Comparison of convective boundary layer velocity spectra calculated from large eddy simulation and WRF model data

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Introduction

- The Weather Research and Forecasting (WRF) model (Skamarock et al. 2008) has evolved toward a self-contained numerical weather prediction system, capable of modeling atmospheric motions ranging from global to microscales.
- The promise of such capability is appealing to both operational and research environments.
- The ability of the WRF model to adequately reproduce small-scale motions O(100m) remains questionable.
- Turbulent flows in a dry CBL were reproduced using a traditional LES code (OU-LES; Fedorovich et al. 2004a,b) and the WRF model applied in an LES mode (WRF-LES).

Model Description: OU-LES

- Incompressible Navier-Stokes equations under Boussinesq approximation
- 2nd-order, centered advection scheme
- 3rd-order Runge-Kutta time integration scheme
- 1.5-order subgrid TKE closure scheme

$$K_m = C_k l \sqrt{E}$$

$$\epsilon = C_e \frac{E^{\frac{3}{2}}}{l}$$

$$C_k = 0.12$$

$$C_e = f_c \left(0.19 + 0.51 \frac{l}{\Delta} \right)$$

$$l = \begin{cases} \Delta & \text{(unstable)} \\ \min\left[\Delta, 0.5\frac{\sqrt{E}}{N}\right] & \text{(stable)} \end{cases}$$

$$f_c = 1 + \frac{2}{\left(\frac{z_w}{\Delta z_w} + 1.5\right)^2 - 3.3}$$

Model Description: WRF-LES

- Compressible, flux-form Navier-Stokes equations
- 5th-order, upwind-biased advection scheme
- 3rd-order Runge-Kutta time integration scheme with time-splitting procedure for acoustic modes
- 1.5-order subgrid TKE closure scheme.

$$K_m = C_k l \sqrt{E}$$

$$\epsilon = C_e \frac{E^{\frac{3}{2}}}{l}$$

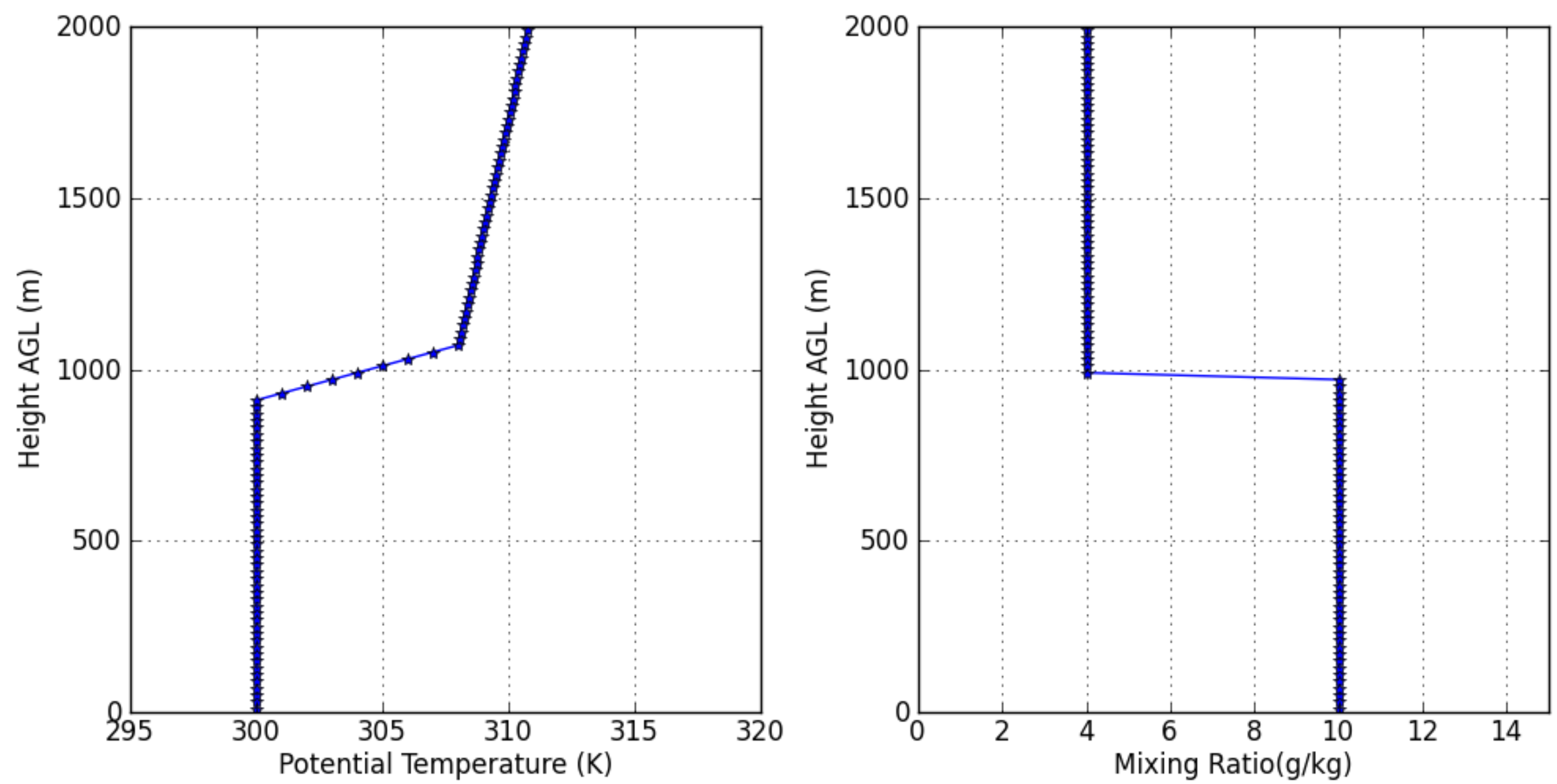
$$C_k = 0.12$$

$$C_e = 1.9 C_k + \frac{(0.93 - 1.93 C_k) l}{\Delta}$$

$$l = \begin{cases} \Delta & \text{(unstable)} \\ \min\left[\Delta, 0.76 \frac{\sqrt{E}}{N}\right] & \text{(stable)} \end{cases}$$

