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Quantifying sediment flux under moderate wave energy on beaches south of Agadir, Morocco

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ABSTRACT

This study presents the results of a real-time quantification of sediment transport through sand trapping on the beaches south of Agadir using Kraus 1987-type sand traps. The traps were installed in the wave breaking zone, measuring longshore, cross-shore and vertical sediment fluxes. A total of ten sites were studied, distributed across five beaches (Sidi Ouassai, Sidi Rbat, Tifnit, North Tifnit, and Sidi Toual), with three measurement points taken at each site (first breaker, Trough, last breaker). The results presented in this article only represent sediment transport rates measured under low- to medium-energy meteomarine conditions, as it is difficult to measure transport rates under high-energy conditions. The results obtained show a variation in sediment flux between the different measurement sites. The sediment fluxes recorded during the various measurement campaigns ranged from a maximum rate of 0.366 $kg.s^{-1}.m^{-1}$ to a minimum rate of 0.018 $kg \cdot s^{-1} \cdot m^{-1}$. The correlation between the total transport rate and the prevailing hydrodynamic forcing conditions during the different measurement campaigns indicates a strong link between the quantity of sand displaced and wave characteristics (height, period and angle of incidence). Sediment fluxes tend to rise in time where the significant wave height and period, as well as the slope of the bathymetric profiles, are increasing. In addition, sediment transport is highest at the last wave break at all measurement sites, confirming that sediment transport is higher near the shore. This spatial variability in sediment transport volume is accompanied by granulometric variability in the trapped sediments.

Keywords: beach, wave breaking zone, sand trap, sediment flux, South of Agadir.

INTRODUCTION

Understanding beach dynamics and their evolution requires a good knowledge of the natural factors interacting among different morphological compartments of subtidal, intertidal, and supratidal beaches. These compartments evolve as a complex system with reciprocal sediment exchange. The assessment of sediment transport in the subtidal zone, commonly referred to as the "surf zone," has been extensively addressed in scientific literature (Kraus, 1987; Kraus et al., 1989; Rosati et al., 1990; Rogers and Ravens, 2008; Sundar and Sannasiraj,2022; Agbetossou et al., 2023). Nevertheless, quantifying sediment transport in this wave-breaking zone (surf zone) remains a significant challenge in coastal engineering and marine sciences. Indeed, understanding sediment transport rates is crucial for enhancing the knowledge of sand movement and estimating lateral and vertical sediment transport rates (Kraus, 1987). These estimations aim to assess changes in the morphology of subtidal sandy zones in relation to imposed hydraulic forces. In this regard, quantifying sediment transport and the distribution of sandy sediment sizes in the wave-breaking zone are key elements for understanding the transport process and the geomorphological evolution of beaches.

Despite numerous studies on this subject, the majority have centered around assessing transportation dynamics along beaches with large tidal ranges (macrotidal) (Cartier et al., 2011; Agbetossou et al., 2023). Conversely, only a limited number of studies have examined beaches with moderate tidal ranges (mesotidal) (Kumar et al., 2003), where sediment transportation is influenced by intricate interplays between tidal currents and littoral currents induced by wave action. This intricate relationship is compounded by notable fluctuations in water levels caused by storms. On the Moroccan Atlantic coast, research has long focused on the intertidal and supratidal zones of beaches (Bourhili et al., 2023; Lharti et al., 2024). Various methods and techniques have been employed in these studies to monitor beach dynamics at different spatiotemporal scales. However, little is known about the dynamics of the subtidal zone, which is an integral part of the beach/dune system. Although it plays an important role in the morphodynamic equilibrium of beaches as a potential source of sediment. Studies on this subtidal zone have, until now, received limited scientific attention, particularly when it comes to assessing real-time sediment transport.

Over the past decades, real-time sediment transport assessment techniques have seen significant growth, primarily due to the development of various methods for quantifying sediment transport in the wave breaking zone. Among the techniques used in this field, the Kraus method (1987) stands out. This sand trapping method is particularly valued for its ability to assess sediment fluxes in the wave breaking zone under low to moderate energy conditions, as well as for its capacity to measure sediment transport in subtidal environments with sediments of varying sizes. Admittedly, new acoustic and optical technologies, such as the ADCP (Acoustic Doppler Current Profiler) and OBS (Optical Backscatter Sensor), allow for precise measurement of sediment flux at a microscopic scale, with data integrated over periods corresponding to a tidal cycle. However, the application of these techniques presents significant challenges, particularly with regard to signal calibration (Helsby, 2009). Their use requires specific environmental conditions, characterized by uniform sediment size, low organic matter concentration, and minimal turbulence in the surrounding environment.

The purpose of this article is to assess the rates of longshore, cross-shore, and vertical sediment transport in the wave breaking zone using sand traps inspired by the Kraus 1987 method. First, we will attempt to quantify sediment fluxes at each measurement site. Then, an effort will be made to correlate the total transport for each measurement site with the dominant hydrodynamic and topographic conditions during various trapping campaigns. Finally, a characterization of the collected sediments will be undertaken to highlight the evolution of sandy material in relation to the water column height.

