Non-hydrostatic Modelling of Kelvin-Helmholtz(KH) Billows along the North Passage of Yangtze River Estuary, China

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INTRODUCTION

Induced by velocity shear, Kelvin-Helmholtz(KH) instability arises along an interface of two different fluids. In stratified flows, the KH instability is the first step toward to the onset of intensive mixing in the pycnocline, and it has been thought to be the main mechanism of converting stratified fluids to mixing (Geyer et al., 2010). The direct observation of KH instability in ocean is rare, and a few observations in estuarine and coastal areas are obtained by analyzing the acoustic backscatter profiles from echo sounder. However, the backscatter can only provide qualitative images of the KH billows, which cannot well represent the evolution and influence of KH billows on surrounding density field.

Well treatment of vertical variability of velocity and density, non-hydrostatic model is a new and useful tool for the study of K-H instability. In this study, we established a non-hydrostatic model along the North Passage of Yangtze River Estuary to explore the occurrence of KH instability in the domain.

Model Setup

A non-hydrostatic model NHWAVE is employed to establish the model, which is a parallelized model based on the incompressible Naiver-Stokes equations in σ coordinate system (Ma et al., 2012). To improve the efficiency of NHWAVE, a PDI (Pressure Decimation and Interpolation) method is utilized. The main characteristic of the PDI method is using different vertical grid number in solving the pressure Poisson equation and the momentum equation. The efficiency of non-hydrostatic model can be greatly improved without sacrificing the model's accuracy (Shi et al., 2015).

The numerical domain covers the whole North Passage of Yangtze River estuary. Due to the existence of the jetties in the North Passage, the magnitude of the longitudinal velocity is much larger than that of the transverse velocity. Thus, the flow structures in the North Passage can be simplified in two dimensional. The length of the domain is 52 km, and 40 vertical layers are used to capture the small-scale structures in the processes of fresh-salt mixing. As pointed by Geyer and Farmer (1989), the wavelength of the instability is roughly 10m, the model need to be run at high resolution. The minimum spatial grid size is 2.5m.

RESULTS AND CONCLUSION

As shown in Figure 1, the model can successfully capture the occurrence of Kelvin-Helmholtz billow in the lower part of the North Passage. The results show that the instability is most intensive at the maximum flood. The horizontal length scale of the K-H billows is approximate 60m and the vertical length scale is 6-7 m. The K-H billows occurs between the max flood and high-water slack. The existence of K-H instability induces intensive vertical turbulence, which can greatly accelerate the process of fresh-salt water mixing.

The model was also conducted by hydrostatic version of NHWAVE. The main differences between the results of hydrostatic model and non-hydrostatic model relate to vertical velocity and remain in the region with large velocity shear, which indicates the non-hydrostatic effect is important in the accurate prediction of vertical velocity and vertical variability of velocities. Moreover, the hydrostatic model cannot capture the KH instability leading to differences in diffusion and dissipation of the mixing process.

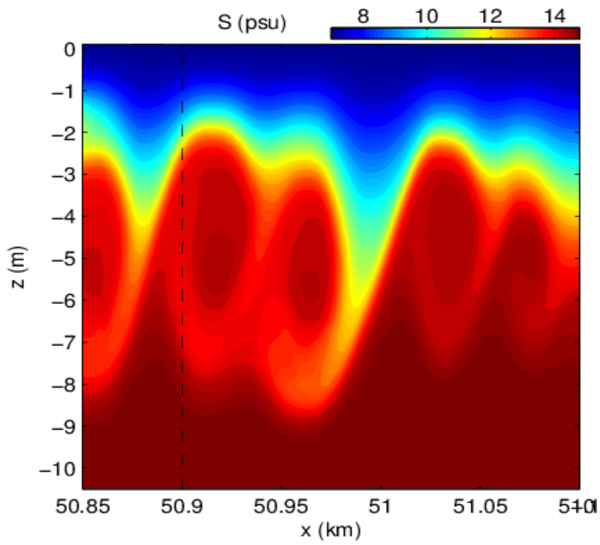

Figure 1 - Snapshot of KH billows

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