Answers to Anonymous Referee #1

The study by Roy et al focuses on the radiative and dynamic impact of enhanced NOx emissions from China and India during the summer monsoon period. The increased NOx emissions are comparable to the observed increase over a 10 year period in the first decade of this millennium. This makes the study especially interesting as it describes a recent development and not a future case scenario. The results presented are interesting as NOx emissions change O3 fields in the monsoon region. The changed O3 fields in turn affect the radiative forcing and circulation. At the end of the manuscript a connection to precipitation changes due to changed atmospheric conditions is presented. I think that the topic of the study is of interest for a large community and suitable for publication in ACP. However, there are still major and minor issues that need to be resolved before the manuscript can be considered for publication.

Reply: 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.

Major Comments:

- In your study you do not consider lightning NOx. However, neglecting this NOx source in the upper troposphere could notably alter your results as the chemical background for the sensitivity studies is different. On p. 8 l. 177-181 you even mention the importance of lightning NOx during the summer monsoon season over Asia. The importance of additional NOx can be inferred from the differences in your Ind73 and Ind38 simulation. Adding lightning NOx could change the results of these simulations! Also you do not state if soil NOx is included in the simulations. This could be an additional source for NOx (see e.g. Vinken et al 2015, ACP, "Worldwide biogenic soil NOx emissions inferred from OMI NO2 observations"), if not considered already. With respect to emissions please provide a table/graphic or a section in the text summarizing the most important details of the emissions used (e.g data set, total NOx emissions per year etc.). A map plot showing the spatial distribution of NOx emissions during the monsoon season for the CTRL simulation would be useful. I personally think that giving references to previous studies only is not sufficient as the emissions are highly relevant for your study.

Reply: We are sorry for the confusion related to the inclusion of lightning NO_X in our model simulations. In all simulations performed for this study, NOx emissions from lightning and soil are in fact included. We now clarify this in the text: (pg 7, L148-155).

The difference between enhanced anthropogenic NO_x emissions and CTRL simulations gives the impact of anthropogenic NO_x, as NO_x emissions from lightning and soil remain the same in both the simulations. In order to estimate impact of lighting NO_x one needs to perform simulation with lightning-off. The difference between CTRL and lightning-off simulations shows the impact of lightning produced NO_x. (pg 7, L153-155; pg 10, L225-230)

Since focus of the current manuscript is to analyze impact of anthropogenic NO_x, results from lightning-off simulations were not shown in the previous version of the manuscript. Fadnavis et al (2015) has already reported the impact of lightning NO_x over the Asian region. Since lightning NO_x is important during the monsoon season, we have now incorporated a figure showing impact of lightning NOx (Supplementary figure S5). As suggested by the reviewer, we have also incorporated a figure showing spatial distribution of anthropogenic emission mass flux of NO_x during the monsoon season (Supplementary figure S1).

- For your CTRL and sensitivity simulations you only have 11 years (2000-2010) of data per simulation. This might be a too short time period to make robust conclusions. Please note significant differences in the plots comparing the CTRL run with the sensitivities. Showing significance will help interpreting the differences, e.g. the noisy areas such as in Fig 3 below approx. 400hPa.

Ans: We have re-plotted figure 3. Ozone production is now shown in mixing ratios instead of percentage change. Statistical significance levels of 95% is shown as contour plots.

- When showing differences compared to the CTRL simulation please use a color scale that makes it easier to see where positive or negative changes are located: this could be done using a red-white-blue color scale centered at "0" (if not centered at "0" at least include a contour indicating the "0"-line). It would be useful to show also the absolute amounts of O3/O3-production or NOx in the CTRL simulation. Otherwise percentages can be rather meaningless.

Ans: We thank the reviewer for this suggestion and in the revised version all the figures have been changed in red-white-blue color scale centered at "0". Net ozone production (figure 3) and NO_x (supplementary figure 2) are now shown in absolute amounts.

- The model set up you are using has a relatively coarse vertical vertical resolution. Please include information on the vertical resolution in Sect. 2.2 (e.g. by adding "The vertical resolution of the model set up is about x km in the UTLS")? Also, how do you expect the vertical resolution to affect your results?

