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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Middle atmospheric changes caused by the January and March 2012 solar proton events" *by* C. H. Jackman et al.

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Reply to Referee #2

We thank Referee #2 for helpful comments and suggestions. The "Referee's Comments" are noted first and then we give our "Reply:" to the comment.

Referee 2: Major comments: The authors use a 2D model to assess the impact of the SPEs on the atmospheric composition. This has limitations since the dynamical variability in such models is artificially low. For example, NOx descending in the polar vortex experiences excursions out of the polar night zone and is photochemically destroyed. Such transport aspects are not captured in 2D models in spite of eddy diffusion parameterizations. So a 2D model overestimates the amount of NOx descent.

Since the SPEs studied in this paper produced a significant amount of ionization directly in the upper stratosphere and lower mesosphere the transport limitations are not critical for short duration in situ impacts. However, the assessment of the longer term impact of the SPEs on the ozone will be negatively impacted. This is apparent in Figures 13, 15 and 16 where the persistence of the NOx anomaly in the 2D model is much higher than in the observations. A 3D model nudged with observed winds or even just the temperature (as the fast balance adjustment processes will pull the large scale winds towards those of the observed state as well) would do a much better job capturing the observations.

The positive and negative anomaly superimposed on the SPEs HO2 signal seen in the MLS data presented in Figure 6 indicates that there is an additional mode of dynamical variability above 65 km in SH polar region that the 2D model fails to capture.

The penetration of NOx anomalies into the stratosphere shown in Figures 17 and 18 and the associated ozone loss cannot be treated as realistic. Any quantification of medium-term impacts on the stratosphere using the 2D model is a dubious proposition. There is no indication in the manuscript why a 2D model was used as opposed to a chemistry GCM. The authors need to justify their choice of a 2D model for this study as they are comparing the results to observations. The chemistry analysis is not sufficiently novel by itself to merit publication. For example, there is no discussion of the lack of ion chemistry in producing the correct HNO3 levels in the stratosphere. Discussion of chemistry model limitations should be included as well.

Reply: The reviewer raises the important issue about which type of model is most appropriate in studying SPE atmospheric impacts. We are puzzled by the point indicated above about 2D models that the “dynamical variability in such models is artificially low.” We found in earlier versions of the GSFC 2D model that the transport was actually overestimated from the polar regions to midlatitudes, due to issues related to improper isolation of the polar vorticies. We think that this is contrary to the

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reviewer's first point.

We certainly agree that conceptually, a 3D model should provide a more accurate representation of atmospheric transport. However, in practice this may not necessarily be the case, due to numerical issues, coarse resolution, and/or overly diffusive winds, etc. The GSFC 2D model has been improved significantly over the years and the present model used for this study represents atmospheric transport quite well, as compared with numerous observational data sets (e.g., see Fleming et al. 2011).

To provide insight into 2D-3D model differences for this study, we have run the SPE perturbations using the Global Modeling Initiative (GMI) three-dimensional (3D) chemical transport model (CTM) driven by winds and temperatures from the MERRA meteorological re-analyses data for 2012. We have re-run the SPE perturbations in the 2D model with the temperature and transport fields also derived from the 2012 MERRA data. In addition to the NOy and ozone changes due to the SPE perturbation, we also compared the long-lived tracers CH4 and N2O to aid in diagnosing the model transport characteristics (although this is not shown in the paper).

The results for the two models are very similar in the Southern polar region. Here, the polar vortex exhibits a good deal of zonal symmetry so that a 2D model can fairly accurately resolve the transport features. In the Northern polar region, the response of the two models is also similar during summer, fall and early winter. During mid-late winter/early spring, the 2D model response is qualitatively similar, but shows some quantitative differences to the GMI 3D CTM as the polar region exhibits more zonally asymmetric behavior. We found that the GMI 3D CTM actually leads to a larger descent of NOy, when compared to the 2D model in the polar NH.

Both models were included in the discussion in sections 5.3 and 6, and shown in Figures 8 and 10-12. The GSFC 2D model provided a more reliable simulation of the SPE-caused HOx enhancement and short-lived ozone impact because it contains Lyman alpha photochemistry, whereas the GMI 3D CTM does not (as discussed in sec-

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tion 4.3). We thought that showing the longer-lived GSFC 2D SPE-caused NOx and NOy enhancements would be useful to provide some continuity with respect to those other shorter-lived constituent results. We also thought that it would be of interest to the readers of this paper to include both model results, when possible. The two models were developed independently and there are strengths and weaknesses in working with the GSFC 2D or the GMI 3D CTM.

Regarding the Referee 2 comment: The positive and negative anomaly superimposed on the SPEs HO2 signal seen in the MLS data presented in Figure 6 indicates that there is an additional mode of dynamical variability above 65 km in SH polar region that the 2D model fails to capture.

Reply: After consolidation of the figures, the old Figure 6 results are now shown in Figure 3 (right side). We agree that some type of HO2 variation is underway for the SH polar region during this time period. We are unsure if it is due to dynamical variability or a combination of dynamical, chemical, and radiative changes going on at that time of year. Since MLS HO2 measurements are not recommended for scientific use above 0.046 hPa or above about 70 km (pointed out in section 5.1, paragraph 2 of the manuscript), then some of the HO2 behavior may be somewhat uncertain. An enhancement of MLS-measured HO2 is clearly seen during the time periods when the January SPEs were most active and we thought that it was important to show these observations.

Regarding the Referee 2 comment: The chemistry analysis is not sufficiently novel by itself to merit publication. For example, there is no discussion of the lack of ion chemistry in producing the correct HNO3 levels in the stratosphere. Discussion of chemistry model limitations should be included as well.

Reply: SPEs and their middle atmospheric constituent influences have certainly been

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studied before; however, each new event offers a chance to investigate the SPE-caused atmospheric perturbation under somewhat different conditions. Some events have even been shown to cause some longer lasting atmospheric changes and thus must be considered with respect to other changes. We focused in this paper on the SPE-caused HOx and NOx enhancements, which have the most relevance in impacting ozone, thus have neglected the SPE-caused impacts on other minor species (such as HNO3). It appears that the impact on HNO3 from ion chemistry could be an enhancement of a few ppbv in the lower mesosphere (see Lopez-Puertas et al. 2005b; Verronen et al. 2008, 2011b). This mechanism to convert NOx constituents to HNO3 is unlikely to explain the large differences between MIPAS and the models for NOx above ∼0.1 hPa, but may reduce some discrepancies in the lower mesosphere. We now discuss this lack of ion chemistry in both models and the possible ramifications in section 5.3 (paragraph 9).

Referee 2 - Minor comments: Figures 1-4 should be combined into one four-panel figure to save space. There will not be any loss of readability

Reply: We combined Figures 1 and 2 and Figures 3 and 4. We found that combining them Figures 1-4 into one figure resulted in a somewhat confusing figure. We did combine several other figures together in the revised manuscript, which now has 12 figures compared to the original 19 figures.

Interactive comment on Atmos. Chem. Phys. Discuss., 13, 23251, 2013.