Authors Reply to Anonymous Referee #1

The authors appreciate the anonymous referee #1 for your useful comments which are very helpful to improve our manuscript. Please see below our responses point by point.

General comments

P.1, line 18: Please, add a reference here. This statement is not obvious!

Reply: The authors rewrote the first sentence from "In the upper troposphere, ozone acts as an important greenhouse gas and, thus, plays a major role in regional energy balance and in climate change." to "In the troposphere, ozone acts as an important greenhouse gas, which has a positive radiative forcing ($0.4 \pm 0.2 W m^{-2}$) through the direct or indirect greenhouse effect for the period 1750–2011. Although relatively short lived, it is therefore very important for the radiation balance of the Earth's atmosphere (Myhre et al., 2013).". Further, we added a reference.

P. 2, line 19: I think Skerlak et al, Atmos. Chem. Phys., 14, 913-937, 2014, mention the Tibetan plateau to be a "hot spot". You should write something like "particularly active region". This is a strong motivation for your measurements!!!

Reply: We rewrote this sentence from " The ASM anticyclone is also an active region for stratosphere−troposphere exchange (e.g., Škerlak et al., 2014; Garny and Randel, 2016; Fan et al., 2017). " to "The ASM anticyclone is an active region for stratosphere−troposphere exchange (e.g., Garny and Randel, 2016; Fan et al., 2017), particularly the Tibetan Plateau region (Škerlak et al., 2014)". And we added the following sentence "Ozone concentration in the planetary boundary layer over the Tibetan Plateau is likely affected by intense deep stratospheric intrusions (Škerlak et al., 2014)." in this paragraph.

P. 2, line 26: "over northern India": Here (or in the following paragraph) you should mention Ojha et al., Atmos. Environ., 88, 201-211, 2014, and Atmos. Chem. Phys., 17 6743-6757, 2017.

Reply: The authors added the following sentence here.

"Balloon measurements over the central Himalayas have shown that stratospheric intrusions enhanced ozone concentrations in the middle and upper troposphere (Ojha et al., 2014, 2017)."

P. 2, around line 28: I am missing some statement on the role of the subtropical jet stream (e.g., Koch et al., Int. J. Climatol. 26 (2006), 283-301; Trickl et al., Atmos. Chem. Phys. 11 (2011), 9343-9366; and references therein). This also adds to the motivation for the paper!

Reply: We added the following sentences at the end of this passage.

"The upper tropospheric subtropical jets steam occur from eastern Asia to the mid-Pacific with high frequency (Koch et al., 2006). Stratosphere-to-troposphere transport along the subtropical jet steam occur over the Pacific Ocean. This is an important process for increasing ozone in the middle and upper troposphere in the region of the ASM (Trickl et al., 2011)."

P. 2, line 29: Here (or below) you should add a sentence on the importance of intensifying observations in this interesting region.

Reply: The authors added following sentences before P.2, line 29.

"In particular, the Tibetan Plateau is a hotspot region for the two-way exchange between the stratosphere and troposphere (Škerlak et al., 2014). However, in situ measurements over this region of chemical compositions in the upper troposphere and lower stratosphere are limited (e.g., Bian et al., 2012; Li et al., 2017). Because of the sparse in situ observations over the Tibetan Plateau, there is a need for further in situ observations in this region (e.g., balloon or super-pressure balloon measurements) to obtain new insights into transport and exchange processes in this region and for climatological survey."

P. 3, line 15: Please, specify SWOP.

Reply: We specified the text "The SWOP (sounding water vapour, ozone, and particle) experiment was conducted in Lhasa (29.66° N, 91.14° E, 3650 m above sea level (a.s.l.)) in 2010, 2013, 2016, and 2018 and Kunming (25.01° N, 102.65° E, 1889 m a.s.l.) in 2009, 2011, 2012, 2014, 2015, and 2017 by Institute of Atmospheric Physics, Chinese Academy of Sciences during the summer monsoon period. The object of the SWOP is to collect the first long-term database of ozone, water vapour, and

particle over the Tibetan Plateau from surface to lower stratosphere, and then to investigate and quantify the character of ozone and water vapour transport within the ASM anticyclone". An detailed statistical analysis of the vertical structure of ozone and water vapour using the complete SWOP data set over nearly 10 years is work in progress.

P. 4, line 31: P. 4, Sec. 2.3: There is a strong need for justifying the extension of trajectory calculations to as much as 50 days!!! There are papers on the quite limited accuracy of trajectories (e.g., Stohl et al.). I think that 10 days are acceptable in the free troposphere due at least for coherent air streams. However, I have seen reasonable results in the literature times up to 20 days in certain cases.