Ans: 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 (figure S2) depicting seasonal (June-September) mean precipitation and circulation at 850 hPa simulated in 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 (pg7, L157-166). We now also acknowledge in the manuscript 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" (Druyan et al., 2008; Abhik et al., 2014) (pg7, L160-162).

- In Sects. 3, 4 and 5 statements about cross tropopause transport by convection and consequent transport in the tropical pipe are made. In my opinion the statements are not always evident from the provided figures. Please see Specific Comments section regarding this issue.

Ans: It is now removed from the revised manuscript.

General Comments:

- I could not find any comments on how well convection is simulated by the model, please add this information e.g. by showing a map highlighting the regions of strong convection. I know representing convection is a difficult task but at least address the possible effect of different than observed convection. Also, do the convective regions or convective activity change w.r.t the different simulations?

Ans: We have now added a figure a map of cloud droplet number concentration and ice crystal number concentration to highlight the regions of strong convection (Supplementary Figure S4(c)).

- How do VOC and CO emissions change over the period considered for the NOx emission increases? Do they remain the same? Would additional VOC and CO emissions have an impact on your results? Please add this information.

Ans: In our model simulations we have increased anthropogenic NO_x emissions only. Therefore VOC and CO emissions do not change in the model perturbation experiments and therefore they do not impact our results. We have incorporated this information on pg 7, L151-153.

- Please include some notion on the size of the Asian monsoon anticyclone. You are referring to the anticyclone several times in the manuscript and a contour showing the size would clearly help to follow your thoughts. For a 3D classificaton of the monsoon anticylcone (see e.g. Barret et al 2016, ACP, "Upper-tropospheric CO and O3 budget during the Asian summer monsoon").

Ans: Thank you for the suggestion, we now show the extent of the Asian monsoon anticyclone in Figure 1. Related discussion are incorporated in the revised manuscript (pg8., L180-184).

- Similarly, add the contours indicating the outline/elevation of the Tibetan Plateau. This would make your argumentations easier to understand.

Ans: Thank you for this suggestion. The elevation of the Tibetan Plateau is now shown in the figures.

- Check capitalization and abbreviation: e.g. "figures" should be "Figs." etc: See http://www.atmospheric-chemistry-and-physics.net/for_authors/manuscript_ preparation.html under "Manuscript composition". There are several places where this should be corrected (e.g. p 9, l 212; p 7, l 145-155,...)

Ans: The above correction regarding abbreviation has now been incorporated in the manuscript.

- Please consider to check the manuscript for grammar and spelling mistakes. I cannot vouch for the suggestions made with respect to this in the Technical Comments section.

Ans: As suggested, grammar and spelling corrections have been taken care of in the revised manuscript.

Specific Comments:

Sect. 2.1.:

-You write that O3 data is convolved with the MLS AKs for comparison. However, later in the text p. 7 l. 145 you say that you use the 90hPa data from the model. Why do you not use averaging kernels also for Figure 1 a? Or are they used but it is not stated in the Figure caption!? This is confusing.

Ans: To account for the comparatively low and altitude-dependent vertical resolution, the model ozone data were convolved with the MLS ozone averaging kernel, in order to be directly compared to MLS measurements. However, Fig. 1(a) shows the spatial plot for MLS ozone at 100 hPa, which doesn't require further smoothing by averaging kernel.

Sect. 2.2:

-Please state which convection scheme is used! Although you are referring to a couple of previous studies, please mention at least the most important facts of the simulation in this section.

Ans: Thank you for the suggestion. We have now added information related to convection scheme (pg 6-, L121-124).

Sect. 3.1:

- You show O3 profiles from 1000hPa to 10hPa. This is ok. However, I think it would be useful to make a comparison also for the relevant height section, say 500hPa to 70hPa only. This way differences are way clearer. For additional comparisons you refer to Fadnavis et al 2015, ACP. The CTRL simulation in their study includes lightning NOx! In the abstract of Fadnavis et al 2015, ACP it is stated that lightning NOx can change Ozone values by 30% and NOx by 70% in the convectively affected regions. Please comment on this issue! This also connects to the first point of the Major Comments section.

