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Energy spectrum in stratified turbulence and its application to the atmospheric mesoscales

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It is known from observations that the horizontal kinetic energy spectrum follows a k^{-5/3} power law in the mesoscale phenomena in the upper troposphere. Nastrom et al. (1984) found the k^{-5/3} power law in the scales less than about 500 km from the observation in the upper troposphere. From the aircraft observation, Cho et al. (1999) showed that this spectral slope can be applied to the atmospheric motion with the hoizontal scales less than 100 km in the troposphere except the boundary layer. Lilly (1984) attemped to understand the energy spectrum in the mesoscales from inverse energy cascades in stratified turbulence. However the results from numerical simulations of stratified turbulence indicate that inverse energy cascades does not occur unless the Coriolis parameter f is extremely large (Herring and Metais; 1989, Metais et al., 1994). On the other hand, Vallis et al. (1997) reproduced the above spectral slope in the mesoscales with the regional model including water vapor and Koshyk and Hamilton (1999) did with GFDL SKYHI GCM. These models include many physical processes so that it is difficult to understand their results as energy cascades in stratified turbulence.

We conduct numerical experiments with a three dimensional nonhydrostatic model assuming the Boussinesq approximation in order to consider upscale and/or downscale energy cascades in stratified turbulence. The results obtained in these experiments are as follows. When the dynamical forcing function has a peak at the horizontal scale of 20 km, inverse energy cascading due to interactions between horizontal vortices is too weak to explain the spectral slope in the mesoscales, even if the amplitude of the forcing function and the stratification are strong. When the forcing is given at the domain size (400--800 km), the spectral slope depends largely on the stratification and the forcing amplitude. The energy transfer to small scales is smaller as the stratification is strong. This result implies that eddy viscosity should be smaller according to the extent of the stratification.

We also examine the Smagorinsky-Lilly parameterization and the 1.5 order TKE parameterization, which are based on LES. In both parameterizations, the energy transfer in high wavenumbers increases and the energy spectrum in the horizontal scales larger than 20--30 km is close to that of the observations. The dissipation of the vortical mode increases in high wavenumbers, while that of the gravity mode deareases in low wavenumbers. However, the kinetic energy near the grid scale is not sufficiently removed because of too weak eddy viscosity at this scale. This artificial accumulation of the energy emerges remarkably as the forcing amplitude is weak.