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INTERACTION BETWEEN WIND AND TEMPERATURE FIELDS UNDER THE HETEROGENEOUS HEAT FLUX IN THE PLANETARY BOUNDARY LAYER

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1. INTRODUCTION

The planetary boundary layer (PBL) is usually affected by the heterogeneous features at the surface such as the surface heat flux and the bottom topography. This can modify the characteristics of turbulent eddies significantly, which determines the vertical transfer of heat and momentum in the PBL.

The previous studies using large eddy simulation (LES) suggested that the effects of heterogeneous surface heat flux are the most significant when its length scale is comparable to the PBL height (Shen and Leclerc, 1995; Raasch and Harbusch, 2001). It was also found that its effects disappear when the velocity of the background geostrophic wind becomes larger than 5.0 m s^{-1} (Avissar and Schmidt, 1998).

However, the previous studies were concerned with only how the background wind affects the temperature field of the PBL. Nonetheless the wind field is also expected to be modified by the heterogeneity of the surface heat flux as well. This suggests that we must understand the modifications of both wind and temperature fields simultaneously while considering their mutual interaction. Moreover, Shen and Leclerc (1995) and Raasch and Harbush (2001) suggested that the interaction might be different, depending on the relative directions of wind and of the surface heat flux variation.

Here we attempted to examine how the heterogeneous heat flux at the surface affects the wind fields as well as how the wind field modifies potential temperature fields from the heterogeneous heat flux, and how they interact each other, using LES data. For this purpose, we considered two different relative directions between surface heat flux variation and the background geostrophic wind; the one that is parallel to and the other that is perpendicular each other.

2. MODEL AND EXPERIMENTS

We used the LES model PALM (Raasch and Schröter 2002) in this study.

The domain for all simulations has dimensions 4000 x 4000 x 1600 m^3 with the resolution of 40 x 40 x 25 m^3. The heterogeneous surface heat flux Q is given as $Q = Q_0 + A\sin(2\pi x / \lambda)$ (EXP B) or $Q = Q_0 + A\sin(2\pi y / \lambda)$ (EXP C), where $Q_0 = A = 0.2$ and $\lambda = 2000$ m. We also carried out the simulation of the homogeneous surface heat flux. The background geostrophic wind velocities were given by U_g = 0.0, 2.5, 5.0, 15.0 ms^{-1} in the x-direction. We integrated over 12,000 seconds for all runs. Coriolis parameter f was 10^{-4} s^{-1}.

3. RESULTS AND DISCUSSION

Fig. 1 presents the horizontal cross-sections of potential temperature fields from EXP B and C at z = 112.5 m.

Two-dimensional plumes appear along the line of the maximum surface heat flux, but they disappear when the wind speed becomes larger than U_g = 5.0 ms^{-1} when the directions of the background wind and surface heat flux variation are parallel each other (EXP B). On the other hand, when they are perpendicular (EXP C), two-dimensional plumes are maintained at larger values of U_g.

We also examined various physical quantities in the PBL (Fig. 2). The profiles of $\langle u'^2 \rangle$ shows that the relatively larger values near the inversion layer and smaller values in the middle of the PBL in EXP B, because the velocity field is dominated by two-dimensional plumes. On the other hand, it is much smaller in EXP C.

The w-variance of EXP C has the elevated maximum compared to that of homogeneous surface heat flux (fig. 2(b)), reflecting the characteristics of large-scale plumes. However, in EXP B the pattern disappears and its value is slightly smaller over the whole PBL, suggesting that the two-dimensional plumes are more severely disturbed in this case.

The vertical transportation of turbulent kinetic energy (TKE) is much larger in the cases of heterogeneous surface heat flux, which reveals much efficient vertical transport of TKE by plumes than convective eddies. Much reduced values of $\langle wE \rangle$ are found in EXP B than EXP C, as expected. Fig. 2(d)

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shows that the momentum deficit is larger than the case from the homogeneous heat flux in EXP B, and smaller in EXP C. This leads to the increased drag in EXP B.

The profiles of potential temperature, heat flux and potential temperature variance have no significant differences even in the heterogeneous surface heat flux cases.

