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Interactive comment on "Stratosphere-troposphere exchange in a summertime extratropical low: analysis" *by* J. Brioude et al.

J. Brioude et al.

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The paper presents an interesting case study of stratosphere-to-troposphere exchange in a summertime extratropical low by using the reverse domain filling technique (RDF) and backward trajectories to explain unexpected features in observed tracer measurements. Using forward trajectories, the STE events were shown to be irreversible. The value of such a case study lies beside the presentation of a new data set in its use for validation of weather forecast models such as ECMWF or of dynamical processes in chemistry transport models. However, some issues have to be addressed and the structure of the manuscript improved before publication is recommended.

Specific comments:

Major points:

1) Corresponding to the ECMWF PV-analysis in Figure 10a, the air masses of flight section 3 originate in the lowermost stratosphere. The measured values of around 200 ppbv O3 and 70 ppbv CO are not unusual for this region around 20 K above the tropopause at mid-latitudes (Pan et al., JGR 2004; Hoor et al., ACP 2004). If understood correctly, the discussion about the supposed discrepancy between origin of air masses and tracer mixing ratios of flight section 3 arises from the RDF calculation which attributes tropospheric origin to the air masses. The question is therefore whether we trust the RDF or not. The discussion on P12481 L8-28 might be rendered unnecessary (see also next comment).

Reply: Reviewer 1 raises the question about the confidence we have on RDF calculations for air mass 3. As shown in Table 1, the degree of confidence we assess for the origin of air mass 3 is uncertain. However, the uncertainty does not come from eventual errors in the starting location of the back-trajectories for this group. The latter statement is demonstrated as air masses in the horizontal (Fig. 9b) and vertical (Fig. 10c) vicinity of air mass 3 all come from the troposphere. Applying the RDF technique, an uncertainty may come from an overestimation of the upward deformation of the tropopause at the location of air mass 3, which makes the aircraft flying in the uppermost troposphere (Fig. 10c) instead of in the lowermost stratosphere (Fig. 10a). Two sources of error may explain an excessive tropopause deformation: i) a too strong mid- and upper-tropospheric divergent outflow in the ECMWF cycle of analyses and forecasts, ii) interpolation errors on 3D wind velocities in the Lagrangian technique. Going further on this topic is the subject of another study in progress for which a mesoscale model is used. Nevertheless, the accuracy of back-

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trajectories may rightfully indicate a tropospheric origin for air mass 3. Then, the purpose of the discussion on P12481 L8-28 is to further identify mixing processes that would explain the origin of large ozone mixing ratios in air mass 3.

2) P12481 L8-28: It seems somehow arbitrary to pick out one specific vertical cross section along the backward trajectories and to start a RDF analysis from this position in a second step. Mixing in other locations along the back trajectories might be missed which produces errors in the interpretation. Please discuss this possibility.

Reply: The purpose of the present work is not to quantify mixing processes but to identify their impact instead. The LAGRANTO model we have used in this study is not suitable for studying mixing processes, unlike a Lagrangian dispersion particle model like FLEXPART (Stohl et al., 1995, 1998). We agree that there are other locations along the back trajectories where mixing might be missed. The farther the cross section along the back trajectories is located compared to the location of the aircraft measurement, the more likely mixing processes might have occurred and be missed in the interpretation of the RDF analysis. Starting from the aircraft airpath and going backward in time along the back trajectories, the vertical cross section that is chosen is located at the first place where strong mixing processes might have occurred, deep convection in this case. This is the reason why the choice of this specific cross-section minimizes the errors in the interpretation of the RDF analysis. The range of mixing processes that may have occurred between the time of the cross-section and the time of the observations is limited to mixing processes in the upper level divergent outflow, once air parcels have been processed by the convection embedded in the warm conveyor belt.

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A more obvious approach would be to start the RDF calculation from a grid box encompassing the flight track and to determine the air masses processed by the WCB in this box. Eventually, the air parcels surrounding flight section 3 exhibit a more stratospheric character than the ones surrounding flight sections 1 and 2. An error in the starting location of the back trajectories then could have caused flight section 3 to be (wrongly) attributed to the troposphere.

Reply: As stated above in the case of flight section 3, results on the origins by the RDF technique are not sensitive to the exact starting locations of the back trajectories. The approach with a grid box encompassing the flight track is very similar as the one we have with RDF analyses in horizontal and vertical sections intersecting the flight path. Figures 9b and 10c respectively demonstrate that air masses in the horizontal and vertical vicinity of flight section 3 all come from the troposphere.

The very low O3 and CO mixing ratios in flight sections 1 and 2 further might be explained by the specific origin of the air parcels, i.e. from the maritime lowermost troposphere in the subtropical region where both species are known to exhibit low mixing ratios (McMillan, JGR 1997). Please check this possibility by calculating 10 day backward trajectories.

Reply : We agree with the referee. In this case, 10-days backward trajectories show that air parcels from flight sections 1 and 2 come from the eastern subtropical Atlantic, moving south of the Azores high along the easterly trade winds. We have added the reference to McMillan (1997) in the revised draft.

3) The structure and readability of the paper should be improved by splitting Section 3 into a method section and a result section. The method section should present the cal-culation of the back trajectories and the RDF technique. Clarify if the trajectories used for the RDF technique were also calculated with

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Lagranto and specify further the used ECMWF fields. The new result section further might be organized in two subsections corresponding to the two separate flights.

