Atmos. Chem. Phys. Discuss., 12, C8574–C8580, 2012
www.atmos-chem-phys-discuss.net/12/C8574/2012/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Age of stratospheric air in the ERA-Interim" *by* M. Diallo et al.

M. Diallo et al.

mdiallo@lmd.ens.fr

Received and published: 25 October 2012

Answer to referee #3

We thank referee #3 for his comments and suggestions. Comments by the referee are highlighted and followed by our answers.

Major Comments:

1. ***Section 2.3. I am confused by how the age spectrum and mean age are calculated in this study. My understanding is that $F(\tau)$ in equation 1 is the age spectrum. Equations (1) and (2) are not correct because mean age is the first moment, not the mean, of the age spectrum [e.g., equation (1) of***

Scheele et al., 2005]. This is not a trivial issue: mean age weighs heavily on the tail of the age spectrum and thus could be significantly older than what is calculated from equation 1. Please clarify.

   Equations (1) and (2) have been corrected. See also the answer to referee #1.

2. ***Section 4.4, My personal opinion is to drop this section. Reanalysis data should not be used for trend analysis, especially for highly derived diagnostics such as age of air. If the authors really want to keep this part, they should also investigate what causes the trend of age.***

   If it is a matter of opinion, ours is that trends in the reanalysis need to be documented and understood, and eventually reconciled with observations and other modelling studies. In the present stage, the ERA-Interim disagrees with trends found in chemistry climate models but agrees with the observation based studies of Engel et al. (2009) and Stiller et al. (2008, 2012). It is difficult to estimate ages from observations and reanalysis are liable to biases due to a changing observation systems. However such results should not be a priori discarded especially when they do not comfort modelling results. Investigation to identify trends in the assimilation increments and relations between ages and changes in the observation systems are the focus of a forthcoming study but are beyond the scope of this work.

Minor Comments:

1. ***Page 17094, line 20, Age of air cannot be directly measured. It is deduced from CO_2 and SF_6 measurements with some assumptions [e.g., Garcia et al., 2011].***

   We are aware that there is no instrument providing a direct measure of ages. The word 'measured' has been replaced by 'retrieved'

2. ***Page 17097, line 1, Tropical pipe is not the ascending branch of the Brewer-Dobson circulation.***

   The conceptual model of the tropical pipe is clearly associated with a confinement of the tropical upwelling in Plumb (1996) and Neu and Plumb (1999). We do not mean, however, that in practice the location of the maximum average tracer gradient coincides with the boundary of the average upwelling. The sentence has been modified to avoid any confusion.

3. ***Page 17098, lines 11-15. I don't follow this statement.***

   We found that only 6% of the parcels in the mid-latitude extra-tropical stratosphere have travelled above 700 K since they entered the stratosphere or in other words that the mass flux associated with the deep Brewer circulation is much smaller than the mass flux of its lower branch. This is a mere consequence of the stratification of the atmosphere. The sentence has been rewritten to improve clarity.

4. ***Page 17099, lines 12-13, The previous sentence explains why mixing leads to older age. So why do you expect that mixing should lower the mean age?***

   Perhaps this is not clear enough but we are pointing out the apparent inconsistency between the two papers Schoeberl et al. (2003) and Schoeberl and Dessler (2011) who invoke mixing as a common explanation of two opposite observations. In the first work, young kinematic ages were explained as resulting from a standard diffusive argument: excessive mixing means that air is transported too rapidly from the tropical source and thus is too young. In the second work, old kinematic ages are explained as resulting mixing induced recirculation: too much air descending in the mid-latitude is transported back in the tropical upwelling and trapped in the stratosphere. Both effects may exist but cannot be assessed without a quantitative study. This sentence has been rewritten and fitted to the

   discussion of the new Fig. 3 showing the differences between kinematic and diabatic ages.

5. ***Page 17099, line 13, What is indeed observed?***

   The kinematic ages are systematically younger than the diabatic ages in the ERA-40. The sentence has been moved and rewritten.

6. ***Section 3.2, It would be interesting to compare the seasonal variations of the mean age with observations [e.g., Andrews et al., 2001; Bonisch et al., 2009] and models [Reithmeier et al., 2008; Li et al., 2012].***

   The mean ages of Andrews et al. (2001) are used in Fig. 4. We have redrawn our results in the online supplement in such a way that they can be directly compared with Reithmeier et al. (2008) or Li et al. (2012). We find older ages but the seasonal patterns are showing a striking agreement even in the details.

7. ***Page 17099, last paragraph, There are many factors that could cause different ages in CCMs and in this study. For example, the stronger gradient in mean age between the tropics and midlatitudes means that the tropical upwelling is weaker in this study than in CCMs. Maybe that is the most important factor. In addition, it is not clear to me why large numerical diffusion makes the mean age younger in CCMs.***

   The tropical upwelling in the ERA-Interim does not seem to be weaker than that of CCMs, see Fig.4 of Garny et al. (2011). This is confirmed by Seviour et al. (2011) who found a mean mass flux of near $6\,10^9\,\mathrm{kg\,s^{-1}}$ at 70 hPa well in the range of fluxes derived from CCMs.

8. ***Section 3.4, I suggest the authors to compare the seasonal and latitudinal variations of the age spectrum with previous model studies [Reithmeier et al., 2008; Li et al., 2012].***

The comparison is done in the online supplement and reaches again excellent agreement in the patterns with Li et al. (2012).

9. ***Page 17101, lines 8-17, I don't understand what is a "flat maximum at about 4-5 yr" and I don't see it in the figure. I suggest dropping the discussion of the two-modal spectrum structure.***

   The curves have been redrawn using a kernel that does not have the side effect of damping the annual oscillations. We agree that there is little evidence of a bimodal distribution. The paragraph has been modified.

