

Interactive comment on “Characteristics of lower stratospheric transport as inferred from the age of air spectrum” by F. Ploeger and T. Birner

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We thank all three reviewers for their careful considerations of the manuscript and their well thought-out comments. These certainly helped to significantly improve the paper. In the following, we address all comments and questions raised (Reviewer's comments in italics). Text changes in the manuscript are highlighted in color (except minor wording changes). The main concerns of the reviewers were:

- (i) 'The manuscript is not very focused.' (Reviewer 3)
- (ii) 'The paper is a bit long.' (Reviewer 2)
- (iii) 'The discussion is too terse in places.' (Reviewer 1)
- (iv) 'The manuscript does a poor job of discussing previous studies.' (Reviewer 3)

We have taken this criticism seriously and applied several changes to the manuscript. To intensify the focus, the paper now concentrates clearly on the main question regard-

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ing the variability of lower stratospheric age spectra on seasonal to inter-annual time scales (as suggested by Reviewer 1), and on the additional aspect regarding the effects of residual circulation and mixing on the spectrum from a global perspective. We removed 3 figures (Figs. 5, 10, 15 in the submitted version), two subsections of the discussion (Sects. 6.2, 6.3 in the submitted version), and the discussion of ENSO-related variability in Sect. 5 (suggested by Reviewer 1). The parts from the old Sect. 6.2, concerning variability of the fraction of young air, are now included in Sect. 3, which presents the results regarding seasonality. The revised discussion therefore clearly focusses on the seasonal and inter-annual variability in the age spectrum and how this variability generates the multiple peaks in the spectrum. Regarding inter-annual variability, we only discuss the QBO, as this is the dominant mode of inter-annual variability in the tropical lower stratosphere and its effects on the age spectrum have not been studied in detail, so far. The discussion of QBO-related effects in Sect. 5 is enhanced (as suggested by Reviewer 2) and an additional figure (new Fig. 12) is used, presenting easterly and westerly QBO composites, to further illustrate these effects (as suggested by Reviewer 3). A by-product of these changes is that the revised manuscript now is substantially shorter (as requested by Reviewer 2).

We changed large parts of the text and included ‘strategically placed clarifying phrases’, as required by Reviewer 1, in order to enhance clarity of the discussion. A new figure (Fig. 2) is introduced, showing the dispersal of the winter/summer tracer pulses, and is referred to in Sect. 2 and in the discussion to illustrate the transport processes discussed. In particular, we thank Reviewer 3 to point out certain passages in the text where the submitted manuscript was not precise about the existing literature. It was definitely not our intention to mix up results of this paper with what is already known. Hence, we carefully revised the manuscript in order to cite existing literature correctly and to clearly state what is known already and what is not.

General comment:

This paper uses trajectories from the CLaMS transport model driven by ERA-Interim meteorology to analyze stratospheric age of air spectra. This work provides unique and revealing insights into the stratospheric transport on various time scales and latitude regions. The authors have recently done nice work on explaining various aspects of the stratospheric mean age of air and how the residual mean circulation and isentropic mixing contribute to the observed mean age distributions. But as they mention here, the age spectra provide another level of information, in particular how the transport variability imprints on the age spectra for years afterward. The analysis is excellent and I highly recommend publication with consideration of the minor comments below. The paper is a bit long, 16 figures is quite a lot but I don't have any specific suggestions on what could be left out. Perhaps with fewer figures a bit more time could be spent explaining some of the new and unique features of the remaining plots.

Thank you for your encouraging comments. As explained in our 'General comment' above, we revised the manuscript in order to better focus and shorten it.

Minor comments:

P. 2, line 14: *awkward sentence, change to something like "comes with the benefit of allowing one to separate. . ."*

Done.

P. 2, line 35: *". . .and allows one to calculate the. . ."*

Done.

P. 2: *Just a comment that in my Ray et al. [2014] paper figure 4 shows age spectra from the TLP model with multiple peaks with clear seasonal and QBO influence. We didn't explain what caused the peaks beyond the known variability in the MERRA transport input to the model but thought you might want to include a mention of this paper here.*

We apologize for missing this reference here. A notice is included in the introduction of

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the revised manuscript version.

P. 7, line 13: “. . .allows one to quantify air. . .”

Done.

P. 8, line 13–15: *The younger tropical spectrum peak in DJF in Figure 6 is hard to see. I'll take your word for it but this figure doesn't seem to back up that statement unless I'm missing something.*

We admit that it is difficult to read this difference from the figure. We therefore explicitly state the numbers of the 20N/S average modal age in the text now (3.5 months during NH winter versus 4.1 months during summer).

P. 10, line 1–8: *Figure 9 is really nice and has so many features it takes some time to appreciate them all and what they mean. The propagation of the signals to older parts of the age spectra with time is reminiscent of the tropical tape recorder signal but has a different physical meaning. It's actually difficult to interpret physically what's going on with these signals because it's in a different phase space than we're used to thinking about. For instance, in Figure 9c-f there are anomalous peaks and troughs in the spectra that appear to propagate from the time when an event like a QBO easterly phase occurred at ages from 1-2 years for the following 4 years out to ages of 6 years. The actual air masses that were influenced by the QBO transport anomaly move around the stratosphere and many of them actually leave the stratosphere over the following 4 years and yet at this theta level and latitude range there is a signal that remains. It's as though the air influenced by the particular QBO event circulates around and enough of it comes back through this theta and latitude region to maintain an anomalous signal. That's actually remarkable! It might be worth spending a bit more time explaining the physical meaning of this plot and the features since I don't think it's obvious and I'm not even sure I'm getting the full picture.*

We significantly enhanced the discussion of the QBO-related inter-annual age spec-

trum variability in Sect. 5 (including the new Fig. 12 showing QBO composites), trying to thoroughly address all points raised by the Reviewer.

Figure 5: *in the caption the hemispheres are switched for (b) and (c).*

Yes - however, we removed this figure from the revised manuscript order to shorten the paper. The corresponding discussion now refers to Fig. 7.

Figure 6: *in the caption should be “show”*

Corrected.

Figure 7: *In the interest of shortening the paper could be one to consider removing.*

We kept this figure, but removed other figures as explained in our ‘General comments’.

Figure 9: *Really interesting as mentioned above and a lot going on here. My suggestion to be able to see the features more clearly on b,d and f primarily is to separate out the delta age, mode and RCTT that are on the right axis into their own plots. It’s hard to see their oscillation around the zero line as it is and it obscures somewhat the propagation of the pdf anomalies.*

We admit that the figure includes a lot of information. However, we think it is good to have the delta age, mode and RCTT and age spectra together in one figure to be able to relate them easily, without the need to compare different figures. As the modal age anomalies for the extratropics (Fig. 13 d/f) are characterized by particularly large scatter and contain no substantial additional information we removed these from the respective panels, following the Reviewer’s advice. Furthermore, we enlarged Fig. 13 a bit to enhance readability.

Figure 14: *Is each of the 3 lines of each color an individual month within DJF?*

Each line is the average over DJF, with different age spectra of the same color representing different latitudes within the respective latitude band (corresponding to the respective color). We state this explicitly in the caption now.

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