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Analysis of subgrid-scale vertical transport in convective boundary layers at gray-zone resolutions

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The gray zone of a physics process in numerical models is defined as the range of model resolution in which the process is partly resolved by model dynamics and partly parameterized. In this study, we examine the effects of grid size on resolved and parameterized vertical transport for horizontal grid scales including the gray zone. To assess how stability alters the dependency on grid size, four convective boundary layer (CBL)s with different surface heating and geostrophic winds are considered. For this purpose, reference data for grid-scale (GS) and subgrid-scale (SGS) fields are constructed for 50–4000 mesh sizes by filtering 25-m large-eddy simulations (LES) data.

As wind shear becomes stronger, turbulent kinetic energy and the vertical transport of potential temperature and momentum are more resolved for a given grid spacing. A passive scalar with bottom-up diffusion behaves in a similar fashion. For a top-down diffusion scalar, the cospectral peak scale of the scalar flux is larger than the horizontal size of the thermals and increases in time. For the scalar, the entrainment ratio, in conjunction with the shear, influences the mesh-size dependency of GS and SGS transport. The total vertical transport of heat and the bottom-up scalar is decomposed into a non-local mixing owing to the coherent structures and remaining local mixing. The contribution of the resolved parts is larger when roll-like structures are present than when only thermals exist, for both non-local and local fluxes. The grid-size dependency of the non-local flux and its sensitivity to stability predominantly determines the dependency of total (non-local plus local) transport.