Approach

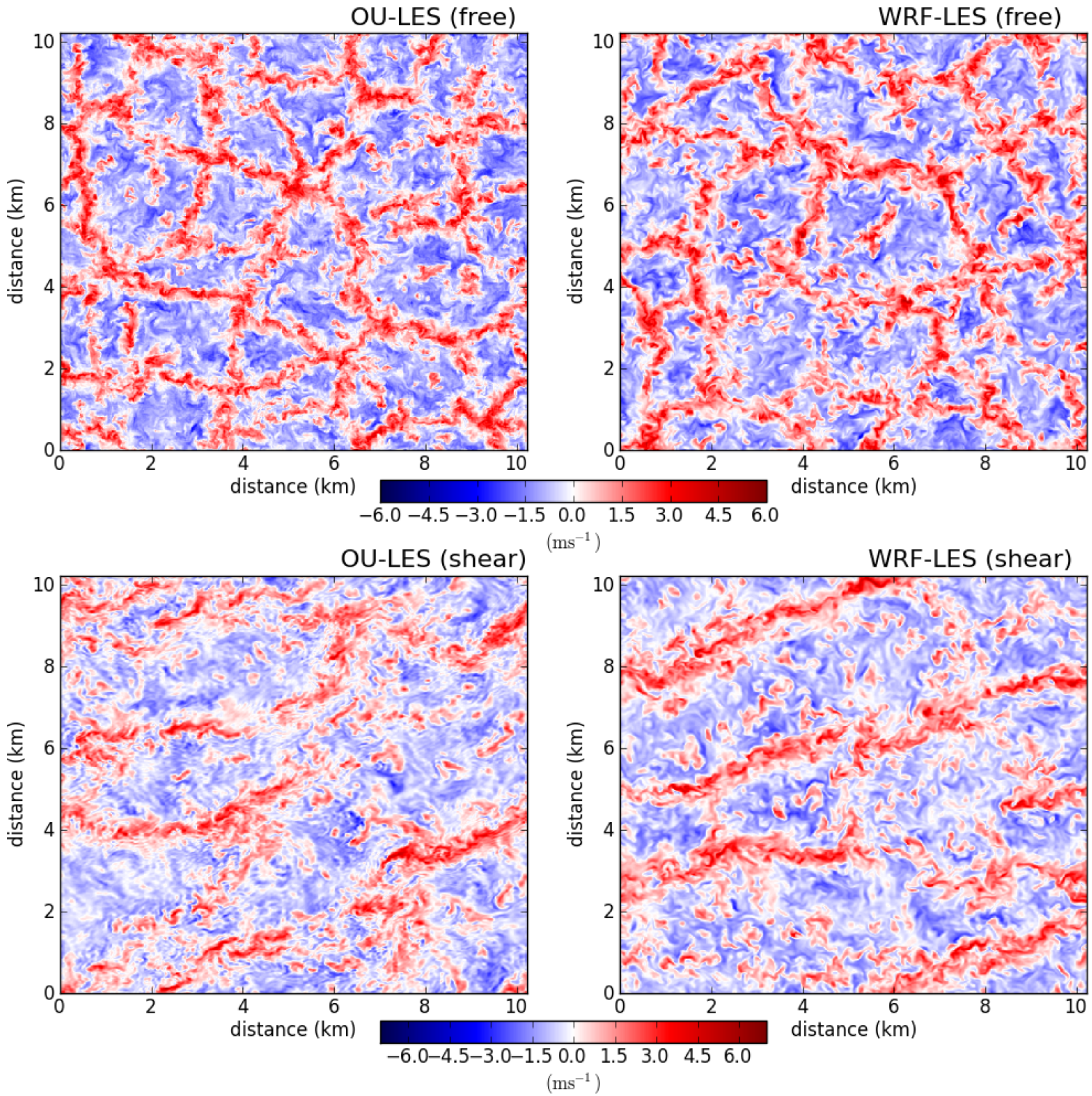
- Numerical domain of 10.24×10.24×2 km^3
- Initialized with the same idealized vertical profiles of velocity, temperature, and moisture.
- The respective CBL forcings were set equal and held constant.
- The effects of CBL flow types (with/without shear) and of varying isotropic grid spacing (20/40/80 m) were investigated.