Ans: As suggested, ozone profiles are plotted on the scale 500hPa to 70hPa only and quantitative differences are now mentioned in the revised manuscript (pg9, L195-207).

Ans: The CTRL simulation used in this study is in fact the same as in Fadnavis et al., 2015 (we mention this in the manuscript at page 6, line 141-142. As mentioned in our reply to the first major comment, lightning NO_x is in fact included in all the simulations, i.e. CTRL and anthropogenic NO_x emission perturbations. The impact of lightning NOx gets cancelled out when we analyze difference between CTRL and anthropogenic sensitivity simulations. In the current version we have added a figure S5 depicting lightning produced NOx. This is now made clear in the manuscript. (pg.7 L151-159). Therefore reasons for observed differences do not pertain to lightning NO_x.

Sect. 3.2.:

- Please show a map plot of ICNC/CDNC to make your statement about convection over the Bay of Bengal and the southern slopes easier to follow.

Ans: Thank you for the suggestion. We have now added a map plot (supplementary figure S4(c)) of ICNC/CDNC depicting convection over the Bay of Bengal, South China Sea and the southern slopes of Himalayas.

- Please include orography in the lat/lon vs height plots.

Ans: Thank you for the suggestion orography is now included in the lat/lon vs height plots.

- Due to the color scale one could think that positive anomalies in Fig. 2 (d) reach up to almost 100hPa. This is not the case. They are vertically limited to approx. 400hPa! Could it be that the color scale does not fit for Fig. 2 (d)? As I see it transport across the tropopause is only visible in Figs. 2 (c) and (f). Please comment on that or restate in the text.

Ans: The color scale has now been changed to blue-white-red (as suggested). Now it can clearly be seen that in Fig. 2 (d), positive NO_x anomalies reach up to almost 100hPa (~1-4%).

- How do you attribute the signatures to convective outflow? Convective outflow could be at lower levels followed by slow upward transport to higher levels. Additionally, I think that Garny and Randel 2013 do not make a statement on transport of pollution to the deep stratosphere.

Ans: This sentence has been reframed.

Sect. 3.3:

- The lower part of Fig. 3 looks relatively noisy please check for statistical significance or add a sentence that this should not be interpreted (see also Major Comments). You could add contours showing NOx changes (i.e. the analysis in Fig 2) to Fig. 3, so your statement in lines 212-214 is easier to follow.

Ans: We have re-plotted figure 3. Net ozone production is now expressed in ppt/day and not in percentage. We have added contour plots of 95% confidence levels to show statistical significance.

- The color scale makes it almost impossible to distinguish positive and negative differences in Figs. 4 (a) and (d) (see Major Comments section). Also I don't see real cross TP effects on O3 in Figs 4 (d)-(f). Consequent transport in the tropical pipe is only a hypothesis, right? Please clarify or restate.

Ans: We have re-plotted the figures in blue-white-red color scale (as suggested). This makes it easier to distinguish between positive and negative values in Figs. 4(a) and (d).

Sentence related to transport in the tropical pipe is removed. We have shown arrows in Figs. 4(d) and (f), to depict cross tropopause transport of ozone (although the magnitudes are low ~0.5-2%).

Sect. 3.4:

- The NOx maps in Fig. 5 show that at 110hPa large increases in NOx are only present in the Chin73 simulation. This fits the comment I made about cross TP transport in Sect. 3.2! Changing the color bar would be very helpful (see Major Comments section).

Ans: As suggested, the figures are re-plotted in blue-white-red color scale for better understanding.

- How do you explain that in the Ind38 there is more NOx at 110hPa but less O3 than in the Ind73 simulation (Fig. 5)?

Ans: Satellite observations show a maximum in ozone precursors (CO) and low ozone in the monsoon anticyclone. The reason this is not yet known. In agreement with these observations model simulations also show more NO_X and less ozone. It is now mentioned in the revised version of the manuscript. (pg 13, L292-296).

Sect. 4:- Why is the radiative forcing of Ind73 not stated? I think it is missing throughout the whole manuscript.

