***Atmospheric Chemistry and Physics manuscript review of*:**
"Future trends in stratosphere-to-troposphere transport in CCMI models"
By: Abalos et al. 2019

Overall this is nice paper that adds new insights to the literature regarding future changes in atmospheric transport. I have some questions regarding interpretation of figures, and I hope at the same time the authors can expand/clarify a bit regarding the physical mechanisms at play (mostly in the NH extratropics between 500 hPa and the lower stratosphere). I think that sorting out and discussing the physical mechanisms in this region is important because as it stands, the authors have provided convincing explanations for the stratospheric transport mechanisms, but less so for the STT that is the main topic of this paper. Nevertheless, if those issues can be addressed, then I would be happy to recommend this manuscript for publication.

Major comments:

Comment #1 – page 2 lines 26-30: I would be a little more careful with your language here regarding the physical mechanisms underlying STT. I say this because purely quasi-isentropic mixing is only one mechanism whereby STT occurs. For example, *cross isentropic* mixing related to transverse circulations cannot be ignored even when you are talking about mixing events that begin as PV disturbances on isentropic surfaces (e.g., Langford JGR 1999). Another way to say this is that one needs to be cognizant of the fact that the actual exchange mechanism associated with wave breaking can take on a very different flavor depending on where you are on the globe. For example, quasi-isentropic mixing (at least in my mind), generally refers to the downgradient (scale-wise) mechanical mixing of filaments that occurs *along isentropes*. That is, there is not a whole lot of *cross-isentropic* mixing taking place (i.e., largely horizontal, but not so much in the vertical). This is typically the dominant mechanism in places like in the deep subtropics where STT is occurring on or near to the 350 K surface (e.g., Waugh and Polvani 2000 or Albers et al. 2016) or say in the interior of the stratosphere in the form of the south-north "eddy mixing" portions of the BDC.

In the extratropics on the other hand, and in particular in association with the polar front, wave breaking begins with three dimensional folding/corkscrewing of the tropopause along isentropes, but in this case, a great deal of the mass exchange is associated with *vertical* turbulent mixing/erosion and diabatically induced cross-isentropic mixing of the fold itself. These are the ideas discussed in Shapiro (1980), Langford and Reid (1998), Wernli and Sprenger (2007), and Sprenger et al. (2003) (as well as the Stohl STACCATO paper you reference). Now, I'm not suggesting that you go into as much detail as the Wernli/Sprenger papers, i.e., it's probably not relevant for your paper to spend time discussing the intricacies of how wave breaking STT is manifest as folds vs. streamers vs. cutoff lows; however, I do think that you should be a little more precise with your discussion of the physical mechanisms responsible for mass exchange and the fact that in different regions of the globe, there are different processes at play.

Comment #2 – page 7 lines 15-25: I must be missing something here, because when I look at Figure 5, I do not see common behavior across all models, rather EMAC and GEOS have one behavior in the NH UTLS (positive trends), while all the other models (WACCM, CMAM, etc.) have a negative trend. This seems like a pretty notable difference that needs to be addressed.

Comment #3 – page 7 lines 15-25: This question is related to my comment #2 immediately above. In Fig. 5, the negative trends in the tropical stratosphere are easily explained via the enhancement of the BDC, so that portion of your physical explanation seems fine. However, when you state that "…*as stated above, these trends around the extratropical tropopause*….", it is unclear which explanation above you are referring to because it would seem that the rise in the tropopause (which is not particularly large) cannot alone explain the bulk of the negative trends in O3S that extend all the way down to 500 hPa in the extratropics. This would leave isentropic mixing and the residual circulation to explain the trends. I can think of a couple options here, but some of them don't seem to be consistent with your streamfunction plots in Figs. 7 and 10.