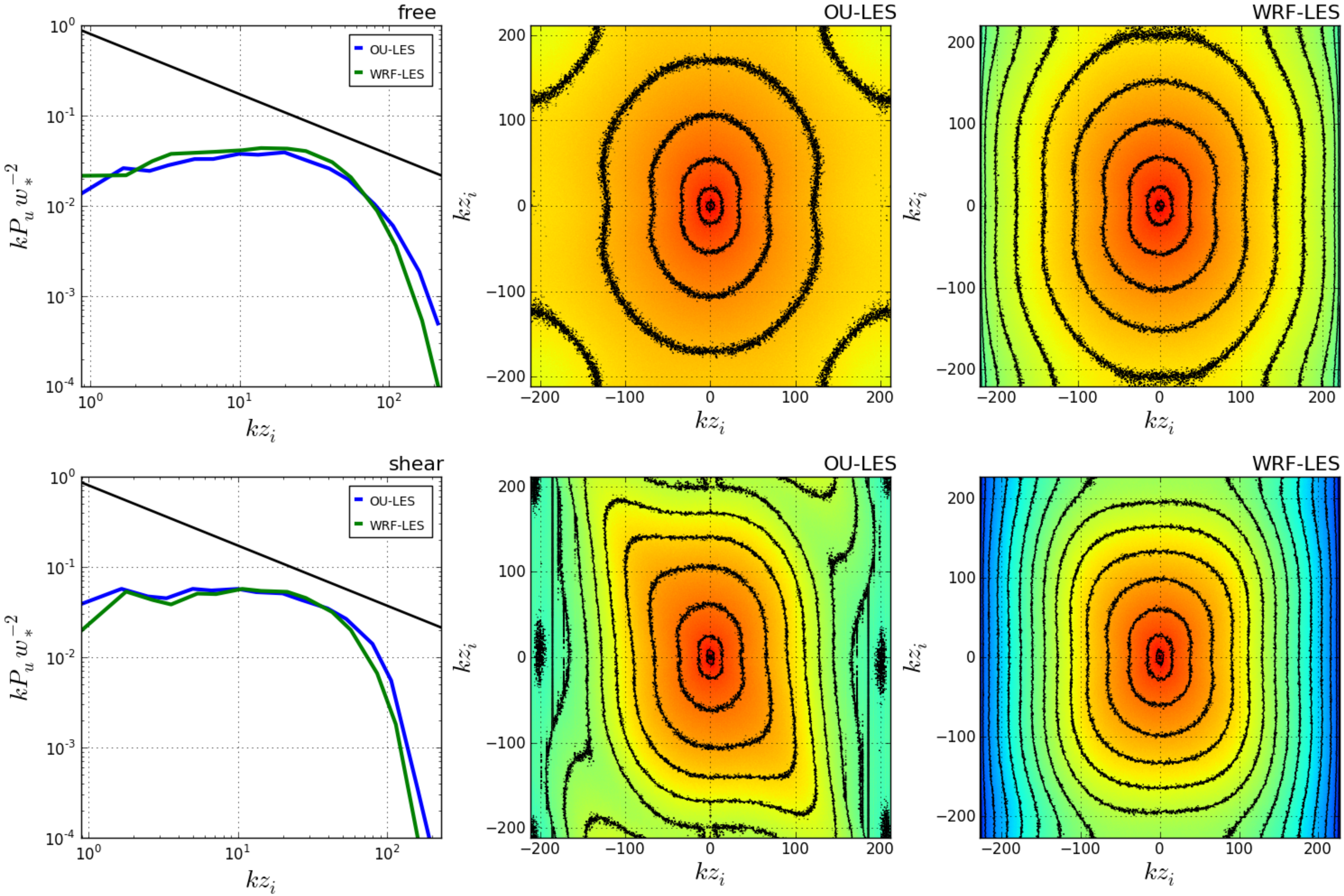
Why Spectra?

- Non-traditional validation measure, why use it?
- Many scales of interest are not predictable due to lack of observational data
- Spectra can indicate whether a model has correct energy statistics
- This in turn elucidates whether a model is true to expected atmospheric dynamics
- Spectra also allows investigation of model numerics and effective resolution

