LES OF STRATIFIED BOUNDARY LAYER

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Abstract

Large eddy simulation (LES) of planetary boundary layer (PBL) under the effects of buoyancy is performed by model KLMM (KMOP large-eddy microsynoptic model). Both convective and stable cases are considered and compared with other computations and similarity theories.

Introduction

The framework of the large eddy simulation was originally developed for simulations of the PBL (Lilly, 1966; Deardorf, 1972). We extended capabilities of our KLMM model by the effects of buoyancy by the Boussinesq approximation and performed similar computations of the PBL in it's whole vertical extent. In the case of stable stratification we choose a well-established case for computation from the model intercomparison project GABLS (Beare et al., 2006).

Numerical methods

Model KLMM solves Navier-Stokes equations for incompressible flow with Boussinesq approximation for buoyancy. The time integration is done by the 3rd order Wray's Runge-Kutta method. Disretizetion in space is performed by central differences for momentum and by the piecewise linear method with van Albada limiter for temperature.

The subgrid terms are computed by the Vreman model (Vreman, 2004) which although being an algebraic model produces results similar to a dynamic model (e.g. zero turbulent viscosity in laminar flow). The turbulent diffusivity for temperature is computed from turbulent viscosity using constant subgrid turbulent Prandtl number of 0.5.

The subgrid terms at the surface are modeled using Monin-Obukhov similarity and resulting nondimensional wind and temperature profiles. For the stable case we used GABLS recommended similarity function and Dyer functions for the unstable case.

Boundary and initial conditions

We used a uniform grid for all computations. The domain size was 4 x 4 x 2 km^3 for the convective boundary layer (CBL) and 400 x 400 x 400 m^3 for the stable boundary layer (400). The resolution for the presented results is 128x128x129 for CBL and 64x64x69 for SBL.

The initial wind field was set to the geostrophic wind velocity. The potential temperature was constant from the ground to 1 km for CBL and 100m. The setup for the SBL followed Beare et al. (2006). The computations last 10000s for CBL and 9 h for SBL.

The lateral boundary conditions were periodic and at the top they were free-slip with a sponge zone.

Results

We simulated the CBL for values of the geostrophic speed 0, 2 and 5 m/s. In all cases the top of the boundary layer rose to z_i~1370 m. The convective currents developed as expected. According to the free convection scaling, the profiles of mean and turbulent quantities above the surface layer scaled by $w_*=((g/T)Q_s z_i)^{1/3}$, where Q_s is surface temperature flux, are universal functions of z/z_i. The vertical profiles of vertical buoyancy flux and vertical velocity variance fit with comparable computations and measurements (Holtslag and Moeng, 1991; Nieuwstadt et. al., 1992).

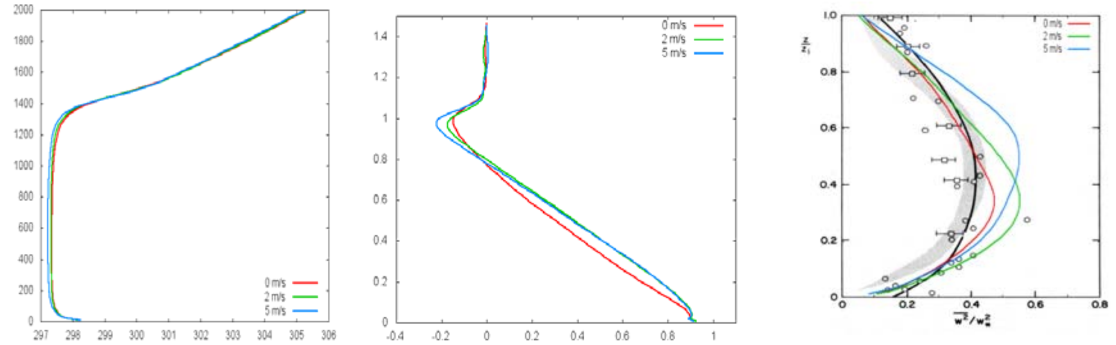

Fig 1. Vertical profiles for CBL a) final temperature profile b) heat flux scaled by it's surface value c) vertical velocity variance scaled by w_*. In b) and c) height is scaled by z_i (adapted from Holtslag and Moeng, 1991)

The SBL case is more challenging due to lower values of turbulence. The main features of the flow are correct only qualitatively. The boundary layer is to high and the inversion too weak. The values of surface momentum and heat flux are in the range of Beare et al. In analogy to subgrid sensitivity discussion in Beare et al. We expect the source of errors to be mainly in the subgrid models.

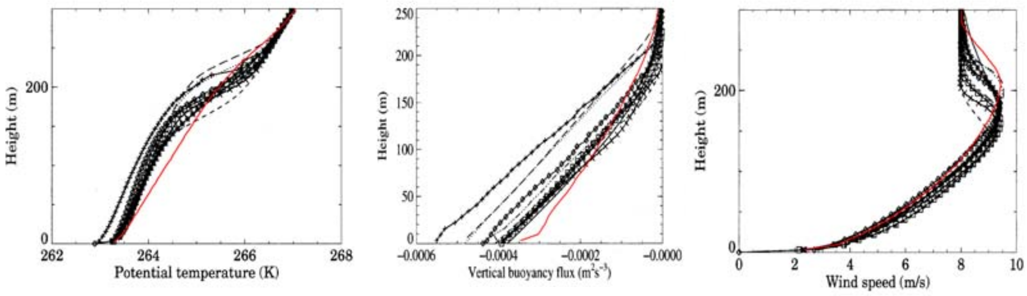

Fig 2. Vertical profiles for SBL. Adapted from Beare et. al. (2006). The red straight line is our computation in comparison with other computations at the same resolution. The difference is clear.

Conclusions

We tested the LES code KLMM for computations of the stratified planetary boundary layer. There were The results are promising, but the detected errors have to be corrected.

References

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