The impact of model numerics on trace gas transport in the stratosphere: A dynamical core benchmark test using the age of air

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Accurate transport of trace gases continues to be a challenge in atmospheric models. Uncertainty in trace gas transport is one of the key sources of spread in simulations of stratospheric ozone loss and recovery, potentially a larger source of error than that associated with ozone chemistry (Karpechko et al. 2013). Such differences also impact the distribution of volcanic aerosols and water vapor in models, with significant implications for radiative transfer. We create a test bed to quantify and understand the impact of model numerics on trace gas transport in atmospheric models. Our benchmark tests reveal a substantial spread in tracer transport, even in state-of-the-art dynamical cores, but also allow us to quantify systematic improvements in tracer transport with increased resolution, particularly in the vertical.

We compare 4 atmospheric dynamical cores developed by the Geophysical Fluid Dynamics Laboratory and the National Center for Atmospheric Research, which employ different underlying numerics (pseudospectral, finite volume, and spectral element) and grids (latitude-longitude, cubed sphere). They are identically forced with an idealized scheme that generates a realistic climatological circulation, and an idealized tracer (age of air) is used to study their tracer transport. The idealized forcing helps us focus exclusively on the impact of model numerics and resolution on tracer transport by removing any possible uncertainties associated with parameterizations. The models agree remarkably well in terms of their circulation, but differ substantially in terms of the age-or-air distribution, suggesting that differences in numerics have greater impact on tracer transport than dynamics.

We assess and interpret differences in the tracer transport with the conceptual leaky pipe model (Neu and Plumb 1999) using the theory of Linz et al (2016) to quantify the contribution of key transport processes: advection, isentropic mixing and diffusion. This analysis allows us to identify inconsistencies in tracer transport in the pseudospectral core, and quantify improvement in tracer transport in more modern cores as the vertical and horizontal resolution is enhanced. Moreover, quantification of diffusive fluxes reveals that the vertical diffusion rapidly decays with increasing vertical resolution, suggesting that improving vertical resolution (more so than improving horizontal resolution) will improve stratospheric trace gas transport in models.

Key words: trace gases, atmospheric models, ozone loss and recovery, stratospheric transport and mixing

References

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