Geophysical Research Abstracts
Vol. 21, EGU2019-14468, 2019
EGU General Assembly 2019

The influence of mixing on stratospheric transport today and in the future

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Deficits in simulating transport along the Brewer-Dobson circulation (BDC) in global models can lead to biases in tracer distributions, and subsequently to model biases via radiative coupling. Therefore, we analyze stratospheric mean age of air (AoA) simulated by the Chemistry Climate Models (CCMs) that participated in the CCMI (Chemistry-Climate Model Initiative) project to study the models' capabilities to represent the BDC. The well-known large model spread in stratospheric AoA is investigated by untangling the effects of the two mechanisms that control AoA, namely mean transport along the residual circulation and two-way mixing.

In the hindcast simulations, we find that the AoA model spread is caused to a small extent only by differences in residual circulation strength, the main reason are differences in the relative strength of mixing, the so-called mixing efficiency. Possible reasons for the large differences in mixing efficiency between models are subgrid scale mixing, advection schemes, resolution dependence and the relative contribution of resolved versus parametrized wave forcing. However, as each of those factors vary between models, the individual influences of these specific features are hard to disentangle with the given methodological approach.

In the climate projection simulations, the models consistently predict an acceleration of the BDC due to climate change. However, the strength of this acceleration varies considerably among the individual models and thus we find a large model spread in the magnitude of the AoA decline over the simulation period. While large parts of the AoA trend can be attributed to the well known acceleration of the residual circulation, we reveal that the mixing efficiency decreases in most models. The decrease in the mixing efficiency (i.e. mixing strength increases less strongly than the residual circulation) causes an additional decrease in AoA, contributing about 10% to the long-term AoA decrease over the 21st century. Furthermore, we show that model differences in mixing efficiency trends among models considerably enhance the model spread in AoA trends. We present evidence that the trends in mixing efficiency are likely caused by changes in potential vorticity gradients.

The studies presented here imply that both for the spread in mean stratospheric transport among models as well as the simulated trend in AoA, mixing plays an important role, and constraining the mixing efficiency better will be key to improved simulations of stratospheric transport.