

## ***Interactive comment on “Influence of enhanced Asian NO<sub>x</sub> emissions on ozone in the Upper Troposphere and Lower Stratosphere (UTLS) in chemistry climate model simulations” by Chaitri Roy et al.***

### **Anonymous Referee #1**

Received and published: 2 August 2016

The study by Roy et al focuses on the radiative and dynamic impact of enhanced NO<sub>x</sub> emissions from China and India during the summer monsoon period. The increased NO<sub>x</sub> 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 NO<sub>x</sub> emissions change O<sub>3</sub> fields in the monsoon region. The changed O<sub>3</sub> 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

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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.

### **Major Comments:**

- In your study you do not consider lightning NO<sub>x</sub>. However, neglecting this NO<sub>x</sub> 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 NO<sub>x</sub> during the summer monsoon season over Asia. The importance of additional NO<sub>x</sub> can be inferred from the differences in your Ind73 and Ind38 simulation. Adding lightning NO<sub>x</sub> could change the results of these simulations! Also you do not state if soil NO<sub>x</sub> is included in the simulations. This could be an additional source for NO<sub>x</sub> (see e.g. Vinken et al 2015, ACP, "Worldwide biogenic soil NO<sub>x</sub> emissions inferred from OMI NO<sub>2</sub> 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 NO<sub>x</sub> emissions per year etc.). A map plot showing the spatial distribution of NO<sub>x</sub> 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.
- 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.
- 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

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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 O<sub>3</sub>/O<sub>3</sub>-production or NO<sub>x</sub> in the CTRL simulation. Otherwise percentages can be rather meaningless.

- 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?

- 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.

### **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?

- How do VOC and CO emissions change over the period considered for the NO<sub>x</sub> emission increases? Do they remain the same? Would additional VOC and CO emissions have an impact on your results? Please add this information.

- 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 classification of the monsoon anticyclone (see e.g. Barret et al 2016, ACP, "Upper-tropospheric CO and O<sub>3</sub> budget during the Asian summer monsoon").

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

- Check capitalization and abbreviation: e.g. "figures" should be "Figs." etc... See [http://www.atmospheric-chemistry-and-physics.net/for\\_authors/manuscript\\_preparation.html](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,...)

- 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.

### **Specific Comments:**

Sect. 2.1.:

-You write that O<sub>3</sub> 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.

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.

Sect. 3.1:

- You show O<sub>3</sub> 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 NO<sub>x</sub>! In the abstract of Fadnavis et al 2015, ACP it is stated that lightning NO<sub>x</sub> can change Ozone values by 30% and NO<sub>x</sub> by 70% in the convectively affected regions. Please

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comment on this issue! This also connects to the first point of the Major Comments section.

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.
- Please include orography 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.
- 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.

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 NO<sub>x</sub> changes (i.e. the analysis in Fig 2) to Fig. 3, so your statement in lines 212-214 is easier to follow.
- 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 O<sub>3</sub> in Figs 4 (d)-(f). Consequent transport in the tropical pipe is only a hypothesis, right? Please clarify or restate.

Sect. 3.4:

- The NO<sub>x</sub> maps in Fig. 5 show that at 110hPa large increases in NO<sub>x</sub> are only present

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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).

- How do you explain that in the Ind38 there is more NO<sub>x</sub> at 110hPa but less O<sub>3</sub> than in the Ind73 simulation (Fig. 5)?

Sect. 4:

- Why is the radiative forcing of Ind73 not stated? I think it is missing throughout the whole manuscript.
- Please show which regions are used to calculate the changes in radiative forcing, e.g by including boxes in Fig. 5!
- Please include orography in Fig 6. This would help to follow your discussion about the TP warming in the sensitivity simulations.
- Why is there less ozone heating in Ind73 than in Ind38 although Fig. 5 (d) and (e) show that O<sub>3</sub> 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)?
- Why are some dots not on the lines in Fig 7(a)?
- 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.
- Clarify "Indian region" with respect to precipitation changes.
- Because of the open questions, I have problems to combine the results in this Sect.3 and 4 to a coherent picture.

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.

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## 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.

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 NO<sub>x</sub> 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?

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

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

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.

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

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

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

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

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

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

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p 3, l 56: "and the tropopause"

p 3, l 67: Just out of curiosity: Which one of the studies shows enhanced methane, ethane and N<sub>2</sub>O concentrations?

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

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".

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

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

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

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

p 6, l 126: Add "sensitivity"

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

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

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

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

p 8, l 169-171: "The vertical ..." change to "Vertical distributions of NO<sub>x</sub> ... from the CTRL simulation are ...". Also "figures" should be capitalized and abbreviated.

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

p 8, l 174: Delete "together"

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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.

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.

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

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

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

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.

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

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

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?

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

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.

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

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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"

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

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

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

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

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

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

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