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Nearshore sediment transport: Coupling sand tracer dynamics with oceanographic forcing

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ABSTRACT

The understanding of the sedimentary links between the beach and the continental shelf is crucial for the evaluation of the coastal sediment budget. However, the comprehension of this dynamics is still poorly understood owing greatly to the lack of direct sediment transport measurement at seasonal and longer time scales. This work aims at evaluating sediment transport just seaward of the closure depth through a sand tracer experiment coupled with wave–current monitoring and modelling. Observations were carried out over 1 year at 14 m depth over a sandy continental shelf offshore Tavira (southern Portugal). The sand tracer experiment was carried out by injecting 400 kg of fluorescent tracer followed by four sediment sampling surveys. Tracer results show a high dispersion of the tracer cloud with a net transport of low magnitude. Time-averaged alongshelf sediment transport rate was estimated in 0.61 m^3/m/yr (southwestward) while the cross-shelf transport rate was estimated in 0.31 m^3/m/yr (onshore). During the observational period nearbed currents were dominated by the northeastern component, thus flowing in the opposite direction of the tracer displacement. However, when wave-current bed shear stress exceeded the threshold of particle motion, nearbed currents were dominated by a southwestern component which is compatible with tracer displacement. Overall this study showed that seaward the closure depth bottom sediment dynamics is characterized by frequent remobilization but with very low net transport rates.

1. Introduction

Concerns regarding coastal management issues associated to imbalances in the coastal sediment budget have significantly increased in recent years (Hapke et al., 2010). One of the main consequences of these sedimentary imbalances can be reflected in coastal erosion, compromising the long-term stability of the coastline. The continental shelf is often identified as a potential sediment source/sink to the coastal system (Niedoroda et al., 1985; Schwab et al., 2013). However, the depth of closure (DOC — the offshore limit for significant morphological changes) concept is opposite to the notion of significant sediment exchanges between the beach and the continental shelf. Indeed, it is generally considered that sediment dynamics is weak seaward the DOC. Thus, sand mining, for example, is generally performed offshore this limit to ensure minimal morphological impacts on the beach (Robertson et al., 2008). Notwithstanding, the sedimentary dynamics deeper than the DOC is still poorly understood owing greatly to the lack of direct sediment transport measurement at time scales longer than a month. This knowledge gap is explained by the complexity of the processes that drive the sedimentary dynamics and the logistical constraints concerning in situ measurements. So far, in this region most of the work dealing with the understanding of sediment transport is based on numerical models (van Rijn, 1997; Ferré et al., 2010), focusing on short time scales (hours to days) and rarely reports quantitative estimates at longer time scales, which prevents a more realistic evaluation of the sedimentary dynamics. In order to contribute to fulfill this lack of knowledge, this work aims at understanding and evaluating sediment transport beyond the closure depth at a seasonal time scale. To reach this goal, in situ measurements were performed through a sand tracer experiment with simultaneous hydrodynamic data acquisition.

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2. Regional settings

The study area is located at Tavira (Portugal) nearshore zone offshore the eastern sector of the Ria Formosa barrier system (Fig. 1). At this location, the continental shelf, up to 30 m depth, is characterized by a gentle slope of approximately 1:170 oriented NE–SW. Bottom sediment is largely dominated by fine to medium sand down to 10 m water depth (all depths refer to the mean sea level in this study); in deeper areas (10 to 15 m) gravel-sized sediments become important representing between 10 to 30% of the total sediment as well as the presence of mollusc shells that comprises 30 to 45% (Rufino et al., 2008; Rosa et al., 2013). Sediments below 10 m water depth have textural characteristics and a reddish coating suggesting a relict nature as defined by Swift et al. (1971). The depth of closure of this region was estimated to be around 10 m depth by Almeida et al. (2010), while the work of López-Doriga et al. (2015) developed specifically in the study area of the present work revealed a DOC of about 6 m depth.

The tidal regime is semi-diurnal with average ranges of 1.3 and 2.8 m for neap and spring tides, respectively. According to Costa et al. (2001), wave climate is characterized by an offshore average significant wave height of 0.92 m and average mean wave period of 4.7 s with incident waves predominantly from W–SW (71% of occurrences). A particular condition called "Levante", marked by short period waves generated by SE winds, represents 23% of the occurrences. The storm regime within this region is characterized by significant wave heights higher than 3.5 m which occurrences are mainly from SW (64%) and SE (32%) directions (Costa et al., 2001).

The study area constitutes the equatorward extremity of the Iberian upwelling system. The nearshore circulation is predominantly alongshore, characterized by northeastward coastal upwelling jets alternating with coastal counter-currents of opposite direction (Relvas and Barton, 2002). Various studies suggest a significant control of large-scale wind conditions on this coastal circulation (Sánchez et al., 2006; Garel et al., 2016). Recent analyses of multi-year current observations have indicated that the alongshore flow is mainly barotropic, with (depth-averaged) magnitudes up to 0.4 m/s, a predominance of northeastward currents (≈ 60% of time) and no seasonal variability (Garel et al., 2016). Cross-shore currents are one order of magnitude lower and mostly tidal.

