A Large-Eddy Simulation Study of the Stable PBL

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1. Introduction

In this work we have generated a stable boundary-layer (SBL) using large-eddy simulation (LES) technique. To generate a SBL we started from a convective barotropic simulation, in which a step capping inversion was imposed in the mean potential temperature profile. After a period of physical time, the heat flux was set to zero and a neutral boundary layer (NBL) was simulated for the successive hours. This was followed by cooling the boundary-layer through the gradual decrease of the potential temperature at the surface. After this period of gradual cooling, the SBL was then cooled further for a relative long period so that the temperature flux reached a minimum. One of the most important features during the simulation is the formation of the low-level jet at the top of the boundary layer.

2. The large-eddy model

Large-eddy simulation of the PBL is a well-established technique following the pioneering work of Smagorinsky (1963), Lilly (1967), Leonard (1974), Moeng (1984) and Sullivan et al. (1994). Most LES codes utilize the incompressible Boussinesq form of the Navier-Stokes equations and consider a horizontally homogeneous boundary layer. The PBL variables are spatially filtered to define resolved components and subfilter scale (SFS) components. Additional details of the LES model used in the present work can be found in Moeng (1984), Sullivan et al. (1994) and Saiki et al. (2000).

3. Results and conclusion

To generate a stable boundary-layer we have followed the guidelines described in the paper of Saiki et al (2000). The simulations were performed on a one kilometer square domain with 128 × 128 128 spaced grid points. The initial conditions consisted of a convective PBL with a geostrophic wind of $(U_g,V_g)=(15,0)$ m s^{-1} driven by a positive heat flux of =0.05 m °K s^{-1} applied at the surface. The initial mean potential temperature profile imposed a steep capping inversion at 500 m where the temperature increased 8 °K over twelve levels. Above the capping inversion the temperature increased at a lapse rate of 0.003 °K m^{-1}.

After an hour of physical time, the heat flux was set to zero and a neutral boundary-layer (NBL) was simulated for the successive two hours. This was followed by cooling the boundary-layer through the gradual decrease of the potential temperature at the surface. After this period of gradual cooling, the SBL was then cooled further for five hours from 300.4 °K to 293.9 °K so that the temperature flux reached a minimum of –0.06 m K s^{-1}. The mean statistics characterising the simulated SBL during the last hour of the simulation are =0.34 ms^{-1} (friction velocity scale), =450.0 m (stable boundary-layer height), L=66.0 m (Obukhov length) and =6.8 (stability parameter).

The horizontally averaged vertical profiles of the potential temperature and wind velocity are shown in Figures 1 and 2. In Figure 1 it is depicted the evolution of temperature profiles, starting from the convective (CON) conditions, passing along the neutral intermediate state (NEU) and three stable profiles (STB) taken at different times. In Figure 2, it is exhibited the time evolution of the mean wind speed , where (U,V) are respectively the longitudinal and lateral components of the resolved velocity field. The most important feature is the formation of the low-level jet at the top of the boundary layer (18 m s^{-1} between 300 and 400 m). Figure 3 presents the hodograph evolution of the ageostrophic velocity components of the low-level jet simulated by LES. The low-level jet is a well known phenomenon due to inertial oscillation associated with the Coriolis force and characterizing the stable condition of the planetary boundary-layer.

4. References

Moeng, C.-H.: 1984, 'A Large-Eddy-Simulation Model for the Study of Planetary Boundary-Layer Turbulence', *J. Atmos. Sci.* **41**, 2052–2062.

Leonard, A.: 1974, 'Energy cascade in large eddy simulation of turbulent flow', *Adv. Geophys.*, **18A**, 237-248

Lilly, D.K.: 1967: 'The representation of small-scale turbulence in numerical simulation experiments' *Proc. IBM Scientific Computing Symp. on Environmental Science*, Thomas J.Watson Research Center, Yorktown Heights, 195-210.

Saiki, E.M., C.-H. Moeng and P. Sullivan (2000), Large-eddy simulation of the stably stratified planetary boundary layer, Bound.-Layer Meteor., 95, 1-30.

Smagorinsky, J.: 1963, 'General circulation experiments with the primitive equations. I. The basic experiment', *Mon. Wea. Rev.* **91**, 99-164.

Sullivan, P.P., Mc Williams, J.C., Moeng , C.H.: 1994, 'A subgrid-scale model for large-eddy simulation of planetary boundary layer flows', *Boundary-Layer Meteorol.* **71**, 247.

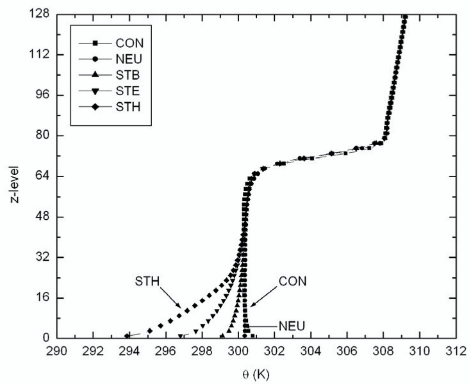

Figure 1. Horizontally averaged potential temperature.

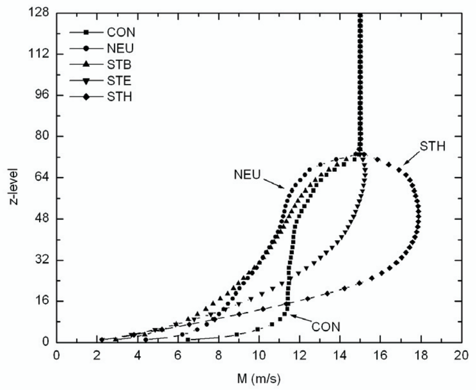

Figure 2. Horizontally averaged velocity profiles.

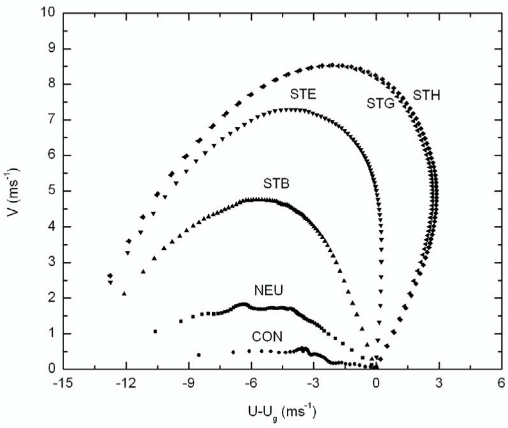

Figure 3. Hodographs of the ageostrophic velocity components.