Turbulent mixing due to surface waves implemented into a turbulence model

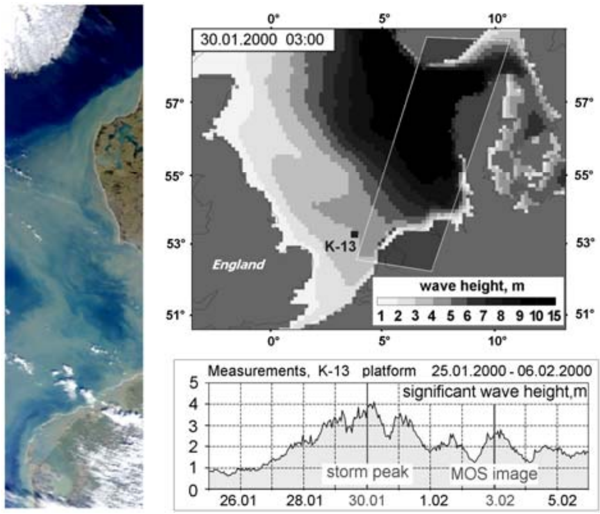
Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

A. Pleskachevsky, German Aerospace Centre, Oberpfaffenhofen, Germany**, M. Dobrynin,** Danish Meteorological Institute, Copenhagen, Denmark**,**
A. V. Babanin, Swinburne University of Technology, Melbourne, Australia**, H. Günther,** Helmholtz-Zentrum Geesthacht, Germany,
E. Stanev, Helmholtz-Zentrum Geesthacht, and University of Oldenburg, Oldenburg, Germany

Abstract

Surface waves have an impact on the turbulent mixing. Satellite observations of suspended particulate matter (SPM) at the ocean surface are used as indicator of flow turbulent quantities. In a water column, SPM builds a vertical profile depending on particle settling velocities and vertical mixing processes. Observations in the North Sea show that surface SPM concentrations grow rapidly during a storm, building plume-shaped, kilometres long uninterrupted and consistent structures. After the storm has passed and wave height decreased, SPM rapidly sinks to the seabed.
Non-breaking wave-induced turbulence is parameterized, and implemented into a turbulent kinetic energy equation. The ratio between dissipated and total wave energy is used to describe the influence of wave damping on the mean flow. Numerical tests reproduce experiments in a wave tank and support the SPM observations in the North Sea. The motion of an individual non-breaking wave includes turbulent fluctuations, if the critical Reynolds number for wave motion is exceeded, independent of currents due to wind or tides. These fluctuations produce high diffusivity and strong mixing in the upper water layer of the ocean.

Ref.: Pleskachevsky et al., Turbulent Mixing due to Surface Waves Indicated by Remote Sensing of Suspended Particulate Matter and Its Implementation into Coupled Modeling of Waves, Turbulence, and Circulation. JPO 41, pp. 708-724, 2011.



Storm events in the North Sea at 29.01-04.02.2000. Optical MOS image of German Bight on 03.02.2000 (left) and significant wave height in the North Sea at the storm peak (right).

Parameterization

The effect of the motion induced by a non-breaking wave on the turbulent mixing requires the coupling of wave, turbulence and circulation models. Our goal is to implement the wave action directly in the equation of evolution of the turbulent kinetic energy (TKE), aiming to improve the circulation model by taking into account the wave-induced diffusivity. Two views of the wave motion have been considered:1) The symmetrical oscillation of the individual waves and 2) The asymmetry of the wave-induced water-particle motion.
We postulate: Both effects are important and must be taken into account, the overall effect on turbulent diffusivity can be obtained based on an idealized solution (linear wave theory), if the dissipation of the wave is known. Taking this into account the TKE production P_s can be rewritten. It then describes the mean flow and includes the wave effects:

$$P_s = P_{\substack{mena\\curr}} + P_{wave} = \nu_t \left(M^2_{\substack{mean\\curr}} + M^2_{\substack{asym\\wave}} \right)$$

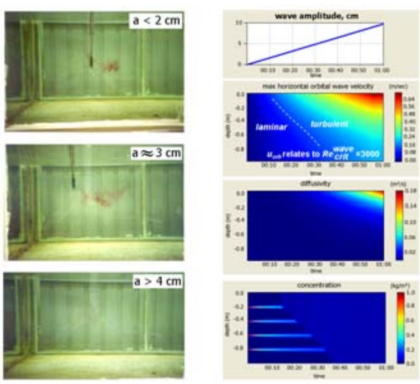
$$\nu_t = \nu_{\substack{mean\\curr}} + \nu_{wave} \qquad \nu_{wave} = l^2_{wave} M_{\substack{symm\\wave}}$$

where ν_t the eddy viscosity modified by the viscosity of the wave action and l_{wave} is the length scale for the wave-induced turbulence.

Results

A simple experiment in a water tank

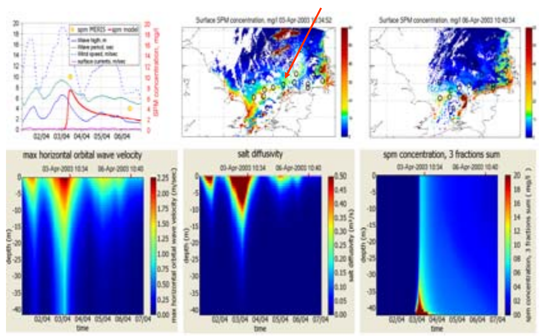
The experiment (no wind and no currents, waves with *f*=0,667 Hz) shows that wave-induced motions have turbulent fluctuations. As a result, the injected ink marker is diffused completely after the critical Reynolds number for wave motion is exceeded.



Experiment in the water tank: Ink is injected for different wave amplitudes *a* (left), and reproducing of the experiment by numerical simulation (right).

Wave-induced mixing during a storm event in the North Sea

The maximum of SPM erosion in the model corresponds to the storm peak. Eroded SPM are strongly mixed vertically, and the concentration at the surface rises rapidly during a very short interval (about 6 h) and reproduces, with a good quality, the process visible in the MERIS scene.



The storm period 01.04.2003-07.04.2003 in the southern North Sea.
MERIS scenes, presenting the SPM concentration at sea surface (upper row, right).
Model results: The control factors wave height, wave period (*Tm1*), wind speed, circulation currents (5m surface layer), surface SPM concentration derived from MERIS (left). Next row presents vertical distribution in the time of maximal horizontal wave velocity, diffusivity and resulting SPM concentration.

Helmholtz-Zentrum Geesthacht • Max-Planck-Straße 1 • 21502 Geesthacht • Phone +49 (0)4152 87-0 • Fax +49 (0)4152 87-1403 • www.hzg.de
Contact: Dr. Heinz Günther, E-mail: Heinz.Guenther@hzg.de