3A.2 IMPACTS OF BREAKING WAVES AND LANGMUIR CIRCULATIONS ON THE OCEAN MIXED LAYER IN HIGH WINDS

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1. INTRODUCTION

Breaking waves are the signature feature of the ocean surface layer in high wind conditions. Dynamically, wave breaking is important since it is believed to be the primary path for stress transfer between a wind-generated wave field and the underlying oceanic currents (Melville, 1996). Wave breaking is triggered in the open ocean by wave-wave, wave-current, and wind-wave interactions (Melville, 1996), but even in equilibrium conditions it is highly intermittent in space and time. For example, Melville and Matusov (2002) find that the percentage of surface area that is actively entraining air increases with wind speed cubed, and for wind speeds less than 15ms^{-1} is O(1%). It increases to about 8% for wind speeds of 20ms^{-1}. Wave breaking events occur over a spectrum of wavelengths ranging from centimeters or less to tens or hundreds of meters (plunging breakers in high seas; see review by Melville, 1996) with the associated time scale of active breaking approximately proportional to the period of the breaking wave (Melville and Matusov, 2002). Further, wave breaking co-exists and interacts with Langmuir circulations, which are generated by vortex forces associated with the wave Stokes drift. Hence, a model of ocean currents under high wind conditions needs to consider the wave field.

2. MODELING WAVE INFLUENCES

Ocean mixed layer models that utilize ensemble averaged turbulence closures ignore the wave field and drive the underlying currents by a mean surface wind stress $\langle \boldsymbol{\tau} \rangle$ which spatially and temporally filters out the events (*e.g.,* wind gusts and breaking waves) responsible for actual stress transfer from winds to waves to currents. The wave field is however critical to mixed layer dynamics and is included to a certain degree in most large-eddy simulation (LES) models (*e.g.,* Skyllingstad and Denbo 1995; McWilliams et al. 1997). LES models account for the interaction between Stokes drift and resolved vorticity ($\mathbf{u}_s \times \boldsymbol{\zeta}$) as first suggested by the Craik-Leibovich asymptotic analysis. These LES however still omit the intermittency of the surface stress associated with wave breaking.

We are interested in investigating the combined and interacting influences of Stokes drift and intermittent stress transmission, caused by wave breaking, on the mixed layer. Our modeling approach is of modest complexity compared to a full microphysical simulation of air and water and incorporates the following essential elements: (1) a Stokes drift profile, $\mathbf{u}_s(z)$, developed from the Pierson-Moskowitz equilibrium wave spectrum as function of the U_{10} winds; and, (2) a stochastic model for breaking waves developed from laboratory (Melville et al., 2002) and field measurements (Melville and Matusov, 2002). In our model, the wave breaking field is assumed to be a collection of horizontal impulses (*i.e.,* body forces) $\mathbf{A}(\mathbf{x},t)$ that have similar 3D space and time dependencies. Restricted to the $x-$direction,

$$A = k_b \frac{c}{T} \mathcal{T}(\alpha)\mathcal{X}(\beta)\mathcal{Y}(\delta)\mathcal{Z}(\gamma), \qquad (1)$$

where $(\mathcal{T},\mathcal{X},\mathcal{Y},\mathcal{Z})$ are space-time shape functions that describe the evolution of a breaking event. All breakers are assumed to be self similar and separable in dimensionless time and space coordinates $\alpha = (t-t_o)/T, \beta = (x-x_o)/c(t-t_o), \delta = 2(y-y_o)/\lambda$ and $\gamma = z/\chi c(t-t_o)$. $(t_o,x_o,y_o,z_o = 0)$ is the onset time and position of the chosen breaker and (c,λ,T) are its phase speed, wavelength, and period. The wave characteristics (c,λ,T) are related to each other through the deep water linear dispersion relation $c^2 = g\lambda/2\pi$ with $T = \lambda/c$. The constant $0 < \chi < 1$, which is just the aspect ratio of the depth to length of the breaker, controls the depth penetration of the breaker forcing.

The breakers are randomly located at the surface of the water, but their number at any time t is constrained to match the observed white cap coverage for a given U_{10}. The phase speed c is drawn from an exponential distribution that matches observations and the breakers are oriented at random angles $-\pi/2 < \theta < \pi/2$ about the

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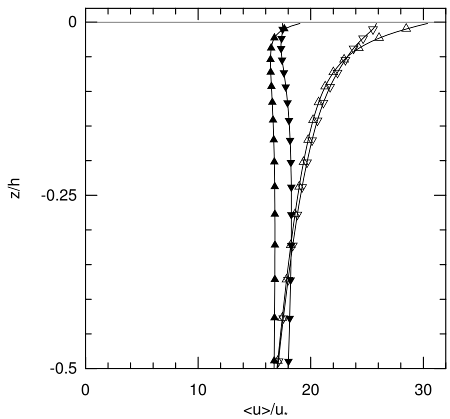

Figure 1: Vertical current profiles normalized by u_* for DNS driven by: constant stress △; 100% breaking ▽; constant stress plus Stokes forcing ▲; and 100% breaking plus Stokes forcing ▼. h is the height of the computational domain.

$x-$axis. At present, observations are uncertain as to the exact partitioning of the forcing between wind stress and breaking. We thus introduce the modeling constant k_b so as to examine regimes spanning zero and full stress intermittency (*i.e.*, 0 to 100% breaking). The final ingredient of our stochastic model adds a work density to the parameterization for the subgrid-scale turbulent kinetic energy to account for fine scale breaker processes. Further details are provided in Sullivan et al. (2004).

3. SIMULATION RESULTS

The above modeling components have been evaluated in direct numerical simulations (DNSs) and are presently being implemented in an ocean boundary layer LES code. The DNS are performed with $200 \times 200 \times 96$ gridpoints and utilize a monochromatic Stokes profile and a single breaker phase speed. Various combinations of upper surface forcing have been considered: results for neutrally stratified flow driven by constant stress or 100% breaking waves with and without Stokes forcing are presented. We find that a small amount of active breaking, less than 2%, significantly alters the instantaneous flow patterns as well as the ensemble statistics. The importance of intermittent breaking and Stokes forcing to the near surface currents and velocity variances is illustrated in figures 1 and 2. Model breakers are effective agents in energizing the surface region of ocean mixed layers and can adequately drive ocean currents in the absence of any other mechanism of momentum transfer from the winds. The greatest mixing occurs with 100% breaking co-existing with Langmuir circulations: a situation

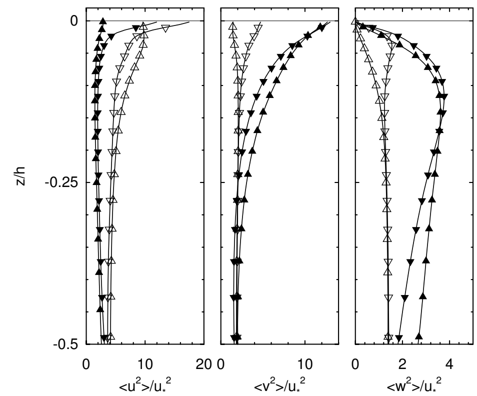

Figure 2: Vertical variance profiles normalized by u_*^2 for the same cases as in figure 1.

where the mean current shear is near zero. Langmuir circulations are disrupted by breaking, but the combined influences of breaking and Stokes forcing leads to the highest amount of turbulent kinetic energy. Analysis of the DNS profiles shows how the effective surface roughness z_o increases with wind speed and scales with the breaker field. LES solutions and comparison with hurricane observations will be discussed.

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