Dear Andrea Stenke,

we thank you and the referee for the thoughtful comments on our paper. We have included your additional recommendations in our new, revised version.

Please find below our detailed answers to the points mentioned in the review:

Model setup and confusion about temperature differences:

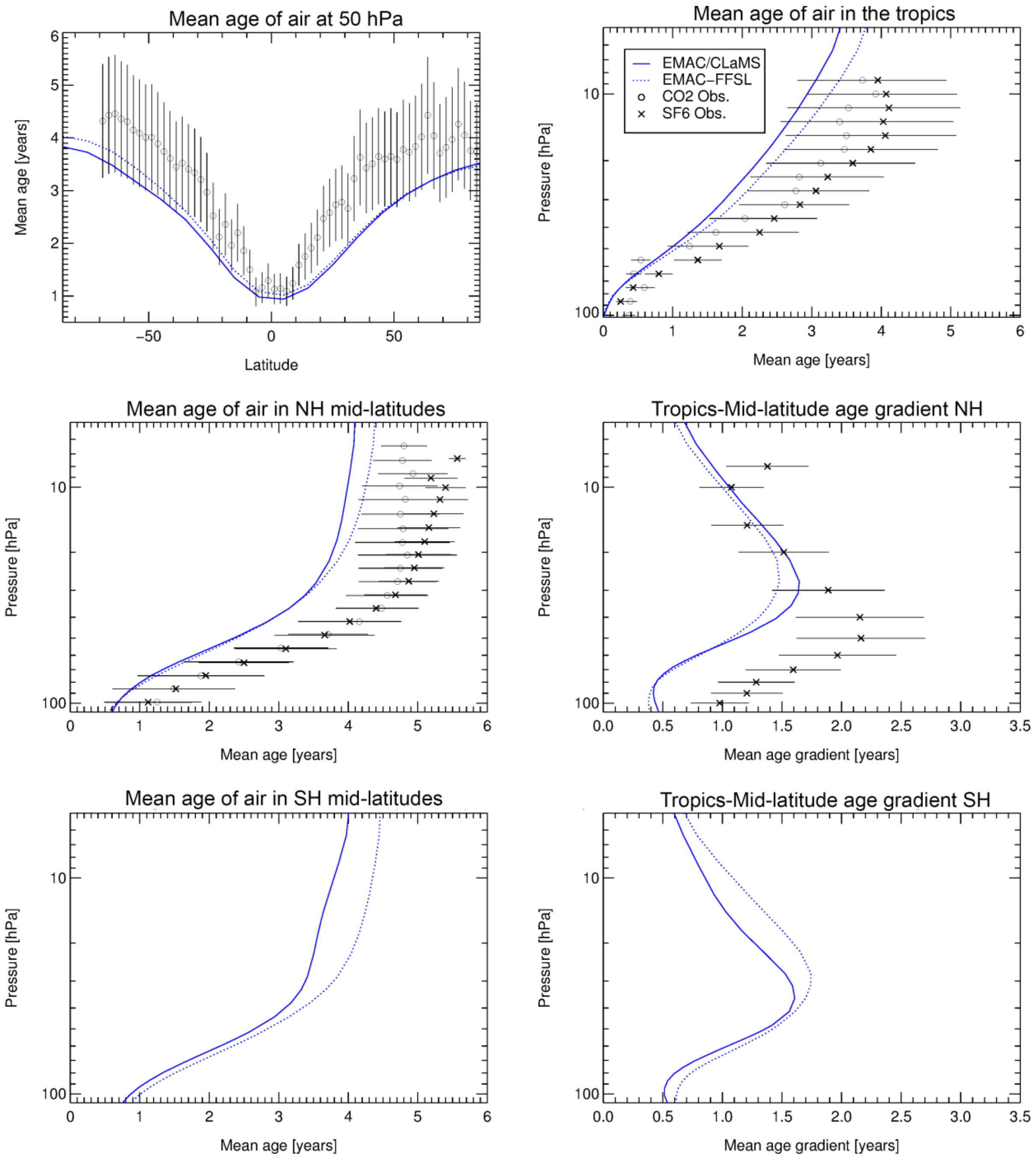
We see that the fact that both transport schemes are run in the same model simulation and that only one-way coupling was used did not become clear in the former versions of the paper. Therefore, we changed the formulation in the first paragraph of Section 3 to clearly point this out and avoid further confusion:

Here we present results of a ten-year time-slice simulation with the EMAC/CLaMS model. In this simulation, two transport schemes were applied with two similar tracer sets. The two transport schemes were run in parallel in the same climate simulation, thus the meteorological fields (e.g. horizontal winds and temperature) were identical. The only exception to this are the vertical wind fields, which were also derived from the same simulation, but using different methods (see Sections 2.1.1 and 2.2). Here one-way coupling was used, i.e. the trace gas distributions calculated in this study did not influence climate model dynamics. Tracer distributions calculated with the CLaMS full-Lagrangian transport scheme are compared to tracer fields derived from the flux-form semi-Lagrangian transport in EMAC. The transport with the full-Lagrangian transport scheme will be referred to as "EMAC/CLaMS" in the following, and the one using the flux-form semi-Lagrangian transport will be denoted "EMAC-FFSL".