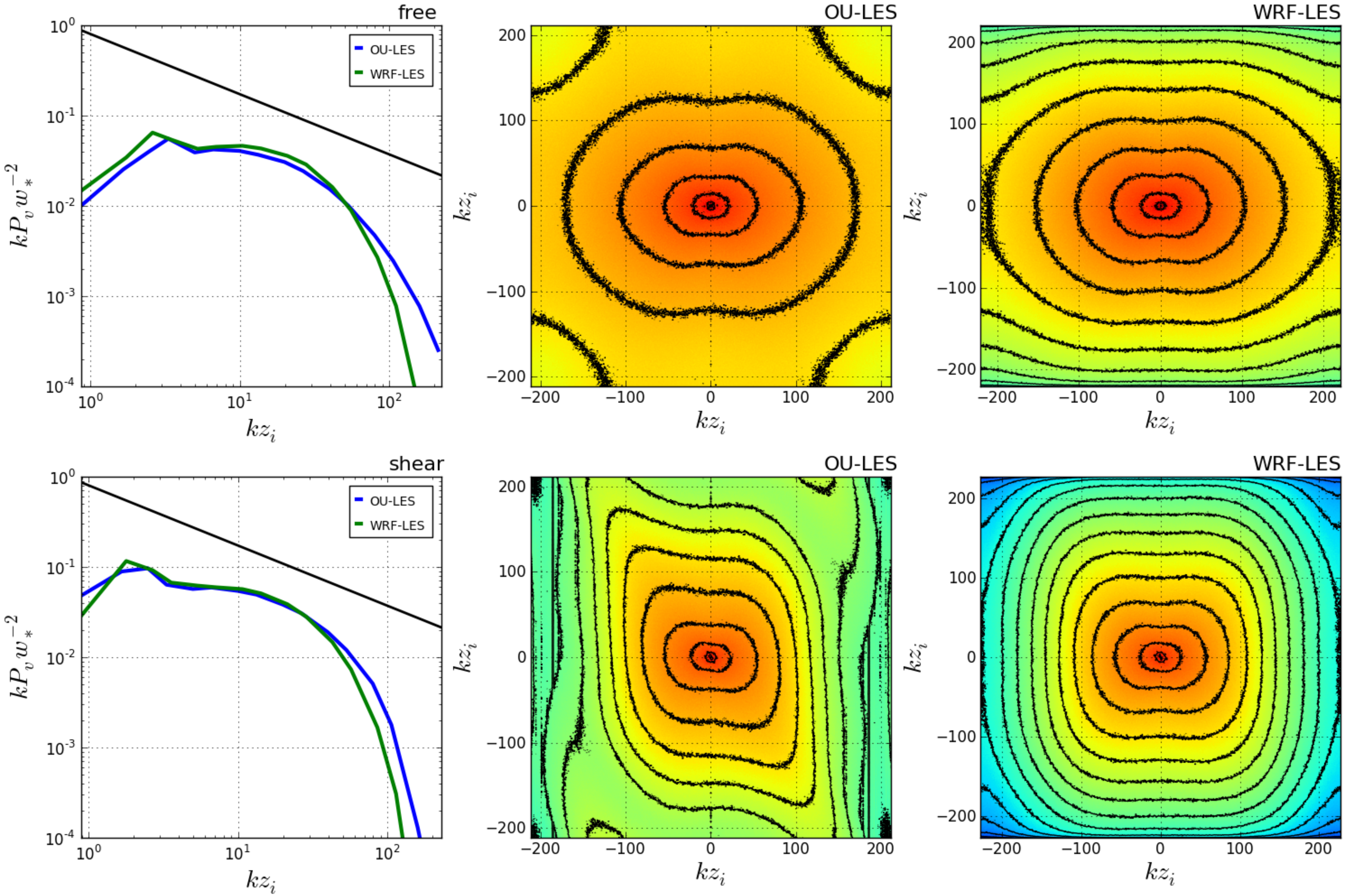
w-component velocity (z/z_i=0.25)



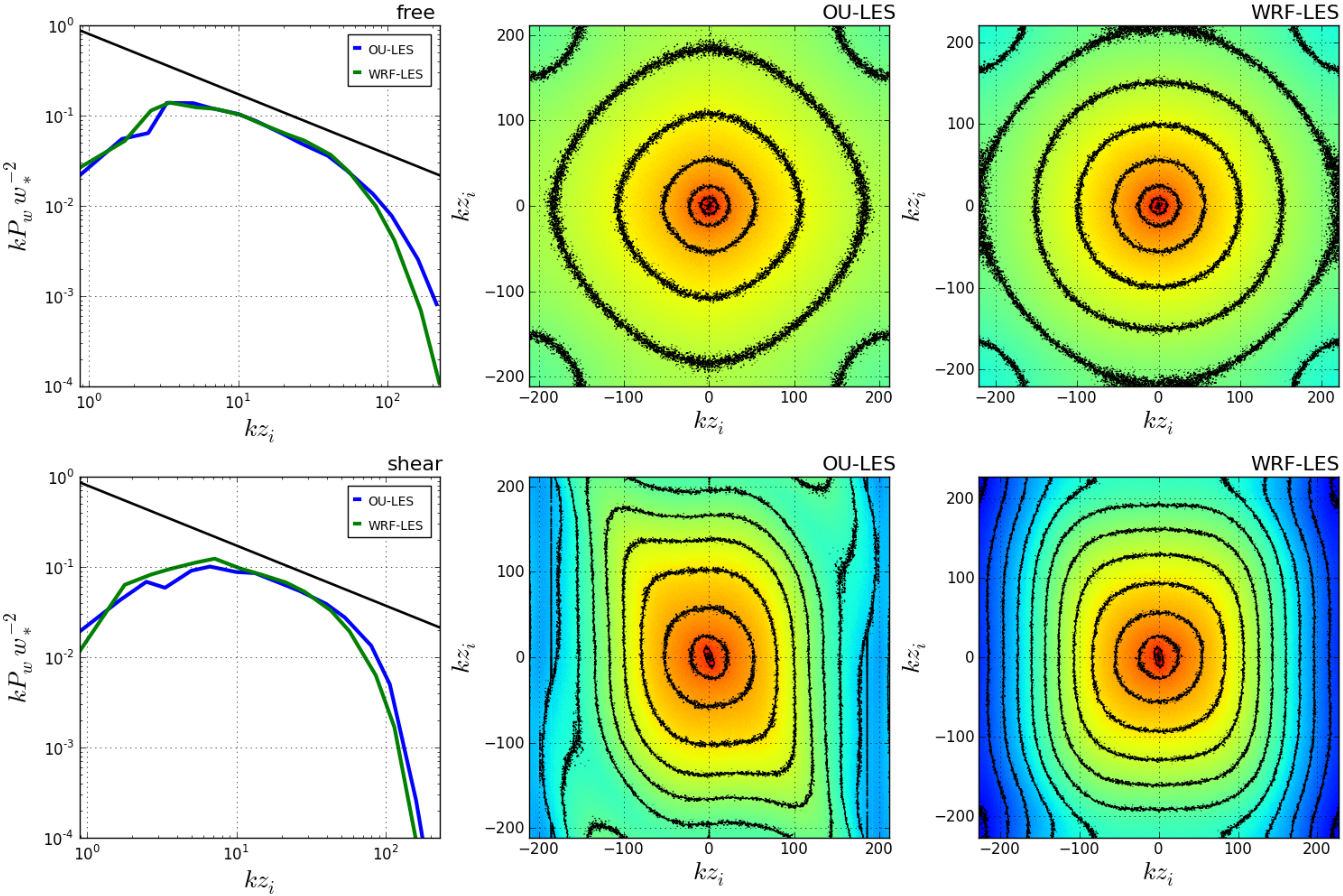
normalized *u*-component velocity spectra (z/z_i=0.25)



