Note: Reviewer's comments are presented in black font; authors' responses are presented in teal plain font; manuscript text quotations are presented in teal italics font.

Anonymous Referee #1

We would like to thank Reviewer #1 for his/her time devoted and the constructive and helpful comments.

This paper investigates the role of tropopause folds in controlling high tropospheric ozone concentrations that are consistently observed in the eastern Mediterranean and the Middle East (EMME) region. The ECAM model is used to assess the frequency of strong tropopause fold events, the percentage of ozone in this region that has been transported from the stratosphere, and the interannual variability of tropopause folds. The analysis is well presented and, as the global community continues to work to set stringent yet attainable air quality standards, the topic should be of great interest to ACP readers. I believe that there are several issues, described below, that are deserving of more discussion and analysis, but recommend publication following these minor revisions.

We thank the Reviewer for the comments, to which we will respond point by point.

Specific comments:

P3, L33 – The T42 resolution (~2.8 degree) is fairly coarse for resolving these events. Finer scale models can show substantial differences in the amount of stratospheric ozone transported to the mid- and lower troposphere (e.g. see Lin et al., 2015 supplementary material). Though this resolution may be necessary for the longer timescale simulation presented in this work, the potential impact should be noted and discussed.

We agree with the Reviewer, that the potential implications of a finer resolution should be mentioned and further discussed in the manuscript. The following paragraph was added in the revised manuscript (Page 3, Lines 20-28): *"Model sensitivity studies suggest that relatively high horizontal resolution might be beneficial for the representation of tropopause fold events and the associated intrusion of stratospheric ozone into the troposphere (Kentarchos et al., 2000). Lin et al. (2012) showed that a global high-resolution (50 km x 50 km) chemistry-climate model (GFDL AM3) captures the observed layered features and sharp ozone gradients of deep stratospheric intrusions. Moreover, Lin et al. (2015) carrying out sensitivity studies with the GFDL AM3 model, pointed out that using a finer horizontal resolution of 50 km x 50 km revealed an improvement in the reproduction of the day-to-day variability in the upper troposphere, as tropopause fold filamentary structures are better resolved in the finer model resolution* *simulations. Nevertheless, they suggested that the multidecadal hindcast simulations with the coarser resolution of 200 km x 200 km were also found suitable for quantifying the regional-scale interannual variability of stratospheric influence on lower tropospheric ozone over the western US."* Please also note, that according to a comment from Reviewer #2 regarding the coarse resolution of EMAC and its respective capability to reproduce the features of tropopause folds frequency, we included Figure S1 (Supplementary Material) which reveals a good agreement between the EMAC-simulated tropopause fold activity and the results of the study by Tyrlis et al. (2014) which was based on the ERA-Interim reanalysis data (see discussion at the revised manuscript at Page 5, Lines 15-21).

P4, L8-11 – Zhang et al. (2014) showed that diagnosing the stratospheric influence over the United States was strongly dependent on how stratospheric ozone was defined (e.g. ozone produced in the stratosphere or ozone transported from the above the tropopause). It would be good to mention and discuss the implications of this assumption.
We agree with the Reviewer that different definitions of stratospheric ozone tracer are likely to have different impacts on stratospheric ozone contribution to tropospheric ozone. To this end, and following the reviewer's suggestion, the following discussion was included in the revised manuscript (Page 7, Lines 5-13): *"It should be mentioned that different definitions of stratospheric ozone tracer may have implications for the estimated stratospheric contribution, as has been pointed out by Zhang et al. (2014). More specifically, a doubling of the diagnosed stratospheric ozone influence was found in GEOS-Chem simulations when the produced ozone in the troposphere, which was temporarily transported above the tropopause, was also considered as stratospheric (Lin et al. (2012) approach). The amount of ozone that is recirculated across the tropopause in the model depends on the vertical resolution. Thus, following the approach by Lin et al. (2012) is likely to yield an upper limit to the stratospheric contribution to tropospheric ozone in our results. Nevertheless, because the presently used middle atmosphere version of the EMAC model has relatively high resolution in the upper troposphere and lower stratosphere (about 500m), and because we initialize O3s well above the tropopause (100 hPa), we expect this effect to be small."*

P6, L5 – 7 ppb is the mean enhancement for the tropopause fold composite, but what is the range? Since many people may be interested in this work from an air quality perspective, a discussion not just of the mean case but the extremes would be of great interest.

We thank the Reviewer for the suggestion. As it is mentioned in the manuscript, 7 ppb is the maximum O3 enhancement in the middle troposphere (400, 500 and 600 hPa) due to fold activity, resulting from the differences between the average O3 during fold events and the average O3 during the remainder summer timesteps. To present the range of tropopause folds impact on tropospheric ozone, we present in Figure S2 (Supplementary Material) the box-whisker plots of O3 concentrations (averaged over the regions where the positive anomalies in Fig. 5 are found) during the fold events, along with the respective average O3 concentrations during the remainder summer timesteps. According to this, the following sentence was added in revised manuscript (Pages 6, Lines 27-29): *"During extreme events (above the 95th percentile of O3 concentrations during fold events), the range of O3 enhancement is found to be 19-33, 16-31, 17-24 and 11-19 ppb at 400, 500, 600 and 700 hPa respectively (Fig. S2 in the Supplementary Material)."*

