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A modulated gradient model for large-eddy simulation: application to a neutral atmospheric boundary layer

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The subgrid-scale (SGS) parameterization represents a critical component of a successful large-eddy simulation (LES). It is known that in LES of high-Reynolds-number atmospheric boundary layer turbulence, standard eddy-viscosity models poorly predict mean shear in the near-wall region and yield erroneous velocity profiles. In this paper, a modulated gradient model is proposed. This approach is based on the Taylor expansion of the SGS stress, and uses local equilibrium hypothesis to evaluate the SGS kinetic energy. To ensure numerical stability, a clipping procedure is used to avoid local kinetic energy transfer from unresolved to resolved scales. Two approaches are considered to specify the model coefficient: a constant value of 1, and a simple correction to account for the effects of the clipping procedure on the SGS energy production rate. The model is assessed through a systematic comparison with well-established empirical formulations and theoretical predictions of a variety of flow statistics in a neutral atmospheric boundary layer. Overall, the statistics of the simulated velocity field obtained with the new model show good agreement with reference results and a significant improvement compared to simulations with standard eddy-viscosity models. For instance, the new model is capable to reproduce the expected log-law mean velocity profile and power-law energy spectra. Simulations also yield streaky structures and near-Gaussian probability density functions of velocity in the near-wall region. It is found that using a constant coefficient of 1 yields a slightly excessive SGS dissipation, which is corrected when the coefficient is modified using the above mentioned correction.