Figure 2 Discussion

We thank the reviewer for the very helpful remark about the interpretation of the age gradients. In the newly revised version, we corrected the point of how to use the age gradient diagnostics in terms of tropical ascent rate. Further, to give a complete picture of the transport characteristics, we added the same diagnostic for the Southern hemisphere.

New version of Figure 2:



Zonal mean age of air [years]: simulation results of EMAC/CLaMS as solid blue line, EMAC-FFSL as dotted blue line, and mean age from measurements (SF_6 (black crosses), CO_2 (black circles), Andrews et al. (2001); Engel et al. (2009)), shown with 1σ-uncertainties. The top left panel shows zonal mean age of air at 50 hPa. The top right panel shows tropical profiles (10 N–10 S), the middle left panel NH mid-latitude profiles (35°N–45°N) and the bottom left panel SH mid-latitude profiles(35°S–45°S). The difference between the mid-latitude and the tropical profiles are presented in the middle right panel for the Northern hemisphere, and the bottom right panel for the Southern hemisphere.

We replaced the discussion of Figure 2 by:

We show mean age of air for the EMAC/CLaMS and EMAC-FFSL climatologies in comparison to mean age of air derived from measurements in Fig. 2. The latter age of air values are derived from CO_2 *and* SF_6 *measurements (Andrews et.al., 2001; Engel et.al., 2009). Figure 2 shows that both models produce a similar age of air distribution, which lies in most cases at or below the lower boundary of the one-sigma uncertainty range of the age of air values derived from measurements.*

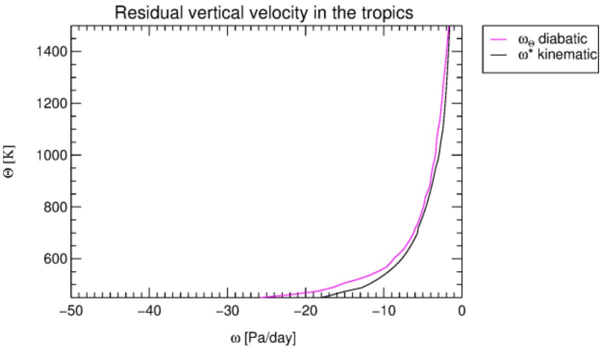
Annual zonal mean age at 50 hPa for all latitudes is displayed in the top left panel of Fig. 2. The simulated age of air pattern is consistent with the general features of the stratospheric circulation. There is upwelling of young air masses in the tropics, and downwelling of old air masses in the polar regions. Both simulations exhibit slightly older air in the Southern Hemisphere compared to the Northern Hemisphere. The age in EMAC/CLaMS is slightly younger than EMAC-FFSL in the Southern hemisphere. The differences in the zonal, annual mean between the two model representations do not exceed three months, but regional and seasonal differences may be larger.

The tropical profile for EMAC/CLaMS shows younger age than EMAC-FFSL (Fig.2, top right panel). This indicates, in the case of comparable ascent rates that the subtropical transport barriers at the edges of the tropical pipe are stronger in EMAC/CLaMS. This means that more mid-latitude air is mixed into the tropical pipe in EMAC-FFSL.

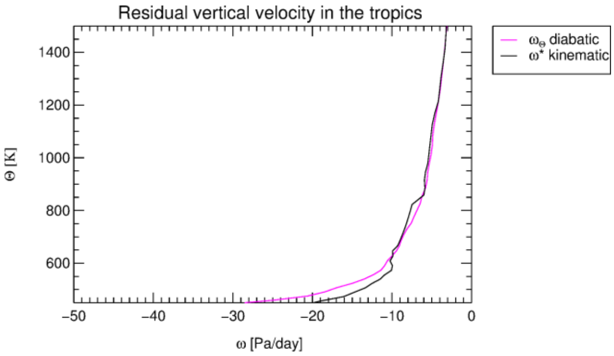
In mid-latitudes in the Northern hemisphere, age of air profiles from the two simulation climatologies are about 1 to 1.5 years younger than the age of air profile derived from CO_2 *and* SF_6 *measurements (Fig. 2, middle left panel). This is a typical feature in models, thus the profiles shown here are comparable to many models, which are compared in a similar way in SPARC (2010). A comparison of the EMAC/CLaMS and EMAC-FFSL mid-latitude profiles reveals that the age is younger in EMAC/CLaMS, in the Northern as well as in the Southern hemisphere (Fig.2, bottom left panel). However, the difference in age of air is larger in the Southern hemisphere than in the Northern hemisphere.*