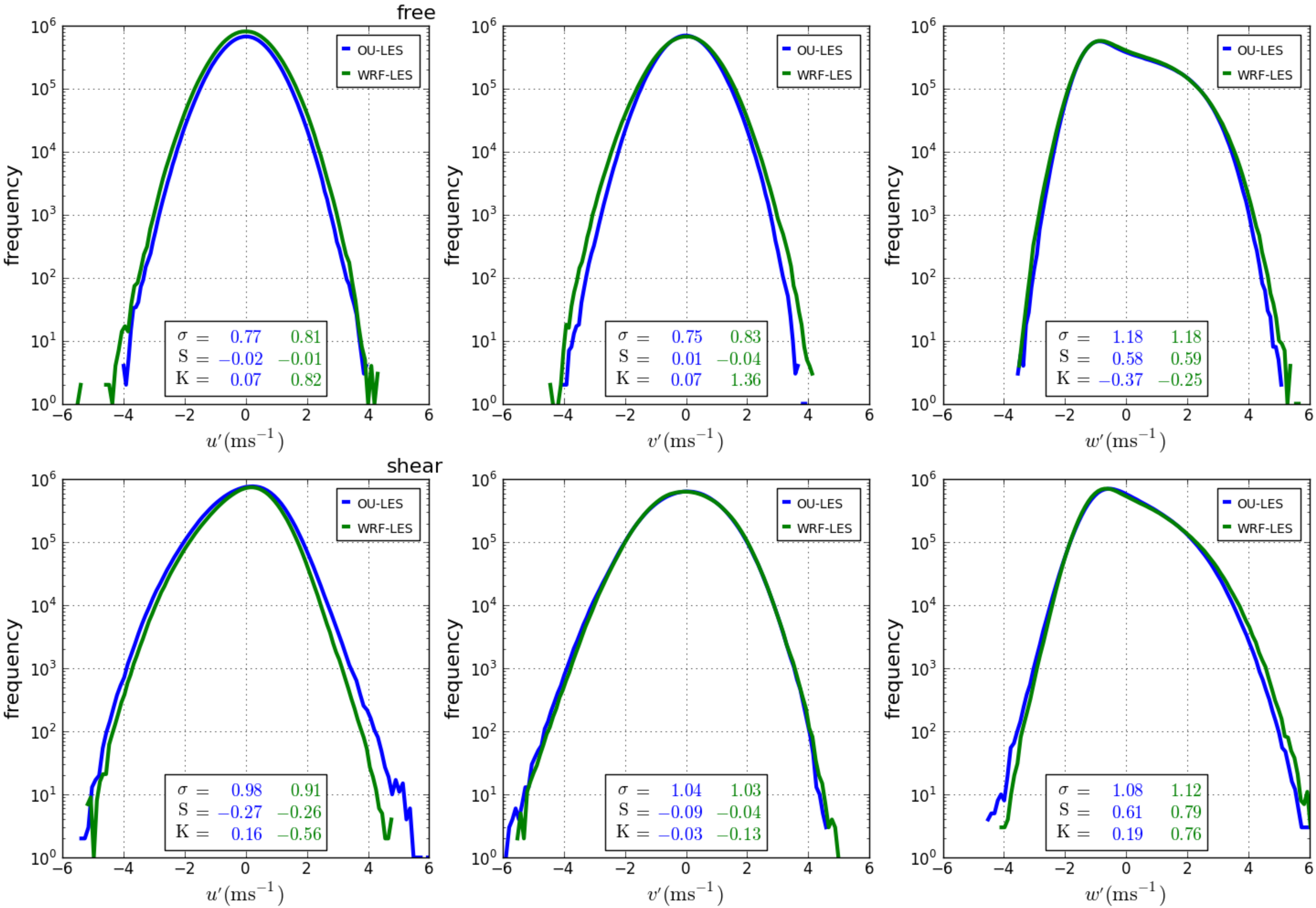
normalized *v*-component velocity spectra (z/z_i=0.25)



