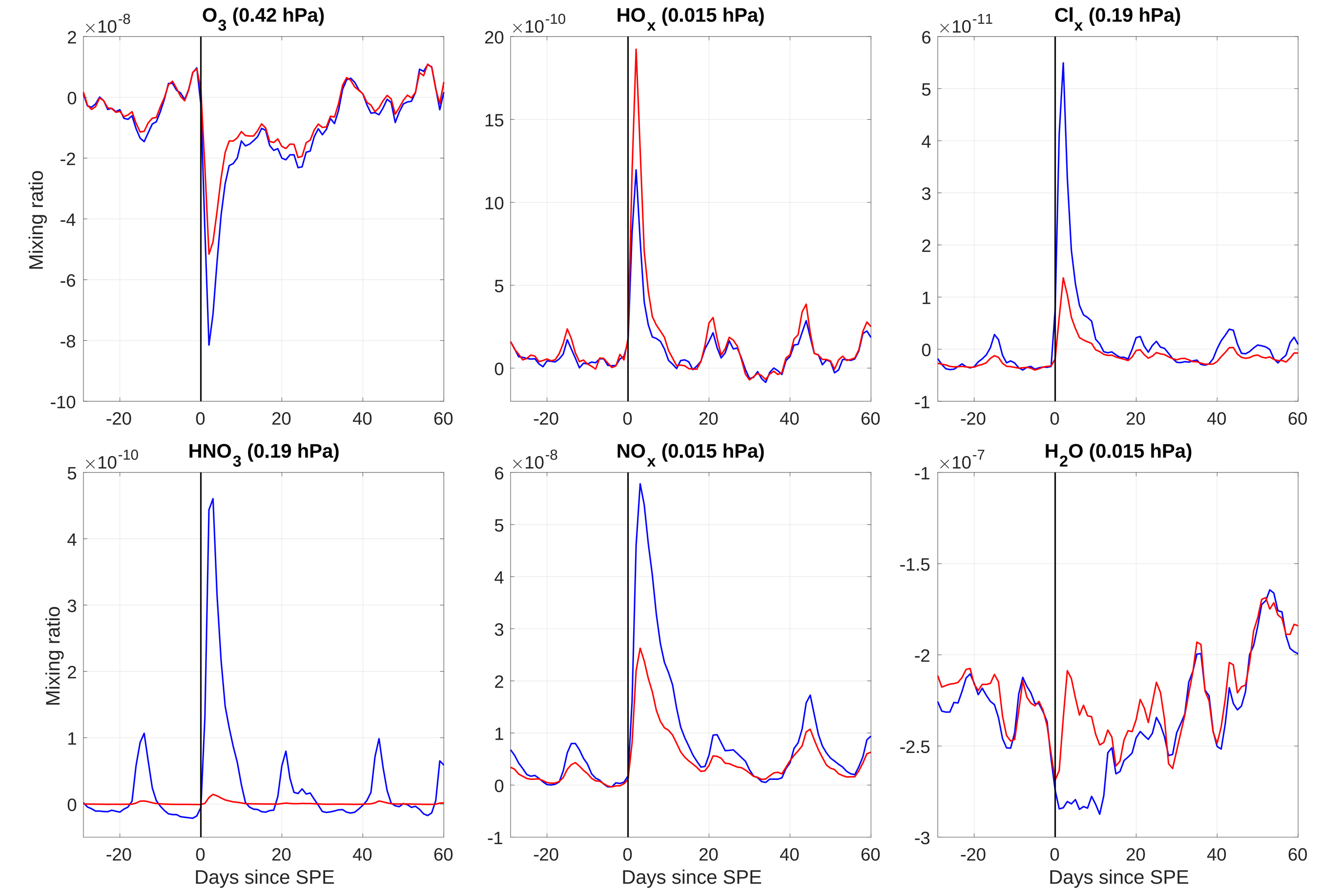

Figure 4: Epoch differences for WACCM-D (blue) and standard WACCM (red) for northern polar cap (area-weighted, latitude > 60°N) at selected pressure bands (three pressure levels, pressure of the center shown in panel title). X-axis shows the number of days before and after the event (day 0, solid black line)

Results and conclusions

- Addition of set of D-region ion chemistry reactions to WACCM leads to several statistically robust changes SPE response.
  - O_3 depletion near 1 hPa enhanced due to increased activation of chlorine species.
  - HO_x production reduced in upper mesosphere due to lower water vapour amounts.
  - Conversion of Cl_x species from Cl and ClO increased in mesosphere by the ion chemistry.
  - HNO_3 production enhanced by several orders of magnitude, effect that is essentially missed by the standard parametrization.
  - NO_x production and consequent downward transport enhanced throughout the mesosphere.
  - Negative H_2O anomalies generally attributed to solar cycle. Moderately robust enhancement of the reduction observed at 0.01 hPa.

Acknowledgements

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