3. Materials and methods

This work is supported by extensive field data (sedimentologic and oceanographic) acquired over one year. Complementary data were attained through numerical modeling of wave propagation and wave–current bottom boundary layer dynamics.

3.1. Oceanographic forcing

3.1.1. In situ measurement

Local hydrodynamic conditions were measured at two sites at the nearshore zone (Fig. 1). The first one was located offshore Armona Island where waves and currents were measured using an upward-looking ADCP (Workhorse 600 kHz, TRDI) bottom mounted on top of an 1.4 m-height artificial reef, at 23 m water depth (ADCP I in Fig. 1). Several deployments were performed during the studied period, with durations from 27 up to 93 days (Fig. 2). Current velocities along the water column were measured for at least 15 min every 60 min within 0.5 m cells. The first valid ADCP record was at 3.6 m above bottom. Waves were registered during a minimum period of 10 min every 3 h. The vertical distribution of the flow velocities was also measured by an upward-looking ADCP (Sentinel V 500 kHz, TRDI) bottom-mounted offshore Tavira Island during a shorter period (84 days — see Fig. 2) using the same configuration above-mentioned (ADCP II — in Fig. 1). At this site, an S4 electromagnetic current meter (from InterOcean Systems Inc.) was configured for acquiring 2 minute-averaged current measurements every 30 min, and wave parameters every hour computed from 10 minute-long bursts collected at a 2 Hz sampling rate. Overall information concerning the periods of observation for each instrument is summarized on Fig. 2.

Along and cross-shelf near bottom current components were calculated according to the angle of maximum variance of the measured velocities. Positive values of the two components are oriented northeastward (alongshelf) and onshore (cross-shelf).

Due to observational gaps on the ADCP I deployment, ADCP data represents 100%, 63%, 33% and 76% of the encompassed time on observation periods P1, P2, P3 and P4, respectively. These periods are bounded by the dates of the five sea missions (C0 to C4) of the sand tracer experiment (see Fig. 2).

The spatial representativeness of the current data acquired offshore Armona was checked through data supplied by the 3D global ocean model NEMO (Nucleus for European Modeling of the Ocean) with a 0.028 degree resolution. NEMO is an ocean modeling framework which is composed of 'engines' nested in an 'environment'. The 'engines' provide numerical solutions of ocean, sea-ice, tracers and biochemistry equations and their related physics (Madec, 2012). Results from NEMO ocean currents as well as the comparison between both flow velocities acquired by ADCP I and II revealed a relatively uniform spatial circulation over the continental shelf of the study area on both alongshelf and cross-shelf directions with minor variations regarding its magnitude and direction. This observation allowed to use current data from ADCP I to characterize the flow pattern at the sand tracer experiment site.

3.1.2. Wave modeling

Offshore wave regime recorded at Faro buoy (Fig. 1), between April 2014 and May 2015, was propagated using SWAN 3rd generation model (Booij et al., 1999) under stationary mode over a 4.32 km × 5.10 km local grid nested into a 42.5 km × 50.5 km regional grid with cell sizes of 20 m and 500 m, respectively. The model incorporates shallow-water wave effects such as depth-induced breaking, refraction and bottom friction. The wave frequency space was set from 0.04 to 1.00 Hz in 31 frequency bins and 36 directions using the JONSWAP-type spectrum as boundary.

3.2. Bottom boundary layer modeling

The bottom boundary layer dynamics was evaluated through a unidimensional numerical model based on the wave–current nonlinear interaction parametrized by Soulsby et al. (1993) using the fitting coefficients of Grant and Madsen (1979). Thus, the sediment mobilization was only computed when simultaneous current and wave data were available.

The significant nearbed orbital velocities (U_w) were calculated using an approximation for real waves (polychromatic) parametrized by Soulsby and Smallman (1986) using the water depth measured by the ADCP. The $_{Uw}$ together with the wave friction factor (f_w) were used to calculate the wave induced bed shear stress (τ_w) for a rough turbulent flow as described in Soulsby (1997):

$$\tau_w = \frac{1}{2}\rho f_w U_w^2 \tag{1}$$

where ρ is the density of sea water (1026 kg/m^3) based on the typical bottom water characteristics of the study area (16 ° C and 35 salinity) and $f_w = 1.39\left(\frac{A}{z_0}\right)^{-0.52}$, being A the semi-orbital excursion and z_0 the bed roughness length.

The current-related bed shear stress (τ_c) was also calculated in terms of a friction factor (f_c) as described in Smyth and Li (2005)