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Towards higher fidelity simulations of aerosol growth in aircraft plumes for feasibility and impact assessment of sulfate stratospheric aerosol injection

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There are many uncertainties surrounding solar radiation management (SRM), not in the least concerning the technological feasibility of hypothetical deployment scenarios. In sulfate stratospheric aerosol injection (SAI) scenarios, the radiative effectiveness of the aerosol is governed by its size distribution. In turn, aerosol size distribution is governed by the aerosol-precursor injection rate and injection plume conditions. Hence, uncertainties in cost and environmental impact of aircraft-based sulfate stratospheric aerosol injection (SAI) are primarily determined by uncertainties in injection plume conditions. In addition, the climate impacts and side effects of SAI as simulated by climate models depend on the prescribed initial conditions concerning aerosol characteristics, which also hinge on injection plume dynamics and microphysics.

Up to now, studies into aircraft-based SAI have used simplified plume models, which estimate plume dynamics with considerable uncertainty, and which do not account for effects of the local plume dynamics on the microphysical processes. Here, we work towards reducing this uncertainty by using full computational fluid dynamics representations of plume dynamics within simulations incorporating state-of-the-art microphysics models for the computation of aerosol size distributions in aircraft engine plumes.

In order to anchor our approach in the current literature, we first consider simplified problems with the objective of validating our methodology using existing results. These experiments confirm the attainability of favourable initial aerosol size distributions under roughly the same conditions as shown with other lower-fidelity models. However, our results retain disagreement with respect to previous studies concerning the exact aerosol growth behaviour, highlighting a sensitivity to model choice which may also explain apparent contradictions in those previous studies.

We then consider a RANS computational fluid dynamic representation of an engine plume. This differs from the simplified plume representation in several ways, including realistic local variations in temperature, vorticity, and eddy viscosity resulting from the inflow determined using a state-of-the-art engine model. This representation is currently being employed in combination with the

previously validated microphysical models to simulate realistic aerosol size evolutions for aircraft-based delivery scenarios.

We anticipate our results to (1) provide a higher-confidence foundation on which to base the discussion concerning technological feasibility of SAI-based SRM and (2) constrain the uncertainty range of inputs for model and impact studies, improving reliability of simulations of (desired and undesired) effects of potential SRM scenarios and thereby informing the scientific and public debate.