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An actively coupled momentum and heat flux subgrid-scale turbulence model for large-eddy simulation of flow in the planetary boundary layer

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We previously developed a generalized linear algebraic subgrid-scale (GLASS) model for the subgrid-scale (SGS) stress and passive heat flux. This version of GLASS included production, dissipation, and pressure redistribution terms. With the inclusion of a passively coupled turbulent heat flux model, GLASS is applicable to a range of atmospheric stability conditions for the dry atmosphere. Now we include an additional buoyancy term in our SGS stress model, which actively couples the SGS heat flux with the SGS stress.

Prior LES at various resolutions in a neutrally-stratified boundary layer flow over a flat, rough surface indicate that the GLASS model is a more physically complete SGS stress turbulence model that provides near-wall anisotropies that eddy-viscosity models do not and yields proper shear stress values in the logarithmic layer. In addition to near-wall stress anisotropy, GLASS represents the SGS heat flux anisotropy for wall-bounded flows that isotropic eddy diffusion models cannot. The heat transport in the temperature field of wall-bounded shear flows is known to be anisotropic at inertial and dissipative scales (Warhaft, Annual Review of Fluid Mechanics 32, 2000, 203ff). We have applied GLASS to moderately convective and stable boundary layers and found that GLASS predicts the evolution of resolved and SGS turbulent quantities at least as well as the LESs with diffusion models, while including additional physics.

For this presentation, we revisit our previous convective and stable boundary layer simulations and apply the actively-coupled SGS stress and heat flux model to a suite of simulations with a wider set of stability conditions and forcings. Our sheared, convective boundary-layer LES mimics the geostrophic forcing cases of Fedorovich and Conzemius (Acta Geophysica 56, 2008, 114ff). For model comparison, we created a moderate stable boundary layer as in Zhou and Chow (Journal of the Atmospheric Sciences 68, 2011, 2142ff). Lastly, we briefly study a transitioning convective boundary layer (Sorbjan, Boundary-Layer Meteorology, 123, 2007, 365ff) to highlight that GLASS can be applied to various stability conditions without the need of tuning model coefficients. Results of these simulations and previous resolution studies show that GLASS overcomes the need to alter model coefficients for different positions in the flow, grid/filter aspect ratios, and atmospheric stabilities, etc.