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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Middle atmosphere response to the solar cycle in irradiance and ionizing particle precipitation" *by* K. Semeniuk et al.

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Response to Referee # 2

General Comments This is a process study so inclusion of variable SSTs, QBO and tropospheric chemistry are not central to the results. Most models in CCMVal-1 and CCMVal-2 lack a QBO. Recently published research such as the process study of Tsutsui et al. (2009) used fixed annually varying SSTs and had no QBO. Tropospheric ozone changes in our simulations are small and have a negligible effect on heating. Given that the tropospheric ozone amounts in the model are reasonable we believe that the impact on middle atmosphere dynamics is small.

Specific Comments

p24858, l9: Some additional text has been in section 2 added for clarification. The model version we use in our study does not have interactive oceans. The tropospheric chemistry is limited but covers most of the major gas phase reactions as noted in the text.

p24858, l11: A discussion has been added to section 2 to address the questions raised by the referee (see highlighted version of manuscript in the included supplement). The absence of NAT in the model implies that we are underestimating by up to 30% ozone loss in early spring below 23 km. The bulk of the ozone loss that occurs above 23 km is through gas phase chemistry and not through heterogeneous reactions on PSCs. This ozone depleted air is pumped below 23 km in the polar vortex interior in both hemispheres.

The chemical impact of PSCs on ozone occurs in a limited window during spring. So they do not affect the evolution of the polar vortex during the late fall and winter (aside from any memory of ozone loss from the previous winter). EPP, on the other hand, does affect the polar vortex evolution at the critical late fall stage.

p24858, l11: We already highlight this point in the text. Our HNO_3 production is indirect. We have added the additional reference specified by the referee. In the long term, large scale view of the dynamics taken in our paper, this limitation is of secondary importance when it comes to ozone loss.

p24858, l19: There is no contradiction since SSWs are not the only source of polar vortex variability. We have changed the text from “disturbed” to “leaky” and added reference to Müller et al. (2005) for more detail.

ACPD

10, C13063–C13071, 2011

Interactive Comment

Müller, R., Tilmes, S., Konopka, P., Grooß, J.-U., and Jost, H.-J.: Impact of mixing and chemical change on ozone-tracer relations in the polar vortex, Atmos. Chem. Phys., 5, 3139–3151, 10.5194/acp-5-3139-2005, 2005.

p24863, l1: We have changed the text to discuss these issues in more detail. The latitudinal span of the polar night, in terms of SZA, is much narrower at 100 km than it is at 50 km. In addition, the meridional and vertical excursion of air parcels due to resolved model waves increases with height. Observations indicate that there are large amplitude planetary waves in the polar MLT winter that can produce significant air parcel excursions in latitude. References and discussion have been added to section 2.2.1 about the dynamics in this region.

The statement "transport retains mixing ratio" is only valid if there is no mixing of any sort. In reality and in models there is sufficient diffusion to dilute air parcel contents. This is apparent from the structure of descending plumes of air. They do not decrease in volume exponentially as would be required for mixing ratio conservation and in fact disperse horizontally during descent. So the mixing ratio of NO descending in a 70-90 degree polar cap will decrease rapidly with depth.

p24863, l13: The daily composites identify the peak value of the auroral oval. We assume that the auroral oval does not have very large spatial and temporal variation in amplitude around its circumference and that the composites are producing a daily mean distribution. Averaging the values in the twelve sectors reduces the peak value seen by the MEPED instruments. However, this scheme does over-estimate the flux since there is significant and rapid temporal variation.

The values of NO_x that we obtain between 80 and 90 km in the polar regions are close to those observed by the ACE-FTS instrument (e.g. Randall et al., 2009). This is one of the main constraints for auroral impact on the stratosphere since, the other being transport in the polar mesosphere. This discussion has been added to the text.

ACPD

10, C13063–C13071, 2011

Randall, C. E., Harvey, V. L., Siskind, D. E., France, J., Bernath, P. F., Boone, C. D, and Walker, K. A.: NO_x descent in the Arctic middle atmosphere in early 2009, Geophys. Res. Lett., 36, L18811, doi:10.1029/2009GL039706, 2009.

p24864, l3: This has been clarified in the text. Realism in this case means that the original auroral oval parametrization does not look like the daily observations (http://www.swpc.noaa.gov/pmap/index.html). The parametrized oval of the original scheme is too thin. The modifications make the parametrization look closer to observations. A more sophisticated model would be preferable.

p24866, section 4: The text has been revised with some parts removed others enhanced in the discussion. Given the study of particle effects in CCMs is in the early stages and much remains to be explored, we believe that this part is necessary for readers that are not familiar with the particular subject.

p24866, l22: We are constrained by including too many figures as other referees note. There is sufficient content in the anomaly plots to understand the dynamics. The jet redistribution is consistent with changes in wave drag as indicated by the streamfunction. If these anomalies were merely vortex shifts then there would be a meridional dipole structure in the mass streamfunction and none is to be found. In other words, the dynamical heating explains the vortex difference.

p24867, l9: We are showing the mass streamfunction so anomalies are increasing exponentially with depth. Small changes in the tropospheric circulation appear large in this metric. Similar amplitude tropospheric anomalies can be obtained by the differences between any two members of the same ensemble. There is no large scale change in the tropospheric circulation and cross tropopause transport.