Ans: We have re-computed ozone radiative forcings using the Edwards and Slingo (1996) radiative transfer model. Figures 6 and 7 and related discussions are revised in the current version of the manuscript. The value for radiative forcing for Ind73 has now been incorporated in the revised manuscript. (pg13,L303-304).

- Please show which regions are used to calculate the changes in radiative forcing, e.g by including boxes in Fig. 5!

Ans: Thank you for the suggestion. The region where the changes in radiative forcing are calculated is now shown with a box in Fig. 5a. This is also mentioned in the revised manuscript (pg13, L303).

- Please include orography in Fig 6. This would help to follow your discussion about the TP warming in the sensitivity simulations.

Ans: As suggested orography is included in Fig 6.

- Why is there less ozone heating in Ind73 than in Ind38 although Fig. 5 (d) and (e) show that O3 anomalies are higher in the Ind73 simulation. With respect to this matter, why is the profile negative for Ind73? How does this fit with Figs 4(d)-(f)?

Ans: As mentioned above we have re-computed ozone radiative forcing using the Edwards and Slingo (1996) radiative transfer model and related discussions are rewritten.

- Why are some dots not on the lines in Fig 7(a)?

Ans: We have re-computed ozone radiative forcing using the Edwards and Slingo (1996) radiative transfer model and therefore figure 7 is re-plotted.

- To me Figs. 8 (b) and (c) look more alike than (a) and (c). In both Figs. (b) and (c) there is anomalous subsidence at approx. 20N. Also the anomalous ascent in the Ind38 is rather located at 10N, not 20N as stated in the text. Please clarify.

Ans: We have now explained figure 9 (b) and (c) as per suggestion (page 14, L324-338).

- Clarify "Indian region" with respect to precipitation changes.

Ans: We have now defined Indian region 70º-90º E; 8º-35º N in the revised manuscript (pg 14, L330).

- Because of the open questions, I have problems to combine the results in this Sect.3 and 4 to a coherent picture.

Ans: We have re-written discussion section (section 4) and tried to produce a coherent picture. (pg 13-15, L299-344).

Sect. 5:

- As before, you make a statement on cross tropopause transport and consequent transport via the tropical pipe that is not clear to me. See also the comments I made on this topic made before.

Ans: This statement is now removed from the revised manuscript.

Technical Comments:

p 1, l 10: change ": : : to the anticyclone." to "to the Asian summer monsoon anticyclone.". You could also add a sentence introducing the Asian monsoon anticyclone.

Ans: This sentence is reframed pg 1, L11-12.

p 1, l 14-16: The sentence on the emissions for the sensitivities is not precise. Maybe change to something like: "In these simulations covering the years 2000-2010 anthropogenic NOx emission have been increased by : : : with respect to the emission base year 2000. These emission increases are comparable to the observed linear trends of 3.8% and 7.3% per year during the period 2000 to 2010." Is that what you want to convey?

Ans: Above suggestion is incorporated at pg1, L19-22.

p 1, l 19: Change ": : : are partially transported over: : :" to ": : : are partially transported to : : :", if that is what is meant by the authors

Reply: This sentence is re-written.

p 1, l 22: Change ": : : produces : : :" to ": : : produce : : :"

Ans: Above suggestion is incorporated at pg1, L23.

p 1, l 24: Change for example to ": : : India (73%) - resembling the observed increase over China - produces : : :". Please use present tense in the following as done in the first part of the abstract.

Ans: Above suggestion is incorporated at pg 2, L26-27.

p 2, l 25: "It induced : : :" could be rephrased to "The higher ozone conentrations in turn induce a reversed monsoon Hadley : : :"

Ans: Above suggestion is incorporated at pg2, L27-29.

p 2, l 26: "suppressed" should be "suppresses"

Ans: Above suggestion is incorporated at pg2, L29.

p 2, l 27: Change ": : : the anticyclone." to ": : : the Asian summer monsoon anticyclone."

