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On the parameterization of atmospheric convection with a realistic plume model

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In this work, we present an alternative theory for the parameterization of atmospheric convection based on plumes with a realistic description. The convective source terms, which provide the feedback of the convection upon the large-scale variables are obtained by performing a sub-grid averaging, considering that the convective variables are fluctuations from the mean, large-scale, state. In this way, we do not need to consider that the large-scale is described by the environmental state, which means that we do not need to consider that the fractional area occupied by the convection is very small. Thus, our formulation can be implemented in numerical weather prediction (NWP) and climate models with high resolutions, in which case a stochastic representation for the fractional area occupied by the convection in every grid box must be considered. In our parameterization, the convective variables in each grid box are described by one round steady-state convective plume placed in the center on the box with radial profiles which respect the condition that the convective variables represent fluctuations from the mean state. Performing an integral analysis over the plume's domain in the radial direction, we obtain a system of ordinarily differential equations (ODE) which take into consideration both the buoyancy-driven and the turbulent entrainment, offering thus a more accurate description of the convective dynamics then the classic entrainment hypothesis. Moreover, the influence of the large-scale is taken into consideration at any height, not just at the cloud base as in the standard mass-flux formulation. The system of ODE that we obtain can be analytically solved between the vertical grids of the NWP or climate models if we consider that the plume radius is constant and we use the scaling argument that the buoyancy-driven entrainment scales with the inverse of the height. The radial coefficients which result from the radial integration of the plume can be obtained by prescribing the exact form of the radial profiles of the vertical velocity, scalar components and turbulent fluxes, or determined using large-eddy simulations. The closure of our model consists in prescribing the vertical velocity and the radius of the plume at the initial level, which can be considered to follow a given probability density function as in the existing stochastic parameterizations.