INTERMITTENT MIXING BY MULTISCALE BREAKING OF WIND WAVES: IMPLICATIONS FOR OIL DISPERSION

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Summary We simulated the intermittent mixing by breaking waves with the use of non-stationary 1D two-equation turbulence model. The wave-breaking layer with thickness of half significant wave height was included into consideration. An injection of turbulence by penetrating breakers in this layer was parameterized by source term in the turbulent kinetic energy and dissipation equations. The Monte-Carlo simulations of intermittent mixing were carried out. They support assumption that observed log normal distribution of dissipation rate is associated with breaking of waves in many scales. An intermittent mixing effects on the scales of breakup and dispersion in water of oil droplets in the wave breaking layer. The detailed results of simulations of turbulence and droplet spectre and concentration in the wave enhanced layer for stormy conditions by linked model of surface turbulent layer and 3D Lagrangian model of oil spill are presented.

INTRODUCTION

Breaking serves to limiting height of surface waves, dissipating surface-wave energy, some of which is available for turbulent mixing [1]. Breaking is multi-scale process: from large-scale breaking waves and smaller-scale waves breaking on longer waves to micro-scale breaking. Direct measurements show that breaking generates spectre of the intensive outbursts of turbulence with dissipation rate that is orders of magnitude larger than the mean value. These events result in the roughly log normal probability distribution of the dissipation rate [2]. Oil spilled at sea often entrained by breaking waves in stormy conditions and forms clouds of oil droplets that are dispersed by subsurface turbulence and shear currents. Aim of this paper is to clarify role of turbulence injected by breaking waves in mixing of near-surface layer and to estimate effects of intermittent injection of oil by highly energetic breaking wave events.

INTERMITTENT MIXING BY WAVE BREAKING

We simulated an intermittent mixing by breaking waves by non-stationary 1D two-equation turbulence model. The wave-breaking layer with thickness of half significant wave height was included into consideration (Fig. 1). An injection of turbulence by penetrating breakers in this layer was parameterized by source term in the turbulent kinetic energy and dissipation rate equations. The Monte-Carlo simulations of intermittent mixing were carried out. Example of time series of kinetic turbulent energy flux in wave-breaking layer is given in Fig. 2. Both simulated (curve 2) and observed [2] (curve 1) distribution of near-surface dissipation in Fig. 3 support assumption that observed quasi-lognormal distribution of dissipation rate is associated with breaking of waves in many scales. Time averaged profiles of dissipation rate (curve 7) agree with measurements (1-3) and stationary solutions (curve 4) in Fig. 4. Curves 5-6 show limits in the variability of the dissipation rate. However, temporally intermittent mixing effects on the scales of breakup and dispersion in water of air bubbles and oil droplets in the wave-breaking layer.

OIL DISPERSION IN WAVE ENHANCED LAYER

To simulate breakup and oil dispersion the 3D Lagrangian oil dispersion model was developed [4]. It describes entrainment of oil in the water by breaking waves and resurfacing entrained droplets. The turbulent diffusion processes are simulated by use Lagrangian stochastic simulation technique based on the random walk method for Gaussian "spillets". It was shown that almost all statistical models of break-up of an immiscible fluid immersed into a turbulent flow [5] were not able reproduce observed distribution of oil droplet size. Instead, the new model of the breakup based on Kolmogorov approach [6] was proposed to reproduce observed log normal distribution of oil droplet sizes (Fig.5). The detailed results of simulations of turbulence and droplet concentration in the wave enhanced layer for stormy conditions by linked model of surface turbulent layer and 3D Lagrangian model of oil spill are presented. The hypothetical scenario of oil spill 75,000 tons of crude oil on the north-western shelf of the Black Sea 25.09 2002 at distance around 50 km from Odessa oil terminal was considered. As seen in Fig.6 the model reproduces processes of surface slick entrainment by the breaking waves, generation of oil droplets, diffusion by subsurface turbulence and gradual resurfacing of droplets by buoyancy forces that contributes in the forming of frequently observed thin oil film tail ("sheen") behind the thick slick area. The calculations show that knowledge of mean characteristics of breaking wave field wave field such as wave height, length, breaking frequency and whitecapping is not enough to simulate breakup and dispersion of liquid and gas in the surface layer