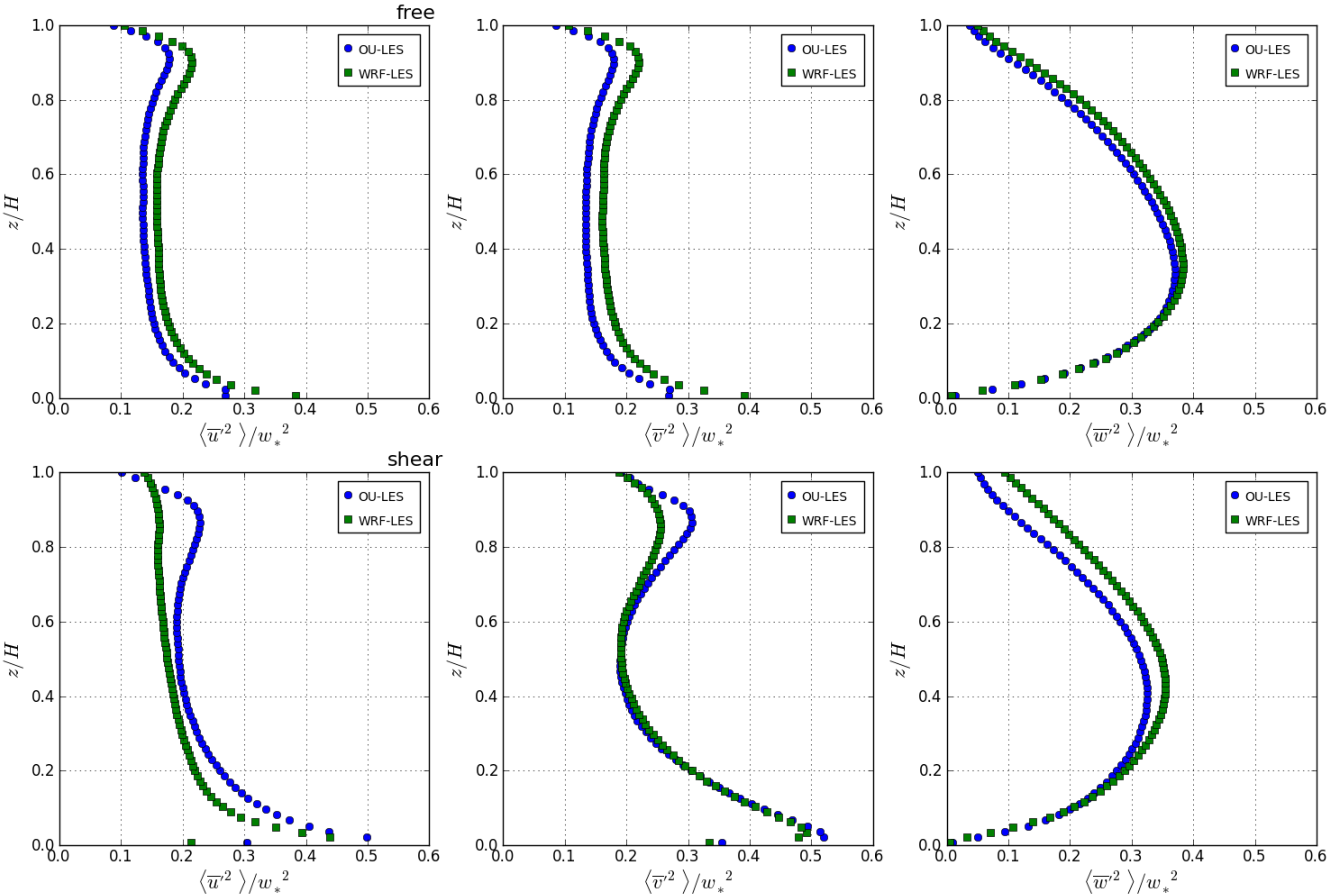
normalized w-component velocity spectra (z/z_i=0.25)



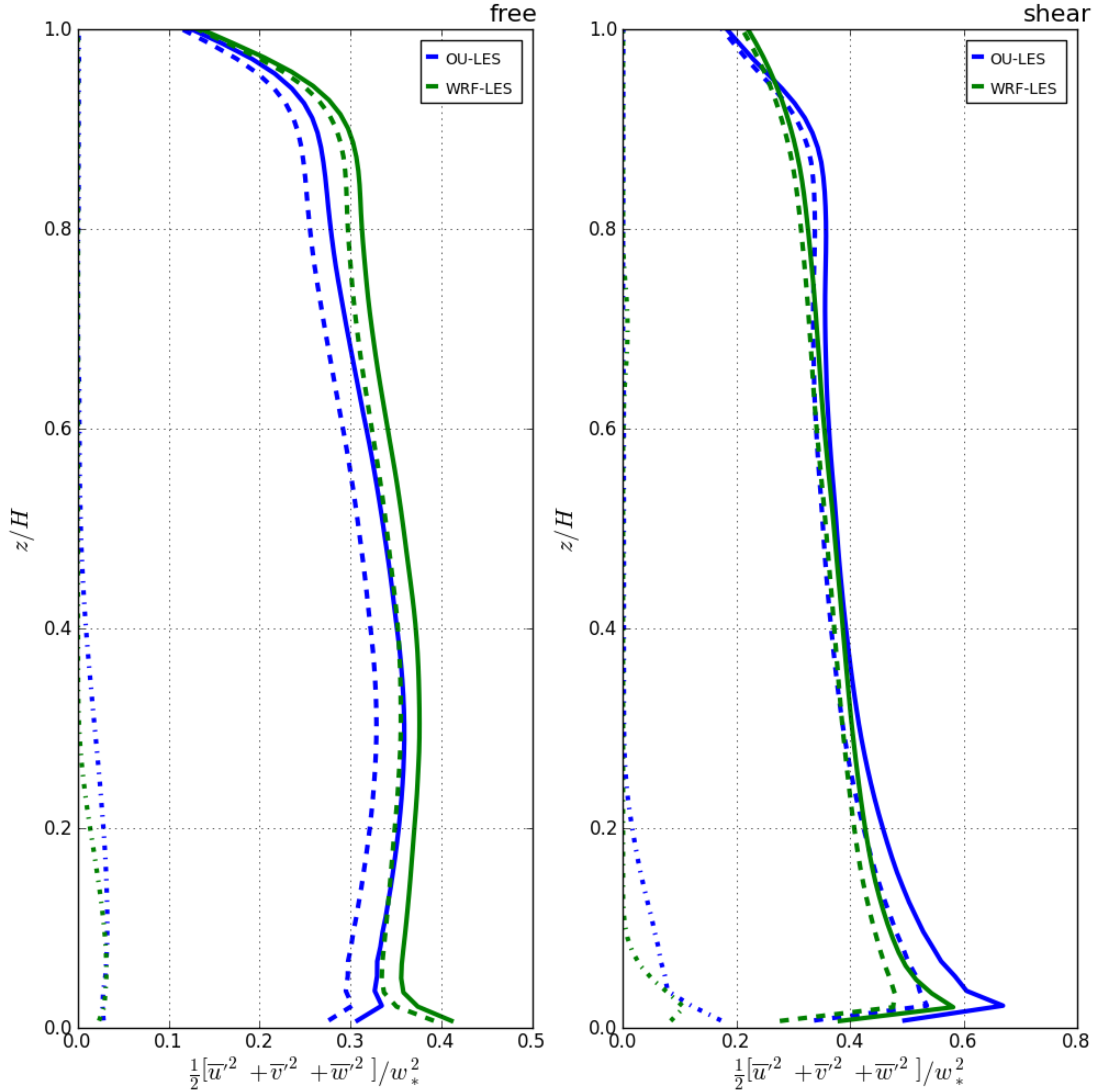
velocity histogram (z/z_i=0.25)



