

Reply to Anonymous Referee #2

We greatly appreciate those well-meaning comments, and thank the reviewer for his/her efforts to provide detailed suggestions to improve the paper.

5 Major comments:

General:

10 *This is very interesting and important paper which is worth to be published. The most important finding is the explanation of high ozone within the Asian summer monsoon anticyclone. The authors show that photochemical ozone production in the circulating air masses as well isentropic in-mixing from the stratosphere are key processes defining ozone. In this picture the anticyclone can be understood as a photochemically active and not well-isolated reactor. In this reactor there are two parts: “convectively driven” eastern (Tibetan) part and more “chemistry driven” western (Iranian) part. Although the paper is well-written, it suffers from an inadequate presentation (see major points). Because of this, the paper needs a major revision.*

15
20 *1. As you show in many places, isentropic mixing between the stratospheric air (you call it TP layer) and the interior of the anticyclone is an important process in your chain of arguments. In Fig. 7 you show how such isentropes connecting the extratropical lower stratosphere intersect the tropopause (some almost perpendicular) and penetrate into the anticyclone itself. The mixing (stirring) happens on such isentropes and is almost a 2d process. So I do not understand, why you do not show the respective tracer distributions at such isentropes. I guess $\theta = 360$ K would be the right choice instead of using the 168hPa level (e.g. Fig. 8, Fig 9 or Fig. 10). I would recommend to show Fig. 7 much earlier in the text (e.g. as the second figure of your paper) and than use much more isentropic analysis. As you mentioned, such isentropes are tilted in pressure space, but transport occurs much more on such isentropes.*

25
30 The 168 hPa pressure level was chosen for analyzing the HALO ESMVal flight segment, which is the focus of the accompanying paper. Back-trajectories from the flight path showed that the ASMA circulation roughly stayed at that pressure altitude in that case.

30 However, we agree that isentropes are better than pressure levels for the current, more general study and will revise the manuscript accordingly.

35 *2. For me it is unreasonable to include 16 figures into the supplement! If your story exceeds something like 10-12 main figures and 2-5 figures of your appendix, you should divide the story into two parts or make your story shorter. The last point seems for me to be more your case. Your abstract roughly describes your main results (see also my general comments). So maybe, you can go through the text and remove everything what is not supportive for your main results (see also my minor points).*

40 We agree that the main text should be shortened to better convey the main results and we thank the reviewer for the corresponding detailed recommendations. Some figures have already become obsolete during the revision process. Some aspects (LiNO_x, O₃ photochemistry) need to be clarified, others become less important. However, the final shape of the paper will depend on the outcome of this discussion. Therefore we are cautious singling out individual paragraphs for shortening at this stage, but we are working on making the main text of the revised version more concise and shorter.

45 The approach to put quite a bit of information in the supplement is a compromise between getting a concise main text without compromising the reproducibility of our arguments. The revised main text will less heavily reference figures of the supplement, thus less feel to be part of the main story. Appendices are another means to keep the main text short, and contain self-contained discussions of aspects that might be of interest only to a minority of readers.

Minor Points:

1. P 1/L 18-19

“contrasted by...in autumn and winter” - ASM anticyclone does not exist in autumn and winter. Why we should talk about it.

5

This note in the abstract reflects the approach we follow in the main text: Highlighting the specific features of the monsoon by comparing it to other seasons. For instance, LiNO_x in summer is not higher than in spring, but net O₃ production at maximum in the ASMA. This comparison shows that LiNO_x alone is not responsible for enhanced O₃ production in summer.

10

2. P 1/L 20

“is regularly entrained a the eastern flank” - This is the isentropic in-mixing mentioned in my major point and not correctly described in your paper

15 We will revise the text to make clear that the lateral entrainment of the ASMA is an adiabatic process.

3. P 1/L 24

“by northerly” - I think “by southerly”

20 Corrected. We mean “winds from the south”.

4. P 1/L 24

“Although...” - this sentence is not clear for me. I would remove it

25 We removed the above sentence and now state at the beginning of the abstract that the measurements reflect the main processes acting throughout the monsoon season. It is one of the main objectives of the paper to put the HALO ESMVal measurements in the ASMA into perspective.

5. P 2/L 11

30 *I think that also “the eastward propagation of eddy shedding” is important now (Dethof et al., 1999; Vogel et al., 2014).*

Agree. We mentioned eastward eddy shedding only later in the paper, and have added the above recommendation to section 1.

35

6. P 2/L 15

“the associated heat low” - do not understand what you mean

Reformulated to: “The heat low associated with the hot desert conditions in summer ...”

