Deep-Sea Research I 95 (2015) 54–66

Contents lists available at ScienceDirect

Deep-Sea Research I

journal homepage: www.elsevier.com/locate/dsri

Hydrodynamics over the Gulf of Valencia continental slope and their role in sediment transport

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ARTICLE INFO

Article history:
Received 2 June 2014
Received in revised form
8 October 2014
Accepted 13 October 2014
Available online 23 October 2014

Keywords:
Hydrodynamics
Sediment transport
Gulf of Valencia
Continental slope
Western Mediterranean

ABSTRACT

Circulation patterns and sediment dynamics were studied over the Gulf of Valencia (GoV) continental slope during spring and winter 2011–2012. Two moorings were deployed at two locations; at 450 m depth from February to May 2011, and at 572 m depth from October 2011 to February 2012. At both mooring sites, observations were made of currents, temperature and near-bottom turbidity within the lowermost 80 m above the seafloor. The temperature measurements allowed distinction of the different water masses and their temporal evolution. The fluctuations of the boundary between the Western Mediterranean Deep Water (WMDW) and the Levantine Intermediate Water (LIW) masses were monitored, and several intrusions of Western Mediterranean Intermediate Water (WIW) were observed, generally coinciding with changes in current direction. At both mooring sites, the currents generally maintained low velocities $< 10\ \mathrm{cm\ s^{-1}}$, with several pulses of magnitude increases $> 20\ \mathrm{cm\ s^{-1}}$, and few reaching up to $35\ \mathrm{cm\ s^{-1}}$, associated with mesoscale eddies and topographic waves. The current direction was mainly towards the SSE on the first deployment and to the ESE on the second deployment. This second location was affected by a strong bottom offshore veering presumably generated by local topographic effects. Increases in suspended sediment concentrations (SSC) were observed repeatedly throughout the records, reaching values $> 3\ \mathrm{mg\ l^{-1}}$. However, these SSC variations were uncorrelated with changes in velocity magnitude and direction and/or with temperature oscillations. Results presented in this paper highlight the complex relation between the hydrodynamics and sediment transport over the GoV continental slope, and suggest that other potential sediment resuspension mechanism not linked with current fluctuations, might play a key role in the present-day sedimentary dynamics. Resuspension due to bottom trawling appears to be the most plausible mechanism.

1. Introduction

Ocean management efforts have focused on the need to identify the actual mechanisms that control the sediment transport and the final fate of most particulate matter introduced from the continental to the marine system. Fine particles (settling and suspended) are responsible for much of the flux of matter and energy in the marine environment, playing a key role in the global oceanic biogeochemical cycles and in the marine ecosystems (Asper et al., 1992). Sedimentary processes control the transport of most particulate elements introduced or generated in the oceans, being especially important in continental margins because of the large material inputs from both fluvial and high productivity coastal waters (Walsh, 1991). However, the study of sedimentary dynamics on continental margins is complex because in these areas coexist anthropogenic activities and oceanographic processes that combine their action to influence sediment particles transport and fate.

The general oceanographic circulation of the northwestern Mediterranean has been widely described in numerous studies (Font, 1987; Millot, 1999; Robinson and Leslie, 2001; Salat et al., 2002; Millot and Taupier-Letage, 2005; López-Jurado et al., 2008), with specific ones devoted to the Balearic Sea (García et al., 1994; Pinot et al., 1994, 1995, 2002; Salat, 1995; Monserrat et al., 2008). The Gulf of Valencia (GoV) is located at the southern part of the Balearic Sea between the Ebro continental margin and the promontory Cap La Nao (Fig. 1). Circulation in the GoV is characterized by water mass mixing between the Northern Current flowing along the continental slope towards the southwest carrying old Atlantic Waters (oAW), and the northward intrusions of recent Atlantic Waters (rAW) through the Ibiza Channel (Pinot et al., 2002). Below these surface waters, three water masses types are also present: from 200 to 400 m depth the seasonal Western Mediterranean Intermediate Water (WIW) is found, characterized by a temperature relative minimum of 12.7 °C and salinity of 38.1. Between 400 and

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http://dx.doi.org/10.1016/j.dsr.2014.10.004
0967-0637/

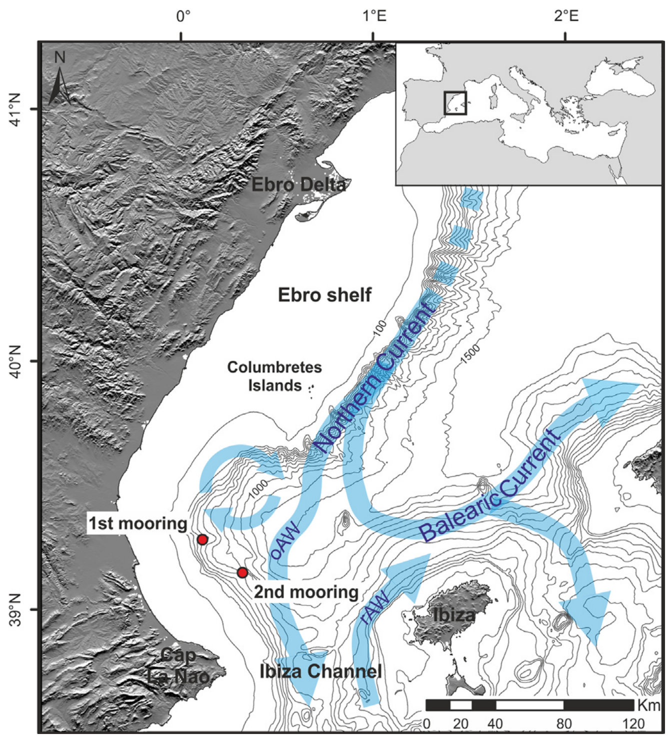

Fig. 1. Bathymetric map of the southern part of the Balearic Sea, including the Gulf of Valencia, showing the major currents characterizing the regional surface circulation scheme (blue arrows, synthesized from Pinot et al (2002) and Ribó et al. (2013)). Red dots indicate the mooring locations. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

