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Numerical simulation of tide-induced transport of heterogeneous sediments in the English Channel

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ABSTRACT

The three-dimensional numerical model COHERENS (COupled Hydrodynamical-Ecological model for REgioNal and Shelf seas) has been adapted to compute the rates of transport as bedload and suspended load of heterogeneous bottom sediments induced by the dominant M_2 tide in the English Channel. A pre-processing of an extensive surficial sediments dataset has been performed to determine the seabed composition (grain-size distribution or presence of rocks) at the computational grid nodes. Maximum bedload and suspended load transport rates over the tidal cycle as well as the contributions of the 10 different sedimentary classes to the mean transports are computed. Highest sediment transport rates occur in fine sediments areas located in the surroundings of high shear stresses areas. Medium sand ($d_4 = 350\,\mu m$) is found to be predominant in bedload, while suspension load implies mainly silts ($d_1 = 25\,\mu m$) in the inner shoreface and both fine and medium sands ($d_3 = 150\,\mu m, d_4 = 350\,\mu m$) in the outer shoreface. The offshore residual bedload transport pathways are orientated westerly in the western part of the Channel and easterly in the eastern part defining a "parting" zone which runs from the Isle of Wight to the Cotentin Peninsula. An offshore "bedload convergence" occurs in the southwest of the Dover Strait; a narrow transport pathway bypassing it along the French coastline. These features reproduce those predicted by Grochowski et al. (1993a) and provide higher resolution features like inshore headland-induced gyres, particularly along the English coastline. The new predicted general pattern of residual suspended load transport is very similar to the bedload pattern. Differences arise in the central "divergence" zone which exhibits a "Y" shape with two branches ending on both sides of the Isle of Wight, in the Baie de Seine characterized by a central "convergence" and along the English coastline studded with many headland-induced recirculations.

1. Introduction

The English Channel, narrow arm of the Atlantic ocean tapering eastward to its junction with the North Sea at the Dover Strait, is an active tidal shelf environment with elevation ranges as large as 13 m and current amplitudes exceeding $2\,m\,s^{-1}$ between Southampton and Cherbourg (Service Hydrographique et Océanographique de la Marine, 1973). This environment is occasionally subjected to wind-generated surface gravity waves and swell. Nevertheless, under "normal" wave conditions, near-bottom water motions and related sediment movements in water depths greater than a few metres appear mainly controlled by tidal currents (Draper, 1967; Dyer, 1986; Grochowski and Collins, 1994).

The spatial distribution of bottom sediments is highly heterogeneous with very fine sands, silts and muddy sediments in bays and estuaries (e.g., Lyme Bay, Baie de Seine) and pebbles in the Dover Strait, off the "Pays de Caux", off Brittany and over an extensive zone in the Central Channel between the Isle of Wight and the Cotentin Peninsula that divides the western Channel where bioclastic material between 0.5 and 2.5 mm and gravels abound from the eastern Channel where gravelly sand and sand of 0.15–0.5 mm predominate (Vaslet et al., 1979; Larsonneur et al., 1982, Fig. 1). Rocky seabeds are found mainly off Brittany, the Cotentin Peninsula (Channel Islands Gulf) and the Cape Gris Nez. Residual bedload transport pathways deduced from morphological (asymmetry of bedforms) and sedimentological observations (e.g., Kenyon and Stride, 1970; Stride et al., 1972; Hamilton, 1979; Johnson et al., 1982) comprise an irregular "S" shaped "bedload parting" zone over the section between the Isle of Wight and the Cotentin Peninsula, and a "bedload convergence" zone between Hastings and the Baie de Somme (Fig. 2).

Numerous bi-dimensional horizontal (2DH) and three-dimensional (3D) numerical models have been set up to understand tide-induced hydrodynamics, namely the distributions of free-surface elevations, harmonic components, instantaneous and residual currents over the northwest European shelf and the

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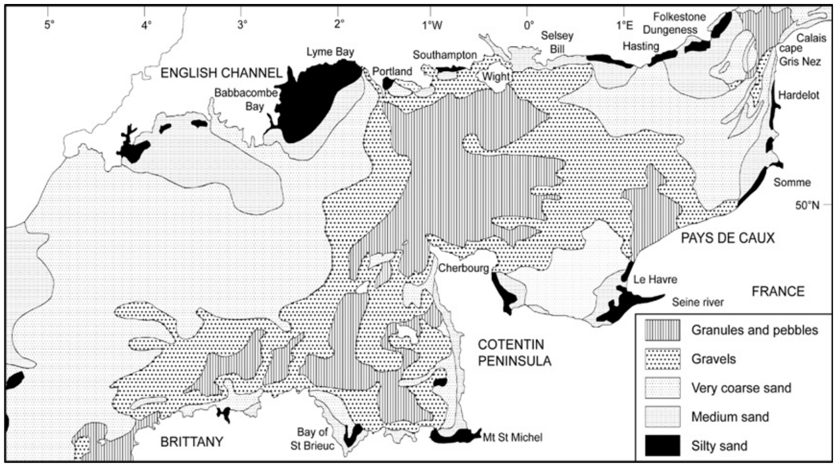