Ans: Above suggestion is incorporated at pg2, L30

p 2, l 34: You could probably delete the etc

Ans: Above suggestion is incorporated at pg2, L37.

p 3, l 49: Change ": : :during monsoon season: : :" to ": : :during the monsoon season: : :"

Ans: Above suggestion is incorporated at pg3, L51.

p 3, l 53: ": : :forcing increasing: : :" should be ": : :forcing due to increasing: : :"

Ans: Above suggestion is incorporated at pg3, L55.

p 3, l 56: "and the tropopause"

Reply: Above sentence is reframed.

p 3, l 67: Just out of curiosity: Which one of the studies shows enhanced methane, ethane and N2O concentrations?

Ans: Xiong et al., (2009) have shown enhanced methane; Abad et al., (2011) has reported ethane. We have added these references in the revised manuscript. The statement related to N2O is now removed. (pg3, L70-72)

p 4, l 74: ": : : Bay of Bengal and the Arabian Sea." Please include a reference for this statement.

Reply: This sentence was creating confusion. It is now removed in the revised manuscript.

p 4, l 74-77: "Balloonsonde observations: Thus observations show that: " Switch these sentences. Maybe cut the second "thus" in this section and change "variation" to "variations".

Ans: Above suggestion is incorporated at pg4, L77-80.

p 4, l 90: "measurement" should be "measurements"

Ans: Above suggestion is incorporated at pg4, L94.

p 4, l 91-92: To my knowledge MLS is an instrument onboard the Aura satellite. Please rephrase.

Ans: Above suggestion is incorporated at pg4, L95-96.

p 5, l 119: "validation" could be changed to "evaluation", which is more accurate

Ans: Above suggestion is incorporated at pg6, L134.

p 6, l 122: "simulation" should be "year" right? Please clarify.

Ans: Above suggestion is incorporated at pg6, L135-137.

p 6, l 126: Add "sensitivity"

Ans: Above suggestion is incorporated at pg6, L141.

p 6, l 143 ": : :.AIRS: : :" should be ": : :MLS: : :"

Ans: Above suggestion is incorporated at pg8, L175.

p 7, l 157: "over the various" should be "over various"

Ans: Above suggestion is incorporated at pg9, L205.

p 7, l 159: "ozone mixing ratio." should be "ozone mixing ratios."

Ans: Above suggestion is incorporated at pg9, L207.

p 7, l 163: Add "summer" to "Asian monsoon season" to be clear

Ans: Above suggestion is incorporated at pg9, L211.

p 8, l 169-171: "The vertical : : :" change to "Vertical distributions of NOx : : : from the CTRL simulation are : : : ". Also "figures" should be capitalized and abbreviated.

Ans: Above suggestion is incorporated at pg9, L217; pg10, L219.

p 8, l 172-176: In Fig. S2 I would expect number of particles per volume, i.e. m□3, as units. Could you please clarify?

Reply: Model gives cloud droplet number concentration (CDNC) and ice crystal number concentration (ICNC) in the units ‘ kg-1’ we have converted it in mg-1.

p 8, l 174: Delete "together"

Ans: Above suggestion is incorporated at pg10, L222.

p 8, l 184: Figs. 2 (a) and (d) only refer to the Ind38 experiment. Chin73 is shown in Figs 2 (c) and (f), right? Please change in the text.

Ans: Above suggestion is incorporated at pg10, L233.

p 8/9, l 192/193: Change "along the descending branch of circulation" to "along the descending branch of the large scale monsoon circulation" or something like that. Please include the reference: Rodwell, M. J. and Hoskins, B. J.: "Monsoons and the dynamics of deserts", QJRMS, 1995. Here they describe the broad scale circulation with descent in the western part of the monsoon circulation system.

Ans: Above suggestion is incorporated at pg11, L242-243.

p 9, l 207-208: Change "estimate" to "calculate". Also add "simulation" after "CTRL".

Ans: Above suggestion is incorporated at pg11, L250.

p 9, l 211: Add "additional" in front of "net ozone production"

Ans: Above suggestion is incorporated at pg 11, L254.

p 9, l 214: Change to "In the Ind73: : :"

Ans: Above suggestion is incorporated.

p 10, l 222: Why should convection transport ozone upward? Usually convection is thought to bring up air with low O3 values. Are you talking about O3 from in-situ production and O3 from production in the source region which is consequently transported upward? Please clarify.