Reply : Section 3 has been modified accordingly. It is mentioned that trajectories used for the RDF technique are also calculated with Lagranto. Used ECMWF fields are further specified.

Minor points 4) The used measurement techniques for O3 and CO, the precision and the accuracy of the measurements should be mentioned in the MOZAIC observation section. The concept of the MOZAIC program should also be explained shortly.

Reply: Following your suggestion we have added a short description of MOZAIC observations. The text that has been added: "Since 1994 the MOZAIC program (Marenco et al., 1998) has equipped 5 commercial airliners with instruments to measure ozone, water vapour, and carbon monoxide (since 2001). One aircraft carry an additional instrument to measure total odd nitrogen (since 2001). Measurements are taken from take-off to landing. Based on the dual-beam UV absorption principle (Model 49-103 from Thermo Environment Instruments, USA), the ozone measurement accuracy is estimated at $\pm$ ***[2 ppbv + 2%] (Thouret et al., 1998a). Based on an infrared analyser, the carbon monoxide measurement accuracy is estimated at*** $\pm$***5 ppbv*** $\pm$***5% (Nédélec et al., 2003) for a 30s response time. For water vapor, a special airborne humidity sensing device is used for measuring relative humidity and temperature of the atmosphere (Helten et al., 1998). Measurements of total odd nitrogen (not used here) are described in Volz-Thomas et al. (2005). Measurements for more than 26 000 long-haul flights are recorded in the MOZAIC data base (http://www.aero.obs-mip.fr/mozaic/), the scientific use is free of charge."***

5) A similar study to the present analysis had been carried out by Bethan et al. (JGR 1998). Please include a reference to this work and discuss its relevance for the here presented paper.

Reply: The work by Bethan et al. (1998) has been referred and discussed in the introduction. Text that has been added: "Bethan et al. (1998) demonstrate that well-defined chemical signatures exhibited by coherent flows in developing baroclinic waves can be used to show that interleaving of the dry intrusion and the warm conveyor belt may occur in the vicinity of the occluded front. "

6) Please clarify if PV or rPV is depicted in Figure 5 lowest panel. If it is rPV change axis and caption notation and also change the notation of the pressure to rP.

Reply: rPV and rP are depicted in Fig. 5. Accordingly, we have changed the axis and caption notation, and the notation of the pressure. Furthermore, in order to answer to an inquiry of another referee, we put in the revised version of Figure 5 both the analysed PV and the RPV signals along the flight track.

7) The accurate localization of the different air flows in the here discussed split front is expected to be a difficult task for the ECMWF model. Therefore, it would be interesting to analyze ECMWF winds interpolated onto the flight path and to compare it to measured wind directions and speeds. This evaluation would yield further information about how much we can trust the calculated back trajectories.

Reply: ECMWF winds interpolated onto the flight path compare well to measured wind directions and speeds. RMS differences along the flight track are generally less than 30° for wind directions and less than 5 ms-1

for wind speeds. The most sensitive part of the comparison stands for flight section S2 where ECMWF north-easterly winds (60-90°) poorly compare to south-easterly observed winds (120-150°). The wind direction difference in flight section S2 is reduced to less than 30° if the interpolation is made on a flight track moved 0.4° further north. Given the hypothesis of linear time evolution of meteorological features that stands between 3-hourly ECMWF fields in the present work, this comparison does not reveal a major failure of the ECMWF analyses to correctly reproduce the system, neither prevent to rely on back trajectories.

Technical comments

Reply: Typos have been corrected following your suggestions.

Figure caption 2: Suggestion to explain abbreviations or refer to text for further information.

Reply: In the caption, we refer to the text for further information on abbreviations used.

Figure caption 4: Denote x-axis with RH(%), O3 (ppbv) and remove last sentence " The scale for... "

Reply: It has been corrected.

Figure caption 5: ...Aircraft path is shown in Fig. 7 ...

Reply: It has been corrected.

Figure caption 9: Indicate integration time of the RDF reconstruction.

Reply: the integration time is written in the caption.

Figure 1 or 2: Suggestion adding flight tracks.

Reply: flight track has been added on figure 2c. Caption has been changed.

Figure 5: Please show the time series of CO instead of using the coloring. This allows better comparison between the two tracers and eventually reveals an expected anticorrelation in the stratospheric parts of the flight.

Reply: The figure 5 has been modified following your suggestion.

Figure 6: Denote x- and y-axis with CO (ppbv) and O3 (ppbv), respectively.

Reply: x and y labels have been added.

Figure 8,9,10,11,12,13: Use larger font-sizes for the colorbars and label them with PV.

Reply: The font-sizes have been changed, and the colorbar labelled.

Figure 7: Suggestion to denote the two black lines i.e. the different locations at which the cross sections are taken with Roman numbers I and II and label them correspondingly in Figs. 11 and 12.

Reply: The two cross sections have been denoted, then labelled.

Figure 10: Please label flight section 3.

Reply : Corrected.

Figure 13: Group S2 is not labeled in the figure and it is not clear if the white shaded regions are supposed to indicate groups S2 and S3. Improve figure caption.

Reply: Group S2 has been labeled. The white shaded regions show air parcels that come from the lower troposphere (pressure larger than 800 hPa) 30 h ago.

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