Mixing and internal waves behind the wakes of horizontal and vertical strips traversing a stratified fluid

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Abstract

Using experiments on the decay of strongly stratified turbulence behind a grid and vertical and horizontal bars [1]. A numerical model for stratified flows [2,3] has been developed and extended to simulate the laboratory experiments performed in a salty water channel at low and intermediate Reynolds numbers In continuation to previous works modeling a vertical strip towed in a channel [4], new numerical results are presented for the more delicate case of an horizontal plate. [5,3] These results are discussed both using theoretical approaches of Wave-Vortex interaction and singular components as well as with new observations in the atmosphere and the ocean [6].

Using LES on the passage of a single bar in a linearly stratified fluid medium has been compared with the experiments identifying the different influences of the environmental agents on the actual effective vertical diffusion of the wakes. The equation of state, which connects the density and salinity, is assumed to be linear. The experiments and simulations are parametrized by The Reynolds number, $Re = ul/$ and the Froude number: $Fr = u/(gh)^2$. The generation of internal

waves is detected in the experiments using Shliering. The regions of high turbulence are also detected in a Shadowgraph. There are several techniques that are used to track pliolite particles and produce the velocity and vorticity plots used to calculate spatial correlations and intermittency [7], but dye released also shows the horizontal velocity profiles. The salt induced density scalar field as the turbulence decays after the passage of the grid in the strongly stratified interface is measured with transversing conductivity probes [1,2].

The numerical simulations are compared with laboratory experiments and with different 2D-3D aspects of the turbulence cascade. The numerical experiments used a quasi 3D mode with a Smagorinsky type closure model for large Reynolds numbers. The numerical results for vertical and horizontal strips in stably stratified flows have been compared between different numerical methods, such as compact finite-difference semi-discretisation, with high order compact discretization in space, while the time integration is carried out using a Strong Stability Preserving the RungeKutta scheme.

The qualitative flows exhibit reasonable agreement with data of Schlieren visualization, density marker and probe measurements of the internal wave fields, at the corresponding Brunt-Vaissalla frequencies. We compare the evolution of fluxes as molecular mixing takes place, in the decaying vortex and internal wave field interactions, with the Mixedness parameter.

The presence of the density interface extracts energy from the turbulence source via internal waves, which are often trapped. Even in a linear density profile, mixing is a complex non-linear function. Internal gravity (or buoyancy) waves are characteristic of the stable boundary layer and contribute to its transport processes, both directly, and indirectly via internal wave-induced turbulence.

A comparison of the range of entrainment values from laboratory experiments with those occurring in nature, both in the atmosphere and in the ocean[5,6], shows the importance of modelling correctly the integral length scales of the environmental turbulence. I most cases the vertical extent of the mixing wake is related to Ozmidov lengthscale and grows with the Froude number.

The internal wave measurements in laboratory experiments on a linearly stratified tank match rather well the LES numerical results of the collapse of a bar wake, but also show the complexity of the non-linear internal waves. The initial growth of the wake is a power law, but the subsequent collapse and in particular, how the internal waves affect mixing efficiency, is not clear.

Results of performed experiments with Schlieren observations of flow fields generated by oscillating and uniformly moving obstacles of different conditions are still necessary. Only in very controlled situations[1] it has been possible to identify the individual instabilities that lead to turbulent mixing. (Vortices, Kelvin-Helmholtz, Holmboe, Waves, etc...) From a statistical point of view the non-homogeneity of the processes leads also to intermittency but due to the improvement of image analysis techniques, now it should be possible to evaluate clearer multifractal and spectral indicators of the mixing processes[9, 10].

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