Ans: We agree with reviewer that convection is thought to bring up air with low O_3 values. However we force the model with enhanced NO_x emissions. Thus production of ozone increases via NO_x photolysis. This increment in ozone anomalies leads to air with high 'ozone anomaly' which is transported upwards. (pg11-12, L262-271).

p 10, l 224: Please give longitudes you associate with Arabia. Is the statement regarding O3 levels valid for all simulations?

Ans: As suggested we have replaced "Arabia" with broader region "west Asia" (Pg12,L269).

p 11, l 241: "estimate" should be "calculate"

Ans: This sentence is reframed.

p 11, l 252: Change to "These figures show that the tropical easterly jet transports : : :". Also it is clearer for O3 (Figs 5 (d)-(f)) than for NOx, right?

Ans: It is clearer for ozone (Figs 5 (d)-(f)), but is seen in case of NO_x as well (Figs. 2(a)-(c)) (pg13, L295-296).

p 11, l 264: "These simulations: : :" refers to Ind38 and Chin73 only, right? I don't see surface warming in this region for Ind73.

Ans: This sentence is reframed.

p 12, l 276-278: In the text you write that Fig. 7(b) shows O3 heating rates over the Plateau (20N-40N), whereas in the Figure caption you state (20N-30N). Please correct.

Ans: Figure 7(b) is re plotted.

p 13, l 304: Add information that anomalies are shown!

Ans: This sentence is reframed.

p 13, l 309: There is no "Figure 9 (e)" should be "Fig. 8(e)". Also change "(figure 8(d)) whereas they" to "(Figs. 8(d) and (f)) whereas they"

Ans: Above suggestion is incorporated at pg14, L331-332.

p 14, l 320: "enhancement, 38% over India" could be changed to "enhancements of 38% over India "

Ans: Above suggestion is incorporated at pg15, L349.

p 14, l 321: Add "of" after trends

Ans: Above suggestion is incorporated at pg15, L350.

p 14, l 324: Change to "..that an increase: : :" or alternatively ": that increased anthropogenic: ::"

Ans: Above suggestion is incorporated at pg15, L355.

p 15, l 335-343: I think it would be correct to use present tense throughout this part.

Ans: Above suggestion is incorporated

p 15, l 341: "resisted" should be "impedes"

Ans: Above suggestion is incorporated at pg16, L365.

Answers to Anonymous Referee #2

The study by Roy et al. investigates how the increasing Asian NOx 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 NOx 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 some concerns (1) the low vertical resolution applied in the model simulations and (2) the fact that NOx production by lightning is not considered in the model simulations. Before publication the following points of criticism and suggestions for improvements should be considered:

Reply: 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" (Druyan et al., 2008; Abhik et al., 2014) (Pg.7, L160-162).

Sorry for the confusion. Statement about lightning NOx 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 NOx 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 lighting and related discussions. (Fig S5) (pg 10, L228-230).

Specific comments:

p2, l40: What is meant with NOx limited regions?

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

p5, l118: 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, l122: 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, l123: 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).

p6, l123: 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 NOx 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 NO_2 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, l127: 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, l127ff: How were the assumed numbers of increase motivated? How large is the observed trend?

Reply: The assumed numbers of increase are obtained from observed NO_2 trends (manuscript pg 6, l146-148). Over the Indian region SCHIAMACHY observed NO_2 trends are 3.8% per year during January 2003-October 2011 (Ghude et al., 2013), and OMI NO_2 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).

p7, l155: 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, l181: Lightning is important for the amount of NOx 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, l212: I have difficulties to see the connection that ozone production is found where there is NOx 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, l227: 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, l228: It would be helpful for the reader if the areas of the Tibetan Plateau, Bay of 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 NOx 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.L192-207).

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.

p5, l102: Is 8.3 x 3 really correct or is there a typing error?

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

p7, 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, NOx, HNO3 and O3 mixing ratios."

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

p6, l127: I would rather call it "simulations" than "experiments".

Ans: Above suggestion is incorporated at pg6, L141.

p7, l167: skip “etc” or move it forward so that it reads “.....aerosols etc.....

Ans: Above suggestion is incorporated at pg9, L214.

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.