Authors Reply to Anonymous Referee #2

We thank the anonymous referee #2 for your useful suggestions which help us to improve the manuscript. Our detailed replies are shown below. The text with all changes in manuscript are highlighted in red color.

1. The Introduction section is weak. The significance of the study is not well explained. A question addressed in the study should be in the interest of the larger community.
Reply: The authors added more information about importance of this study in introduction. Please check the revised manuscript with tracked changes.

2. Does ozone increase during few epochs have implication on upper troposphere?
Reply: In our case studies, we find that the increasing ozone in the upper troposphere transported within the Asian summer monsoon anticyclone with a timescale of several days. 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. In Li et al., 2018, the focus is to understand the detailed transport pathways. A single "ozone increase episodes" influence the local chemical composition of the troposphere, however, frequently occurring "ozone increase episodes" have the potential to change the radiation balance of the atmosphere in the region of the ASM.

3.Present study show features from total column ozone. Ozone in the troposphere and stratosphere has different production and loss processes. During the monsoon season, lightning is one of the important agents for upper tropospheric ozone production. I suggest including a discussion on these aspects.
Reply: We replaced Figs. 4b−d with ERA-Interim PV on 370 K, AIRS ozone and water vapour mixing ratios at 83 hPa to show the equatorward transport process (please see Fig. 1).

The authors added the following sentences in discussion and conclusions. "During the ASM period, deep convective clouds occurred over the South Asian subcontinent, the southern Himalayan region and the Tibetan Plateau that caused lightning activity (Qie et al., 2014). NO_x produced by lighting has the potential to impact upper tropospheric ozone via photochemical reactions (Kita et al., 2002; Schumann and Huntrieser, 2007; Fadnavis et al., 2015; Gottschaldt et al., 2018). Uplifted ozone precursors and NO_x produced by lighting contribute to photochemical ozone production in the upper troposphere in the ASM anticyclone. An ozone increase by 30% is found over the monsoon convection region due to NO_x enhanced by lightning according to sensitivity simulations with and without lightning (Fadnavis et al., 2015). In our case studies, ozone is increased by 90%, compared to monthly mean ozone, this value is still higher than the ozone increase due to lightning reported by Fadnavis et al. (2015). Lightning is an additional source of tropospheric ozone, which is not included in the trajectory calculations neglecting chemistry employed here. However, in addtion to lightning produced NO_x, ozone precursors likely uplifted by convection are necessary. Therefore, convective uplift is the basis transport mechanism for enhanced ozone in the middle and upper troposphere. Enhanced ozone measured over Lhasa is caused by uplift of ozone-rich air from the lower troposphere or produced by lightning, it is likely caused by a combination of both with a transport time from the planetary boundary layer to Lhasa of 20–30 days"

