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Interactive comment on "NO_y production, ozone loss and changes in net radiative heating due to energetic particle precipitation in 2002–2010" *by* Miriam Sinnhuber et al.

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We would like to thank the reviewer for the careful review of the paper, which certainly has made the paper more interesting.

As suggested by reviewer 2, pressure is now given in hPa, not in Pa. Figures, tables and text have been redone accordingly. A bug in the zonal averaging of the 3dCTM data has been corrected. This has no impact on the conclusions, but leads to slightly higher NO_y (figures 2, 4, and 6, particularly after the SSW in early 2009) and ozone losses (former figure 9) in the Northern hemisphere. Results shown in former figures 7, table 2, and former figures 10 and 11 are not affected as those were averaged correctly.

Following the suggestion of Reviewer 2, new figures have been included showing a comparison to MIPAS ozone observations, and a comparison to (modeled) net radiative heating rates. New references have been included: Semeniuk et al. (2011); Natarajan et al. (2004); Randall et al. (2005); B-M. Sinnhuber et al. (2002); Damiani et al. (2016).

On page 26 (around line 20) the authors speculate that application of the boundary condition in EMAC at 80 km may be resulting in excessive ozone loss. Semeniuk et al. (2011) using CMAM simulated large ozone losses around 50 % at 80 km in the winter polar caps (70-90) South and North due to EPP HOx. Peak loss values were over 70 % which agrees with the EMAC predicted losses averaged over the same period. CMAM did not use a boundary condition to drive EPP NOx but used the Jackman scheme for EPP NOx production and the Solomon scheme for EPP HOx production. So author's speculation about excessive O3 destruction based on excessive activity of the NO + O3 reaction does not apply to the CMAM and hence appears to be dubious. I suggest the authors either change the discussion of this aspect or conduct a more detailed chemistry analysis.

Thanks for pointing this out. A comparison of the modeled ozone loss with the CMAM results in the stratosphere and mesosphere has been added to the paper. A reference to (Semeniuk et al., 2011) has been added to the introduction, to the discussion of the stratospheric and mesospheric ozone loss in former Sec. 4.1, and also to the discussion of temperature changes at the stratopause in the Conclusions.

The discussion of the strong mesospheric ozone loss in the EMAC model has been adapted to include the reaction NO + $HO_2 \longrightarrow NO_2$ + OH, which re-partitions HOx, leading to an increase in HOx and enhanced mesospheric ozone loss as shown in (Verronen and Lehmann, 2015). However, we would like to point out the following: the increase of mesospheric HOx due to particle impact ionization is considered in EMAC only for solar proton events, not for medium-energy electrons. The strong ozone loss in EMAC therefore is not comparable to the CMAM results (or, to put it another way, mesospheric ozone loss in EMAC likely agrees well with CMAM for the wrong reasons).

The strong mesospheric ozone loss in EMAC is an artefact of the method of prescribing NOx in the form of NO.

At the same time the ozone loss in the stratosphere aside from the peak years (2004-2005, 2006-2007) in the northern hemisphere is below 10 % (closer to 5 %) which agrees with CMAM as well. The CMAM EPP energy deposition was nonlocal extending below 80 km in a rapidly evanescent tail unlike in EMAC where an upper boundary condition was used. So it appears consistent with the vertical transport in EMAC being hyperactive at least in the mesosphere.

A comparison with CMAM results has been added to the discussion of the stratospheric and mesospheric ozone loss.

However, it is not clear that electron EPP is zero below 80 km during winter. In fact, there is likely to be a substantial energy deposition between 70 and 80 km associated with relativistic electrons.

Yes, and in 3dCTM and KASIMA, particle precipitation is precribed throughout the stratosphere and mesosphere. As the upper boundary condition used in EMAC is based on observations of mesospheric NOy, it implicitly includes the direct impact of particle precipitation into the mesosphere; the observations cannot separate between direct and indirect impacts. However, the direct impact of particle precipitation on HOx is included in EMAC only during solar proton events.

Differences in transport above 80 km between the two high lid models likely account for the large NOy differences compared to MIPAS. In some sense the boundary condition approach in low-lid EMAC may be better since the EPP NOy (and HOx) production is not as affected by model transport pathologies above 80 km. Both KASIMA and EMAC have better NOy distribution patterns in the upper mesosphere compared to 3dCTM (e.g. 2003-4, 2009-10 in both hemisphere) but EMAC appears to be best.

Yes. E.g., further experiments with KASIMA show that the upper boundary condition at

120 km affects the NOy budget at 80 km. Fixing the NOy value to a parameterization of observation avoids such problems. In this sense and not unexpected, the approach used in the EMAC simulation is perhaps more appropriate to assess the NOy impact in the MA.

The differences in terms of ozone loss shown in Figures 8 and 9 do not necessarily reflect problems with EMAC. There is sufficient reason to question the realism of chemical conditions in the upper mesosphere in 3dCTM and KASIMA.

The method of implementing the impact of auroral and medium-energy electrons in EMAC by the upper boundary condition is unrealistic for two reasons: a) HOx production due to medium-energy electrons in the upper mesosphere (70–80 km) is not considered in the model, and b) NOy is precribed in the form of NO, which probably leads to an unrealistic partitioning of both NOx and HOx; particularly the partitioning of HOx has a big impact on ozone as discussed by Verronen and Lehmann (2015). It is possible that the change in HOx partitioning partly balances the missing EPP HOx; however, in this case, ozone in EMAC may be correct, but for the wrong reasons.

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