LARGE EDDY SIMULATION OF of PARTICLE SETTLING IN THE OCEAN MIXED LAYER

By YIGN NOH[1], MARCUS HEROLD[2] AND SIEGFRIED RAASCH[3]

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[1]Department of Atmospheric Sciences, Yonsei University, Korea
[2]Institute of Aerospace Systems, TU Braunschweig, Germany
[3]Institute of Meteorology and Climatology, University of Hannover, Germany

I. Introduction

Understanding the settling process of suspended particles in the ocean mixed layer is important in various upper ocean processes. In particular, the estimation of the particle flux from the upper ocean to the deep ocean provides critical information on the global carbon cycle through biological pump (Ittekkot et al. 1996).

No information is available yet on it, and the mean particle concentration is usually predicted by using a diffusion equation with constant eddy diffusivity and particle settling velocity (Lande and Wood 1987). Meanwhile, Stommel (1949) suggested that particles be suspended indefinitely under a strong vortex field, which was confirmed by Tooby et al. (1977) and Maxey and Riley (1986).

In the present study, we investigated the settling process in the ocean mixed layer by analyzing the Lagrangian motion of a large number of particles in the turbulent flow field generated by LES, especially in the presence of a large-scale vortex structure such as Langmuir circulation (LC).

2. LES model and simulations

The LES model used in this study is based on the PALM (Raasch and Schröter 2001). To simulate LC, momentum equation was modified by including a vortex force and an additional advection by the Stokes drift following the theory by Craik and Leibovich (1976), (Skyllingstad and Denbo 1995, McWilliams et al. 1997, Noh et al. 2004).

The model domain was 300 m in the horizontal direction and 80 m in the vertical direction , and the grid size was 1.25 m in both horizontal and vertical directions. Only the case of uniform density was considered in this study.

We investigated two different types of the ocean mixed layer; that is, with and without LC (EXP O and L), and three different types of particles, EXP a (w_s/u^* = 0.1), b (w_s/u^* = 1), and c (a passive scalar) (u_* = 0.01 ms^{-1}). After 8 hour integration without particles until the equilibrium was approached, 80,000 particles were released near the surfacr (z = 2.5 m).

**Corresponding author address*: Yign Noh, Yonsei Univ., Dept. of Atmospheric Sci., Seoul 120-749, Korea; e-mail: noh@atmos.yonsei.ac.kr.

3. Results

3.1 *Patterns of the flow field and particle settling*

Streaks of the strong downwelling zone beneath the surface convergence appear in parallel each other in EXP L, but no organized structure appears, and the velocity field is more or less isotropic in EXP O (Fig. 1).

In EXP O, the downward transport of particles occurs more or less uniformly in the horizontal direction, but in EXP L, it is dominated by the sweeping of particles by the downward jets associated with LC (Fig. 2).

3.2 *Evolution of the mean concentration of particles*

In EXP L, the mean concentration propagates downward rapidly and almost uniform concentration C appears throughout the whole column of the mixed layer at t ~ 10^4 s, and it decreases uniformly at all depths with time thereafter. On the other hand, in EXP O, the vertical diffusion of particles is much slower, and the depth of the maximum concentration goes down with particle settling (Fig. 3).

3.3 Settling velocity of particles

Soon after the release of particles, the mean settling velocity W increases rapidly initially. It is mainly due to the fact that particles are present only in the downward eddies during the initial downward propagation. This effect diminishes with the lapse of time, and becomes negligible after $t^*(= t/(h/w_s))$ ~ 1, as we can refer from W of a passive scalar.

In all experiments, W is smaller than w_s, but the decrease is larger in the presence LC and for smaller w_s. In EXP La, W decreases to as much as W/w_s = 0.55 (Fig. 4).

The reduced particle settling velocity leads to the decreased downward particle flux. For example, as much as 15% of particles still remain within $z < h$ (= 50 m) even at t^* = 2 in EXP La, while all particles must pass through the depth $z = h$ at t^* = 1 in the still fluid.

