Evaluating turbulent length scales from local MOST extension with different stability functions in first order closures for stably stratified boundary layer

Andrey Debolskiy[1,2,3], Evgeny Mortikov[1,3,4], Andrey Glazunov[1,3,4], and Christof Lüpkes[5]

[1] Moscow State University, [2]Institute of atmospheric physics RAS, [3]Moscow Center of Fundamental and Applied Mathematics,
[4]Institute of Numerical Mathematics RAS, [5]Alfred Wegener Institute for Polar and Marine research

and.debol@srcc.msu.ru

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Introduction

Monin-Obukhov similarity theory for surface layer:

$$\frac{\partial \mathbf{U}}{\partial z} = \frac{\mathbf{u}_*}{\kappa z}\phi_m(\zeta)$$
$$\frac{\partial \theta}{\partial z} = \frac{\theta_*}{\kappa z}\phi_h(\zeta)$$

First order 1d turbulent closures:

$$\tau = K_m \frac{\partial \mathbf{U}}{\partial z}, F_z = K_h \frac{\partial \theta}{\partial z}$$
$$K_{m,h} = f_{m,h} l^2 \left|\frac{\partial \mathbf{U}}{\partial z}\right|$$

Generalized MOST for extention to ABL by assuming fluxes in Obukhov length are defined localy, makes possible to connect surface stability functions to stability functions of first order closure: $\Lambda = \frac{u_*^2}{\beta \kappa \theta_*}$

$$f_m = \phi_m^{-2}(\zeta),$$
$$f_h = \frac{1}{\phi_m(\zeta)\phi_h(\zeta)}$$

To solve them for local mean variables: $$\mathrm{Ri}_g = \frac{\beta \frac{\partial \theta}{\partial z}}{\left|\frac{\partial \mathbf{U}}{\partial z}\right|^2} = \frac{\beta \theta_* \kappa z}{u_*^2}\frac{\phi_h}{\phi_m^2} = \frac{\zeta \phi_h}{\phi_m^2}$$

