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Wave-energy dissipation by bottom friction in the English Channel

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ABSTRACT

The energy dissipation by bottom friction of wind-generated surface-gravity waves is evaluated in relation to the seabed roughness magnitude in the English Channel (western Europe). The investigation is based on the phase-averaged wave model SWAN (Simulating WAves Nearshore) modified to account for a new parameterisation of the wind-drag coefficient at high wind speeds. Two formulations of the bottom-drag coefficient are evaluated: (1) the default constant empirical values derived from the JONSWAP experiment and (2) the eddy-viscosity model of Madsen et al. (1988) integrating the hydrodynamic conditions and the bottom roughness length scale considered successively constant and parametrised according to the grain size of bed sediments. Model performances are evaluated by comparing predictions with available measurements of the significant wave height and the peak period at (1) three offshore lightships and (2) two nearshore wave buoys off Le Havre and Cherbourg harbours. The heterogeneous bottom roughness length scale associated with the grain size of seabed sediments improves globally numerical estimates. Mappings of coastal regions influenced by bottom friction are produced exhibiting significant energy dissipation in areas of pebbles and gravels of the Normano-Breton Gulf and the surroundings of the Isle of Wight exposed to the incoming waves from the North-Atlantic ocean.

1. Introduction

Refined estimations of the transformation of wind-generated surface-gravity waves in shelf environments are crucial for many offshore and coastal engineering applications dealing with the safety and reliability of marine structural mechanics, the exploitation of waves renewable energy or the design of harbours and waterfronts. Among the different dissipation and dispersion mechanisms of wave energy in coastal waters (*e.g.*, refraction, diffraction shoaling, etc.), seabed interaction processes may be significant in nearshore areas leading to a substantial decrease by 40–50% of the wave height during extreme storm events such as hurricanes (*e.g.*, Riedel et al., 2005; Siadatmousavi et al., 2011).

The interaction between the surface waves and the sea bed can appear in different ways depending in particular on bottom conditions. These processes reviewed by Shemdin et al. (1978) include percolation into a porous bottom, motion of a soft muddy bed, scattering on bottom irregularities and friction created by the orbital motion of water particles under wave conditions. In many continental shelves covered by sandy bottoms, bed friction is considered to be the dominant mechanism (*e.g.*, Shemdin et al., 1978; Bertotti and Cavaleri, 1994).

In the energy balance equation of third-generation wave models, this dissipation process is integrated using the formulation proposed by Weber (1991a,b) introducing a bottom-friction coefficient determined by the hydrodynamics, the bottom topography and the bed roughness. Numerous formulations have been proposed to approach this coefficient ranging from empirical constant values (*e.g.*, Hasselmann et al., 1973; Bouws and Komen, 1983) traditionally implemented in operational applications (*e.g.*, Komen et al., 1994) to more complicated models integrated the effects of wave-induced bottom velocity and bed-sediment properties (*e.g.*, Hasselmann and Collins, 1968; Collins, 1972; Madsen et al., 1988). Detailed reviews have been established by Luo and Monbaliu (1994) or the WISE Group (2007). Nevertheless, given the lack of information on bottom materials, the nature and properties of bottom sediments were considered in few applications (*e.g.* Ardhuin et al., 2003a,b; Siadatmousavi et al., 2011).

The present study extends these numerical investigations evaluating the effects of bed-sediment grain-size distributions and associated sand ripples features on wave-energy dissipation by bottom friction. The site of application is the English Channel (western Europe) (Fig. 1). This shelf environment is occasionally subjected to storm events with a significant wave height reaching 5 m at its western entrance for around 5% of the time (*e.g.*, Benoit and Lafon, 2004). It presents furthermore a highly heterogeneous spatial distribution of bottom sediments with (1) very fine sands,

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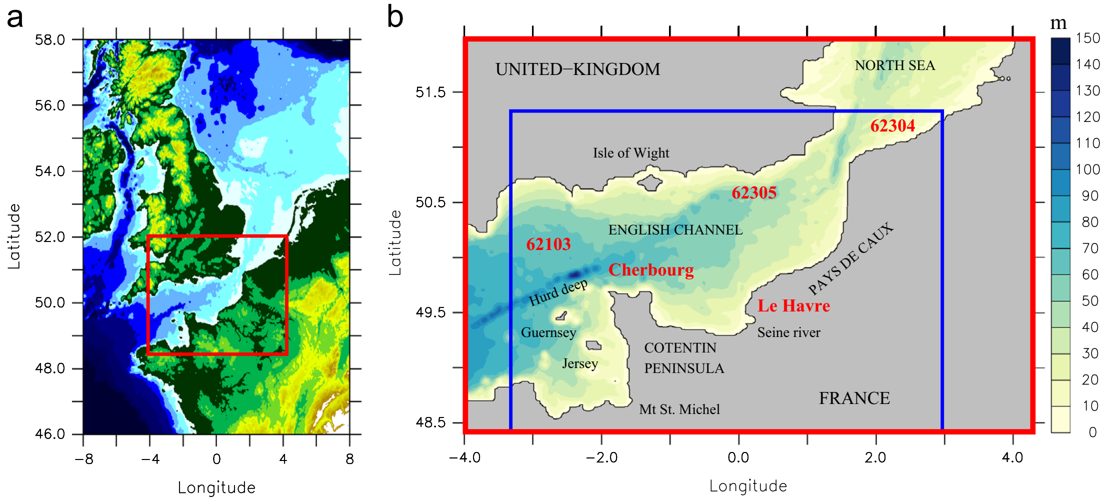

Fig. 1. (a) Location of the English Channel in the North-western European continental shelf, (b) bathymetry of the computational domain with the locations of the measurement points. The blue rectangle shows the area where the spatial heterogeneous bottom roughness is introduced. (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this paper.)

