

Interactive comment on “Influence of enhanced Asian NO_x emissions on ozone in the Upper Troposphere and Lower Stratosphere (UTLS) in chemistry climate model simulations” by Chaitri Roy et al.

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Answers to Anonymous Referee #2

The study by Roy et al. investigates how the increasing Asian NO_x emissions and associated ozone production affect the ozone radiative forcing and monsoon circulation. Roy et al. employ the ECHAM5-HAMMOZ model and from the model simulations they find that a doubling of NO_x emissions produces high ozone in the lower troposphere, a reverse monsoon Hadley circulation and negative precipitation anomalies over India. The paper is quite well written and interesting results are derived. However, I have

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some concerns (1) the low vertical resolution applied in the model simulations and (2) the fact that NO_x production by lightning is not considered in the model simulations. Before publication the following points of criticism and suggestions for improvements should be considered:

Ans: We thank the reviewer for their positive comments on our work. In the revised manuscript we have addressed all the major and minor issues raised by the reviewer. Changes are marked in red color.

We agree with the reviewer that it would have been desirable to run the model in higher horizontal and vertical resolution, but this was not possible with the available resources. We have added a supplementary figure S2 depicting seasonal (June-September) mean precipitation and circulation at 850 hPa obtained from the CTRL simulation. This figure shows the general spatial pattern of precipitation and low-level circulation is well simulated (Rajeevan et al., 2005). This is now mentioned in the revised manuscript (Pg.7, L162-166). We have also added a sentence to alert the reader to potential resolution impacts: "The accuracy of the simulation of the monsoon circulation will likely depend on the model resolution and increased vertical resolution may improve the model performance" (Druryan et al., 2008; Abhik et al., 2014) (Pg.7, L160-162).

Sorry for the confusion. Statement about lightning NO_x is rewritten. In the model set up we have analyzed the impacts of anthropogenic NO_x by enhancing anthropogenic NO_x emissions over India (38% and 73%) and China (73%) in comparison with control simulation. In these simulations NO_x production due to lightning is also incorporated. It was not mentioned explicitly in the previous version of the manuscript. The impact of lightning NO_x is cancelled out when we analyze difference between CTRL and anthropogenic sensitivity simulations. In the previous version, we had not compared CTRL with lightning-off simulations since impact of lightning-on NO_x production in the upper troposphere over the ASM is already reported by Fadnavis et al., (2015). However as suggested by the reviewer we have now added figures on NO_x production due to lightning and related discussions. (Fig S5) (pg 10, L228-230).

Specific comments:

p2, I40: What is meant with NO_x limited regions?

Ans: As suggested, we have now explained NO_x limited regions (Pg2, L43-45).

p5, I118: A horizontal resolution of T42 and a vertical resolution of 31 levels is a quite low resolution. In the horizontal it probably may not be a big deal for the results of this study, but I am a bit worried about the vertical resolution. For the monsoon circulation vertical transport is quite important and I could imagine that you would derive different (probably more accurate) results when performing simulations with a higher vertical resolution. The impact of the low model resolution on the results of this study should be discussed in the paper.

Ans: As mentioned in the Ans-1, impact of low model resolution on the results is discussed in the revised manuscript ((Pg.7, L160-166).

p6, I122: Do I understand it correctly that for each following year the emissions of the year 2000 are used? I would suggest rewriting the sentence to make this more clear.

Ans: The base year for trace gas emissions is taken as 2000 and emissions were repeated every year throughout the simulation period. This part has been rewritten in the manuscript (pg6., L135-137).

p6, I123: I guess for varying the SST and sea ice for each year a data base is used which provides these values. Which database was used? Which database has been used for the emissions?

Ans: Above sentence is rephrased as “Meteorology varied due to varying monthly mean sea surface temperature (SST) and sea ice (SIC). The AMIP2 SSTs and SIC varying for the period 2000 – 2010 were specified as a lower boundary condition” (Pg6. L138-139). As suggested we have given brief information related to emissions since details are given by Fadnavis et al 2014, 2015 (Pg.6, L133-134).

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p6, I123: Why has the time period 2000-2010 been chosen? Why is the simulation not continued until a more recent year as e. g. 2015 or why is the simulation only covering a 10 year period and not a longer period of e. g. 30 years?

Reply: In the present study we analyze the impact of enhanced anthropogenic NO_x emissions on the upper troposphere and lower stratosphere. In our model experiments NO_x emissions are increased over India by 38% and over China by 73%. The emission perturbations were obtained from observed NO₂ trends of 3.8% per year over India for the period January 2003-October 2011 (Ghude et al., 2013) and 7.3% per year over China during August 2002- August 2011 (Schneider and van der A., 2012). In order to match the simulation period with observations and to obtain statistically significant results, we performed simulations for 10 years during the period of 2000-2010. We have now shown 95% and 85% confidence level contours in figure 3.

p6, I127: The four experiments should be summarized in a table giving the values used for initialisation as well as the resulting values (e.g. as the estimated heating rates).

Ans: Thank you for the suggestion. Experiments set up, initialization, etc. are now summarized in Table -1. We have provided figure for heating rates (figure 7) therefore they are not included in the table.

p6, I127ff: How were the assumed numbers of increase motivated? How large is the observed trend?