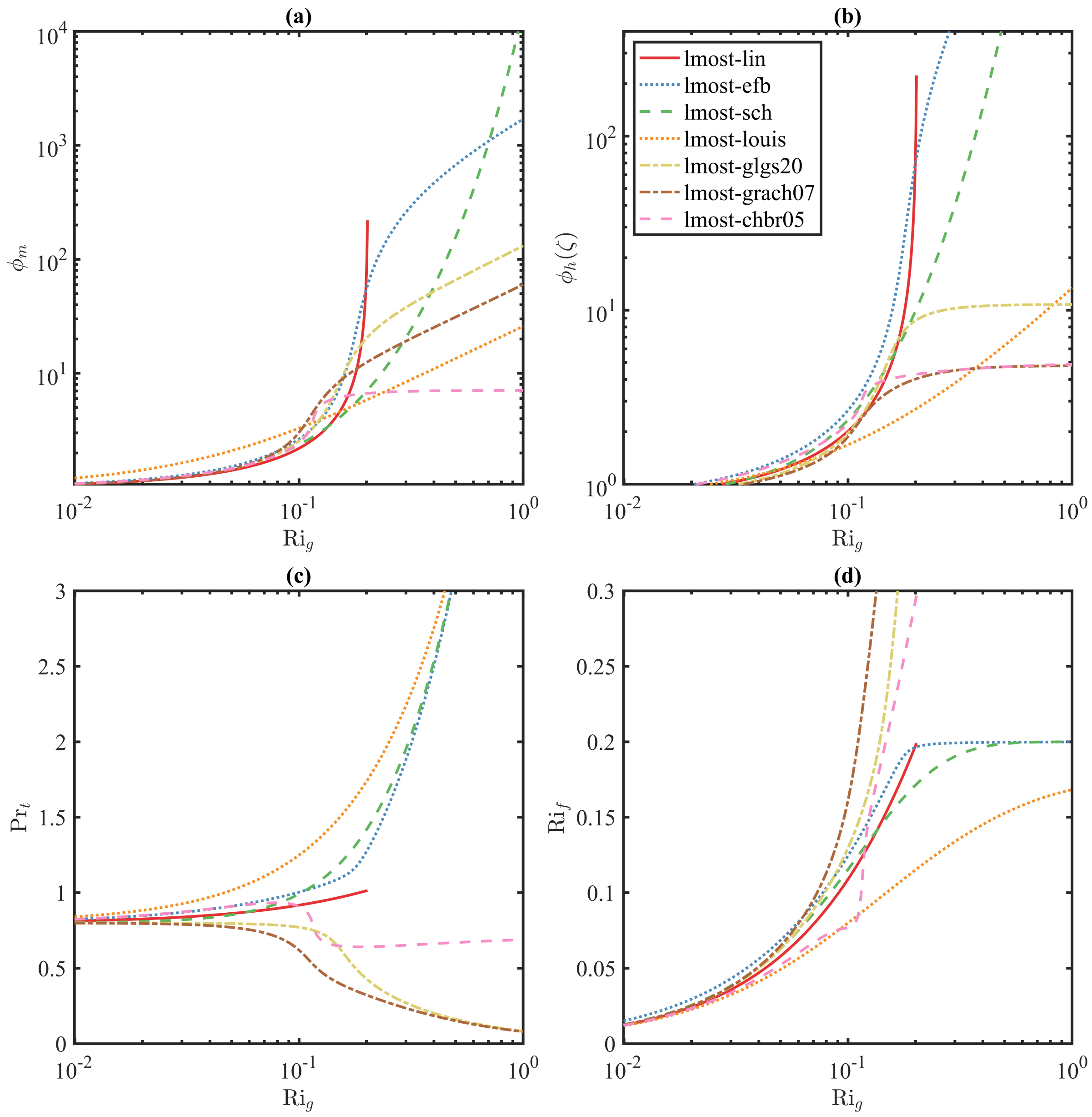
Stability functions

Linear velocity gradient:

- (Businger 1971) - lmost-lin
