Similarity scaling and vorticity structure in high-Reynolds-number stably stratified turbulent wakes

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The mean velocity profile scaling and the vorticity structure of a stably stratified, initially turbulent wake of a towed sphere are studied numerically using a high-accuracy spectral multi-domain penalty method model. A detailed initialization procedure allows a smooth, minimum-transient transition into the non-equilibrium (NEQ) regime of wake evolution. A broad range of Reynolds numbers, \( Re = UD/V \in [5 \times 10^3, 10^5] \) and internal Froude numbers, \( Fr = 2U/(ND) \in [4, 64] \) (\( U, D \) are characteristic velocity and length scales, and \( N \) is the buoyancy frequency) is examined. The maximum value of \( Re \) and the range of \( Fr \) values considered allow extrapolation of the results to geophysical and naval applications.

At higher \( Re \), the NEQ regime, where three-dimensional turbulence adjusts towards a quasi-two-dimensional, buoyancy-dominated flow, lasts significantly longer than at lower \( Re \). At \( Re = 5 \times 10^3 \), vertical fluid motions are rapidly suppressed, but at \( Re = 10^5 \), secondary Kelvin–Helmholtz instabilities and ensuing turbulence are clearly observed up to \( Nt \approx 100 \). The secondary motions intensify with increasing stratification strength and have significant vertical kinetic energy.

These results agree with existing scaling of buoyancy-driven shear on \( Re/Fr^2 \) and suggest that, in the field, the NEQ regime may last up to \( Nt \approx 1000 \). At a given high \( Re \) value, during the NEQ regime, the scale separation between Ozmidov and Kolmogorov scale is independent of \( Fr \). This first systematic numerical investigation of stratified turbulence (as defined by Lilly, J. Atmos. Sci. vol. 40, 1983, p. 749), in a controlled localized flow with turbulent initial conditions suggests that a reconsideration of the commonly perceived life cycle of a stratified turbulent event may be in order for the correct turbulence parametrizations of such flows in both geophysical and operational contexts.

Key words: ocean processes, stratified flows, turbulence simulation

1. Introduction

1.1. The importance of stably stratified wakes
Stably stratified turbulent wakes are fundamental fluid flows of relevance to environmental and ocean engineering applications. Geophysical examples include

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, fossil turbulence!