Authors comment (AC1) to Referees comment (RC1)

Dear Referee,

on behalf of all authors I would like to thank you very much for taking your time to comment during the open discussion of the preprint. We very much appreciate your valuable propositions and included nearly all of them in our text. Our answers are in italic and blue.

Best regards,

Johannes Pletzer

General Comments:

This paper addresses the potential impacts of a future fleet (~2050) of hypersonic aircraft emissions (H_2O, H_2, CH_4, and NOx) on middle atmosphere composition (i.e., H_2O, NOy, HOy, etc…) and the resultant chemical impacts on ozone. The stratospheric-adjusted radiative forcing from hypersonic aircraft perturbations is examined in "exhausting" detail. This paper will be a benchmark study for how perturbations from aircraft or any other vehicle emitting gases in the middle atmosphere affect climate forcing.

Overall, I find this work suitable (as is) for publication in ACP. I have a few comments below that the authors may find useful.

Specific Comments:

Line 13: "… can have a large

We prefer to remain with "… can have a larger …" due to the comparison.

Line 20: "… simulated years by one-third and thus cost and climate impact." Do you mean by running simulations in a shorter period, you are not contributing as much to global warming? This may be correct, but is that really necessary to point out (at least at the abstract level)?

We removed this part from the text. Thank you for your viewpoint.

Line 26: "…strong noise"? maybe "…"loud noise"?

We changed "strong" to "loud".

References seem to be duplicated, e.g., Jockel, et al., 2016a and Jockel et al. 2016b are the same paper. There are many examples of this type of duplication. Please double check all your references.

We checked all references and removed duplicates. Thank you for pointing that out.

Page 2. It would be nice for the "uninformed" reader what the primary difference is between a proposed supersonic and hypersonic aircraft are (i.e., relative to the speed of sound).

Following your comment, we added this explanation: "Technically there are three categories of aircraft: subsonic aircraft that fly slower than the speed of sound, supersonic aircraft, whose speed exceeds the speed of sound, whereas the speed of hypersonic aircraft is at least five times the speed of sound."

Line 41: Grammar, please reword. "One of the newest analyses the climate impact and the growth potential using projections of different technological development scenarios (Grew et al., 2021).

We restructured the sentence for a better understanding. It now reads:

"One of the newest estimates analyses both, the climate impact and the growth potential, using projections of different technological development scenarios (Grewe et al., 2021)."

Line 51: Not sure what you mean by "…climate change is manifold that of subsonic aircraft…"?

We changed it to "… climate impact per revenue passenger kilometer "

Line 68: (EMAC)j? Is "j" a typo?

It is a typo and was changed accordingly.

Line 72: "In section three, we present the EMAC model…" You actually present this in sections 2.1. I believe you need to rename all the section numbers here.

Thank you for pointing that out. The references were changed accordingly.

Line 88: My next statement is a personal preference… The details of the EMAC model setup could easily be in an appendix. I'm not sure why the reader needs to muddle through all the sub-model process names. Maybe just have a more top-level model description in the main paper. One could probably reference a few EMAC publications in this section and only highlight what was important for this study.

We very much appreciate your viewpoint. The extensive submodel descriptions are moved to the appendix (section 11.1).

Section 2.3. I would highly recommend a table that discusses the model configurations. You do state in words what simulations are performed in this work – however, I had to read sections 2.1 through 2.3 several times to figure out exactly what you did. A table would help the reader.

We added a table to subsection 2.2 (Table 1: Overview of key properties used in the model setup). Enumeration of other tables was changed accordingly.

Specified Dynamics. Based on the discussion in section 2, it seems you are using "observed" specified dynamics met fields (present-day ERA-Interm) for the 2050 aircraft scenarios (line

129). You should probably say in a few words why this is justifiable, instead, using model specified dynamics fields from an interactive climate run for the year 2050.

We extended the text on specified dynamics with the following reference:

"Note that the impact of a 2050 meteorology would be – coarsely estimated – a 8-10 % strengthening of the middle atmospheric circulation, which would reduce atmospheric perturbations from hypersonic aircraft accordingly (subsubsection 7.1.2, Pletzer et al., 2022)."

Section 2.4. Enhancing the efficient use of computer time. Very interesting approach!! This could be adopted by many research studies that run a model to a steady state condition.

Thank you very much for the feedback. The approach is currently being applied for similar simulations inhouse and might become even more useful for higher resolution simulations.

Section 3.2. Can you put the emissions (H_2O, H_2, NOx) in context, i.e., how many aircraft are considered in this scenario? You mention the LAPCAT-PREPHA aircraft design; but are the number of planes significant to other published SST, HSCT scenarios. This is important when you discuss later the impact of emissions on Ozone and CH_4 lifetime.

The scenario considers on average 206 flights per day, which is nearly equivalent to numbers from e.g. Ingenito (2018):

https://www.sciencedirect.com/science/article/pii/S0360319918331379

We extended the sentence describing LAPCAT-PREPHA in section 3.2 with this piece of information.

Line 260. "For each emitted trace gas (H_2O, NOx, H_2) we have a total of eight simulations, which sum up to 24 simulations in total. The annual magnitude of emitted trace gases is 21.24 teragram of H_2O, 0.031 teragram NO_2 of NOxand 0.236 teragram of H_2." Question: the scenarios are designed to emit one emission species per simulation. I understand why you chose to emit on species per scenario. However, you might want to mention why did you not combine all the emissions of H_2O, NO_2, and H_2 in one simulation to examine how the chemistry responded (e.g., ozone chemistry)? I do note that later in the paper you did discuss this topic in section 7.3 and 7.4. Possibly point to this section for later discussion.

