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Estimation of horizontal eddy diffusion coefficients in convective mixed layers

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Numerical models for geophysical fluids require parameterization of sub-grid scale turbulence. This study estimates the horizontal turbulent diffusion coefficient to prescribe the flux of the sub-grid scale horizontal turbulence in the daytime atmospheric convective mixed layer.

In contrast to the recent advances in parameterizations of vertical turbulent fluxes that have been validated by both observations and Large Eddy Simulation (LES) (e.g. Nakanishi and Niino 2009), those of horizontal turbulent fluxes are studied little; even physical mechanism of them is poorly understood. Horizontal fluxes in numerical models have often been tailored for damping unphysical oscillations in high frequency. However, we need a precise model that is based on a deep understanding of horizontal turbulence fluxes for the state-of-art high-resolution numerical models.

In this study, we carried out LES (Nakanishi 2000; Ito et al. 2010) with the grid size of 50 m for all (x-, y-, z-) directions; the size of domain is 36 km for the horizontal directions whereas 5 km for the vertical direction; the lateral boundaries are doubly periodic; no wind with a uniform stable stratification (4.0 K/km) is imposed; sensible heat flux Q of 0.2 K m/s is introduced from the bottom surface horizontally uniformly. The convective mixed layer gradually develops from the bottom in the LES.

To estimate the horizontal turbulent diffusion coefficient K_h of a passive scalar c, a uniform slope of the passive scalar is imposed at a time step t=0, and a prognostic equation of deviation c' from the initially assumed c is integrated in the LES. A horizontal average of the horizontal turbulent flux in LES divided by the slope of the initial c gives K_h at each height.

The passive scalar is stared at time when convective mixed layers are well developed (i.e. several hours after the initiation at least). Soon after the introduction, estimated K_h increases in proportional to t due to autocorrelation of the turbulent velocity. During a turnover time of an eddy, it gradually approaches to a constant K_h, which shows the eddy diffusion by the convective motion comes to realize. K_h turns out to be of the order of 100 m^2/s when it reaches a quasi-steady state and apparently has a different trend when compared with the vertical turbulent diffusion coefficient: K_h has local maxima at the lowest layer and top of the convective mixed layer.

K_h increases in accordance with the development of the convective mixed layer, and it appears to be scaled by the product of the height of the convective mixed layer and the convective velocity $w*$. Nevertheless a bit deviation from this scaling is found. The deviation is believed to arise from insufficiency of the resolution of our numerical model: it is found that resolution of LES is enough for reproducing the horizontal convective motions is much higher than that for vertical motions. We will certify the above scaling for K_h by means of a finer resolution LES whose grid spacing is 25 m.

Keywords: turbulence diffusion coefficient, eddy diffusivity, horizontal sub-grid flux, convective mixed layer