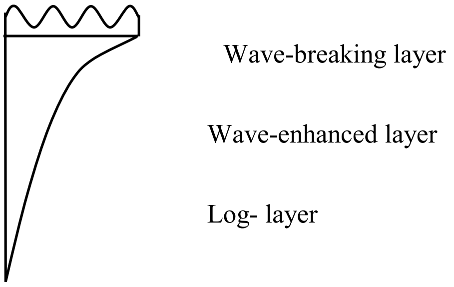

Fig. 1 Vertical structure of surface layer

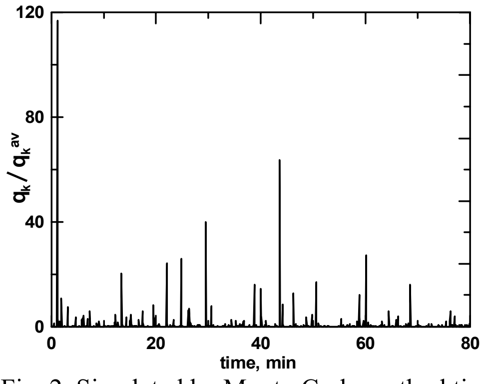

Fig. 2 Simulated by Monte-Carlo method time series of flux of kinetic turbulent energy in wave-breaking layer

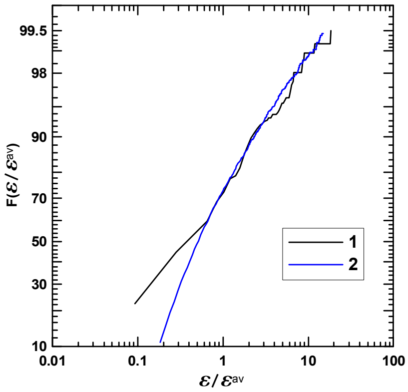

Fig. 3 Simulated (2) vs. observed (1) [2] distribution of near-surface dissipation normalized on time-averaged value

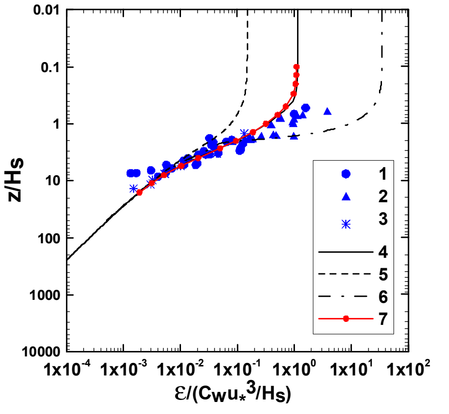

Fig. 4 Profiles of normalized dissipation rate in surface layer.

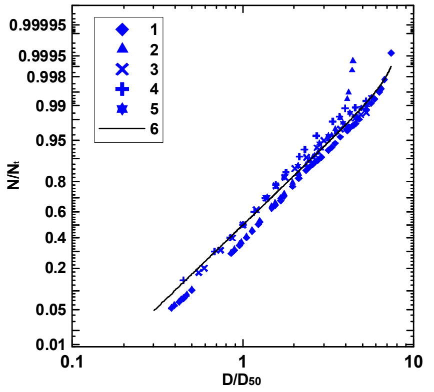

Fig. 5 Simulated (curve 6) vs. measured (1-5) self-similar size distribution of oil droplets.

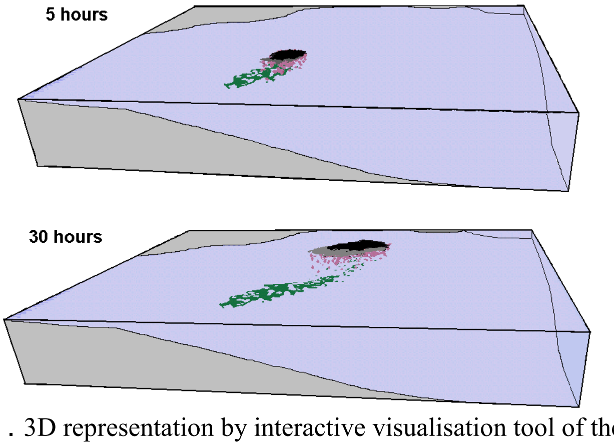

Fig. 6 . 3D representation by interactive visualisation tool of the oil spill at the North-western shelf of the Black Sea. The surface slick, oil-in-water and oil-on-bottom concentrations are shown by black, red and green, respectively.

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