Reply to Editor Comments

Manuscript-No: acp-2017-1190

Comparison of ECHAM5/MESSy Atmospheric Chemistry (EMAC) Simulations of the Arctic winter 2009/2010 and 2010/2011 with Envisat/MIPAS and Aura/MLS Observations

We thank the editor for the suggestion for revision. Please find our point by point reply below.

General Comments

1. The extreme winters are taken for testing the model performance, which is good and challenging (e.g. which is why the differences are up to 40-45%). However, the average/normal state should also be known as the extreme cases are rare. Therefore, a discussion based on a normal (not very cold/warm) winter would have been a good addition to these analyses. If you have already a simulation, it would be helpful to include or at least mention the performance of the model for a normal year. Although you have mentioned about your previous work on Antarctic, please do mention the models performance for the Antarctic region in the discussion section to make the sensitivity tests complete.

We have also performed comparisons for the rather warm Arctic winter 2008/2009. For the comparison of HNO_3 a better agreement is found throughout the winter simply due to the fact that the PSC season is shorter. The development throughout the course of the winter of e.g. HNO_3 time series is the same as for the cold winters, differences in HNO_3 between model simulation and observation increase as soon as PSC are present, but differences do not get as large as for the cold winters due to the smaller amount of PSCs. We added the following sentence in the conclusion: *Since we have chosen two extreme winter for this study, the here derived differences are the largest possible differences since not all Arctic winters are extreme. Nevertheless, the here discussed issues in the model performance remain, but differences between model simulation and observations are throughout the PSC season not as large for a rather warm winter, as e.g the Arctic winter 2008/2009.*

We added the following sentence in the conclusion discussing the earlier study on the Antarctic by Kirner et al. (2015): *In the study by Kirner et al. (2015) only qualitative comparisons of ClO, O_3 and HNO_3 to Aura/MLS measurements were performed mainly based on multi-year averages.* However, it is not useful to discuss/mention their results since they had a completely different approach than we have (using multi-year averages while we focus on the performance of a single winter). Further, their simulations are based on an older version of the model while we use a newer version that has been significantly improved.

2. You were also talking about the relationship between ozone loss and denitrification. However, nothing is done for this, as you were focussing completely on the latter. Therefore, please indicate how the ozone loss or chlorine activation is simulated in the model.
We added now the following sentences in the conclusion: *As found in Khosrawi et al. (2017) for the Arctic winter 2015/2016, also here a very good agreement between the simulated and measured O_3 is found at the beginning of the winter. However, during the course of the winter when ozone destruction and descent become important, an increase of the differences is found. These however do not exceed 20% (2009/2010) or 30% (2010/2011), respectively.*

3. How was performance of this model in CCM val exercise? Please briefly mention that too, either in the introduction or in the discussion. Also, mention whether your sensitivity tests will improve the performance of the model for further assessments and reports. It is also good to include a general statement on this in the abstract.
Also here, it is unfortunately not very useful to discuss the performance of EMAC in the frame of CCM val since also here the simulations were performed with an older version of the model and the comparisons were focusing on climatological aspects rather than the performance of a single winter. Nevertheless, the here derived results will help to improve the set-up of the model and thus the simulations which will be of benefit for future model intercomparison studies. Therefore, we changed the last sentence of the conclusions as follows: *Further, the here derived results and upcoming sensitivity simulations will serve as benchmark for the development of the PSC parameterisation in other atmospheric models as e. g. ICON-ART (ICOsahedral Nonhydrostatic Model - Aerosols and Reactive Trace gases) and will help to improve the performance of EMAC in future model intercomparison studies.* In the abstract we added the following sentence: *The here found differences between model simulations and observations stipulate farther improvements in the EMAC set-up for simulating PSCs.*

Technical corrections
Page 1:
Line 2: delete ERA
Why? we have used ERA-Interim reanalyses, so therefore this should also be stated in the manuscript.

Line 3: winters
This has been corrected.

Line 4: as previous studies
This has been changed as suggested.

Line 5: for the Arctic winters
In line 5 it should read Antarctic and not Arctic. We have changed the sentence as follows: *This study is the first to perform an extensive assessment of the performance of the EMAC model for Arctic winters as previous studies have only made limited evaluations of EMAC simulations which also were mainly focused on the Anatarctic winter stratosphere..*

Line 9: largest depletion not strongest (strongest can also be episodes)
We would prefer to keep *"strongest"*. We used also *"strongest"* in our 2017 ACP paper (that went through copy-editing and is published).

