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

Anonymous Referee #2

We would like to thank Reviewer #2 for her/his time devoted and the constructive and helpful comments.

General comment:

The authors explore the roles of future climate change in tropospheric ozone changes using a global chemistry-climate model with artificial stratospheric ozone tracer. The results of this study emphasize the importance of downward transport of stratospheric ozone associated with tropopause folds. You've convinced me that changes in tropopause folds are regulated by upper-level jet. Also, I agree that projected increase of tropospheric ozone is associated with changes in BDC and STT. However, I find the linkage between the presence of folds and changes in ozone is relatively weak. I would expect shallow tropopause folds, which are located above 200hPa, account for the most changes in folding frequency. How do these shallow folding activities affect the ozone near 400-500hPa or even below? We know that summertime large-scale subsidence at 500hPa over Mediterranean is projected to change [Cherchi et al., Clim Dyn (2016)]. Perhaps the large changes in ozone near 400hPa are primarily associated with changes in descent, while the presence of tropopause folds is secondary. Except the one concern I've pointed out, this paper is very well structured and is certainly within the scope of ACP, although improvements can be applied to make it clearer. Therefore, I only have some minor comments.

We thank the Reviewer for the comments, to which we will respond point by point. Indeed the vast majority of tropopause folds are shallow. Nevertheless, considering that the average pressure of the tropopause in the extratropics is about 250 hPa and that the vertical extend (Δp) of shallow folds range from 50 to 200 hPa below the tropopause, the shallow foldings extend down to approximately 300-450 hPa. Of course, the large scale subsidence over specific regions, such as the summertime EMME, can further transport high ozone concentrations towards lower tropospheric levels in greater timescales. Thus, the folding mechanism enriches the upper and middle troposphere with high ozone concentrations, which might be further vertically transported under favorable meteorological conditions.

1. What's your rationale for choosing RCP6?

Please refer to our response in Reviewers' #1 Specific Comment #1.

2. Ozone is difficult to simulate in models due to biases in photochemistry processes and precursor emissions. Have you evaluated model performance in ozone? Discussion regarding how biases in EMAC would affect the estimated changes is necessary.

All ESCiMo simulations, including the RC2-base-04 simulation, are evaluated in the study by Jöckel et al. (2016) using the BSTCO (Bodeker Scientific combined total column ozone database; Bodeker et al., 2005) for total column ozone, the AURA Microwave Limb Sounder/Ozone Monitoring Instrument (MLS/OMI; Ziemke et al., 2011) for tropospheric and stratospheric partial column ozone and the ozonesonde dataset by Tilmes et al. (2012) for ozone profiles. In general the seasonal cycle and the spatial distribution of total column ozone are well reproduced in the simulation, with an overestimation of up to 9%. The following sentence has been extended in the RM: P4, L17-18 *"A detailed description of the simulation along with a comprehensive evaluation of ozone with satellite and ozonesonde measurements can be found in Jöckel et al. (2016).".*

3. In Fig.1, wintertime medium and deep fold frequency are much higher than those shown in Škerlak et al. (2015). Will it affect your results? Also, it'd be good to address that the climatological distribution of tropopause folds in your model is consistent with what shown in previous studies.

Given the fact that medium and deep folds are very rare to occur, as the order of magnitude of their frequencies in a global scale are -1 and -2 respectively (please mind the x10 and x100 notations in Figure 1) the impact on our results is expected to be very small. As concerns the climatological distribution of tropopause folds in RC2 simulation compared to previous studies, Figure 4 depicts the spatial distribution of tropopause folds frequency (green contours) for the REF period, which is also discussed compared to the climatology of Škerlak et al. (2015) in the manuscript as follows (P6, L8-13): *"The spatial distribution of fold frequencies during the REF period (green contours in Fig. 4), indicates that in principal folds occur in the regions with high zonal wind speed (colour shadings in Fig. 3). Noteworthy are the hotspots over Asia and Middle East during DJF and JJA, and over the southern Indian Ocean during JJA, whereas during the transition seasons the maxima are located over Asia in MAM, and over Asia and southern Indian Ocean in SON, being consistent with the ERA-Interim derived tropopause fold climatology of Škerlak et al. (2015)."*

4. I'm worried whether the future changes of tropopause folds are robust. Have you compared with other models?

To our knowledge, this is the first projection of tropopause fold frequencies under a future scenario, so we are not able to compare with other models and studies.

Detailed comments:

1. P18, Fig.4 caption, "black" -> "green"; "circles" -> "dots"

Done

2. P6, line 13, "contrary" -> "on the contrary"

Done

3. P7, "positevely" -> "positively"

Done

References

Bodeker, G. E., Shiona, H., and Eskes, H.: Indicators of Antarctic ozone depletion, Atmos. Chem. Phys., 5, 2603–2615, doi:10.5194/acp-5-2603-2005, 2005

Jöckel, P., Tost, H., Pozzer, A., Kunze, M., Kirner, O., Brenninkmeijer, C. A., Brinkop, S., Cai, D. S., Dyroff, C., Eckstein, J., et al.: Earth System Chemistry integrated Modelling (ESCiMo) with the Modular Earth Submodel System (MESSy) version 2.51., Geoscientific Model Development, 9, 2016

Škerlak, B., Sprenger, M., Pfahl, 5 S., Tyrlis, E., and Wernli, H.: Tropopause Folds in ERA-Interim: Global Climatology and Relation to Extreme Weather Events, Journal of Geophysical Research: Atmospheres, 2015.

Tilmes, S., Lamarque, J.-F., Emmons, L. K., Conley, A., Schultz, M. G., Saunois, M., Thouret, V., Thompson, A. M., Oltmans, S. J., Johnson, B., and Tarasick, D.: Technical Note: Ozonesonde climatology between 1995 and 2011: description, evaluation and applications, Atmos. Chem. Phys., 12, 7475-7497, doi:10.5194/acp-12-7475-2012, 2012.

Ziemke, J. R., Chandra, S., Labow, G. J., Bhartia, P. K., Froidevaux, L., and Witte, J. C.: A global climatology of tropospheric and stratospheric ozone derived from Aura OMI and MLS measurements, Atmos. Chem. Phys., 11, 9237–9251, doi:10.5194/acp-11-9237-2011, 2011