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Dynamic Smagorinsky models in LES of the atmospheric boundary layer over a daily cycle

J. Kleissl(1), **C. Meneveau**(2), M. B. Parlange(3,2) & V. Kumar(2)

(1) Michigan Tech. University USA (kleissl@mtu.edu), (2) Johns Hopkins University (meneveau@jhu.edu), (3) EPFL (marc.parlange@epfl.ch)

Large Eddy Simulation (LES) of turbulent atmospheric boundary layer flow is performed over a homogeneous surface with a diurnal heat flux forcing, covering a wide range of stabilities. The goal is to test the performance of dynamic models in a numerical framework, and to compare the results with those obtained in a recent field experimental study (HATS, Kleissl et al. 2004). In the dynamic model, the Smagorinsky coefficient is obtained from test-filtering and analysis of the resolved large scales during the simulation. Two versions of the dynamic model are examined: the scale-invariant dynamic model that assumes the coefficient to be independent of filter scale, and the scale-dependent model that does not require this assumption. In the simulation, the numerical prediction of the coefficient from the scale-invariant model is too small, whereas the coefficients obtained from the scale-dependent version of the model are consistent with results from HATS. Interestingly, in the mixed layer, the dynamically computed coefficient exhibits hysteresis behavior wherein different values of the coefficient are obained during the evening and morning transitions. As a consequence, neither a surface layer parameter (Obukhov length) nor other stability parameters (gradient Richardson number) can uniquely characterize the coefficient during the important transition times. We conclude that the dynamic model, which does not require such model characterizations, is an attractive strategy for LES of the atmospheric boundary layer at moderately stable, neutral, and unstable stratification. Conversely, simulations under strongly stable conditions display instabilities that point to basic flaws within the eddy-viscosity closure, no matter how accurately the coefficient is determined from the scale-dependent dynamic model. More research is needed to address subgrid-scale parameterization for strongly stable conditions.