For example, your streamfunction plots show that the residual circulation accelerates coming up and out of the tropics (as expected if the deep branch of the BDC accelerates), but then there is a notable region of deceleration between 30º-80º N between 10-15 km (depending on the model). Now, I'm not sure how to label this region of negative streamfunction trend though it would seem that it could qualify as being part shallow branch and part of the lowermost portion of extratropical deep branch (perhaps this distinction is a bit ill-posed), but regardless of the what aspect of the BDC it is, the fact that it weakens could plausibly mean that less ozone is being transported downwards into the UTLS, hence helping to explain the decreasing ozone trend right at or above the tropopause. And if there is less ozone around the tropopause, then there is less ozone to be mixed via tropopause folds etc into the extratropical mid-to-upper troposphere, which would in total help explain the overall negative extratropical UTLS trend. However, all of the models have the same qualitative streamfunction trend, yet as I stated above, EMAC and GEOS do NOT show the negative O3S trend. Thus, it would seem difficult to explain the extratropical UTLS trend via the residual circulation (your Fig. 8 seems to confirm this conclusion because again, all of the models have the same qualitative advective changes, yet not all models get the same extra. UTLS O3S trend).

That leaves mixing to explain the trends. However again, the eddy transports don't (at least to my eye) seem to help explain why there is a negative trend in some models but a positive trend in others.

Please help me and other readers to understand what is physically going on here.

Comment #4 – page 9 line 11: I'm not sure I agree with your statement that Fig. 9 shows that ADV is the same in all models. I would agree that it is qualitatively the same in the UTLS between -30º-30º in all models. However, the extratropical UTLS shows two different behaviors (CMAM and EMAC vs. GEOS and WACCM). And again, this seems to point to the fact that you cannot explain the different O3S trends in the extratropical UTLS shown in Fig. 5 via advection, because while in Fig. 5 EMAC and GEOS show similar behavior (positive trend), WACCM and CMAM show a negative trend, yet in Fig. 9, WACCM and GEOS have similar extratropical patterns (somewhat complicated, but consistent), while CMAM and EMAC show similar behavior (essentially no trend in the extratropics). Now I realize that s80 and O3S are different tracers, but given that they are both being advected via the same dynamics, it would seem that there should be some underlying commonality that can help rectify the different extratropical UTLS O3S patterns between the different models. Thus, it would help if the differences were at a minimum mentioned and hopefully the implications of these differences explained.

Minor comments:

Comment #1 – page 7 line 17: Where you state "…*are attributed to changes*…", instead of 'changes' can you be more precise and state what the change is? A 'decrease'?

Comment #2 – Figures: A bunch of your figures are missing pressure labels on their axis. Some figures have the labels, while other don't. Personally I find the pressure labels helpful, so perhaps you can add them for all figures?

References:

Langford, A. (1999). Stratosphere-troposphere exchange at the subtropical jet: Contribution to the tropospheric ozone budget at midlatitudes. *Geophysical Research Letters*, *26*(16), 2449–2452.

Shapiro, M. (1980). Turbulent mixing within tropopause folds as a mechanism for the exchange of chemical constituents between the stratosphere and troposphere. *Journal of the Atmospheric Sciences*, *37*(5), 994–1004.

Langford, A., & Reid, S. (1998). Dissipation and mixing of a small-scale stratospheric intrusion in the upper troposphere. *Journal of Geophysical Research*, *103*(D23), 31,265–31,276

Waugh, D. W., & Polvani, L. M. (2000). Climatology of intrusions into the tropical upper troposphere. *Geophysical Research Letters*, *27*(23), 3857 – 3860.

Albers, J. R., Kiladis, G. N., Birner, T., & Dias, J. (2016). Tropical upper-tropospheric potential vorticity intrusions during sudden stratospheric warmings. *Journal of the Atmospheric Sciences*, *73*(6), 2361–2384.

Wernli, H. and M. Sprenger (2007): Identification and ERA-15 Climatology of Potential Vorticity Streamers and Cutoffs near the Extratropical Tropopause, *Journal of the Atmospheric Sciences*.

Sprenger et al. (2003): Tropopause folds and cross-tropopause exchange: A global investigation based upon ECMWF analyses for the time period March 2000 to February 2001. *J. Geophys. Res.*