The gradient (here: the difference) between the NH mid-latitude and tropical profile is shown in the middle right panel of Fig.2. The gradients derived from the simulation climatologies fit well to the measurements at high altitudes down to 30 hPa, whereas in the lower stratosphere the gradient in the model climatology is lower than in the observations. The difference between the tropical and mid-latitude profiles is slightly higher in the EMAC/CLaMS simulation for the Northern hemisphere. In contrast, in the Southern hemisphere, the gradient for EMAC-FFSL shows higher values (Fig. 2, bottom right panel). The gradient between the tropical and mid-latitude profiles can be used as a diagnostic for the tropical ascent rate (Neu and Plumb, 1999; Strahan 2009, SPARC 2010), showing that the ascent rate is too fast in both transport representations at low altitudes. However, comparing the vertical velocities in EMAC/CLaMS and EMAC-FFSL, this relatively simple diagnostic does not provide a clear result, since the EMAC/CLaMS gradient is smaller than the EMAC-FFSL gradient in the SH and larger in the NH. The differences in the annual, zonal mean ascent rates in EMAC/CLaMS and EMAC-FFSL are comparably small. However, the wind fields show a seasonal variation in strength and location which leads to hemispheric differences in the trace gas distributions. The analysis of these complex interactions between seasonal variations in the vertical velocity and trace gas distributions are ongoing work and will be discussed in a future publication.

In our simulation, we have included a diagnostic for the residual vertical velocities that are used by the two transport schemes. We do not like to include results of the vertical velocity diagnostic in this publication. The reason for this is that a description of the two diagnostics, the transformation to w*, and the analysis of the differences in the various seasons and regions is a very complex topic which requires a thorough discussion. This is beyond the scope of this model description paper. Here, we show as an example the annual, zonal mean vertical velocity comparison in the upwelling region of the tropics, where the diabatic vertical velocity used in EMAC-/CLaMS is slightly higher than the kinematic vertical velocity used in EMAC-FFSL. As an example for a different situation in NH winter, where the kinematic vertical velocity is higher in certain heights we also show a profile of the vertical velocities in January.



Annual zonal mean residual vertical velocity



January zonal mean residual vertical velocity

Figure 6 & 8 Discussions

We changed the Figure 6 and 8 discussions according to the referee's suggestion. We were a bit misled by the referee comment in the first review and over-interpreted the PDF diagnostic in the first revised version of the paper. Please find the newly revised discussions for the PDF plots below:

Figure 6:

In Fig. 6 we show N_2O PDFs at 550K from 50 S–80 S for the months August to November. Here, EMAC/CLaMS and EMAC-FFSL results are compared to satellite data from measurements of the Microwave Limb Sounder (MLS) onboard the NASA Aura satellite from 2005 to 2012. The satellite data used here is MLS version 3.3 data (Livesey et al., 2011). The PDFs show a two-peak structure, indicating the separated air masses inside and outside the polar vortex. The peak at lower N_2O mixing ratios at about 30 ppb characterizes the air inside the vortex. In EMAC-FFSL the lowest observed values are not reached, which indicates either that the downwelling in this model representation is too weak or the in-mixing from mid-latitudes too strong, or both. It is also visible that the vortex breaks up too early in EMAC-FFSL, since in October the vortex peak has nearly vanished completely. In EMAC/CLaMS, the peak position is captured well in most months except for October. The peak in EMAC/CLaMS is less pronounced than in the MLS data, but the vortex boundary is less penetrable than in EMAC-FFSL. The second peak around 200 ppb indicates mid-latitude air. The mid-latitude peak is well captured in EMAC-FFSL. In EMAC/CLaMS, the peak value is about 20 ppb higher than in the measurements. The separation (i.e. the range of low probability values) between the two peaks of the

PDF is an indicator for the strength of the transport barrier at the edge of the polar vortex. Here, using EMAC/CLaMS leads to a clear improvement compared to EMAC-FFSL. The separation between the two peaks is well captured in the Lagrangian transport representation. The comparison of CH_4 *PDFs of EMAC/CLaMS and EMAC-FFSL with HALOE measurements (Grooß and Russell, 2005) shows similar results (not shown).*

Figure 8:

In Fig. 8 we compare N_2O *PDFs from 60°N–90°N for February and March with MLS measurements, similar to the analysis for the Southern hemisphere. The peaks of the NH PDFs are wider than in the PDFs for the Antarctic, which illustrates the larger variability of the Arctic polar vortex. The PDFs show the problems of EMAC-FFSL in representing the Arctic polar vortex. In February, the peak* N_2O *mixing ratio in EMAC-FFSL of 170 ppb is much higher than in the measurements, for which the peak value is located around 100 ppb. The separation between the polar vortex air and the mid-latitude air is very weak in EMAC-FFSL. In March, the two-peak structure vanishes in the EMAC-FFSL PDF. EMAC/CLaMS shows improved vortex isolation compared to EMAC-FFSL. In February, the structure of the* N_2O *PDF from measurements is well represented by EMAC/CLaMS. In March, low* N_2O *mixing ratios below 100 ppb inside the vortex appear in EMAC/CLaMS, but they occur less often than in the measurements. Nonetheless, this constitutes a clear improvement compared to the EMAC-FFSL simulation, where no vortex structure is visible in the* N_2O *PDF in March.*