Available online at www.sciencedirect.com
ScienceDirect
Continental Shelf Research 28 (2008) 2048–2070
CONTINENTAL SHELF RESEARCH
www.elsevier.com/locate/csr

Suspended sediment transport in the Gulf of Lions (NW Mediterranean): Impact of extreme storms and floods

C. Ulses[a,b,*], C. Estournel[a], X. Durrieu de Madron[c], A. Palanques[d]

[a]*Pole d'Océanographie Côtière, Laboratoire d'Aérologie-CNRS-Université de Toulouse, 14 avenue E. Belin, 31400 Toulouse, France*
[b]*Centre for Estuarine and Marine Ecology, Netherlands Institute of Ecology, P.O. Box 140, 4400 AC Yerseke, The Netherlands*
[c]*Centre de Formation et de Recherche sur l'Environnement Marin – CNRS-Université de Perpignan, France*
[d]*Institut de Ciències del Mar (CSIC), Passeig Maritim de la Barceloneta, 37-49, E-08003 Barcelona, Spain*

Received 21 March 2007; received in revised form 16 January 2008; accepted 28 January 2008
Available online 8 February 2008

Abstract

In situ observations were combined with 3D modeling to gain understanding of and to quantify the suspended sediment transport in the Gulf of Lions (NW Mediterranean Sea). The outputs of a hydrodynamic–sediment transport coupled model were compared to near-bottom current and suspended sediment concentration measurements collected at the head of seven submarine canyons and at a shallow shelf site, over a 6-month period (November 2003–May 2004). The comparisons provide a reasonable validation of the model that reproduces the observed spatial and time variations. The study period was marked by an unusual occurrence of marine storms and high river inputs. The major water and sediment discharges were supplied by the Rhone, the largest Mediterranean river, during an exceptional flood accompanying a severe marine storm in early December 2003. A second major storm, with moderate flooding, occurred in February 2004. The estimate of river input during the studied period was 5.9 Mt. Our study reveals (i) that most of the particulate matter delivered by the Rhone was entrapped on the prodelta, and (ii) that marine storms played a crucial role on the sediment dispersal on the shelf and the off-shelf export. The marine storms occurring in early December 2003 and late February 2004 resuspended a very large amount of shelf sediment (>8 Mt). Erosion was controlled by waves on the inner shelf and by energetic currents on the outer shelf. Sediment deposition took place in the middle part of the shelf, between 50 and 100 m depth. Resuspended sediments and river-borne particles were transported to the southwestern end of the shelf by a cyclonic circulation induced by these onshore winds and exported towards the Catalan shelf and into the Cap de Creus Canyon which incises the slope close to the shore. Export taking place mostly during marine storms was estimated to reach 9.1 Mt during the study period.

Keywords: Sediment transport; Sediment resuspension; Sediment budget; 3D sediment transport modeling; Continental margins; Northwestern Mediterranean Sea; Gulf of Lions

1. Introduction

Continental margins, which receive large amounts of particulate matter related to the erosion of continents, generally represent regions of massive deposition but are also a sediment source for the deep basins. Sediment transport, seabed reworking and off-shelf export on continental margins are considered to be primarily driven by episodic, high energy events, among which floods, storms and associated swell, and strong wind-driven currents are the most common examples. These extreme events that control the inputs, resuspension, sediment transport pathways and depositional sites, are considered to strongly affect the sediment budget and the formation of strata (Parsons and Nittrouer, 2007). Besides the formation and preservation of event beds in sediment deposits, these events also affect the amount of sediment that escapes the shelf break (e.g., Sommerfield and Nittrouer, 1999). The net off-shelf sediment fluxes are usually quantified as a residual value in sediment budgets, which are generally based on sediment core dating and river inputs. They

*Corresponding author at: Centre for Estuarine and Marine Ecology, Netherlands Institute of Ecology, P.O. Box 140, 4400 AC Yerseke, The Netherlands. Tel.: +31 113 577 472.
E-mail address: c.ulses@nioo.knaw.nl (C. Ulses).

0278-4343/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.csr.2008.01.015

generally represent a "mean" export averaged over a secular time scale (typically 100-year for ^{210}Pb-based accumulation rates). Moored instruments (sediment traps, currentmeters, turbidimeter) describe the temporal variability of sediment fluxes escaping the shelf at shorter time scales (from hours to months) but generally lack the spatial coverage to estimate the export linked to significant events. The study of the impact of energetic sediment transport processes on bed modifications caused by sediment erosion or deposit and sediment budgets at the shelf scale therefore requires the coupling of a field study with a modeling study.

