

***Interactive comment on* “Mixing processes and exchanges in the tropical and the subtropical UT/LS” by R. James and B. Legras**

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We thank Reviewer 1 for carefully reading our manuscript and for his useful comments.

Answer to comments by Referee #1

1. General comment

For clarity, "dynamical tropopause" has been replaced by "subtropical tropopause layer". The flight sections have been superimposed to Figs 4, 7 and 10.

2. p.10644, I.23 The vertical winds are calculated from the divergence in the hybrid coordinates used by ECMWF model and integrating the continuity equation from

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the top of the model (Stohl et al., 2005). Although the mean motion is rising above the tropopause, it is not uncommon that descending motion is observed over a limited region and set of trajectories. Our sampling was indeed restricted by selecting only motion within the [10S-10N] latitude range while many tropical particles actually cross the 390-400 K levels at higher latitudes. We have extended the latitude interval to [10S-30N] and now find that the velocity is positive at all levels with a minimum value of 1.3 mm s^{-1} . The first panel of Fig. 11 has been replaced by this new curve. The main point of this panel is to show that our estimate of the mean vertical velocity is in the same range than that found by Randel et al. (2007) and Park et al. (2007).

3. p.10633, l.6-9 Modification done as suggested.
4. p.10633, l.25 The main point is that the two air masses are initially distant in composition and distance. The two effective processes to perform fast mixing of these two air masses are deep convection or conveyor belt ascent which can be very intense near frontal structures. All other processes are more local in character. We have modified the sentence to improve clarity.
5. p.10635-10636 The splitting of the parcel occurs only at the first time step. A better numerical algorithm would be to split the sub-parcels at various times, saving calculations over the initial stage of the dispersion and allowing a denser sampling of the cloud as time goes on. However, for the same final number of particles, the two methods are both legitimate and would provide the same results, besides fluctuations due to finite sampling, because the advection-diffusion equation is linear. The situation is very different if additional non linear processes are involved like for instance, condensation, if the transported quantity is water vapour. The effect of horizontal diffusion replacing vertical diffusion has been studied in Pissò and Legras (2008) who found some agreement, but probably coincidental, with Hegglin et al. (2005).

6. p.10639, I.4 Yes

7. p.10639, I.10-14

Fig.4 has been drawn mainly to show the properties of quasi-isentropic stirring and mixing. As the flight track is very localized in latitude, latitude dispersion of sources can only be due to large-scale transport. The irreversible part of the TS exchange is most probably due to small-scale diabatic processes in the vicinity of the tropopause fold (shear, turbulence,...). On the contrary, the dispersion in altitude is, at leading order, dominated by the range of altitudes met over the flight track. Hence, we cannot take the pdf dispersion in altitude as a sign of a mixing line. Indeed, the core stratospheric distribution has a range of altitude compatible with a simple descent of 1K/day in the stratosphere and a latitudinal translation from 40N to 32N.

8. p.10641,I9-12

Following the suggestions of referee 1, we have replaced "In the continuity of..." and have added the reference to Berthet et al., 2007 in this sentence: "In agreement with in situ observations of Hoor et al., 2005 in the extratropics, and Lagrangian calculations of Berthet et al, 2007."

9. P. 10642, I.20 Our reconstructions use a simple mixing equation based on two compositions for the end members, which are assumed fixed once for all for simplicity and are not allowed to vary as "tunable" parameters. Indeed, the tropospheric and the stratospheric compositions have been defined using the correlation of Fig. 2c as: $CO^T = 60$ ppbv; $CO^S = 30$ ppbv; $O_3^T = 100$ ppbv; $O_3^S = 400$ ppbv. We had unfortunately provided wrong values O_3^S and CO^S in the manuscript which have raised the attention of the referee.

We do not think that the issue of vertical gradient is important here or perhaps we are just fortunate that Fig. 2a shows that vertical gradients are rather homogeneous over the different locations sampled by the aircraft and exhibit quasi-linear

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CO and O₃ profiles above 380 K. We argue in the manuscript that this pattern can be explained by irreversible TS exchanges on the time-scale of one month.

Water vapour can not be considered as a passive tracer but needs to take into account condensation and precipitation. This study is not part of this paper.

10. p.10629, I3/4 The fact that tracer gradients exhibit a jump does not hinder the possibility of getting a mixed layer above the tropopause as stated on the same page on I19-22. The point is that, regarding vertical diabatic exchanges, we do not see the tropopause as an imperfect transport barrier as Pan et al. (2004) but as a sharp transition in mixing properties. Such a transition is consistent with the existence of a mixing layer above it and does not require to see the tropopause itself as a thick layer.
11. 10629, I.10-12 We have modified the sentence to take into account the remark of the referee. Notice however that the study of Haynes and Shuckburgh (2000) is isentropic and does not involve any diabatic motion.
12. p.10629, I.28 The exchange occurs beneath the jet mainly along sloping isentropes according to Wernli and Bourqui (2002).
13. p.10635, L.5 The sentence has been modified according to the suggestion of the referee.
14. p.10636, L.18 The sentence has been reduced to "We interpolate the ECMWF potential vorticity and potential temperature along the trajectory in order to localize our parcel with respect to the tropopause."
15. p.10636, L.28 This sentence has been reformulated as follows : "In order to investigate further the tropospheric and stratospheric sources, Fig. 4 shows the probability density function (pdf) of the locations after a 9-day backward integration of particles that contribute to the sub-tropical tropopause layer."

16. p.10637, I.7 "distribution" has been replaced by "relative proportion".

17. p.10638, I.3 "flat" has been replaced by "linear".

ACPD

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