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Impact of freeze-drying, mixing and horizontal transport on water vapor in the upper troposphere and lower stratosphere (UTLS)

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Water vapor in the upper troposphere and lower stratosphere (UTLS) is a key player in the global radiation budget. Therefore, a realistic representation of the water vapor distribution in this region and the involved control processes is critical for climate models, but largely uncertain hitherto. It is known that the extremely low temperatures around the tropical tropopause cause the dominant factor controlling water vapor in the lower stratosphere. Here, we focus on additional processes, such as horizontal transport between tropics and extratropics, small-scale mixing, and freeze-drying.

We assess the sensitivities of simulated water vapor in the UTLS from simulations with the Chemical Lagrangian Model of the Stratosphere (CLaMS). CLaMS is a Lagrangian transport model, with a parameterization of small-scale mixing (model diffusion) which is coupled to deformations in the large-scale flow. First, to assess the robustness of water vapor with respect to the meteorological datasets we examine CLaMS driven by ECMWF ERA-Interim and the Japanese 55-year reanalysis. Second, to investigate the effects of small-scale mixing we vary the parameterized mixing strength in the CLaMS model between the reference case with the mixing strength optimized to reproduce atmospheric trace gas observations and a purely advective simulation with parameterized mixing turned off. Also calculation of Lagrangian cold points gives further insight of the processes involved. Third, to assess the effects of horizontal transport between the tropics and extratropics we carry out sensitivity simulations with horizontal transport barriers along latitude circles at the equator, 15°N/S and 35°N/S. Finally, the impact of Antarctic dehydration is estimated from additional sensitivity simulations with switched off freeze-drying in the model at high latitudes of 50°N/S.

Our results show that the uncertainty in the tropical tropopause temperatures between current reanalysis datasets causes significant differences in simulated water vapor in the lower stratosphere of about 0.5 ppmv. We further find that small-scale mixing increases troposphere-stratosphere exchange causing moistening of the tropopause region and the tropical stratosphere. Besides, there is an enhancement of water vapor along the subtropical jets, particularly in the Southern hemisphere, and in the Asian monsoon in the UTLS. In the Northern extratropics above about 430K potential temperature, small-scale mixing causes drying by increasing horizontal transport between tropics and extratropics. The negligible effect of a transport barrier along the equator shows that the impact of intrahemispheric exchange on water vapor in the UTLS is very weak. Comparison to simulations with transport barriers in the subtropics, on the other hand, shows the effect of the Asian monsoon in moistening middle and high latitudes and the impact of transported dry air from the tropics towards high latitudes.