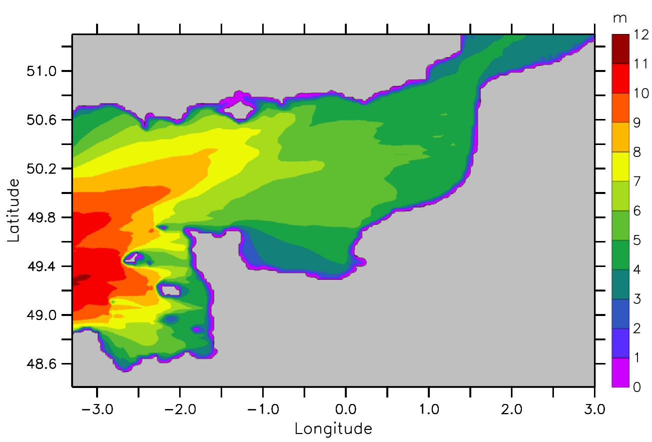

Fig. 2. Maximum significant wave height predicted in March 2008 in the English Channel.

silts and muds in bays and estuaries and (2) pebbles and gravels in the Dover Strait, off the "Pays de Caux" and over an extensive zone in the central Channel between the Isle of Wight and the Cotentin Peninsula (Vaslet et al., 1979; Larsonneur et al., 1982).

The approach retained here relies on a comparison between numerical predictions and observations of the significant wave height and the peak period. Available field measurements are realised at three offshore lightships and two nearshore wave buoys off Le Havre and Cherbourg harbours (Fig. 1b, Section 2.1). Modelling is based on the phase-averaged wave model SWAN (Simulating WAves Nearshore) (version 40.85) (Booij et al., 1999) modified to account for a new parameterisation of the wind-drag coefficient at high wind speeds (Section 2.2). A pre-processing module computes the required surficial sediment granulometric distribution from a series of bottom samples and the associated heterogeneous frictional parameters (Section 2.3). Numerical predictions are compared with observations over the period from December 2007 to March 2008 characterised by an extreme storm event on 10 March 2008 with significant wave heights over 10 m at the western entrance of the English Channel (Fig. 2) (Section 3.1). A preliminary study compares first model performances with (1) the default wind-drag coefficient proposed in SWAN and (2) the new formulation (Section 3.2.1). The effects of a heterogeneous seabed roughness magnitude are then evaluated confronting predictions obtained with (1) constant empirical values of the bottom-friction coefficient proposed by Hasselmann et al. (1973) and Bouws and Komen (1983) and (2) the eddy-viscosity model of Madsen et al. (1988) which integrates hydrodynamics and seabed roughness magnitude (Section 3.2.2). Mappings of numerical predictions are finally produced over the entire computational domain to encompass the spatial and temporal changes of (1) the significant wave height and (2) the bottom-dissipation coefficient with respect to constant default values (Section 3.3).

2. Materials and methods

2.1. Measurements

A series of 2318 bottom sediment samples have been collected from 1971 to 1976 in the framework of the "RCP 378 Benthos de la Manche" program (Cabioch et al., 1977) to characterise the spatial distribution of bed-sediments grain sizes in the English Channel. Samples were passed through a series of nine standard AFNOR (Association Française de NORmalisation) sieves ranging from 50 μm to 2 cm. The 10 corresponding classes are supplemented by a virtual class between 5.5 and 50 cm to account for boulders and rock outcrops. Further details about the resulting discretised granulometric distribution are available in Guillou and Chapalain (2010).

Available wave measurements here used were obtained at the three offshore lightships 62103, 62305 and 62304 of the UK Meteorological Office and the two nearshore wave buoys off Le Havre and Cherbourg harbours of the French CANDHIS database (Centre d'Archivage National de Données de Houle In Situ, Cerema) (Fig. 1 and Table 1). The instrumentation network is deployed in water depths ranging from 19 m at the wave buoy of Le Havre to 70 m at the lightship 62103.

2.2. Model

SWAN solves the time-dependent spectral action balance equation (*e.g.*, Mei, 1983; Komen et al., 1994) ignoring the modifications of waves components by the ambient current and the free-surface elevation whereas it can handle these effects

$$\frac{\partial N}{\partial t}+\nabla_{\mathbf{x}}\cdot[\mathbf{c_g}N]+\frac{\partial c_\sigma N}{\partial \sigma}+\frac{\partial c_\theta N}{\partial \theta}=\frac{S_{tot}}{\sigma} \quad (1)$$

where t denotes times, $\nabla_{\mathbf{x}}$ is the horizontal gradient operator and N is the action density defined as $N=E/\sigma$ with E being the wave