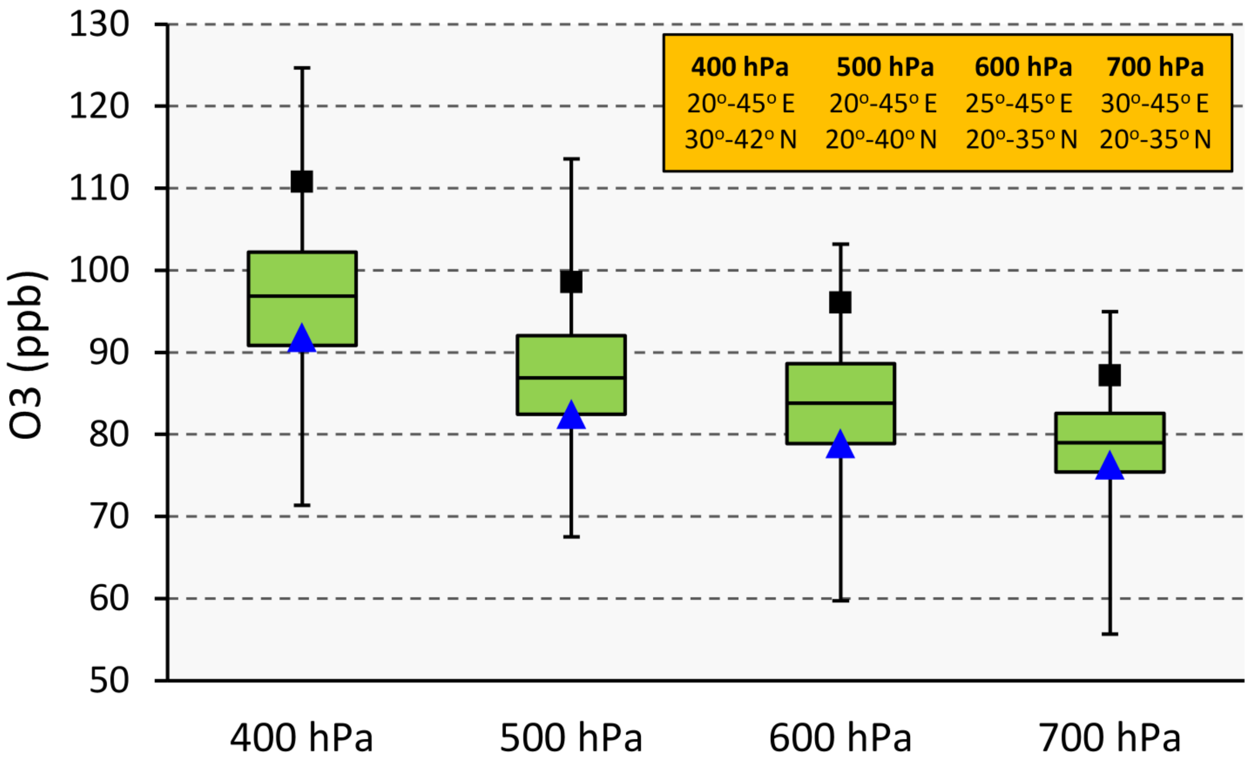

Figure S2. Box-whisker plots of O3 concentrations during fold events at 400, 500, 600 and 700 hPa. The middle line in the box shows the median O3 concentrations, the box represents the range between the 25th and 75th percentiles, the top/bottom whiskers indicate the max/min concentrations and the filled black square shows the 95th percentile. The filled blue triangle represents the average O3 concentrations during the remainder summer timesteps. O3 concentrations are calculated as the spatial average of the regions (orange table) where the positive anomalies in Fig. 5 are mainly found.

All the extra references used are added in the revised manuscript.

Please also note a few minor changes in the manuscript:

- Page 2, Line 22 *"temperature increase may raise"* is replaced with *"climate warming may intensify".*
- Page 3, Line 2 *"Specifically,"* is removed.
- Page 3, Line 31 *"which is explored"* is replaced with *"explored here"*.
- Page 4, Line 20 *"enough"* is replaced with *"sufficient"*.
- Page 4 Lines 24-25 the phrase *", however, since it is initialized above 100 hPa, only a very small fraction is recirculated by multiple crossings of the tropopause"* is added.
- Page 10, Line 5 *"modeling system"* is replaced with *"model"*.

References

Kentarchos, A., Roelofs, G., and Lelieveld, J.: Simulation of extratropical synoptic-scale stratosphere-troposphere exchange using a coupled chemistry GCM: sensitivity to horizontal resolution, Journal of the atmospheric sciences, 57, 2824–2838, 2000.

Lin, M., Fiore, A. M., Cooper, O. R., Horowitz, L. W., Langford, A. O., Levy, H., Johnson, B. J., Naik, V., Oltmans, S. J., and Senff, C. J.: Springtime high surface ozone events over the western United States: Quantifying the role of stratospheric intrusions, Journal of Geophysical Research: Atmospheres, 117, 2012.

Lin, M., Fiore, A. M., Horowitz, L. W., Langford, A. O., Oltmans, S. J., Tarasick, D., and Rieder, H. E.: Climate variability modulates western US ozone air quality in spring via deep stratospheric intrusions, Nature communications, 6, 2015.

Tyrlis, E., Škerlak, B., Sprenger, M., Wernli, H., Zittis, G., and Lelieveld, J.: On the linkage between the Asian summer monsoon and tropopause fold activity over the eastern Mediterranean and the Middle East, Journal of Geophysical Research: Atmospheres, 119, 3202–3221, 2014.

Zhang, L., Jacob, D. J., Yue, X., Downey, N., Wood, D., and Blewitt, D.: Sources contributing to background surface ozone in the US Intermountain West, Atmospheric Chemistry and Physics, 14, 5295–5309, 2014.