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Wave- and current-induced bottom shear stress distribution in the Gulf of Lions

François Dufois [a,b,c,*], Pierre Garreau [a], Pierre Le Hir [a], Philippe Forget [c]

[a] IFREMER, DYNECO/PHYSED, Centre de Brest, BP 70, 29280 Plouzané, France
[b] IRSN, DEI/SESURE, LERCM, Centre Ifremer, BP 330, 83507 La Seyne sur Mer, France
[c] LSEET-LEPI, UMR 6017, CNRS-USTV, BP132, 83957 La Garde, France

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ABSTRACT

Simulations of both currents and waves were performed throughout the year 2001 to assess the relative contribution of each to their overall erosive potential on the Gulf of Lions shelf. Statistical analysis of bottom shear stress (BSS) was compared to sediment grain-size distribution on the bottom. The hydrodynamic features of the bottom layer coincide with the distribution of surficial sediments, and three areas with different hydro-sedimentary characteristics were revealed. (i) The sandy inner shelf (<30 m) area is a high-energy-wave dominated area but may be subjected to intense current-induced BSS during on-shore winds along the coast and during continental winds mainly in the up-welling cells. (ii) The middle shelf (30–100 m) is a low-energy environment characterised by deposition of cohesive sediments, where the wave effect decreases with depth and current-induced BSS cannot reach the critical value for erosion of fine-grained sediments. (iii) The outer shelf, which has a higher bottom sand fraction than the middle shelf, may be affected by strong south-westward currents generated by on-shore winds, which can have an erosive effect on the fine-grained sediments.

Particular attention was paid to features of the current that were found to be predominant on the mid-outer shelf. These currents are strongly dependent on wind direction.

1. Introduction

Studies on the dispersion and accumulation of sediment from rivers to continental margins have mostly been devoted to the continental shelves of open oceans affected by energetic swells and tides and by large rivers, such as the Pacific and Atlantic coasts of North America (Drake and Cacchione, 1985; Lyne et al., 1990; Wiberg et al., 1994). In Harris and Wiberg (2002), the authors used a sediment transport model to illustrate the effect of hydrodynamics on bed properties over narrow and wide continental shelf. According to their academic modelling, cross-shelf gradient in bed shear stress (due to decrease in wave-orbital velocities with water depth) has several implications on the transport, deposition and sorting of sediment depending on the steepness of the shelf. In their study, strong links between present-day hydrodynamics and sedimentological settings are exhibited. As the Mediterranean Sea is a micro-tidal, low-energy system, the dominant hydrodynamic forcings of Mediterranean shelves are likely to be different from that of shelves controlled by tides and swells. At a local scale, storm-generated wave effect on coastal sediment resuspension has been emphasised by several studies on the margin of the Gulf of Lions (GoL) (Ferre et al., 2005; Guillén et al., 2006) and on other margins of the north-western Mediterranean such as the Ebro margin (Puig et al., 2001; Guillén et al., 2002; Palanques et al., 2002). Nevertheless, the respective effect of waves and current on the whole shelf has not been fully studied. Thus, the objective of our study is to assess the potential impact of the wave- and current-induced bottom shear stress (BSS) on the sediment dynamics and bed properties at a regional scale in the GoL.

In their description of surficial deposits on the GoL, Got and Aloisi (1990) reported a sandy area near the coast, a sandy/muddy area near the slope and a mud band on the middle shelf. Although waves are assumed to be the main forcing that influences the sandy inner shelf (Ferre et al., 2005; Guillén et al., 2006), the presence of sand on the outer shelf has not been clearly explained. Most authors consider the off-shore sands present in the outer shelf as relict features (Monaco, 1971; Aloisi, 1986; Berné et al., 1998). According to these authors, only transgressive processes would have been able to rework sediments when the sea level was lower by about 100 m. However, recent studies demonstrated that a mobile carpet of sand is periodically active at the shelf edge (Bassetti et al., 2006). Schaaff (2002, 2003) also showed that the surficial sediment over the shelf presents low critical shear stress corresponding to a fluffy layer that could easily be reworked.

* Corresponding author at: IFREMER, DYNECO/PHYSED, Centre de Brest, BP 70, 29280 Plouzané, France. Tel.: +33 298224760; fax: +33 298224864.
E-mail address: fdufois@ifremer.fr (F. Dufois).

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Knowledge of wave- and current-induced BSS is thus necessary to understand sediment dynamics and bottom properties. At a local scale, this can be achieved by direct measurements. In the GoL, measurements of waves and currents have been made at the canyon head and inner-shelf stations (Canals et al., 2006; Guillén et al., 2006; Heussner et al., 2006; Palanques et al., 2006; Bourrin et al., this issue). However, only modelling can provide relevant information at both regional and long-time scales.

In combination with data analysis, modelling has recently improved our understanding of the high temporal and spatial variability of the circulation in the GoL (Estournel et al., 2003; André et al., 2005; Petrenko et al., 2005; Langlais, 2007). These studies were mainly devoted to surface circulation and mean transport, but were not sufficiently focused on bottom processes to improve our understanding of dynamic sediment processes. More recently, Ulses et al. (this issue) and Ferré et al. (this issue) developed a sediment transport model of the GoL and showed the influence of strong storms, dense water cascading, and even of bottom trawling on sediment dynamics on the shelf. They thus mainly studied the impact of episodic events.