10. ***Page 17101, lines 18-22, These statements are not consistent with what Figure 6 Comment shows.***

    The north and south hemisphere panels were unfortunately inverted.

11. ***Page 17101, line 24, consider "older ages" instead of "larger values".***

    Corrected.

12. ***Page 17102, lines 2-6, This statement is too general. Could you explain in more detail? What does age spectrum at high latitudes look like? Are there significant changes in spectral shape at polar region as reported by previous model studies?***

    We have rewritten this paragraph. As mentioned above the kernel previously used in the density estimation was producing an excessive smoothing of the oscillations. We refer to the comparison to made in the online supplement. An intriguing results is that the oscillations of the spectrum at high latitudes are shifted by a half season with respect to Li et al. (2012) but agree with the interpretation of Reithmeier et al. (2008). The three works all agree at other latitudes.

13. ***Page 17102, lines 15-19, Why the 2-3 years old air has the largest annual cycle?***

    It now appears that oscillations are maximum at the modal age and decrease at older ages in agreement with the finding of Li et al. (2012) who found an exponential decay of the amplitude up to 20 yr.

14. ***Please increase the label font size for all the figures.***

    We have enlarged the font sizes to improve legibility.

15. ***Figure 1, label for x-axis should be "elapsed time" or "transit time", not "mean age".***

The label has been corrected.

References

Andrews, A. E., Boering, K. A., Daube, B. C., Wofsy, S. C., Loewenstein, M., Jost, H., Podolske, J. R., Webster, C. R., Herman, R. L., C., S. D., Flesch, G. J., Moyer, E. J., Elkins, J. W., Dutton, G. S., Hurst, D. F., Moore, F. L., Ray, E. A., Romashkin, P. A., and Strahan, S. E.: Mean age of stratospheric air derived from in situ observations of CO_2, CH_4 and N_2O, J. Geophys. Res., 106, 32 295–32 314, doi:10.1029/2001JD000465, 2001.

Engel, A., Möbius, T., Bönisch, H., Schmidt, U., Heinz, R., Levin, I., Atlas, E., Aoki, S., Nakazawa, T., Sugawara, S., Moore, F., Hurst, D., Elkins, J., Schauffler, S., Andrews, A., and Boering, K.: Age of stratospheric air unchanged within uncertainties over the past 30years, Nature Geoscience, 2, 28–31, doi:10.1038/ngeo388, 2009.

Garny, H., Dameris, M., Randel, W., Bodeker, G. E., and Deckert, R.: Dynamically forced increase of tropical upwelling in the lower stratosphere, J. Atmos. Sci., 68, 1214–1233, doi: 10.1175/2011JAS3701.1, 2011.

Li, F., Waugh, D. W., Douglass, A. R., Newman, P. A., Pawson, S., Stolarski, R. S., Strahaness, S. E., and Nielsen, J. E.: Seasonal variations of stratospheric age spectra in the Goddard Earth Observing System Chemistry Climate Model (GEOSCCM), J. Geophys. Res., 117, D05 134, doi:10.1029/2011JD016877, 2012.

Neu, J. L. and Plumb, R. A.: Age of air in a "leaky pipe" model of stratospheric transport, J. Geophys. Res., 104, 19,243–19,255, doi:10.1029/1999JD900251, 1999.

Plumb, R. A.: A "tropical pipe" model of stratospheric transport, J. Geophys. Res., 101, 3957–3972, doi:10.1029/95JD03002, 1996.

Reithmeier, C., Sausen, R., and Grewe, V.: Investigating lower stratospheric model transport: Lagrangian calculations of mean age and age spectra in the GCM ECHAM4, Climate Dynamics, 30, 225–238, doi:10.1007/s00382-007-0294-1, 2008.

Schoeberl, M. R. and Dessler, A. E.: Dehydration of the stratosphere, Atmos. Chem. Phys., 11, 8433–8446, doi:10.5194/acp-11-8433-2011, 2011.

Schoeberl, M. R., Douglass, A. R., Zhu, Z., and Pawson, S.: A comparison of the lower stratospheric age spectra derived from a general circulation model and two data assimilation systems, J. Geophys. Res., 108, 4113, doi:10.1029/2002JD002652, 2003.

Seviour, W. J. M., Butchart, N., and Hardiman, S. C.: The Brewer–Dobson circulation inferred from ERA-Interim, Q. J. R. Meteorol. Soc., 138, 878–888, doi:10.1002/qj.966, 2011.

Stiller, G. P., von Clarmann, T., Hörfner, M., Glatthor, N., Grabowski, U., Kellmann, S., Kleinert, A., Linden, A., Milz1, A., Reddmann, T., Steck, T., Fischer, H., Funke, B., Lopez-Puertas, M., and Engel, A.: Global distribution of mean age of stratospheric air from MIPAS SF6 measurements„ Atmos. Chem. Phys., 8, 677–695, doi:10.5194/acp-8-677-2008, 2008.

Stiller, G. P., von Clarmann, T., Haenel, F., Funke, B., Glatthor, N., Grabowski, U., Kellmann, S., Kiefer, M., Linden, A., Lossow, S., and López-Puertas, M.: Observed temporal evolution of global mean age of stratospheric air for the 2002 to 2010 period, Atmos. Chem. Phys., 12, 3311–3331, doi:10.5194/acp-12-3311-2012, 2012.

Interactive comment on Atmos. Chem. Phys. Discuss., 12, 17087, 2012.