ACPD

10, C13063–C13071, 2011

p24867, l14: The results presented are not model specific. The figures shown in our paper are long term means. In spite of the fact that the SH does not experience major SSWs (except very rarely as in 2002) the survival of NO_x during descent in the mesosphere and in the stratosphere is still greater in the SH in the long term compared to the NH, as reflected in the results. The NH polar vortex is much more disturbed by planetary waves, not necessarily by SSWs, both in reality and in the model. This leads to lower auroral NO_x concentrations in the NH. Photochemical destruction of NO_x is sufficiently rapid that the multi-day trjectories of vortex interior air parcels into the sunlight/twilight causes them to experience total loss.

Without major SSWs there would be little auroral NO_x transported into the stratosphere as gravity wave drag prevents the formation of a narrow and strong polar vortex in the NH mesosphere. However, major SSW events in the NH are not yearly occurrences and exhibit significant variability between events. So the descent of NO_x seen in February 2004 is not typical.

p24867, l27: We would prefer keep the chemistry details to enhance clarity in the paper given the complexity of the subject and the strong coupling between chemistry and dynamics involved in the interpretation of the results.

p24868, l3: The text has been changed to make this explicit.

p24868, l8: We do not agree. Aside from major SSWs there is no large scale transport of specifically auroral NO_x into the stratosphere in the NH. The survival of any auroral NO_x is reduced in the NH polar middle atmosphere due to the fact that the NH vortex is much more disturbed than the SH vortex. In the NH mesosphere there is a mid-latitude zonal wind maximum so the “polar” vortex interior is not confined to polar night. This is not merely a model feature but an observed feature (e.g. CIRA-86 climatology). NO_x survival in the NH stratosphere polar vortex interior is also greatly reduced due to the

ACPD
10, C13063–C13071, 2011

Interactive Comment

regular deformation of the vortex by planetary waves. As noted above, these NH vortex perturbations are not just SSWs (see Andrews et al., 1987).

p24870, l25: The text has been rewritten for clarity but a detailed quantification of STE is beyond the scope of the paper. There is a statistically significant (over 95%) increase of NO_y below 15 km in the middle and high latitude SH in winter for the auroral case. The origin of this NO_y is auroral production and it does have a chemical impact on tropospheric ozone. The smog reactions require sunlight so the winter polar NO_y increase does not immediately translate into an ozone increase and transport is important. This likely explains why the ozone response is higher than 90% but lower than 95% in the SH high latitudes.

p24871, l1: The water vapour signal is absent in the EPP runs without the solar cycle in irradiance.

p24871, l25: In the NH summer there is upward transport around 80 km (easterly phase speed gravity waves are filtered by summer time easterlies below leaving westerly phase speed gravity waves to dissipate in the upper mesosphere that produce a diabatic circulation with equatorward flow in middle latitudes and upwelling in high latitudes). In contrast, during NH winter when there is downward transport at high latitudes. The maximum NO_x production by SPEs is in the mesosphere.

p24876, l7-8: GCR in our model does not affect ozone above 30 km. Aurora and SPEs produce the loss above 30 km.

p24876, l15: For the EPP forcing that we use our statement holds. None of the EPP types produces a large long-term change in dynamics. If EPP were somehow to produce a larger ozone impact in the long-term mean, then the dynamical signal would

ACPD

10, C13063–C13071, 2011

be more pronounced. Very large and very rare SPEs may produce a larger dynamical response over the span of a couple of years but not on the 11 year timescale. Since they are highly atypical we do not feel they have a bearing on our conclusions. Also, the 28 year period of observed EPP selected for this study was not abnormally quiet and had two such events in 1989 and 2003.

p24876, l25: We get a response that qualitatively agrees with their conclusions with the only difference being the weakness of the signal in both the stratosphere and troposphere in our results. We are not aware of any threshold behaviour in the Polvani and Kushner mechanism. This requires a detailed investigation using a mechanistic model that is beyond the scope of this paper.

p24877, l4: The mistake has been corrected.

p24877, l16: Since the individual combined-EPP ensemble members are being compared to the ensemble mean reference run, the differences presented in Figure 11 are robust. Two of the ensemble members have an opposing response to the third that is statistically significant. The significance test is reflecting actual differences between the ensemble members. The divergence between ensemble members underscores the sensitivity of the system to small differences in composition.

p24878, l17: But there is a statistically significant cooling in the TTL in JJA compared to DJF. The layer 17-25 km appears to be noisy in JJA giving poor Student-t test confidence levels.

p24881, l5: The H_2O variation is seen only in the presence of both the solar irradiance cycle and EPP. Without variation in irradiance EPP does not produce variation in H_2O

ACPD
10, C13063–C13071, 2011

from solar maximum to minimum. The individual EPP type runs also did not have solar cycle H_2O variation.

Quantitative analysis of the radiative forcing is beyond the scope of this paper. We need an interactive ocean model to properly investigate this process as discussed in the conclusions section.

p24896, Fig.2: This figure has been modified to show maximum daily ionization rates for aurora, SPEs and GCR at the given heights.

p24898, figures and contour plots: The figure caption has all the necessary information.

Minor Comments

p24854, l19: Fixed.

p24860, l24: The parameters are SZA, partial ozone column and geometric height.

p24862, l1: The text has been rewritten to remove the confusion.

p24870, l11: Fixed.

p24870, l17: The text has been changed for clarity.

p24882, l10: The role of SSTs was an inference made by Austin et al. (2008) without any in-depth analysis. This is pointed out in the CCMVal-2 report and there are no references given for any detailed study showing how SSTs explain the tropical distribution of the solar cycle signal in ozone.

ACPD

10, C13063–C13071, 2011

Typos

Fixed.

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/10/C13063/2011/acpd-10-C13063-2011-supplement.pdf

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Interactive comment on Atmos. Chem. Phys. Discuss., 10, 24853, 2010.

ACPD
10, C13063–C13071, 2011