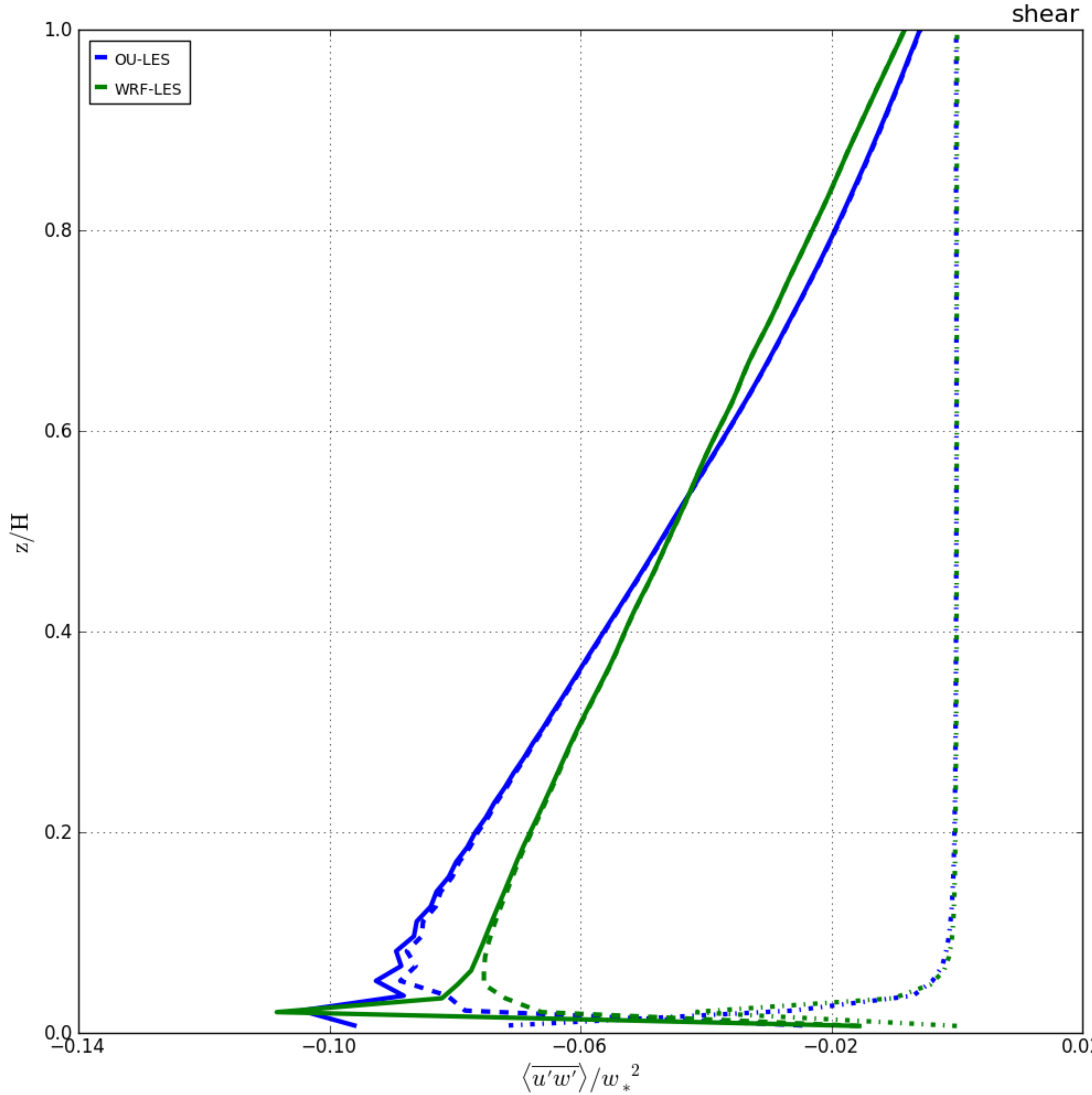
normalized velocity variance



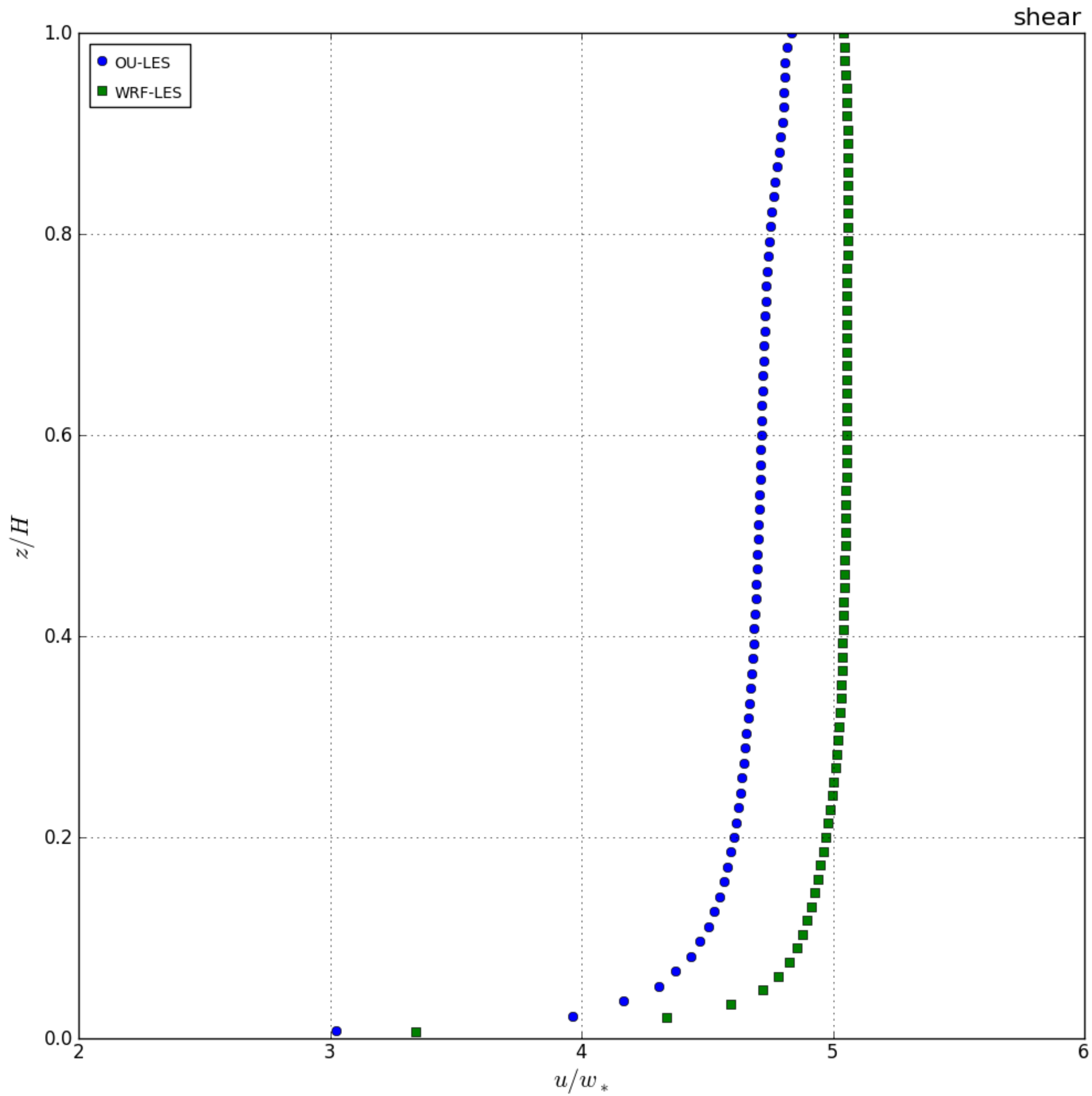
normalized turbulence kinetic energy



normalized vertical momentum flux



normalized *u*-component velocity



Discussion

- Visually, data looks similar
- Histograms show OU-LES has more area of large deviations from mean in horizontal velocity
- This is also seen in variance profiles
- Thus, WRF-LES produces less near-surface TKE and less turbulent momentum flux
- Velocity profiles indicate WRF-LES does not properly extract energy from the system
- Result is unphysical velocity spectra distribution skewed toward to larger scales

Discussion

- Why?
- One possible reason is that acoustic modes in WRF-LES require a time-splitting procedure
- Time-splitting is supposed to only affect high-frequency modes
- Done through explicit horizontal divergence and implicit vertical damping filters
- Possible that these filters smooth modes that are physically important at LES scales.

Summary

- WRF-LES produces results visually similar to a traditional LES
- Statistics indicate that WRF-LES generates less variance for horizontal velocity components
- As a result, near-surface TKE and turbulent momentum flux are insufficient
- Energy is not properly extracted throughout the depth of CBL, which skews velocity spectra toward large scales and creates narrow inertial subranges
- Possible that model numerics associated with compressible code are to blame.

Additional Info

transverse/longitudinal velocity spectra (z/z_i=0.25)