Atmos. Chem. Phys. Discuss.,
https://doi.org/10.5194/acp-2020-1085-RC1, 2020

Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Mixing at the extratropical tropopause as characterized by collocated airborne H_2O and O_3 lidar observations" *by* Andreas Schäfler et al.

Laura Pan (Referee)

liwen@ucar.edu

Received and published: 8 December 2020

Transport and mixing near the extratropical tropopause associated with the jet dynamics, relationship between the meteorological background and the chemical distribution in the extratropical upper troposphere and lower stratosphere (ExUTLS) have been an active line of research for multiple decades. An important development in the past two decades is the use of tracer-tracer correlation. This line of work has been largely fueled by new observations from new satellite and especially research aircraft data. The analysis presented in this work expands the horizon using the new generation of airborne lidar observations that provided co-located ozone and water vapor measure-

ments in a two-dimensional cross section intersects a region of active jet dynamics and stratospheric intrusion.

The authors did an excellent analysis to connect the 2D ozone and water vapor observation with all major prior studies when limited in situ sampling or coarse satellite data were available. The analysis combining the tracer space diagram and geometric space distribution using this unique 2D data is a significant contribution to the topic of ExUTLS research, and it could serve as a road map for analyzing future observations in this layer. Given that the modeling community is working toward improving spatial resolutions of the chemical transport and/or chemistry climate models to resolve the tropopause region, the method demonstrated here can be applied readily for process-specific model evaluations.

In summary, the new data presented is unique and of high value. The analysis presented contributes to the state of art on the topic of research. The large set of analysis details are presented in excellent clarity. I do have a few comments and suggestions below for the authors' consideration.

Major comments and suggestions:

1) It is too much of a missed opportunity not to include lapse rate tropopause in the analysis

An important question in the work of ExUTLS transport and STE is the relationship between various tropopause definitions, in particular, definitions of the dynamical tropopause and the temperature lapse rate based thermal tropopause from WMO. Chemical discontinuity and tracer-tracer relationship is a unique way to shed light on the physical behavior revealed by the relationship of the two definitions. The work did an excellent job diagnosing the dynamical tropopause using PV gradient versus fixed PV surface. It would be very valuable to diagnose the vertical discontinuity at the tropopause represented by the temperature lapse rate (discontinuity of the static stability) and PV contours, and the chemical mixing versus discontinuity associated with the conditions where they agree or show large separation. In this direction, it is worthwhile to present the Lapse rate tropopause on the cross section, and to show additional LRT relative profiles in Fig. 4.

I understand that you don't have vertical legs for in situ measured temperature profiles but ERA5 300m resolution data should be able to provide a good approximation.

2) It is important to have a clear message that mixing processes that created these mixed regions did not happen in the observed cross section, but rather, upstream. As we draw connections between the air masses in the observed cross-section and identify the sources of mixing in the tracer space, we consider that the measurements included the types of air masses that contributed to the mixing. This leads to the next point.

3) Missing domain can lead to misleading interpretation – arrow 2a in Fig.11

Although this is an excellent dataset, it misses an important section of the system. The clouds on the south side of the jet blocked the lidar and the cross section did not cover the lower quadrant south of the intrusion, which is a region actively involved in mixing. Because of this, the interpretation of the data in tracer space needs to take into consideration not all source regions, or the types of air masses supplied the mixing lines, are represented by the measurements. In particular, the missing section would have represented the air mass type supplies "Mix-2". It would be more consistent with the picture of two layers involved in quasi-isentropic mixing: the layer above the jet core (PT > 340K, Mix-1), and the layer below the jet core (PT < 340 K, Mix-2). The presence of the cloud is indirect evidence of upward motion that can generate mixing against the downward intrusion.

Additionally, the data scatters shown in Figs. 9a-b support the strong chemical discontinuity at the high latitude tropopause. Figure 2 also show no evidence of upward mixing across the PV tropopause. Dynamically, this region is dominated by the generally downward motion in the ageostrophic flow behind the fold. These considerations

make the two-way arrow 2a in Fig 11 and the identification of "cross-isentropic transition", which suggests the path of mixing, conceptually problematic.

Similarly, it would be good to discuss the likely implication of missing domain to Fig. 7b. What would it look like if the leading edge of the fold is filled with the TRO3 type of air masses with higher moisture?

4) Take home massages in section 4

Figure 11 is a very good way of summarizing the emerging picture from the analysis (with the arguable point re process 2a). The section 4 overall can be strengthened by a set of distinct take home massages. It would be much more effective than the continued narratives, summarizing the previous sections. A few well distilled points would also help the readers digest the results, for example, which previous understanding or school of thoughts your analysis supports, verifies, or completes? What new questions or hypotheses this work has brought forward?

Minor suggestions for specifics:

1) Mention the WISE configuration is nadir viewing, although it becomes obvious later.

2) Give the flight altitude (FL450, approx. 14 km) for readers unfamiliar with aircraft work jargons.

3) It would be helpful to have the same map projection for Figs. 1 and 2, although you may need to zoom into different areas. This is especially confusing when the track orientations are different and lat/lon grids are not labeled.

4) The inverse ozone vertical gradient on the south side of the jet is confusing to me. It may deserve a few words of discussion: Is the increase to 100 ppb ozone criterion dictated by the high latitude portion of TRO-3?

5) The observation shown in Pan et al., 2006, although not the same system, is a very closely related work of lidar cross section and in situ tracer-tracer analysis in a similar

season and region. It probably should be cited as a contrast to what you have now more than just ozone.

Pan, L. L., P. Konopka, and E. V. Browell (2006), Observations and model simulations of mixing near the extratropical tropopause, J. Geophys. Res., 111, D05106, doi:10.1029/2005JD006480.

Interactive comment on Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2020-1085, 2020.