Line 13: occurred in that winter
This has been changed as suggested.

Line 14: PSC formation and denitrification
This has been changed as suggested.

Line 17: and associated sequestration
This has been corrected as suggested.

Line 18: smaller than that derived from
We think *"smaller than the ones...."* is correct and would thus keep this text part as is.

Line 18: Furthermore
Here, it should not matter if one uses *"further"* or *"furthermore"*. We would prefer to keep *"further"* to be consistent with our way of writing.

Line 19: as high as , is this altitude? Or value?
Yes, as high as in altitude. We added now *in altitude* in parentheses to be more precise.

Line 20: You need a concluding statement here on your model simulations, EMAC or the CCMs in general to put the results in perspective.
We added the following sentence to the abstract: *The here found differences between model simulations and observations stipulate farther improvements in the EMAC set-up for simulating PSCs.*

Line 21: winters
In line 21 there is neither the word "winters" missing nor "s" in "winter". Therefore, we could not change anything with respect to this comment.

Page 2

Line 3, 7: very small sentences make the reading difficult
We have combined the small sentences to make the reading easier.

Line 17: largest depletion
As stated above we would like to keep *strongest*.

Line 24-25: Sentence is not complete
Line 25: two e.g. are there in the same sentence. Please construct a better sentence.
We changed the text as follows and hope that these two sentences are clearer now: *The Arctic winter 2009/2010 has been well analysed both by measurements and model simulations. For example, detailed studies on denitrification during this winter were performed by e. g. Khosrawi et al. (2011) and on dehydration by e. g. Khaykin et al. (2013).*

Line 29: and results ...
This has been changed as suggested.

Page 4
Line 11: delete further
Line 11: temperatures were
We could not find the respective text parts at the page and line number given. Therefore, nothing has been changed here. Anyway, this should be no problem since the copy-editing will correct all remaining language errors.

Page 6
Line 6: Additionally there is no .... There is no connection. Why gravity waves are mentioned here.
During this winter PSCs were formed by both, synoptic-scale cooling and by gravity waves. In the Arctic usually gravity waves are required to initiate the formation of ice PSCs (otherwise temperatures do not get as cold as required for ice formation). However, this winter was quite unusual, because the synoptic cooling was quite strong during this winter and was responsible for almost all ice PSCs. Gravity waves occurred as well, but played in this winter only a minor role.

Line 24: ice PSCs and (4)
We are not sure if the suggested correction is correct or required. Therefore, we would leave that as it is and see what the copy-editing does in this case.

Page 7
Line 10: data are
Line 10: 13 march 2011
Line 10 has been corrected as suggested.

Page 8
Line 14/20: replace somewhat by slightly or give the value here
We have replaced *"somewhat"* by *"slightly"*.

Line 25: mid-January?
Line 27: mid-January and mid-December?
Yes, thanks! This has been corrected.

Line 3033: the e.g and see makes the sentence difficult to read. Please rephrase this.
We agree and we give now the reference of Höpfner et al. (2006) in parentheses.

Page 10
Line 21-22: Any idea how much that would make for chlorine activation and ozone loss estimation or simulation in the model?
The underestimation of denitrification also influences the simulation of chlorine activation and ozone loss, but is difficult to quantify since also other factors play a role like the underestimation of transport in the model and inaccuracies in the partitioning between chlorine species at high solar zenith angles as was discussed in Khosrawi et al. (2017). We added the following sentence at the end of section 4.1: *The underestimation of HNO_3 in the model simulation affects also chlorine activation and ozone loss, but also other factors like the underestimation of transport in the model and inaccuracies in the partitioning between chlorine species at high solar zenith angles as discussed for the Arctic winter 2015/2016 in Khosrawi et al. (2017) play a role.*
Page 13
Line 6-7: This problem is common to most models, as I know. This is also reported in some other studies.
We do not know of any study really discussing this issue. All studies we know of have their focus on the simulation of the occurrence frequency of the SSWs, but not if the strength of the SSW is correctly simulated.

Page 16
Line 1112: Please remove, if this is not published yet.
The paper by Höpfner et al. (2018) has been submitted to AMT and should be published soon.