How robust are stratospheric age of air trends from different reanalysis data sets and different methods?

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An accelerating Brewer-Dobson circulation is a robust signal of climate change in climate model projections, but has been questioned by trace gas observations. We analyze stratospheric mean age of air, the average transit time for transport through the stratosphere, and the full age spectrum (transit time distribution) as a measure for the Brewer-Dobson circulation and its trends. In particular, we analyze age of air simulations with the Lagrangian transport model CLaMS and from backward trajectory calculations to assess the robustness of Brewer-Dobson circulation strength and trends in different current generation reanalysis data sets (ERA-Interim, JRA-55, MERRA-2), and the robustness of using different calculation methods. We find that from a climatological perspective mean age and the age spectrum are robust diagnostics, largely independent of the reanalysis data set used. Smaller differences between the different reanalyses show youngest mean age for JRA-55 and oldest mean age for MERRA-2 throughout most of the stratosphere. Comparison of the age spectra shows a robust representation of stratospheric transport seasonality, with similar seasonal peaks emerging for all reanalysis data sets. Long-term changes over the period 1989-2013 turn out to be similar for the different reanalysis, with mainly decreasing mean age reflecting an accelerating BDC, similar to climate model simulations. Particularly, in the lowest stratosphere (below about 500K) this mean age decrease is a robust feature in the different reanalyses, accompanied by a shift of the age spectrum towards shorter transit times and an increase in the fraction of young air masses. These changes likely indicate a robust acceleration of the shallow Brewer-Dobson circulation branch. At higher altitudes, changes in mean age are less robust in the different reanalyses, indicating a less robust response of the deep circulation branch. For the shorter period 2002-2012 age of air changes are less robust, with only ERA-Interim showing a clear hemispheric dipole pattern in age of air changes. Comparison of age of air calculated using the pulse tracer method in the CLaMS model with a pure advective backward trajectory calculation using the TRACZILLA trajectory model shows larger mean age for the purely advective calculation above about 450K and smaller mean age below. Hence, subgrid-scale mixing (as included in CLaMS) decreases mean age above about 450K and increases age below likely related to changes in vertical diffusivity, consistent with additional CLaMS sensitivity simulations with varied small-scale mixing strength. Remarkably, changes in subgrid-scale mixing may increase the young air mass fraction and the age spectrum tail simultaneously such that the net mean age change results from a subtle interplay between both effects. Hence, the representation of diffusive transport in different models may cause differences in stratospheric age of air which are particularly challenging to interpret.