- EFB (Zilitinkevich et al.2013) –lmost-efb
- (Schumann & Gerz 1995) – lmost-sch

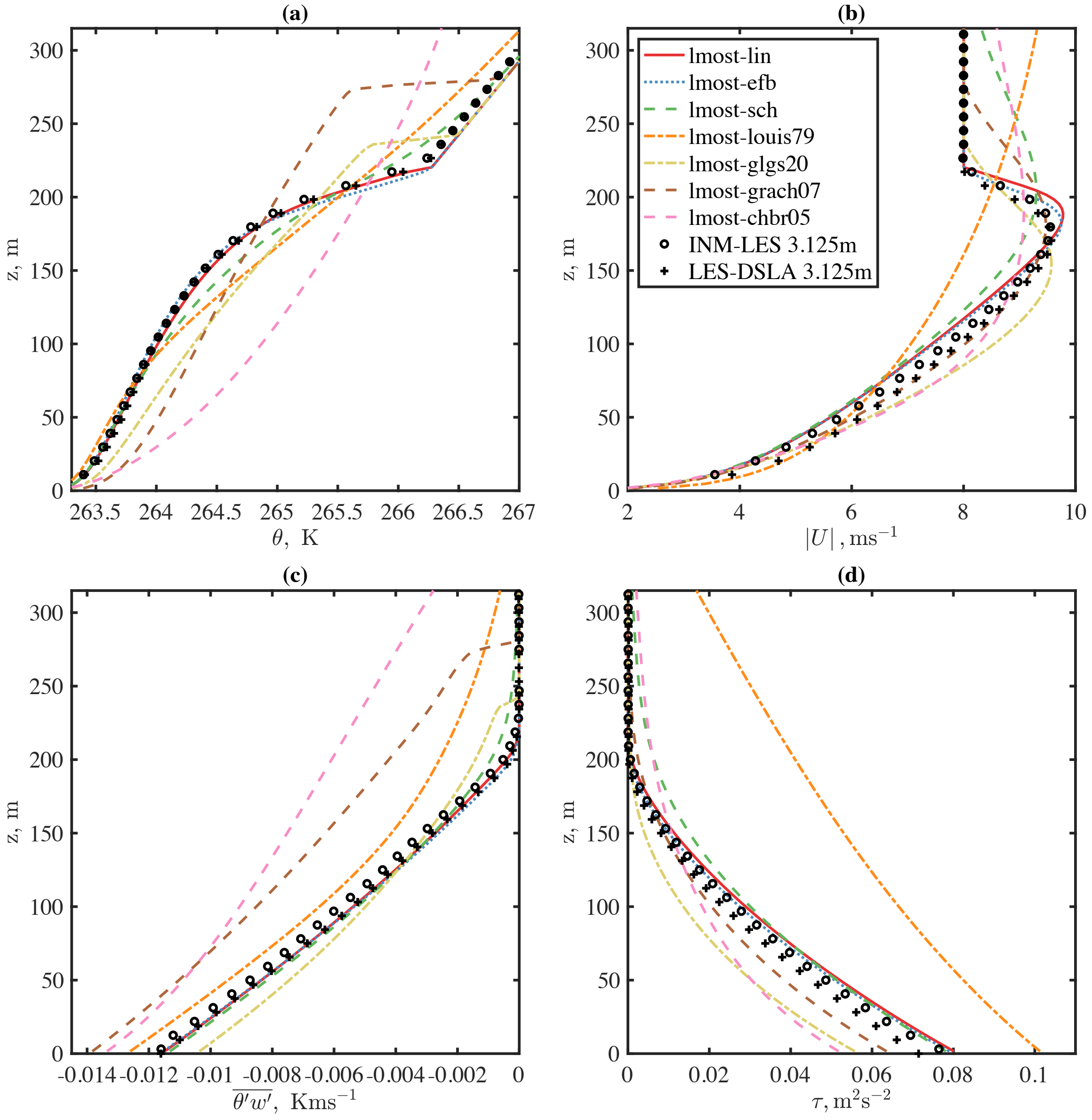
Non-linear velocity gradient:

