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Effect of Surface Temperature Heterogeneity on Turbulent Mixing in the SBL

Dmitrii Mironov (1), Peter Sullivan (2), and Ekaterina Machulskaya (1)

(1) German Weather Service, Offenbach am Main, Germany
(2) National Center for Atmospheric Research, Boulder CO, USA

The effect of horizontal temperature heterogeneity of the underlying surface on the turbulence structure and mixing efficiency in the stably stratified boundary layer (SBL) is analyzed using large-eddy simulation (LES). Idealized LES of two flows driven by fixed winds and homogeneous and heterogeneous surface temperature are compared. The LES data are used to compute statistical moments of the fluctuating fields, to estimate terms in the second-moment budgets, and to assess the relative importance of various terms in maintaining the budgets. The budgets of the turbulence kinetic energy (TKE), of the temperature variance, and of the vertical and horizontal components of the temperature flux are analyzed. As different from most previous studies, the LES-based second-moment budgets are estimated with due regard for the sub-grid scale (SGS) contributions. These contributions may be substantial, particularly in the SBL, and should be retained in order to close the second-moment budgets to a good order.

We find that the SBL over a heterogeneous surface is more turbulent with larger variances and TKE, is better mixed and is deeper compared to its homogeneous counterpart. Perhaps the most striking difference between the cases is exhibited in the temperature variance and its budget. Due to surface heterogeneity, the third-order moment, i.e. the vertical flux of temperature variance, is non-zero at the surface. Hence, the turbulent transport term (divergence of the third-order moment) not only redistributes the temperature variance in the vertical but is a net gain. The temperature variance in the heterogeneous case is large near the surface. The increase in the temperature variance explains the reduced magnitude of the downward temperature (heat) flux in the heterogeneous SBL. The temperature variance enters the budget of the temperature flux as a buoyancy production term. Since that term is positive, it partially compensates the mean-gradient production term that generates the downward (i.e. negative) temperature flux. An increase of the temperature variance in a heterogeneous SBL results in a reduced magnitude of the temperature flux and hence of the buoyancy flux. Then, less TKE is spent working against gravity, leading to more vigorous mixing. Motivated by the LES results, possible ways to incorporate the effect of SGS surface temperature heterogeneity into SBL parameterization schemes are discussed.

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