Stability Dependency of Vertical Turbulent Diffusivity of Passive and Active Scalars in Stationary and Homogeneous Stratified Turbulence

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ABSTRACT
Difference of turbulent diffusivity of passive and active scalars in stationary stratified turbulence was numerically investigated by means of direct numerical simulations. Homogeneous stratified turbulence was reproduced under the condition of energy equilibrium by using a linear forcing method with various sets of energy containing scales, energy dissipation rates, and stratification intensities. Diffusion of massless dye was solved in the reproduced turbulent field and vertical turbulent diffusivity was calculated from its concentration distributions. The calculated diffusivity of passive mass was compared with that of active density, which is estimated as the ratio of buoyancy flux to stratification intensity. It was found that when $R_g > 0.1$, there is a clear trend that the diffusivity of passive mass is greater than that of active density, and their difference increases as stratification stability increases. On the other hand, they are almost equivalent when $R_g < 0.1$. Their dependency on stratification stability is discussed in relation to the existence of counter-gradient fluxes.

KEY WORDS: Vertical diffusivity, passive and active scalars, energy equilibrium, direct numerical simulation, counter-gradient flux

INTRODUCTION
In numerical simulations of ocean environment, turbulent diffusivity has been one of the important parameters for predicting the distributions of heat and mass. The diffusion of mass, which has little influence on density, is considered to be almost passive to fluid motions. Compared with active scalar, which forms the density stratification such as heat or salinity, it is less influenced by the buoyancy effect. In practice, however, diffusion coefficient of passive scalar is often assumed to be identical to that of active scalar in the numerical simulation of stratified turbulence. This assumption may be consistent in the relatively weak stratification where the effect of buoyancy is not significant. In the strong stratification, on the other hand, Nagata and Komori (2001) found a clear difference between them by experimental and numerical studies on grid-generated turbulence. They also reported that there is a difference in the scales where counter-gradient (CG) flux occurs between active heat and passive mass in their DNS. The phenomenon of CG flux was first found by Komori et al. (1983) in the laboratory experiment of stratified open-channel flow. Komori and Nagata (1996) explained its mechanism as a result of potential energy of fluid parcels confined to lower (or higher) fluid surroundings against the density gradient by turbulent mixing. Although their explanation is based on decaying turbulence, the CG transfer has been also reported for the fluid parcel in the growing or steady turbulence (e.g. Rohr et al., 1988; Gerz et al., 1989). Smyth and Moum (2000) carried out direct numerical simulations of shear layers with Kelvin-Helmholz billows and found the CG fluxes in the dissipation range.

In order to explain these persistent CG fluxes, Gerz and Schumann (1996) proposed a conceptual model that the CG fluxes occur by the collision of large-scale fluid parcels. According to this model, when the stratification is weak in shear-driven turbulence, CG fluxes occur in the small-scale by the quick transport of kinetic energy. As stratification becomes strong and dominant, conversions from potential energy to kinetic energy occur at large scales as well as small scales. Iida and Nagano (2005) focused on the analogy between homogeneous shear flow and wall turbulence and explain the generation mechanism of CG fluxes in terms of vortex structures by using the numerical simulation. However, these reports on homogeneous shear flows did not mention transport of passive mass. For the comparison of diffusion of passive and active scalars, Lindborg and Fedina (2009) reported that they are almost identical even in the strong stratification by numerical simulation of stratified shear flows with random forcing. This conclusion contradicts with that of Komori and Nagata (2001) and should be clarified.

In this study, diffusivity for passive scalar is estimated from the diffusion of mass concentration in stationary and homogeneous stratified turbulence. The diffusivity of passive mass is estimated from its distribution and it is compared with that of active scalar in relation to stratification intensity. Finally, the mechanism of diffusion in homogeneous and stratified turbulence is discussed from vertical fluxes of active and passive scalars.