Univariate Flux Partition Functions for Planetary Boundary Layer Schemes at Gray Zone Resolutions

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When the horizontal grid spacing of a numerical weather prediction model approaches kilometer scale, the so-called gray zone range, turbulent fluxes in the convective boundary layer (CBL) are partially resolved and partially subgrid-scale (SGS). Knowledge of the partition between resolved and SGS turbulent fluxes is key to building scale-adaptive planetary boundary layer (PBL) schemes that are capable of regulating the SGS fluxes with varying grid spacing. However, flux partition depends not only on horizontal grid spacing, but also on local height, bulk stability of the boundary layer and the particular turbulent flux. Such multivariate functions are difficult to construct analytically, so their implementations in scale-adaptive PBL schemes always involve certain levels of approximation that can lead to inaccuracies. This study introduces a physically-based perspective for the flux partition functions that greatly simplifies their implementation with high accuracy. By introducing an appropriate scaling length λ that accounts for both height and bulk stability dependencies, the dimensionality of the partition functions is reduced to a single dimensionless group. Based on the analysis of a comprehensive large-eddy simulation dataset of the CBL, it is further shown that λ 's height and bulk stability dependencies can be separately represented by a similarity length scale and a stability coefficient. The resulting univariate partition functions are incorporated into a traditional first-order PBL scheme, i.e. the Yonsei Univeristy (YSU) scheme in WRF, as a proof of concept. Our results show that the augmented scheme sYSU well-reproduces the SGS fluxes at gray zone resolutions, comparable or even slightly better than estabilished scale-aware scheme, Shin-Hong (SH) in WRF.

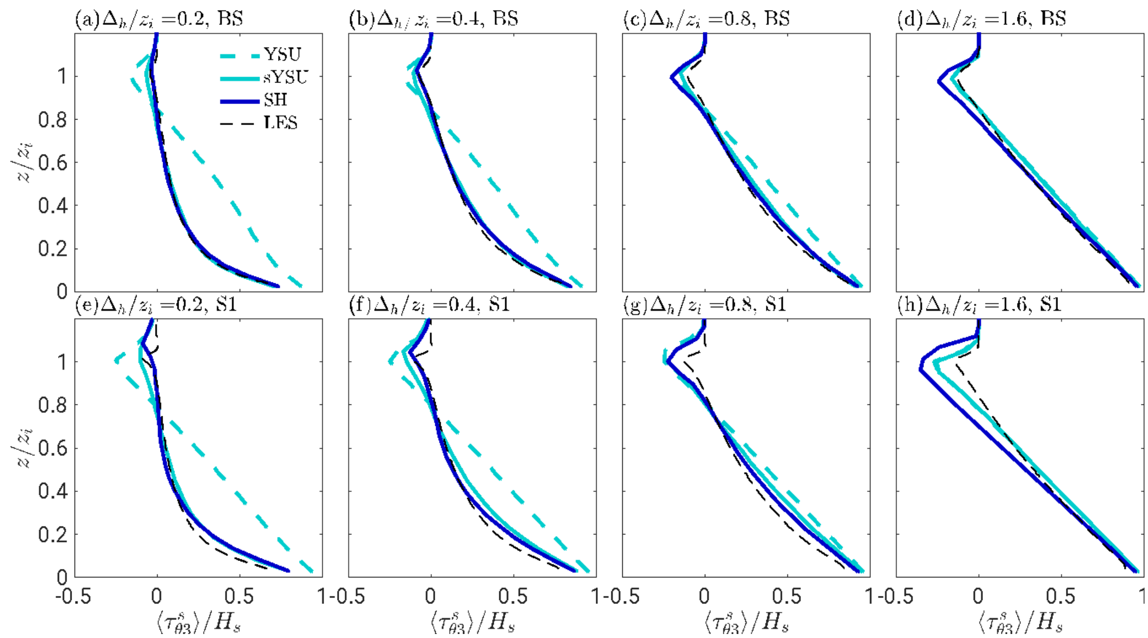

Fig.1. Time-averaged vertical profiles of normalized SGS heat flux simulated by different schemes at (from left to right) $\Delta_h/z_i = 0.2$, 0.4, 0.8 and 1.6, Δ_h is the horizontal grid spacing, z_i is the boundary layer height. The top and bottom panels present results for cases BS and S1 (with different bulk stability), respectively. Black dashed lines represent the LES benchmark profiles.

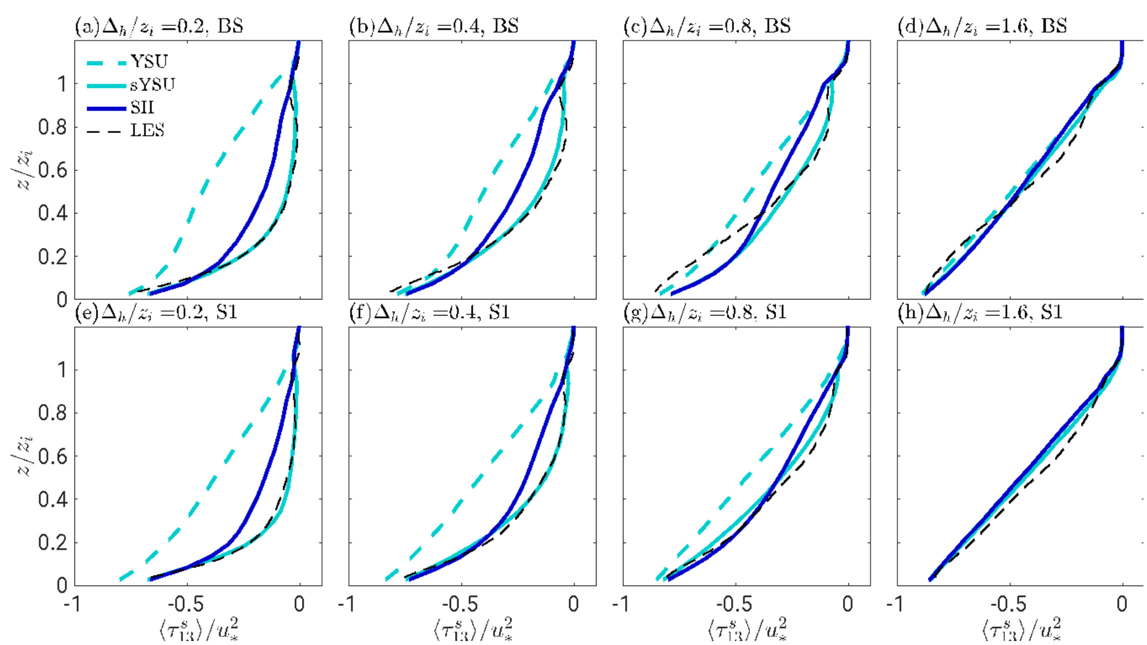

Fig.2. As Fig. 1, but for streamwise momentum flux.