EGU22-12569
https://doi.org/10.5194/egusphere-egu22-12569
EGU General Assembly 2022

Large-eddy simulation and parametrization of turbulence decay in atmospheric boundary layer

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Various types of one-dimensional RANS (Reynolds-Averaged Navier-Stokes) parametrizations are widely used in modern weather and climate models for replicating atmospheric boundary layer (ABL) dynamics. RANS models can accurately reproduce states of ABL close to stationary [1,2], but fail to model the ABL diurnal cycle and other non-stationary processes with similar accuracy[3]. Therefore, one of the purposes of studying non-stationary states of the ABL is using the information about the processes that govern such ABL states for the improvement of RANS models.

This study focuses on the evening transition, which is a part of the ABL diurnal cycle. During this transition, the decay of turbulent kinetic energy (TKE) takes place. Results of large-eddy simulation (LES) experiments where the evening transition is modeled, both sheared and shear-free cases, are presented. The TKE balance between components is analyzed. It is shown that the transition can be broken down into well-pronounced periods of fast and slow TKE decay. TKE anisotropy within these two periods is studied, where the destruction of the large part of TKE due to thermals inertial movement is observed during the fast decay period. This is followed by the redistribution of the energy into horizontal components, which results in the formation of quasi-horizontal turbulence, with TKE decay, in comparison to the isotropic state, slowing down significantly. Finally, the distribution of TKE between large- and small-scale eddies is analyzed, both within the entire ABL domain and at certain heights.

The results are then compared to those obtained in one-dimensional boundary layer model, where k-ε closure is utilized for the parametrization of turbulent diffusion, and it is shown that the latter fails to reproduce evening transition dynamics properly, at least in part due to gradient approximation of turbulent fluxes. The choice of the k-ε closure results in decreased TKE decay rate during the fast decay period and increased rate during the slow decay period, which may be due to the TKE dissipation equation inclusion in the model. Therefore, possible approaches towards modification of RANS closures aimed at correct modeling of ABL non-stationary dynamics are explored.

This study was funded by Russian Foundation of Basic Research within the project #20-05-00776.

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