Large-eddy simulation of Kelvin-Helmholtz waves

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1. Introduction

A large-eddy simulation model is used to study the time evolution of KH waves in several shear flows varying the speed (Case 1) and direction (Cases 2 and 3) with height. The evolution of turbulent kinetic energy (TKE) has different characteristics among the cases. The shear production term of TKE for Case 1 grows nearly symmetrically, while that for the others asymmetrically; the shear production term decreases slowly after it attains a maximum. We examine the cause of the differences through the TKE and flux budgets.

2. Procedures

The LES model used here is a dry version model of Nakanishi (2000). The top and bottom boundaries are free-slip, and the lateral boundary is cyclic. The computational domain has a volume of 5.0km×5.0km×1.2km and is divided by a grid size of 10 m. Simulations are run with a time step of 0.214 seconds during 21600 steps.

Table 1 shows experimental conditions. Case 1 gives the parallel shear flows and Cases 2 and 3 the shear flows varying the directions.

Table 1. Experimental conditions. h is half of the shear depth, z_i is the center of the shear and $\triangle d$ is the difference of wind direction between the upper and lower layers.

Case1	Case2	Case3
$u=\triangle u\times\tanh\{(z-z_i)/h\}$		$u=u_1\cos\theta-v_2\sin\theta$
$v=0$	$v=\{(\triangle u)^2-u^2\}^{1/2}$	$v=u_1\sin\theta+v_2\cos\theta$
		$u_1=\triangle u\times\tanh\{(z-z_i)/h\}+\triangle u$, $v_1=\{(2\triangle u)^2-u^2\}^{1/2}$
$\triangle d=180°$	$\triangle d=180°$	$\triangle d=90°$
$\triangle u=2.4$[m/s], $h=50$[m], $z_i=600$[m], $\theta=45°$		
$T=T_0+\triangle T\times\tanh\{(z-z_i)/h\}$, $\triangle T=-0.265$[K]		

3. Results

Fig.1 shows the ratio of the wavelength of KH waves to the depth of the shear layer is about 5.5 for Cases 1 and 2, and about 7.1 for Case 3.

Fig.2 demonstrates that the redistribution of energy from Eu to Ev in Case 2 is smaller than in Case 1 and then that from Eu to Ew in Case 2 is larger than in Case1, which would be due to the existence of v shear.

Fig.3 reveals that <w’w’> in Case 2 is larger than in Case 1 after 1200 seconds.

Solid lines in Fig.4 indicate $-\langle w'w' \rangle \, \partial \langle u \rangle / \partial z$ and its absolute value in Case 2 is larger than in Case 1 after 2400 seconds, illustrating that the increase of <w’w’> contributes to the increases of -<u’w’> and consequently the shear production of TKE.

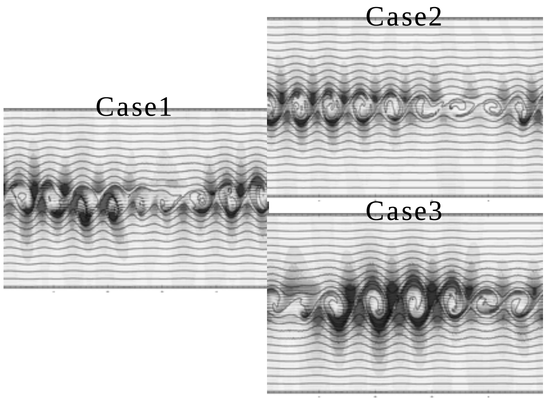

Fig.1. Vertical distributions of potential temperature at the period of the maximum shear production

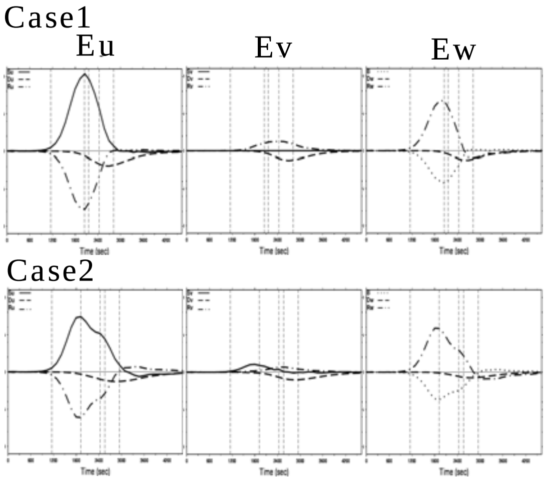

Fig.2. TKE budgets of three components. Solid lines represent the shear production, dashed lines the dissipation, dotted lines the buoyancy production and dash-dotted lines the redistribution

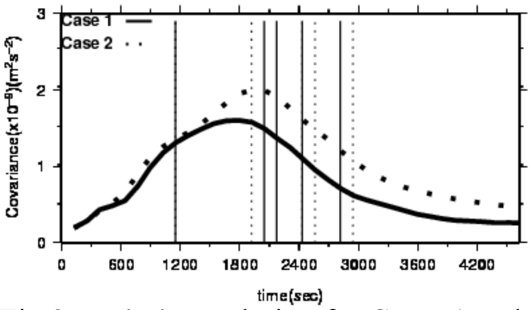

Fig.3. <w’w’> evolution for Cases 1 and 2

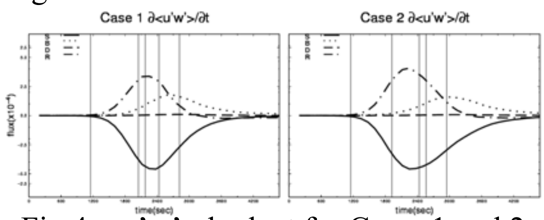

Fig.4. <u’w’> budget for Cases 1 and 2

5. Summary

The redistribution of TKE in Case 2 is distributed from the u to w components more largely than in Case 1, which would be due to the existence of v shear. The increase of <w’w’> contributes to the increase of -<u’w’>. In conclusion, the existence of v shear maintains the shear production of TKE and causes the differences in the energy growth.

References

Nakanishi, M., 2000: Large-eddy simulation of radiation fog, ***Bound.-Layer Meteor.***, **94,** 461 – 493.