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Influence of air-sea fluxes and breaking waves on oceanic mixed layer

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ABSTRACT

Mellor-Yamada model is applied to investigate the influence of bulk algorithms for turbulent fluxes on mixed layer depth (MLD). When bulk algorithms independent of wind waves are used to calculate air-sea turbulent fluxes, it is shown that the differences in MLD are mainly resulted by the disparities of heat fluxes by various algorithms. When momentum flux algorithms including the effect of wind waves are applied, it is found that the wave state significantly affects MLD. It is also shown that the turbulence induced by breaking wave has little effect on MLD deepening despite it is very strong near the air-sea interface.

KEY WORDS: Oceanic mixed layer; Mellor-Yamada model; bulk algorithm; turbulent fluxes; wind wave; breaking wave.

INTRODUCTION

The oceanic boundary layer contacted with air-sea interface is usually called oceanic mixed layer (OML) because it is characterized almost uniform temperature and salinity due to the active turbulent mixing. As the portion of the upper ocean that directly contacts with atmosphere, OML is mainly driven by forcing and free convection. Forcing convection is resulted by wind blowing at the air-sea surface, and free convection is produced by buoyancy fluxes induced by heat and water vapor exchange through the interface. The mixed layer depth (MLD) is defined from the surface down to a depth where the temperature is not colder than a typical value at the sea surface. The magnitude of the typical value adopted by various authors is usually between 0.02-0.1°C. MLD is regarded about 10-200 m over most of the tropical and mid-latitude oceans. In this paper, MLD will be defined at the depth where its temperature difference from sea surface larger than 0.02^0C.

The OML models can be roughly divided into two groups: bulk and profile models (Kantha and Clayson, 1994). The bulk models are integrated over OML, and assume complete homogenization at every time. Thus the momentum and heat balance of entire OML is controlled completely by the momentum and heat fluxes at sea surface (Price et al., 1986). With the increasing of computer capability, the bulk models are rarely used. The profile model, also called diffusion model, try to directly characterize the balance of turbulent mixing, production and dissipation in OML. Because the number of unknown quantities exceeds the number of constraining equations, it is impossible to directly solve the full equations of fluid motion, unless some kinds of simplifications are introduced. Therefore, in the profile model, it has to be brought in various simplifications for the fluxes and higher order moments, known as the turbulence closure schemes, which give rise to various types of OML models (Large et al., 1994; Burchard, et al., 1998). A level 2.5 turbulent closure scheme, developed by Mellor and Yamada (1982), will be applied in our discussion.

As boundary conditions at the air-sea interface, the turbulent fluxes such as momentum and heat fluxes play a key role in the dynamics of OML. However, the turbulent fluxes cannot be directly obtained except for the period of field observations. Therefore, many bulk aerodynamic algorithms have been proposed to relate the turbulent fluxes with the mean meteorological parameters that can be easily acquired by daily measurements, and exchange coefficients for momentum (drag coefficient), moisture (Dalton number), and sensible heat (Stanton number) transfers (Brunke et al., 2003). Bulk algorithms differ from how to parameterize these exchange coefficients. Recent observational evidence has shown that the presence of breaking waves greatly enhances the turbulence near the sea surface (Agrawal et al., 1992; Terray et al., 1996; Gemmrich and Farmer, 2004). This process has been considered important to the dynamics of OML (Crag and Banner, 1994; Craig, 1996; Mellor and Blumberg, 2004).

By using Mellor-Yamada model, the influences of different turbulent fluxes calculated by various bulk algorithms and the presence of breaking waves on MLD will be investigated in this paper. After a brief introduction of Mellor-Yamada model, the effects of different algorithms and turbulence induced by wave breaking on MLD are presented, respectively. Concluding remarks is given finally.

MELLOR-YAMADA MODEL

The equations governing the mean horizontal velocities (the east and north components of current, U and V), potential temperature (θ) and salinity (S) in a horizontally homogeneous ocean boundary layer are usually expressed as

$$\frac{\partial U(z,t)}{\partial t} = -\frac{\partial}{\partial z}\left(\overline{u'w'}\right) + fV \tag{1}$$

$$\frac{\partial V(z,t)}{\partial t} = -\frac{\partial}{\partial z}\left(\overline{v'w'}\right) - fU \tag{2}$$

$$\frac{\partial \theta(z,t)}{\partial t} = -\frac{\partial}{\partial z}\left(\overline{\theta'w'}\right) + \frac{1}{\rho_w C_{pw}}\frac{\partial I(z)}{\partial z} \tag{3}$$

$$\frac{\partial S(z,t)}{\partial t} = -\frac{\partial}{\partial z}\left(\overline{s'w'}\right) \tag{4}$$

where z is the vertical coordinate taken to be zero at the ocean surface and pointing upward, t the time coordinate, f the Coriolis parameter, ρ_w the density of seawater, C_{pw} the specific heat of seawater, and I is the