4. Conclusion

In the present work, we calculated for the first time the settling velocity of suspended particles in the ocean mixed layer by analyzing the Lagrangian motion of a large number of particles in the threedimensional turbulent flow simulated by LES. We have found that the presence of LC can suppress the particle settling in the ocean mixed layer, which has been a subject of conjecture for a long time.

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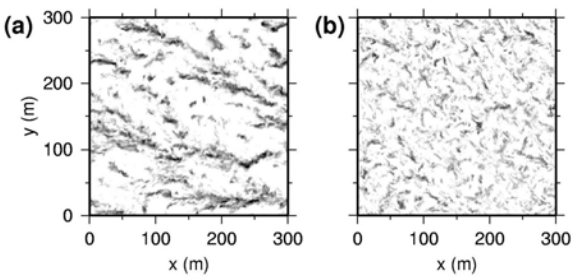

FIG 1 Instantaneous vertical velocity at the horizontal cross-sections (z = 10 m); (a) EXP L, (b) EXP O.

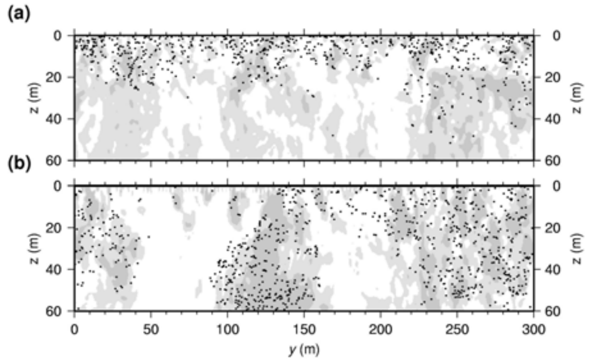

FIG. 2 Instantaneous distributions of particles and vertical velocity at the vertical cross-sections at $t = 4\times10^3$ s; (a) EXP O, (b)EXP L

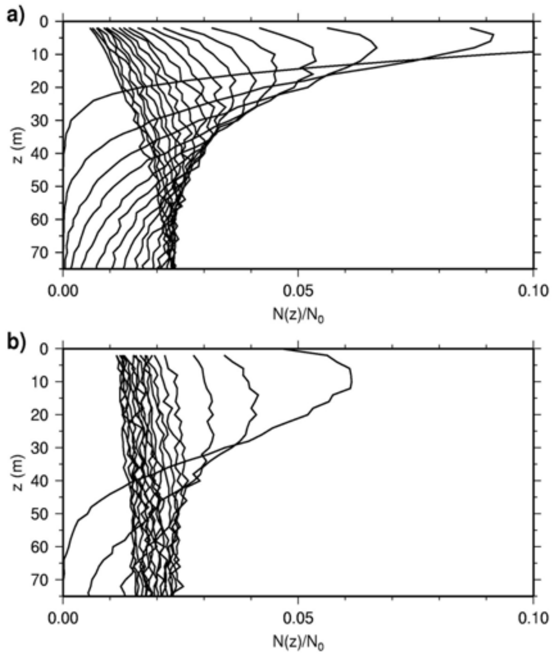

FIG. 3 Evolutions of the mean concentration profiles; (a) EXP Oa, (b) EXP La,

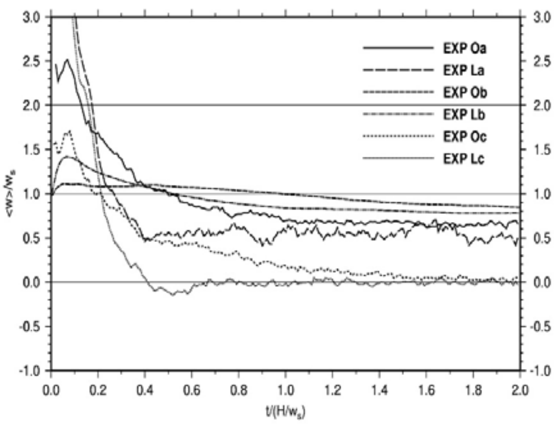

FIG. 4 The variation of W with time for each experiment. The time is rescale by h/w_s and the same time scale as for w_s/u_* = 0.1 is used for the passive scalar