Fig. 1. Schematic distribution of surficial sediment deposits in the English Channel (after Larsonneur et al., 1982, in Salomon, 1991)

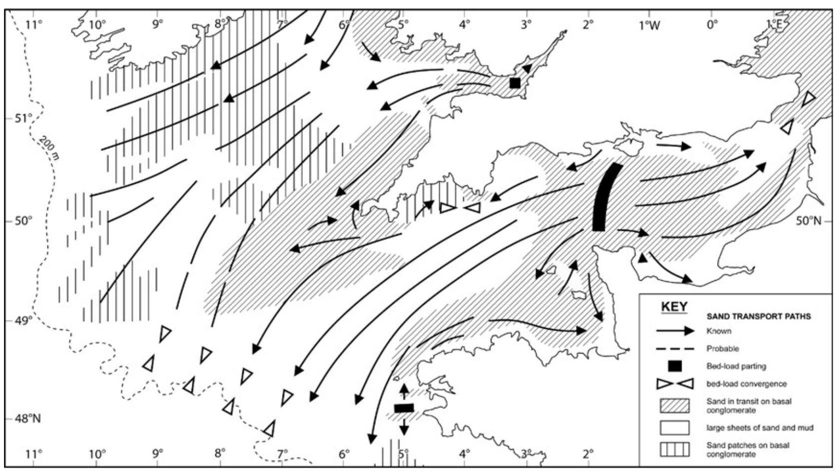

Fig. 2. Transport paths for sand in the English Channel based on geomorphological and sedimentological indicators (reprinted from Hamilton, 1979 with permission from Elsevier).

nested English Channel (Pingree and Maddock, 1977; Le Provost and Fornerino, 1985; Werner and Lynch, 1987, 1989; Lynch and Werner, 1991; Salomon and Breton, 1991a; Prandle et al., 1993; Werner, 1995). Wind effects on the residual tide-induced circulation have been investigated by Salomon and Breton (1991b) and Perianez and Reguera (1999).

This kind of hydrodynamic models has been used to examine the advective and dispersive processes leading to the observed spatial distribution of radionuclides (125Sb, 99Tc and 137Cs) released from Cape of La Hague nuclear plant (e.g., Salomon and Breton, 1991a). Pingree and Griffiths (1979) were the first to apply such models to investigate sediment-transport pathways by relating them to the direction of the maximum tidal bed stress. More recently, this qualitative approach was followed to study the influence of sea-level reduction over the Holocene period (Hall and Davies, 2004).

Grochowski et al. (1993a) have combined outputs from the 2DH hydrodynamic model implemented by Salomon and Breton (1991a, b) with various empirical formulae to estimate sediment bedload and total load transport rates and directions. This off-line computing approach assumes:

(i) a single granulometric mode of sedimentary particles for each specific bottom sediment stratum distinguished by Vaslet et al. (1979) excepted within gravel deposits where a second mode of medium sand (median grain-size diameter $D_{50} = 350\,\mu\text{m}$) is added to examine its potential capability to be transported;
(ii) values of the seabed roughness parameter z_0 issued from observations published in the literature for the different encountered types of bottom sediments;
(iii) rippled sandy seabeds with a constant value of z_0 = 0.6 cm;
(iv) a vertical logarithmic velocity profile through the water column which results from ignoring the effect of the Coriolis force and yields colinear local depth-averaged velocity, near-bed velocity and bottom shear stress;
(v) the Engelund and Hansen's (1972) total sediment transport rate formula meaning also a global suspended load transport without any vertical dependence.

The general residual bedload transport pathways predicted by Grochowski et al. (1993a) and shown in Fig. 3 fit fairly well with the observed pattern (Fig. 2), even if their modelling procedure appears crudely correct for computing bedload sediment transport which remains highly controlled by local processes. Indeed, under typical friction velocity u_* = 1 cm s^{-1} in the English Channel, when computing the bedload velocity U_b taken equal to U_b = 4.8u_* by Nielsen (1992), the excursion of sedimentary particles transported as bedload during a tidal cycle is of the order of a few tens of metres. Nevertheless, improvements could consist