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Large eddy simulation of statically stable atmospheric boundary layers: the effect of stability on SGS modeling

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Vertical density gradients plays an important role in modulating the dynamics of turbulence in boundary layer flows. Convectively unstable flows have a positive density gradient that contributes to turbulence generation and significantly enhances vertical mixing. Convectively stable flows have a negative vertical density gradient that dissipates turbulent kinetic energy and often results in weak and highly anisotropic turbulence, gravity waves, instabilities, and meandering motions that are not observed in neutral or convectively unstable flows. These features of stable flows complicate both modeling and measurements in stable atmospheric boundary layers. However, recent evidence suggests that the large eddy simulation (LES) technique yields better results under stable conditions than classic, Reynolds averaged, numerical simulations. Nevertheless, LES results remain quite sensitive to the modeling of the unresolved, subgrid scales of turbulence and this modeling is in turn sensitive to the convective stability of the flow. For example, the relation between the model coefficients for momentum and heat (the SGS Prandtl number) directly depends on stability.

To perform reliable LES of the stable ABL, we extended a Lagrangian scale-dependent dynamic SGS stress model to the SGS scalar fluxes. The current model calculates both the Smagorinsky coefficient and the SGS Prandtl number dynamically. The Lagrangian averaging allows a spatially-local determination of the model coefficients while the scale-dependent formulation can adjust, near the surface, to the change in the integral scale as it approaches the filter scale. Simulations for stable, neutral, and unstable atmospheric boundary layers with homogeneous and heterogeneous surface fluxes are carried out to investigate the effect of stability and surface variability on the turbulent kinetic energy budget and mixing in the ABL, with a special emphasis on the implications for turbulent transport similarity and turbulence closure in coarse atmospheric models.