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Atmospheric Chemistry and Physics Discussions

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Interactive comment

Interactive comment on "Statistical response of middle atmosphere composition to solar proton events in WACCM-D simulations: importance of lower ionospheric chemistry" *by* Niilo Kalakoski et al.

Anonymous Referee #2

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This paper investigates the impact of explicitly including D-region ion chemistry instead of simple parameterizations in a global model, on the chemical composition of the middle atmosphere during and after large solar proton events (SPEs). This is investigated by comparing results from a model run over the period 1989-2012 using full D-region ion chemistry with a model using the standard parameterizations producing NOx and HOx as a function of the ion pair production rate. A clear impact is shown on the amount of NOx and HNO3 produced during the event, as well as on active chlorine Clx. Ozone is affected mainly around the stratopause, presumably due to the additional Clx avail-

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Discussion paper

able. As energetic particle precipitation from SPEs and the aurora are considered part of the solar forcing of the climate system, this is an interesting and important result in terms of understanding the response of the chemical composition to atmospheric ionization. The paper is well written and to the point, and I recommend publication after addressing a few mostly technical points listed below. One point I want to emphasize here which should be added to the discussion of the results: As the impact of using the full D-region ion chemistry instead of simple parameterizations on ozone seems to be small and restricted mainly to the stratopause, the simple parameterizations are therefore likely sufficient for long climate projections including the particle precipitation contribution to top-down solar forcing.

Page 1, line 3: "SPEs cause production of odd hydrogen and odd nitrogen" better maybe "odd hydrogen and odd nitrogen are produced during SPEs"

Page 1, line 4: "the largest events" –> "the strongest events"

Page 1, line 9: ... to the 66 "strongest" SPEs "which" occurred in "the" years ...

Page 1, Introduction, first sentence: I found this explanation of the nature of SPEs too vague, particularly considering the source of the high-energy protons. Maybe better: "Solar proton events are observed on Earth when high-energy protons accelerated in the sun's magnetic field during a solar coronal mass ejection strike Earth."

Page 1, line 18: ... at "magnetic" (or geomagnetic?) latitudes "polewards of" $\sim 60^{\circ}$.

Page 1, line 18: This causes "excitation", ionization and dissociation ... the excitation is often forgotten in this context, but these are of course what forms the visible aurora or polar cap absorption related to geomagnetic activity and even SPEs, and e.g., N(2D) and O(1D) are actually very important for the response of the chemical composition.

Page 2, line 6: there are much more papers investigating HOx and NOx production and ozone loss during and after SPEs (including a fairly long list by Charlie Jackman starting 1980). I appreciate you don't need to list them all, but maybe add "e.g., " before the references to emphasize that this is just a selection?

Page 2, line 8: Rozanov et al 2005 did not include SPEs, they only considered an upper boundary NOx source. You could cite Rozanov et al, Surv. Geophys., 2012 - they did include SPEs, upper boundary, and GCRs. Likewise Baumgaertner et al 2011 only included an upper boundary NOx source at the top of his model (0.01 hPa, about 80 km), so definitely did not consider SPEs. Seppaelae et al did not exclude SPEs, so her "high geomagnetic activity" probably was biased to SPE years. Even if your statement – SPEs as part of EEP can modulate winter dynamics – is very general, I think you should reference only studies that actually included SPEs here.

Page 2, line 10: the impact of energetic particle precipitation, and in particular SPEs and geomagnetic forcing, on the variability of stratospheric ozone has been discussed in the recent WMO assessment: WMO (World Meteorological Organization), Scientific Assessment of Ozone Depletion: 2018, Global Ozone Research and Monitoring Project – Report No. 58, 588 pp., Geneva, Switzerland, 2018.available online at www.esrl.noaa.gov/csd/assessments/ozone/2018/. This summarizes the state of the art, and should be references here as well.

Page 2, line 17: erase the i.e.

Page 2, line 32: the correct spelling is "von Savigny", no capital on the von.

Page 3, lines 8-9, O3, HOx, NOx "and HNO3"

Page 3, line 23: does the chemistry code include excited species like N(2D), O(1D), O(1S), O2(1Delta), O2(1Sigma) ...? Please add.

Page 4, line 30: underpresented –> did you mean "underrepresented"?

Page 6, line 17: These are most notable in "NOx and HNO3" in NH around ...

Page 6, line 27: ... highest energy protons (E>300MeV) "which" can ...

Page 6, line 31: ... with strongest "and most significant" response ...

Page 7, line 4: This decrease is roughly consistent ... and/or continuous?

Page 8, line 6: 0.5-1 hPa, I would say

Page 8, line 16: Secondary enhancements around day 40 are clearly visible in Clx.

Page 8, line 21: Same for Clx, see comment above.

Page 9, line 9: blank missing in astronger

Page 10, end of conclusion: However, as O3 loss in the stratosphere below 1hPa is not affected significantly, this will likely not have an impact on stratospheric dynamics and possible downward coupling to tropospheric weather systems. This means that in climate projections considering particle impacts as part of the solar forcing, ion chemistry probably does not need to be included.

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