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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Residual circulation trajectories and transit times into the extratropical lowermost stratosphere" *by* T. Birner and H. Bönisch

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We thank the reviewer for her/his valuable comments and constructive criticism.

1) Concept of transit time, minimum pressure and related.

As far as we are aware of, the first use of these concepts appears in Rosenlof (1995), which we cited, five years before the "seminal" paper by Hall (2000). Further, Rosenlof's analysis is closely related to ours as her diagnostics are based on trajectories driven by zonal mean diabatic heating rates, i.e. by the diabatic circulation, which is approximately equal to the residual circulation. On the other hand, Hall (2000) and the other references brought forward by the reviewer rely on the (full) age of air

concept, which includes mixing on top of residual mass transport. The relationship between our analysis to these studies is therefore less clear as to Rosenlof (1995).

We certainly did not intend to treat these concepts as though they are new ideas, and our referencing of a 15 year old paper stating that our "results are qualitatively consistent with earlier results by Rosenlof (1995)" acknowledges the fact that these concepts have been around for a long time.

Nevertheless, we agree with the reviewer that it would be beneficial to the paper to also discuss the relation of the concepts as applied to residual circulation trajectories here, to those applied to age of air calculations (as in Hall, 2000; Reithmeier et al., 2008, and others). This is done in the revised manuscript.

2) Separation of circulation branches.

First, our "statements about different types of wave breaking that force these two branches" are not meant as a conclusion from the results presented. Rather, we use those statements as sufficiently well established – similar statements can be found in modern text books (e.g. Vallis, 2006, Chs. 12, 13). For example, the review paper by Plumb (2002) includes a schematic (Fig. 2 in that paper) that highlights two dominant regions of wave breaking in the stratosphere and their associated circulations (deep and shallow). It seems clear, from Charney-Drazin, that the deep branch must predominantly be forced by planetary-scale waves. The forcing of the shallow branch, on the other hand, will also include contributions from synoptic-scale waves. To be fair, planetary waves can still contribute to the shallow branch and this is clarified (incl. a reference to Plumb) in the revised manuscript.

Our study presents diagnostics that, in our view, rather clearly demonstrate a separation of circulation branches in the stratosphere (e.g. old Fig. 5). We find two extratropical regimes in aspect ratio (AR): one, roughly within 40-65 deg, with small and roughly constant AR $\sim$ 1/1000, and one, roughly poleward of 65 deg, with larger and meridionally increasing AR (there is also an indication of another plateau very close to the poles

- see modified Fig., now Fig. 6, in supplement). The integrated mass flux maximizes in the first region (40-65 deg) and decreases meridionally in the second region (poleward of 65 deg). Furthermore, almost all trajectories that enter the stratosphere in the inner tropics (roughly within 5 deg of the equator) travel deep into the stratosphere and arrive in the extratropical LMS poleward of 65 deg. Likewise, almost all trajectories that arrive in the extratropical LMS equatorward of 65 deg entered the stratosphere more toward the subtropical edge of the tropics (this is also quantified in new Fig. 5, left, see supplement). These aspects/relations are discussed/highlighted in more detail in the revised manuscript.

We agree that it would be interesting to link the different circulation branches quantitatively to regions of wave breaking. However, we believe that our diagnostic study of residual circulation trajectories is sufficiently self-contained to leave these further analyses on wave breaking for future research.

The reviewer finds "the evidence for the separation of the circulation into two branches unconvincing". She/he then centers her/his discussion around Figs. 2, 3. We agree that the circulation branches are less clear in these Figs., which is why we extended the analysis to the AR, the integrated mass flux, and entry latitudes (new Figs. 5, 6). As discussed above, Figs. 5, 6, in our view, rather clearly demonstrate a separation of circulation branches.

The revised manuscript includes the new Fig. 5 (see supplement) which includes a new diagnostic: the scaled transit time, where the scaling is given by 90 deg / abs(arrival latitude - entry latitude). The motivation for this scaling was to remove that part of the latitudinal dependency of transit time, that is related to an extended latitudinal pathlength. The Fig. shows that this scaling removes much of the latitudinal dependence in transit time for the deep circulation branch (scaled transit times roughly collapse to 4-5 years for the deep branch - latitudes poleward of $\sim$ 60 deg and altitudes above $\sim$ 50 hPa). Scaled transit times for the shallow branch (latitudes equatorward of $\sim$ 60 deg and altitudes below $\sim$ 50 hPa) remain between 1-2 years with a resulting fairly strong

transition between these two regimes.

The reviewer is right that "the relationships between mean age, pathways, and maximum altitude reached were thoroughly" discussed in the existing literature. However, the existing literature almost exclusively focuses on age of air which is (numerically and conceptually) different from the residual circulation transit time. Moreover, since age of air includes essential contributions from mixing, these diagnostics cannot easily be used to distinguish circulation branches. We are not aware that these diagnostics, applied to residual circulation trajectories, have been used previously to quantify a separation between different branches of the circulation.

Specifics

3) Results and Section 3.1

The reviewer states "the higher a parcel ascends in the tropics, the greater opportunity it has to travel poleward and hence the parcels arriving at the highest latitudes in the descending branch of the BDC are those that have traveled to the highest altitudes". This inferred relation between vertical and meridional pathlengths is not as natural as the reviewer suggests. One can certainly construct a hypothetical stratospheric circulation in which all pathlengths have the same meridional extent (say the whole hemisphere) but differ greatly in their vertical pathlength. It is true that the chance for a parcel to being mixed quasi-horizontally increases with increasing altitude, which is relevant for the full pathway and age of air. However, this is not relevant for our diagnostics as mixing is excluded by definition when the trajectories are driven by residual velocities only.

4) p. 16843, l. 17-18, vortex isolation

Transport barriers such as the polar vortex edge are certainly important for the full parcel pathway and age of air, because they greatly influence where and when mixing can take place. However, as noted above, mixing is excluded in our residual circulation diagnostics. In fact, the residual circulation does not "feel" transport barriers such as the polar vortex edge or the tropopause (see Fig. 1). Isolation of air inside the vortex does not take place in our two-dimensional residual circulation trajectory calculations.

Another issue with the reviewer's vortex isolation argument is that the meridional gradient in transit time is strongest in the LMS (see revised Figs. 3, 4 in supplement), whereas the vortex isolation is strongest higher up in the stratosphere. The strong meridional gradient in transit time around 60-70 deg is instead consistent with the dominant influence of the shallow circulation branch equatorward of 60 deg in the LMS.

References

Plumb, R. A. (2002), Stratospheric Transport, J. Meteor. Soc. Japan, 80, 793-809.

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/10/C8721/2010/acpd-10-C8721-2010-supplement.pdf

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Interactive comment on Atmos. Chem. Phys. Discuss., 10, 16837, 2010.