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2D tracer transport on Cartesian and icosahedral grids: scheme comparisons for idealized test cases

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The distribution of tracers in the atmosphere results from the presence and emission of gaseous and particulate matter, as well as their transport, sedimentation and (photo-)chemical transformations. Understanding and quantifying these processes in the atmosphere can be addressed through the use of global-scale or regional-scale chemistry-transport numerical models such as CHIMERE (Mailler et al., 2016).

While possible in principle, it is impractical to use this model to represent long-range transport of dense plumes of gas and aerosols, resulting for instance from massive emissions by volcanic eruptions, forest fires and desertic aerosol tempests. Indeed such studies requiring both large domains and high resolution have a prohibitive numerical cost due to the formulation of CHIMERE on a regular Cartesian mesh. This limitation is shared by all currently operational chemistry-transport models. Additionally, traditional Cartesian meshes pose a numerical singularity at the poles, where the longitude lines converge.

These limitations may be lifted by replacing CHIMERE's Cartesian mesh by a fully unstructured mesh. This would allow modelers to vary resolution in space, and hence to focus computational resources in key regions with sharp variations (e.g. volcanic eruptions) where high spatial and temporal resolution is required.

As a first step in this direction, we compare the numerical performance of transport schemes formulated on Cartesian meshes and schemes formulated on unstructured meshes (Dubey et al., 2015). To focus on differences due to numerics, the unstructured mesh is a quasi-uniform icosahedral mesh such as the one used by global dynamical core DYNAMICO (Dubos et al., 2015). Spatial and temporal coupled and de-coupled schemes of various order are implemented in each mesh framework. A suite of test cases is used to evaluate different properties of the mesh-scheme pairings.To avoid the Cartesian pole singularity, the Cartesian mesh covers a limited domain excluding the poles. Analytical wind fields adapted to this limited domain are used. Metrics are evaluated using the quantities obtained in the simulations, such as convergence using root mean square errors, shape preservation using non-linear tracer relations, and diffusion using total entropy. The stability and monotonicity of the used schemes are also numerically validated.

We find that a scheme of the Van Leer family on the unstructured mesh has a performance slightly inferior to a similar scheme on a Cartesian mesh. However, since this loss in quality remains moderate, it should be possible to more than compensate for it with a variable resolution. We are currently investigating this question and will present variable-resolution results if this ongoing work is timely completed. If successful, fully unstructured meshes would be a significant step forward in the modeling of scale interactions in atmospheric chemistry, and would potentially allow breakthrough for the understanding of such interactions.