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The impact of mixing on Age of Air

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Transport in the stratosphere is determined both by the mean meridional circulation and two-way mixing. Stratospheric age of air (AoA) is a measure of the integrated effect of all transport processes that affected an air parcel on its way through the stratosphere after crossing the tropopause. Mean AoA is often used to quantify the transport circulation in the stratosphere, namely the Brewer-Dobson Circulation (BDC). Global models project an increase in the mean meridional circulation in a changing climate, and simultaneously a decrease in AoA. However, evidence of changes in mean AoA from observations is weak. To infer from the AoA measurements on changes in the residual circulation, that cannot be measured directly, a better understanding of the relation between AoA and the residual circulation is necessary. Global models provide residual circulation data consistent with AoA, and thus can be used to investigate this relationship. We use trajectories driven only by the residual circulation to derive the hypothetical 'age' that air would have if it was transported only by the residual circulation. This quantity is referred to as 'residual circulation transit time' (RCTT). The difference between AoA and RCTT is then the additional aging of air caused by mixing processes. It is shown that this aging by mixing is positive throughout the lower stratosphere, only in the lowermost stratosphere at high latitudes, air is younger than expected from residual circulation transport only.

The processes of the impact of mixing on AoA are further investigated using a simple tropical leaky pipe (TLP) model. The TLP model can explain the general increase of AoA in the lower stratosphere and above by mixing with the recirculation of air parcels. Aging by mixing is dependent both on 1) the mixing strength, that controls the fraction of air that recirculates, and 2) the residual circulation strength, that controls the speed of recirculation. Thus, stronger mixing increases aging by mixing, as a larger fraction of air recirculates, while a stronger residual circulation reduces aging by mixing, as the recirculation speeds up. However, the mixing strength and the residual circulation are physically linked as both are driven by breaking waves. Therefore, an increase in wave breaking leads to a faster residual circulation but also to stronger mixing. By fitting the TLP model to the global model results, it is shown that in the lower stratosphere the total effect of stronger wave breaking is to reduce aging by mixing. Thus, the faster recirculation dominates over stronger mixing. Therefore, it can be expected that mixing effects amplify the decrease in AoA caused by a faster residual circulation.