40 For details regarding large scale subsidence in the UT over that region please see Rodwell and Hoskins (1996), for the near surface conditions Lelieveld et al. (2009).

7. P 3/L7-34

I would recommend to focus the attention of the reader on ozone (observation very high in the core, but why, you will discuss it in the paper, also in the interannual context, etc). Instead of this you talk here too much about general aspects...

5

We will revise this section to give it a better focus.

8. P 5/L1-6

For me this is the main motivation for the paper and it should roughly replace the part in P 3/L7-34 !

10

We agree. Apart from stating the main motivation for the paper, the introduction shall also briefly introduce the topic, put the study in the context of the recent literature, and explain the structure of the paper.

15 9. P 5/L14-16

"The extratropics are dominated..." - this sentence is unnecessary.

Removed.

20 10. P 5/L24

...dominate the averages in the chosen regions.

Revised.

25 11. P 5/L29-32

too much. I can only recommend to remove this material

The supplemental figures mentioned in this paragraph seem to be not essential indeed. We will double check with the revised text and shorten the supplement accordingly.

30

12. Figure 1, caption

dynamical proxy of what.... I do not see any grey parts of the flight. "Panel a additionally shows..."????

35

- Changed to: "... dynamical proxy to delimit the ASMA ..."
- There is a grey section over the coast of Oman, which might be hard to see. Since the flight track has been discussed in the accompanying paper, we removed this information here.
- Changed to: "Panel (a) additionally ..."

13. P 7/L21-24

40 *"slowly descending HCl..." - this feature is very strange. Typically, during the considered season (JJA) there is a strong diabatic upwelling in the UTLS region confined by the anticyclone. Maybe you should explain it with model or remove it...*

5 This is explained in the introduction as follows: “In particular, the Rossby wave response to convection in the ASM region results in large-scale subsidence over the Arabian Peninsula (Rodwell and Hoskins, 1996), making it one of the warmest and driest regions on Earth. The associated heat low supports an anticyclone (Lelieveld et al., 2009), which intermittently merges with the ASMA.”

14. P 8/L7

10 *“...differ between the summer monsoon season and the rest of the year..” – I would say the strong difference is during AMJJA and not only during JJA*

Changed to: “Simulated NO_y profiles in the ASMA region from April to September differ to the rest of the year (Figs. 3cd), but the monsoon season is also distinct: ...”

15. P 8

15 *The main part of NO_y in the stratosphere should be HNO₃, so I expect a much stronger correlation with HCl. Please comment.*

Apart from stratospheric contributions, NO_y also contains LiNO_x and uplifted pollutants. HCl is just related to stratospheric air.

20

16. P 8-9

Section 3.4 contains for me too much information. I would reduce it by considering only the ozone-relevant NO_x, NO_y features.

25 We consider the discussion of C- vs E-shaped NO_y profiles interesting in itself, but agree that it is only a side aspect regarding ozone. Depending on other options for making the paper more concise, parts of this section might be moved from the main text.

17. P 10, L5

30 *NO_x, typo*

Corrected

18. P 10

35 *Section 4 is a very important and novel part of the paper. It combines in situ observations (tracer-tracer correlations) with the model. It shows in a very nice way the interaction between the photochemical ozone production and stratospheric in-mixing. Because it does not use so much the observed NO_x, NO_y features, it is the next motivation to shorten section 3.4.*

40 Ok, thank you.

19. P 12, L23

“because HCl ...are decreased” - with the vertical mixing lines you argue that HCl should be constant. Maybe you should reformulate

Corrected to: “There are also a few almost vertical mixing lines in Fig. 5c, indicating case L3 described above.”

5

20. P 13, L20-31 and P 14

Here you show how important is the isentropic transport (mixing between the stratospheric and tropospheric air) on tilted isentropes. Here is also the origin for my major points.

10 *21. On the following pages there are to many references to the supplement (see my major point) I can only recommend to shorten the following sections.*

Points 20 and 21 have already been addressed in the “Major comments” section. We will go through the paper and revise accordingly.

15

References

Lelieveld, J., Hoor, P., Jöckel, P., Pozzer, A., Hadjinicolaou, P., Cammas, J.-P., and Beirle, S.: Severe ozone air pollution in the Persian Gulf region, *Atmos. Chem. Phys.*, 9, 1393-1406, 2009.

20 Rodwell, M. J., and Hoskins, B. A.: Monsoons and the dynamics of deserts, *Q. J. R. Meteorol. Soc.*, 122, 1385-1404, 10.1002/qj.49712253408, 1996.