We added a reference in line 260 to the discussion in section 7.4.

Figure 3. The color bar goes from -6.0 to >4.8. Question. Why are showing negative colors in your color bar? Seems to me that when you inject H_2O you will always have a positive perturbation?

We changed the colorbar accordingly.

Figure 4; section 4.1.2.1 Ozone. Why is ozone increasing in region near 10hPa? I.e., is this HOx chemistry interacting with NOx chemistry?

If compared to Figure 18 (appendix) NOx changes seem to be inversely correlated with O3 between 100-10 hPa. Additionally, HNO3 is increased at 10hPa. The increased oxidation

capacity is most probably the cause of these changes. Here is a Figure with HNO3 changes for reference:

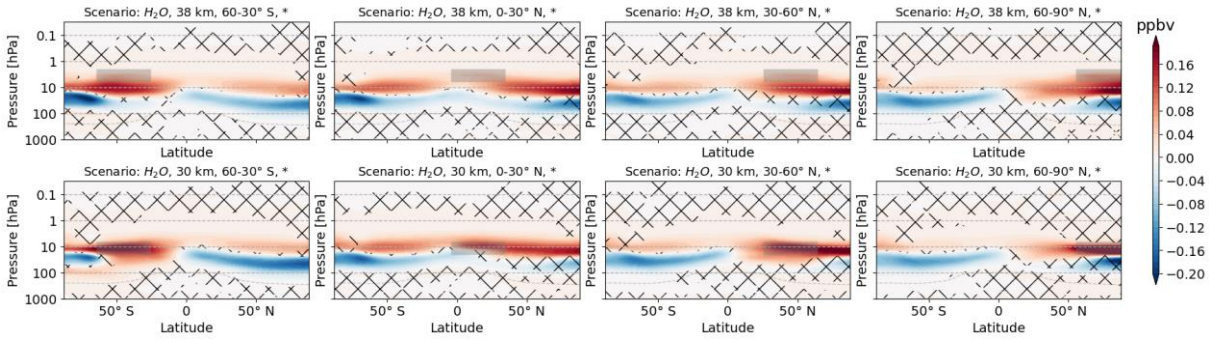

Figure 5: section 4.1.2.3 Methane. I understand why CH_4 is decreased with H_2O emissions – why does it increase? What is the mechanism?

That is a good question that we cannot answer with much certainty. Coarsely described at 100-10 hPa there is, first, increase/decrease of CH4 divided among Hemispheres and, second, changes appear rather at polar regions than in the tropics. We can report that between 100-10 hPa CH4 changes overlap with changes of C2H6 (not shown). Note that we do not want to imply a causal relation here. Additionally, we see an overall reduction of the HNO3 + OH reaction rate, where CH4 increases appear.

Other than that, CH4 increase appears in areas, where Cl and HCl concentration is lower than in the reference scenario. We are referring to the reaction Cl + CH4 → HCl + CH3O2, which we did not track with additional diagnostics unfortunately.

To conclude briefly, the extratropical regions, where most of the changes appear, is very much influenced by transport and it is generally difficult without a model setup tailored to track methane changes to find correct answers. We do hope that we could shed some light on this topic. We would prefer not to include this particular information in the publication, since in our opinion it is beyond the scope of this work.

Section 4.4.1. It seems that the perturbations (emissions) are not impacting the CH_4 lifetime in any significant way!

As shown in Table 4 (formerly Table 3) absolute CH4 lifetime changes are mostly significant for nitrogen oxide emission scenarios. There, tropospheric oxidation chemistry is more active. In our opinion, in the middle atmosphere areas of CH4 increase and areas of CH4 decrease might nearly cancel each other in terms of methane lifetime and the impact of the tropospheric domain is therefore more dominant (for nitrogen oxide emission scenarios).

Section 4.4.3.1. This statement is interesting. “The order of magnitude of changes per molecule of emitted species shows that a molecule of H_2 is roughly 50 % as effective in enhancing the mid-atmospheric H_2O concentration as a molecule of emitted H_2O (Tbl. 3).” Can you discuss the chemistry here? I.e., H_2 +OH => H_2O + H. H_2 can also be converted to H and OH (i.e., HOx). The HOx can also be converted back to H_2O.

We added an explanation:

The relevant reactions include both, loss and production of H2O. Chemically, the production is initiated directly by reaction H2 + OH → H2O + H and indirectly by HO2 + OH → H2O + O2. The latter is facilitated by the general increase of HOx and included in a H2O-HOx cycle via reaction H2O + O(1D) = 2 OH. Increased oxidation, e.g. methane and nitric acid oxidation, contributes a small amount as well. The net production of H2O briefly discussed in subsection 7.2.

Section 4.4.3.2. This section and the previous are very informative on the reactivity of emitted H2! Very nice. "Interestingly, while in absolute values the H_2 emissions are of minor importance to the O_3 depletion, the average effectiveness in destroying O_3 is roughly 5-6 times larger for H_2 than for H_2O (Tbl. 3)." I.e., H_2 (vs H_2O) has opposite effect on Ozone (compared to H_2O; section 4.4.3.1). I do note that this is partially discussed in section 7.2.

Thank you very much for your feedback. We appreciate it very much.

Figure 10 is a very nice summary figure.

Thank you very much for your kind words.