Impact of mixing on the composition of air in the upper troposphere and lower stratosphere (UTLS): A Lagrangian view

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Inaccurate representation of mixing in chemistry transport models strongly influences the distributions of all relevant trace gases and, in particular, quantitative estimates of the stratosphere-troposphere exchange (STE). For this reason, a physics-based numerical representation of mixing is required but remains an uncertain piece in atmospheric transport models. The Lagrangian view of transport offers an alternative to exploit the numerical diffusion for parameterization of the physical mixing to find ways of avoiding this effect.

Here, we follow this concept and discuss how the Lagrangian view of mixing as parameterized in the Chemical Lagrangian Model of the Stratosphere (CLaMS) may improve our understanding of STE. We discuss how the Extratropical Transition Layer (ExTL) is mainly formed by (isentropic) eddy mixing on synoptic to seasonal time scales and how the layers of enhanced ozone in the tropical mid-troposphere often described as the S-shaped ozone profiles can be largely explained by isentropic in-mixing from the mid-latitude stratosphere. In particular, a realistic representation of water vapor (H_2O) in the extra-tropical UTLS, where H_2O mixing ratios change over several orders of magnitude when crossing the tropopause, is critical for predictions of future climate change. Based on CLaMS simulations, we show how model representation of H_2O in the stratosphere can be improved by using Lagrangian transport and how sensitive the representation of stratospheric water vapor in models is due to uncertainties in our understanding of mixing.

Although the current transport scheme in CLaMS shows a good ability of representing transport of tracers in the stably stratified stratosphere, there are still deficiencies in representation of fast convective uplift and mixing due to weak vertical stability in parts of the troposphere. Here, we show how the CLaMS transport scheme can be modified by including additional vertical mixing and unresolved convection by parametrizing these processes in terms of the dry and moist Brunt-Vaisala frequency, respectively. We analyze how well this approach improves the representation of CO_2 in the UTLS, in particular the propagation of the CO_2 seasonal cycle signal from the planetary boundary layer (PBL) into the lower stratosphere. The CO_2 values in the PBL are specified by the CarbonTracker data set and the CONTRAIL observations are used to validate the model. The proposed extension of tropospheric transport increases the tropospheric influence in the middle and upper troposphere and at the same time influences the STE although the effect on the mean age of air in the stratosphere is weak.

Key words: UTLS, stratosphere-troposphere exchange, mixing, stratospheric water vapor, Lagrangian transport