Reply: We agree with the referee's comment about the accuracy of trajectories. The results based on a few trajectories of air parcels may be arbitrary, but there are some reasonable expectation according to a very large number of trajectories. To study transport processes in the region of the Asian monsoon, a trajectory length between few days to few months is found in the literature (e.g., Chen et al., 2012; Bergman et al., 2013; Vogel et al., 2014; Vernier et al., 2015; Garny and Randel, 2016; Li et al., 2017). To study the convective events, a trajectory length of a few days to 20 days is sufficient. Li et al. (2017) using the Lhasa's balloon data in 2013 and the CLaMS trajectory model, have shown that the air parcels with low ozone from marine boundary layer over the western Pacific are the dominant source of low ozone in the tropopause layer in Lhasa resulting from very strong uplift (1–4 days) by typhoons and the subsequent horizontal long-range transport (4–10 days) within the Asian summer monsoon anticyclone. Thus, 20-day backward trajectories from the CLaMS model for the middle and upper troposphere within the ASM anticyclone are generally appropriate. However, to analyze more aged air masses transported in the region of the Asian monsoon anticyclone or originating in the stratosphere trajectories longer than 20 days are necessary (e.g., Chen et al., 2012; Bergman et al., 2013; Vogel et al., 2014; Garny and Randel, 2016). Therefore, we use 50-day backward trajectories in this study.

P. 5, line 4: extremely high
Reply: Changed to extreme high.

P. 5, line 11: RH profiles
Reply: Corrected.

P. 7, line 11: Can you make conclusions about the quality of the trajectories from the results (e.g., from the coherence properties)?

Reply: Thanks for the useful comment. To test the uncertainties of the trajectories, we run a set of trajectories close to the location of Lhasa and found that all these trajectories show a very similar transport pattern over the last 20 days (Fig. 1). Furthermore, we analyzed the PV from ERA-Interim reanalysis on isentropic surface and cross section of ozone from AIRS, and balloon measurements. We found that the satellite observations of PV agree with the PV along the backward trajectories confirming the CLaMS trajectory calculations.

Conclusions: Section 4 looks rather technical. I am missing more scientific statements in relation to the topics mentioned in the introduction. In addition, it would be advantageous to learn (e.g.) what was the idea behind the effort and what is planned. Long-term measurement would be great!.

Reply: We rewrote section 4 to connect the question quote in introduction. Please check section 4 in our revised manuscript.

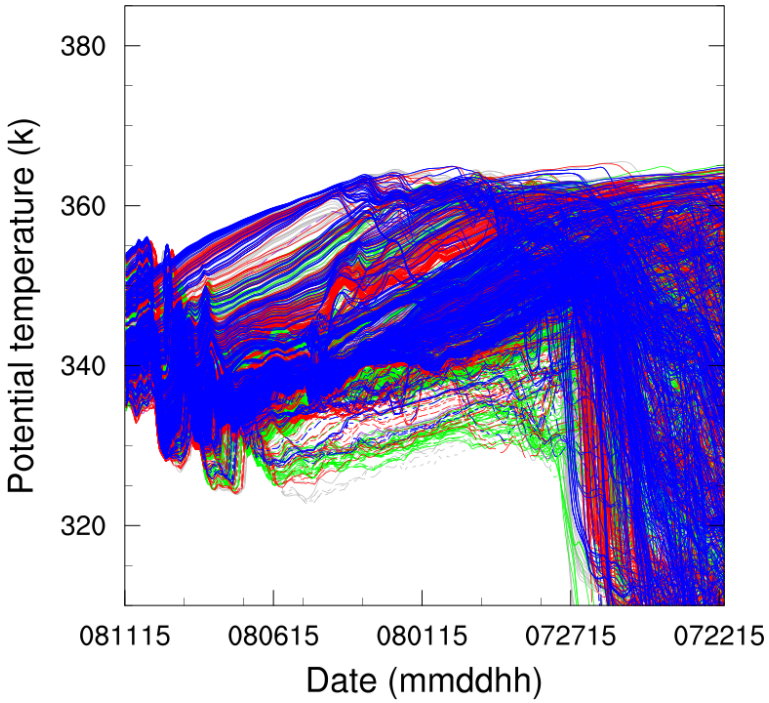

Figure 1. The backward trajectories of air parcels within the high ozone structure (355–362.3 K) as a function of time and potential temperature on 11 August. Blue/grey/red/green/purple lines mark the backward trajectories of (i, j)/(i-Δi, j)/(i+Δi, j)/(i, j-Δj)/(i, j+Δj), (i, j) marks the location of Lhasa and Δi=Δj=1 degree.

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