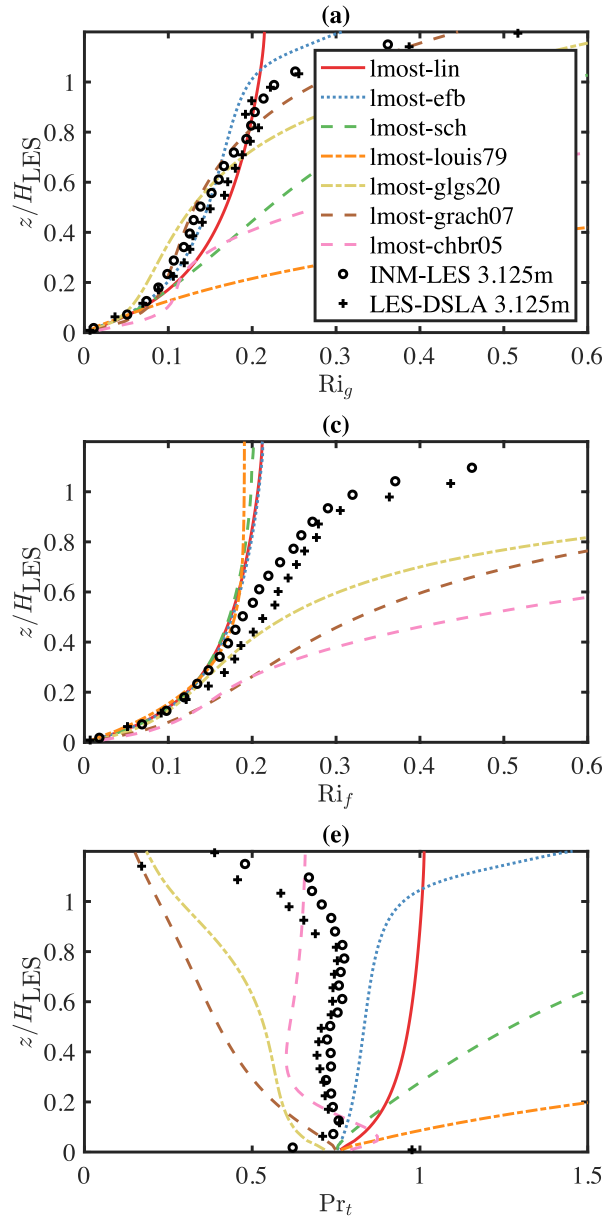
- (Gryanik et al. 2020) – lmost-glgs20
- (Grachev et al., 2007) – lmost-grach07
- (Cheng & Brutsaert, 2005) – lmost-chbr05
- (Louis 1979) – lmost-louis



Evaluation for weakly stable ABL

GABLS1 setup.