The aim of this article is to present statistics for near bed hydrodynamics, and to consider their consequences for sediment transport, using a modelling approach. A one-year analysis of BSS is presented. The respective influences of currents and waves are discussed and specific relationship between current-induced BSS and wind direction is analysed in more detail. Simultaneously, an application to this study is presented in order to clarify the link between the main physical processes and grain-size distribution of surficial sediments on the GoL shelf. The consequences of BSS distribution for sediment mobilisation are discussed along with possible consequences for sediment distribution.

2. Regional setting

2.1. Hydrodynamics

The GoL is hydrodynamically complex as several intense and strongly varying processes coexist (Fig. 1). Millot (1990) described the main hydrodynamic processes: (a) the general south-westward circulation along the slope, called the Northern Current; (b) wind-induced currents; and (c) the formation of dense water both on the shelf and off-shore.

The geostrophic Northern Current is the northern branch of the general cyclonic circulation in the western Mediterranean basin. This current, whose core is several hundred metres thick, occasionally intrudes on the shelf (Petrenko, 2003) and displays seasonal variability. Mesoscale instabilities occur mainly during spring and winter when the water flux of the along-slope current is maximum (Flexas et al., 2002; Albérola and Millot, 2003; André et al., this issue).

Even if these instabilities can affect circulation on the shelf itself (Petrenko, 2003), the shelf is essentially forced by winds and by buoyancy discharge from the Rhone River. Estournel et al. (2003) described the influence of northern and north-western winds, whereas Ulses et al. (2008) focused on the influence of E–SE winds. Intense and frequent continental winds (the Mistral in the eastern part of the GoL and the Tramontane in the western part) (Millot, 1990) push the surface waters off-shore and induce local up-welling. On-shore winds (mainly eastern and south-eastern winds), which are less frequent (Millot, 1990), result in the accumulation of water on the coast and the downwelling of surface water. These winds can be very strong and appear or disappear very suddenly, and thus generate Kelvin waves (Crepon and Richez, 1982) or inertial oscillations, which mainly occur during stratified conditions (Millot and Crepon, 1981; Petrenko et al., 2005). Cold and dry continental winds that appear during wintertime are also likely to generate dense water on the shelf. This dense water, which is preferentially formed on the western part of the shelf, dives on the south-western end part of the shelf resulting in dense water cascading through the canyon (Dufau-Julliand et al., 2004).

Freshwater input, an important forcing factor on the shelf (Gatti et al., 2006), is mainly controlled by the Rhone River, which is the largest source of freshwater in the Mediterranean Sea with 92% of the input in the GoL (Bourrin and Durrieu de Madron, 2006). The Rhone River has two functional branches: the *Grand Rhone* which is responsible for about 90% of the discharge, and the

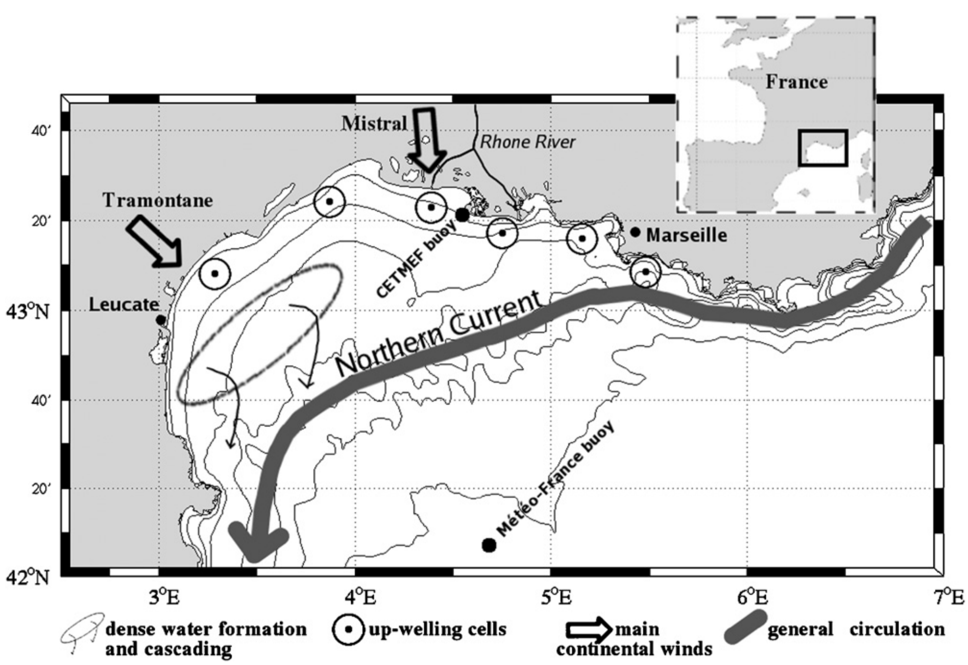

Fig. 1. Study area, main characteristics of the circulation (redrawn from Millot (1990)). Isobaths 20, 50, 90, 160, 500, 1000 and 2000 m are plotted. Positions of the wave buoys Météo-France 61002 and CETMEF 01301 are shown.