700 m depth, the Levantine Intermediate Water (LIW) is present, being characterized by temperature and salinity relative maxima of 13.3 °C and 38.5, respectively. Below 700 m depth, the Western Mediterranean Deep Waters (WMDW) is found, with temperature of 13 °C and salinity of 38.4 (Salat and Font, 1987; Font, 1987; Font et al., 1988). The LIW is carried in the lower part of the Northern Current, and bifurcates to the north of the Ibiza Channel as do the surface waters (Font, 1987; Pinot and Ganachaud, 1999; Pinot et al., 2002). The WIW is formed seasonally, and its production is related to the formation of cold and dense waters in the northwestern Mediterranean in winter. When the WIW is present in or nearby the Ibiza Channel, it usually deflects downwards the LIW, which normally occupies shallower levels when the WIW is absent (Monserrat et al., 2008).

Circulation in the GoV has been described as seasonally dominated by the Northern Current entering as an unstable meandering jet (García et al., 1994; Pinot et al., 1995, 2002). The meandering activity is strongest in winter starting in November–December and persisting until May, anticyclonic meanders being the most developed ones, with a characteristic size of typically 20 to 40 km. On several occasions, anticyclonic vortex eddies are found in the interior of the meanders, corresponding to the mature stage of the instability (Pinot et al., 2002). These mesoscale eddies were described to be presumably produced by the instabilities of the regional circulation, caused by the interactions with the bathymetry (Millot, 1999). As winter forcing relaxes in spring–summer, the Northern Current weakens, and the meandering reduces in parallel with the weakening of the current (Pinot et al., 2002).

Previous studies using moored instrumentation on the Ebro shelf (Puig et al., 2001; Palanques et al., 2002) have suggested that the GoV receives most of the sediment transported southwestwards along the Ebro margin. A recent hydrographic study (Ribó et al., 2013), however, has shown a preferential off-shelf sediment export at the southern end of the GoV, where an important detachment of particulate matter was observed off Cap La Nao, extending seawards all across the Ibiza Channel. Ribó et al. (2013) also described the presence of several near-bottom and mid-slope turbid layers, mainly between 400 and 600 m. The occurrence of such nepheloid layers was related to the presence of internal waves on the mid-slope region causing resuspension and/or inhibiting suspended sediment deposition, as it has been described in other areas (Cacchione and Drake, 1986; Puig et al., 2004; Hosegood and van Haren, 2004; Bonnin et al., 2006).

Internal wave motions on the GoV continental slope have been recently monitored and characterized through detailed mooring observations, and consisted on stratified perturbations and convective overturns reaching the bottom (van Haren et al., 2013). Van Haren et al. (2013) observed a ~11-day periodic turbulence, which moved cold WMDW underneath the relatively warmer LIW, simultaneously enlarging the bottom boundary layer as might be induced in a wave motion or a bore. This turbulence appears convective, producing shear-induced Kelvin–Helmholtz overturning instabilities reaching the entire sampled water column (i.e. 60 m) above the bottom. The authors observed that inertial motions superimposed on the large-scale processes provided very large convective turbulence, and described that the varying of turbulence intensity could affect the generation of short internal waves near the local buoyancy frequency. It was suggested that the turbulent processes associated with such near-inertial internal waves might play an important role in the nepheloid layer formation, dispersing and maintaining the suspended particles over the slope.

In this paper, we analyze the current fluctuations and the temperature variations at two locations on the GoV continental slope, and relate these records with variations on near-bottom suspended sediment concentration (SSC). In addition, trawling activity in the study area has been also analyzed since previous studies (e.g. Martín et al. 2014) have evidenced that deep bottom trawling on the NW Mediterranean can replace natural processes as the main driving force of sediment resuspension on continental regions, and generate increases on near-bottom SSC, similar to the ones recorded over the GoV continental slope. The aim of this paper is to improve the understanding on the hydrographic structure and the regional circulation, and discuss the relation with the sedimentary dynamics over the GoV continental slope, assessing the role that mesoscale current variability and the near-inertial internal waves might play in the sediment transport on this region.

2. Methods

During this study, the observational work consisted of time series measurements at two locations over the GoV continental slope using instrumented moorings. The first mooring was deployed from mid-February 2011 to mid-May 2011, located at 39° 16′N and 0° 06′E, at 450 m depth, while the second one was moored from October 2011 to mid-February 2012, at 39° 10′N and 0° 20′E, at 572 m water depth (Fig. 1). Both moorings were deployed on structural highs over the continental slope, chosen using the bathymetric map of the study area and in agreement with the local fishermen, to avoid interfering with bottom trawling activities. The two moorings were equipped with a downward-looking 300 kHz four-beam RDI Acoustic Doppler Current Profiler (ADCP), located at 80 m above bottom (mab), covering 40 cells of 2 m size vertically. They sampled at a rate of once per 10 min. Noise was recorded near the seafloor due to direct vertical sidelobe reflection, and therefore these data were not taken into account. The first cell with reliable data was at 8 mab. Both moorings also included a thermistor string composed of several 'NIOZ4' self-contained temperature sensors sampling at 1 Hz, with a precision of better than 0.001 °C (van Haren et al., 2009).