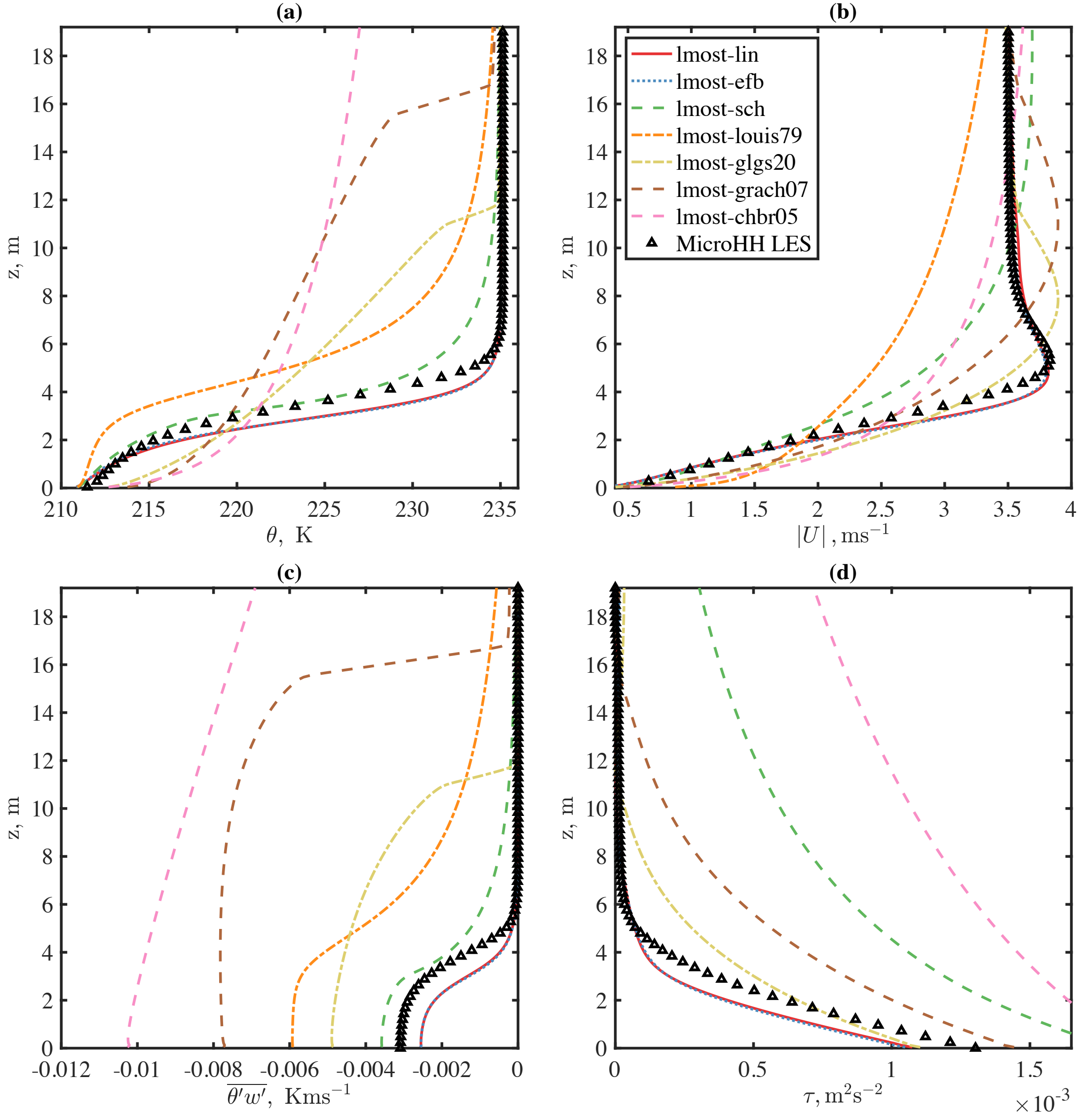


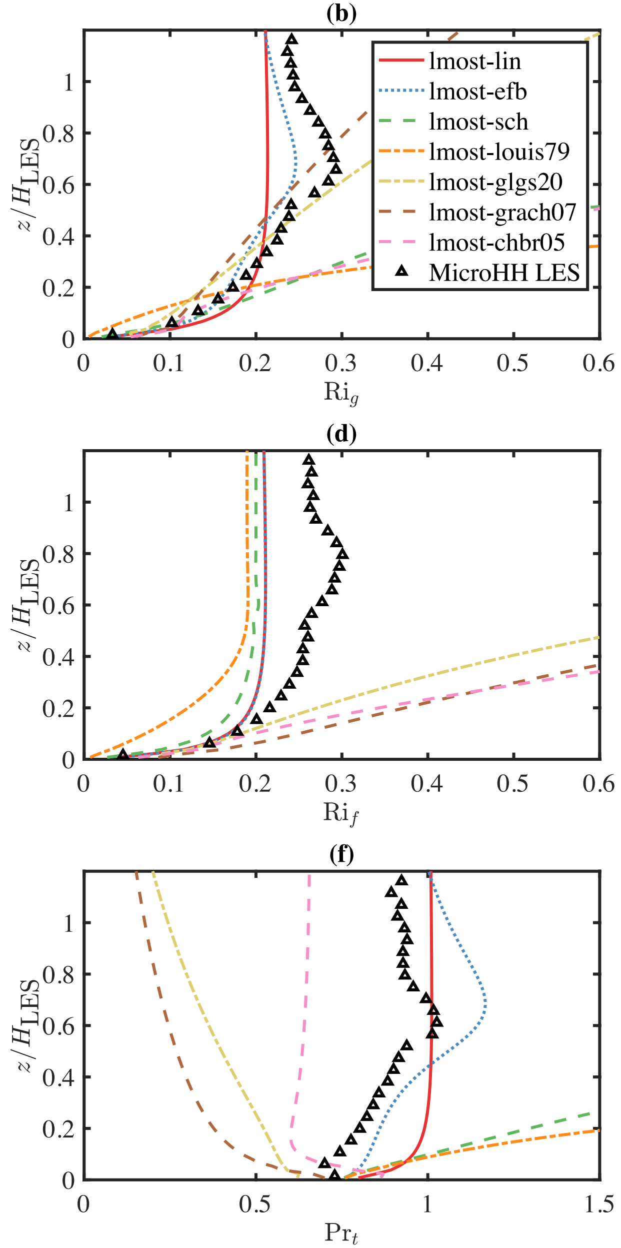


Evaluation for strongly stable ABL

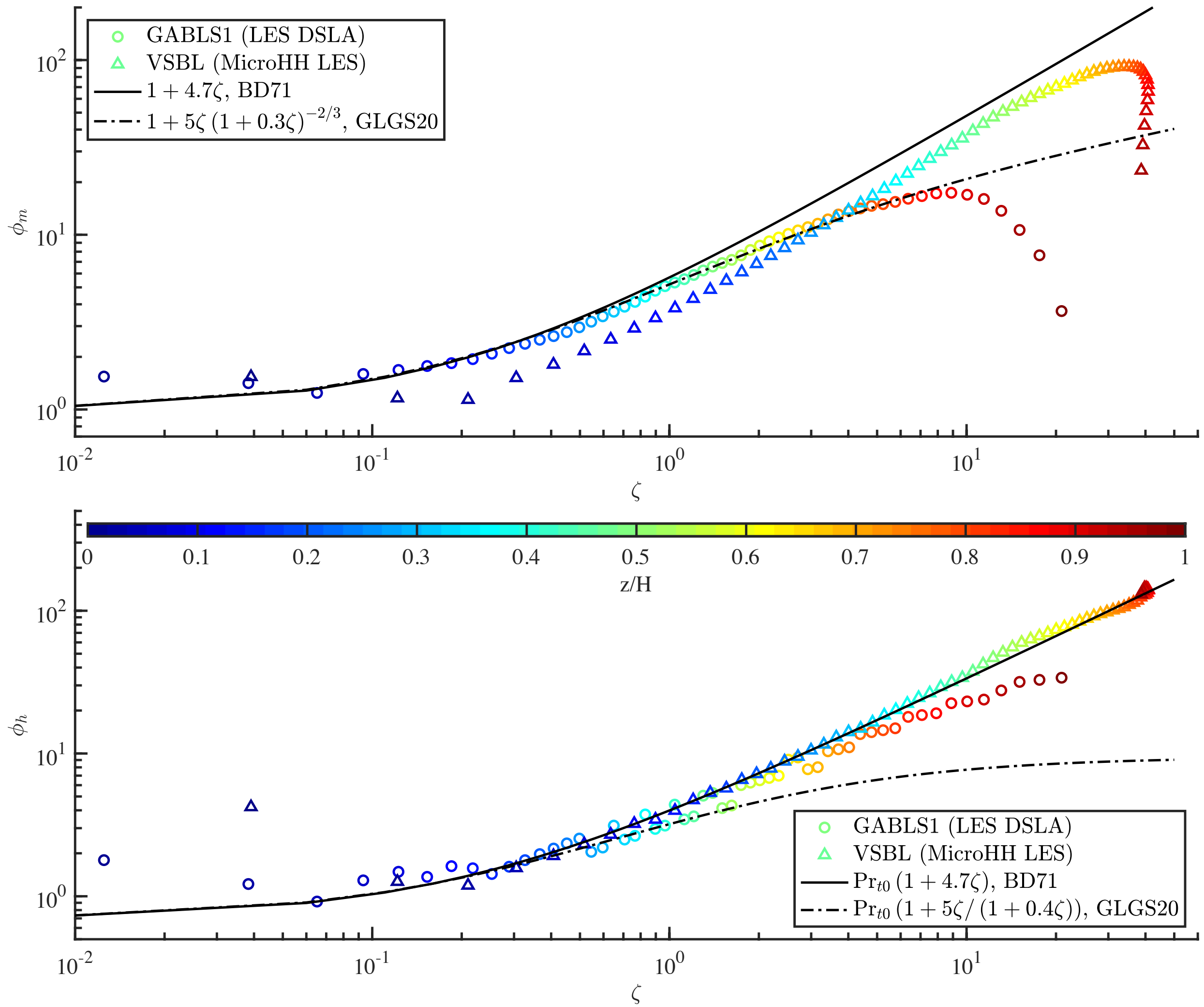
setup – (van der Linden et al. 2019)

LES data curtesy of van der Linden





Evaluation of surface functions based on LES profiles.