Ans: The assumed numbers of increase are obtained from observed NO₂ trends (manuscript pg 6, I146-148). Over the Indian region SCHIAMACHY observed NO₂ trends are 3.8% per year during January 2003-October 2011 (Ghude et al., 2013), and OMI NO₂ observations show trends 7.3% per year over China during August 2002-August 2011 (Schneider and van der A, 2012). In accordance with these observations we have increased anthropogenic NO_x emission over India by 38% and over China by 73% for 2000-2010 (pg 6-7, L143-150).

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p7, I155: I don't really agree with what you state concerning Figures 1(c) to (e). Using the present x- and y-scale and showing the figures in the present (small!) size makes the differences seem to be low. However, if one would change the x and y-scale (zooming in) one would see the differences much better. To have a more objective view on the quality of the model simulations the differences between measurements and model simulation should be quantified, thus a quantitative estimate should be given.

Ans: Thank you for the suggestion. We have now tried to improve figure 1 (c) and (e). Differences between measurements and model simulations are now mentioned in the revised manuscript (pg.8-9, L192-207).

p8, I181: Lightning is important for the amount of NO_x in the UTLS especially during the monsoon season. Why is then lightning not considered in the model simulation? How reliable are your results if lightning is not considered? This is really a drawback of this study and the consequences of not considering lightning for the results of this study need to be discussed in more detail.

Ans: We have clarified this point in the answer of the first comment.

p9, I212: I have difficulties to see the connection that ozone production is found where there is NO_x transport. In Figure 3 one finds ozone production everywhere below 300 hPa. In the area of transport, however, it seems that O₃ production is enhanced. So, I would suggest some rewording of the sentence to be more precise.

Ans: We agree that this sentence was unclear and we therefore decided to remove it from the revised manuscript.

p10, I227: I would say that the transport across the tropopause is only visible in Figure 4f.

Ans: We agree. We have now used a new color scale and also inserted arrows to show cross tropopause transport.

p10, I228: It would be helpful for the reader if the areas of the Tibetan Plateau, Bay of

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Bengal and South China Sea would be marked in the figures.

Ans: Thank you for the suggestion. As suggested, the Tibetan Plateau, Bay of Bengal and South China Sea are marked in figure 1.

p10, l235: Why does one get this behaviour in the subsidence? Is that really discussed in Section 4? What exactly is discussed in Section4? This paragraph should be rewritten.

Ans: We agree that this paragraph would benefit from a more precise discussion and we thank the reviewer for pointing this out. Changes in temperature and associated wind pattern are now discussed in the revised manuscript. We have rewritten section 4. Changes in temperature and associated wind pattern is now explained the revised manuscript. This paragraph has now been rewritten (Pg.13-15,L299-344).

P12, l266: The regions discussed should be marked in the Figures.

Ans: We follow this good suggestion and the Tibetan plateau is now marked in the figures.

P14, l314: The fact that model simulations were performed with a low vertical resolution of 31 levels and without considering NO_x production from lightning should be part of the discussion section. What are the consequences of these simplifications for your results?

Ans: We have discussed this point in the first comment.

Figure 1: How would the differences look like if the x-axis and y-axis would be changed to focus on the UTLS region. In example if one would plot the profiles only up to 50 hPa and up to 1000 ppb. I assume the differences would become more pronounced. As stated before some quantitative estimates on the differences should be added.

Ans: Thank you for the suggestion. As suggested we have re-scaled this figure. Discussion on quantitative estimates on the differences is now incorporated (pg.8-9.L192-

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207).

Technical corrections:

p2, l36: skip “the” before India.

Ans: Above suggestion is incorporated at pg2, L26.

P4, l79: I think it should rather read “increasing” than “rising”.

Ans: Above suggestion is incorporated at pg4, L83.

P4, 85-87: I would suggest to rewrite the sentence as follows: “The paper is organized as follows: In Section 2 the data and model set up are described. The results are summarized in Section 3 and discussed in Section 4 followed by conclusions given in Section 5.”

Ans: Above suggestion is incorporated at pg4, L89-91.

pg5, l102: Is 8.3 x 3 really correct or is there a typing error?

Ans: Above suggestion is incorporated at pg5, L106-108.

pg7, 157-159: I would suggest to combine the last two sentences so that it reads: “Fadnavis et al. (2015) compared the model simulation with aircraft observations over the various regions all over the globe during the monsoon season and found a reasonable agreement for PAN, NO_x, HNO₃ and O₃ mixing ratios.”

Ans: This sentence is reframed (pg9, L205-207).

pg6, l127: I would rather call it “simulations” than “experiments”.

Ans: Above suggestion is incorporated at pg6, L141.

pg7, l167: skip “etc” or move it forward so that it reads “.....aerosols etc.....”

Ans: Above suggestion is incorporated at pg9, L214.

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p8, l182: Change sentence so that it reads: “In Figure 2 longitude-pressure.....”

Ans: Above suggestion is incorporated at pg10, L231.

p11, l249: delete “the” before central India.

Ans: Above suggestion is incorporated at pg13, L290.

p14, l324: Change wording of the sentence to: “These simulations show that an increase.....” or to “These simulations show that increases in : : :.....”.

Ans: Above suggestion is incorporated at pg15, L353.

p14, l32: add “the” so that it reads “across the tropopause”.

Ans: Above suggestion is incorporated at pg15, L356.

p22, l683: “Show the same but.....” Change wording of the sentence.

Ans: Above suggestion is incorporated at pg29, L847-848.

Please also note the supplement to this comment:

<http://www.atmos-chem-phys-discuss.net/acp-2016-582/acp-2016-582-AC2-supplement.pdf>

Interactive comment on Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2016-582, 2016.

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