Within the framework of the EUROSTRATAFORM program (Weaver et al., 2006), the impact of episodic, high energy events on the sediment dynamics and budget was investigated on two Mediterranean margins—the Adriatic Sea and the Gulf of Lions. Despite their distinct shelf morphology, these margins have relatively analogous river discharges, originating both from one large river and smaller rivers, and hydrodynamical forcings. Recent studies in the Gulf of Lions identified the role of waves and currents driven by onshore and off-shore wind regimes as dominant mechanisms for the dispersal of river plumes, resuspension of shelf sediment, and off-shelf sediment export (e.g., Estournel et al., 1997; Ferré et al., 2005; Canals et al., 2006; Guillén et al., 2006; Heussner et al., 2006; Palanques et al., 2006). Secular accumulation rates and grain-size patterns reveal distinct sedimentary facies on the shelf, including prodeltaic and mid-shelf depocenters of fine sediments. A sediment budget suggests that most (ca. 90%) of the river sediment discharge is trapped on the shelf (Durrieu de Madron et al., 2000). However, because of the spatial limitation of measurements, the pathways of riverine and resuspended sediment, the limits of deposition/accumulation patterns on the shelf, and the off-shelf export of sediment during extreme events (flood, storms) are still poorly understood.

Three-dimensional sediment transport models are useful tools to study the fate of river-borne and resuspended sediment of the shelf as well as the transport to the open sea. We combined a 3D sediment transport model with extensive field measurements performed in the Gulf of Lions during a 6-month period (autumn 2003 and winter 2004) characterized by extreme flood and marine storm events. In the present work, we took advantage of previous works by Ulses et al. (2008) who validated the hydrodynamic model and described the physical mechanisms controlling the spatial and temporal variability of the shelf to slope transfer of water, and Palanques et al. (2006) who measured the suspended particulate matter transport, during the study period. The present paper aims at determining (i) the fate of river sediment inputs, (ii) the relative role of wave and wind-driven flows for the reworking and transport of sediment on the shelf, (iii) the amount of sediment escaping the shelf break, (iv) the role of canyons as effective conduits for the off-shelf transport, and (v) the contribution of extreme flood and storms that occurred during the study period.

2. Regional setting

The Gulf of Lions is located in the northwestern Mediterranean. The crescent-shape continental shelf is bounded at its northeastern and southwestern ends by promontories where the shelf almost vanishes. The continental slope is incised by an intricate network of submarine canyons (Fig. 1).

The grain size distribution of superficial bottom sediments is shown in Fig. 1. Sands of the inner shelf broadly display a seaward-fining texture and merge, in water deeper than 20–30 m, with mid-shelf muds, except on the Rhone River submarine delta where a large accumulation of silty muds is located closer to the coast. Sediment gets progressively coarser across the outer shelf. Sandy sediments and even shells are found around the shelf edge and in canyon heads.

2.1. Rivers

Fresh water and sediment inputs to the Gulf originate mainly from the Rhone River although about nine small rivers occasionally may deliver substantial amount of fresh water and sediment (Fig. 1). The major river discharge occurs mostly during flooding events, preferentially in spring and fall, and reveals a strong interannual variability. Thus, annual river inputs of sediment vary within one order of magnitude from 2.4 to 25 Mt yr^{-1}, with an average long-term mean of 8.5 Mt yr^{-1} (1980–1999 period, Ludwig et al., 2003).

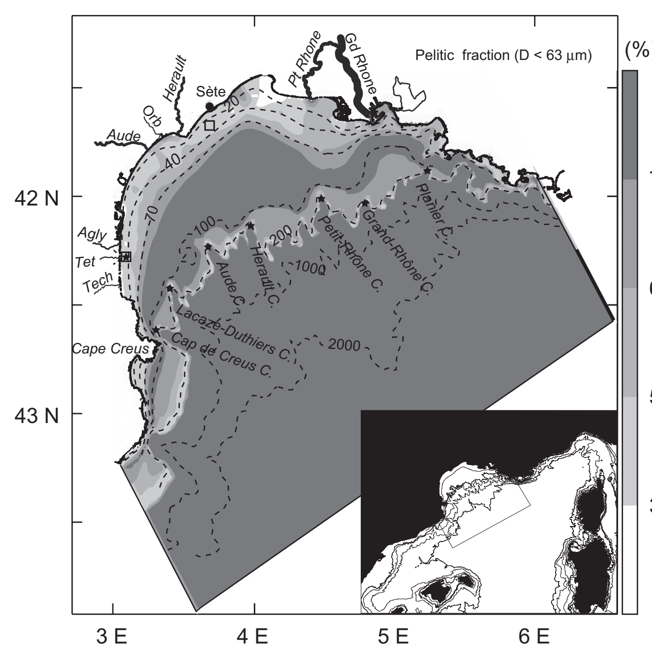

Fig. 1. Map of the Gulf of Lions, showing the bathymetry (m), the fraction of mud (clay and silt) in the sediment bed and the position of the different instruments moored in the canyon heads and on the inner shelf (stars) and the wave gauges (squares). The inset delineates the domain of the Gulf of Lions model in the northwestern Mediterranean.