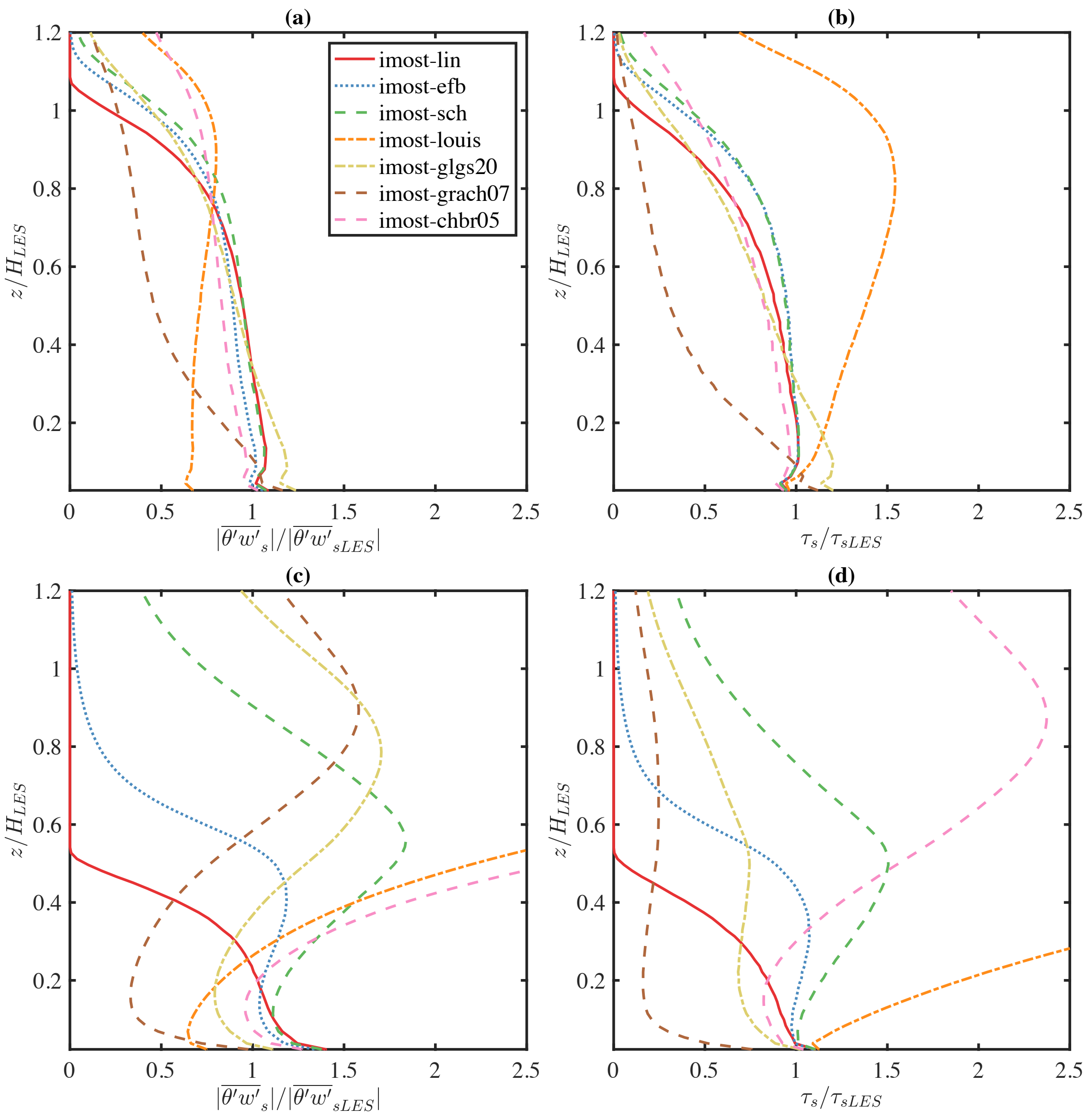
Testing surface functions in surface scheme

$$u_{*s} = \frac{(|U(z)| - |U_s|)\,\kappa}{\Psi_m(z/L_s) - \Psi_m(z_0/L_s)}$$

$$\theta_{*s} = \frac{(\theta(z) - \theta_s)\,\kappa}{\Psi_h(z/L_s) - \Psi_h(z_{0t}/L_s)}$$

$$L = \frac{u_{*s}^2}{\beta\kappa\theta_{*s}}$$

Surface scheme then is caluclated for every height using Wind speed an temperature from LES at that height.



GABLS1

VSBL from (van der Linden et al. 2019)

Conclusions.

- Closures that utilize linear dimensionless velocity gradient and much better coincide with LES data for both weak and strong SBLs, because it relates to TKE balance in steady state. $$\varepsilon^0 = P - \frac{\tau^{3/2}}{L} = \frac{\tau^{3/2}}{\kappa z}\left(1 + C_\varepsilon \frac{z}{L}\right)$$
- Closures which underlying stability functions depart from linear dimensionless velocity show overestimation of SBL height and mixing within it. On the other hand when those stability functions are used for its intended purpose of deriving surface fluxes the allow for less error in resulting fluxes when bulk scheme is used at height quite above the surface flux layer.