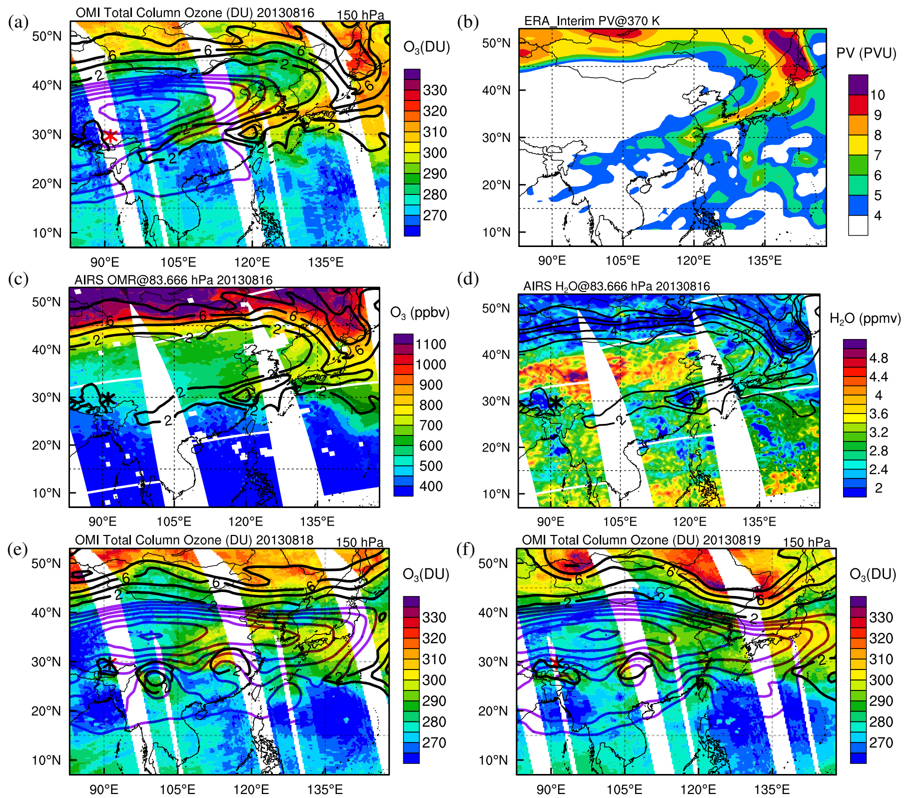

Figure 1. Total column ozone (DU) as measured by OMI with the geopotential height (purple line) and PV (black line, in PVU) at 150 hPa, and the sea-level pressure (white line) of tropical cyclone on (a) 16, (e) 18, and (f) 19 August 2013 using ERA-Interim data. (b) The PV (shade, PVU) on 370 K surface on 16 August 2013. (c) Ozone and (d) water vapour mixing ratios for 83.666 hPa from AIRS on 16 August 2013 with PV at 150 hPa from ERA-Interim. The asterisk marks the location of Lhasa.

4. I suggest showing vertical ozone variations using satellite observations to show stratospheric/tropospheric intrusions. It may be evident in ozone anomalies.

Reply: Thank you for this helpful comment. The authors plot the ozone mixing ratio for 346 hPa (Fig. 2a) and the latitude−pressure cross section of ozone (Fig. 2b) based on AIRS data and add the Fig. 2 in section 3.3 as Fig. 8 in the revised manuscript.

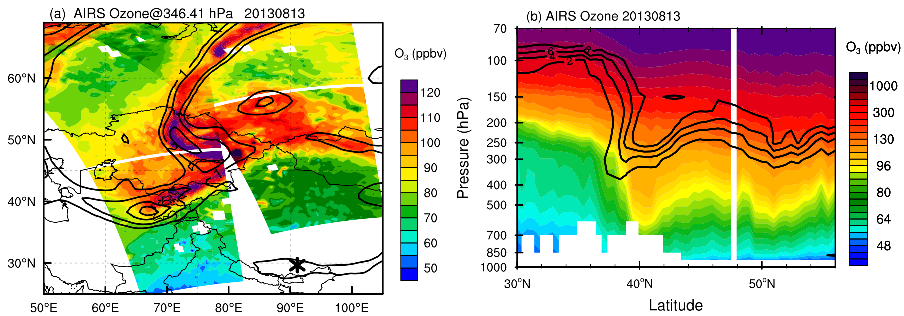

Figure 2. Ozone volume mixing ratio for 346.41 hPa from AIRS satellite (left panel). The latitude-pressure cross section of ozone along 70° E with PV (2, 4, 6, and 8 PVU, black line).

5. Spatial plots of PV on potential temperature surfaces (360 K or 380 K) will be useful to explain equatorward transport.

Reply: We added PV on 370 K (please see Fig. 2b) to show equatorward transport.

6. Vertical cross sections from CLaMS simulations indicating stratospheric contribution for the period 18–20 August 2013 will be useful.

Reply: The authors revised Figs. 4c and 4d using AIRS measurement to highlight equatorward transport of dry ozone-rich air from the lower stratosphere on 16 August 2013 (please see Fig. 1). The authors also added a cross section of AIRS ozone (Fig. 2b) to explain the tropopause fold occurring on 14 August 2013. Because tropospheric ozone chemistry is not included in the CLaMS model, we think it is more useful to present AIRS measurements instead of results of a 3-dimensional CLaMS simulation.

References

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