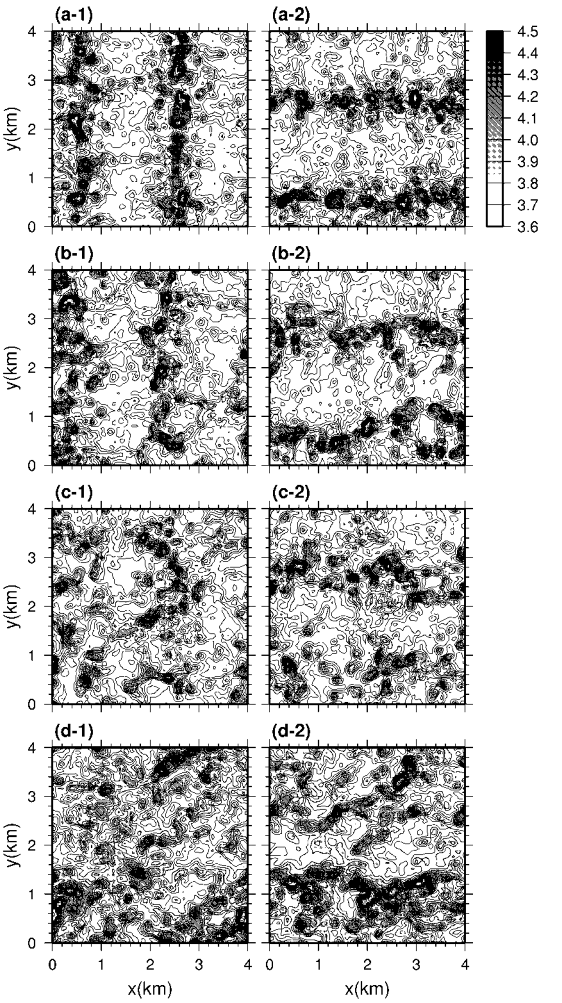

FIG. 1. The horizontal cross-sections of potential temperature (Θ - 300.0) (K) at a height of z = 112.5 m for (1) EXP B and (2) EXP C with (a) zero wind, (b) U_g = 2.5, (c) 5.0 and (d) 15.0 ms^{-1}

4. CONCLUSION

Interaction between wind and temperature fields under the heterogeneous heat flux was investigated by using large eddy simulation (LES) of the planetary boundary layer (PBL). When they are parallel to each other, the temperature and velocity structures influenced by the inhomogeneous heat flux, such as two-dimensional plumes, are destroyed more easily by the background wind and the velocity field due to the background wind is more strongly modified by convection. This leads to the noticeable difference in the profiles of horizontal and vertical turbulent kinetic energy, and the mean velocity.

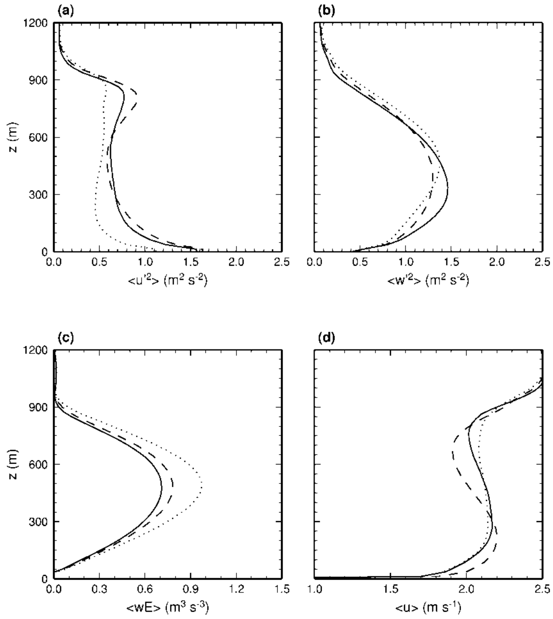

FIG. 2. Horizontally averaged vertical profiles of (a) <u'^2>, (b) <w'^2>, (c) <wE> and (d) <u>, for EXP A (solid), EXP B (dashed) and EXP C (dotted line), when U_g = 2.5 ms^{-1}. Here < > represent the horizontal average.

5. REFERENCE

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