STUDY AREA

Morocco's Atlantic coast features sandy beaches, frequently bordered by active aeolian dunes and interrupted by vast sections of lithified dunes dating from the Plio-Quaternary period (Chaibi et al., 2009; Hakkou et al., 2011; Taaouati et al., 2011; Nmiss et al., 2021a Nmiss et al., 2022). The coastline extending between Agadir and the Massa River displays a notable contrast: Agadir bay, where human activity is prominent (Aouiche et al., 2016a, 2016b; Nmiss et al., 2021b), and the southern of Agadir, at the boundary of a National Park called (Souss-Massa park) (Fig. 1b). This area is an important conservation zone, illustrating the diversity of the Moroccan coast (Nmiss, 2023). The characteristics of the coastline south of the bay, protected by the national park, include an alternation of lithified aeolianite cliffs ranging from 5 to 35 meters in height, and beach areas behind which extensive dune systems develop. These beaches comprise Sidi Ouassai and Sidi Rbat on the Massa River, Tifnit beaches (including Tifnit Bay and North Tifnit), and Sidi Toual beach on the left bank of the Souss River (Fig. 1b; Fig. 2).The topographic monitoring of the intertidal and supratidal zones of these beaches between 2019 and 2021 shows that they are of an intermediate to dissipative type (Nmiss, 2023).

The beaches located south of Agadir belong to the Souss Massa coastal cell, which is highly exposed to North Atlantic swells. Along Morocco's Atlantic coast, these swells are intensified by a deep depression that generates them, with northwest winds aiding their movement and propagation. Wave data used in this study were extracted from both daily forecasts managed by the port authorities of Spain at the SIMAR point 1040022 (coordinates 30.5 N and -10 W) and field measurements in

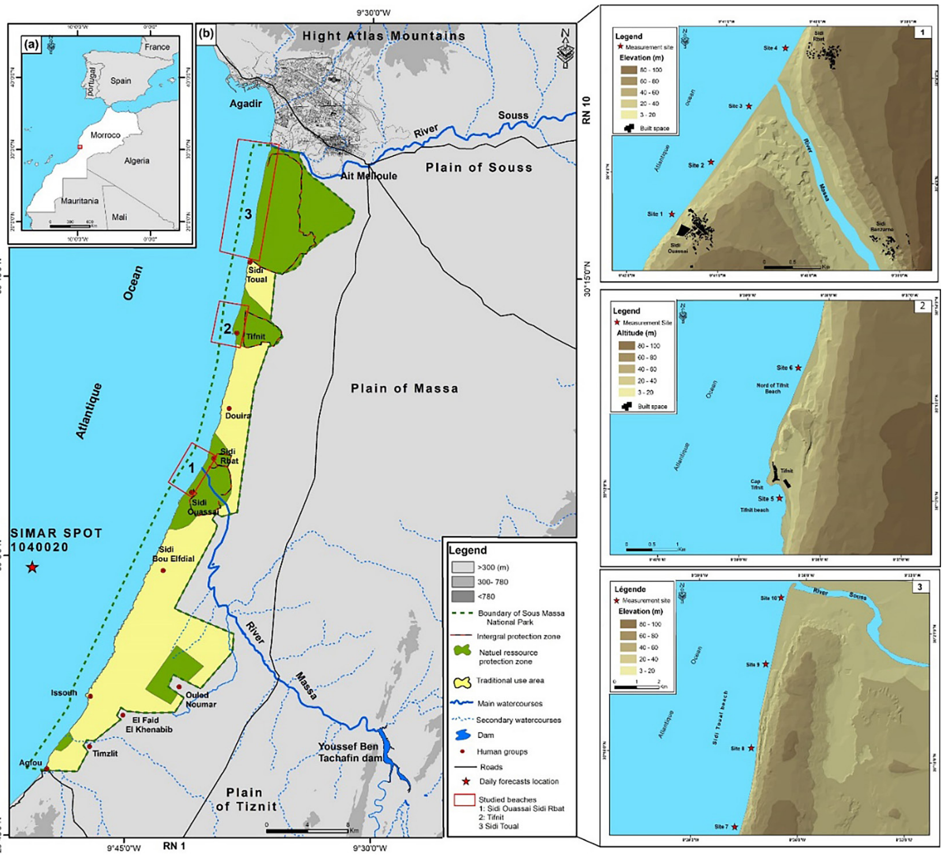

Figure 1. Location of study area (a) an overview of Morocco map; (b) Beaches studied, highlighted within a box, along with the Souss-Massa National Park, (1) Sidi Ouassai and Sidi Rbat beaches; (2) Tifnit beach; (3) Sidi Toual Beach. Red stars represents measurement sites

real-time. Indeed, waves coming from the NNW and WNW directions are dominant. Over the two-month measurement period (October and November), 65% of the recorded waves exhibited a significant height of less than 3 meters, while 35% reached heights exceeding 3 meters (Fig. 3a). Regarding the wave period, 85% have a duration greater than 10 seconds (Fig 3 b). In this work, we selected 10 measurement sites, distributed as follows: 4 sites at the mouth beaches of the Massa River (Sidi Ouassai and Sidi Rbat), 2 sites on the Tifnit beaches, and 4 sites on the Sidi Toual beach. Sediment transport measurements were conducted from October 13th to November 11th in 6 measurement campaigns (Fig 1).

MATERIALS AND METHODS

Quantification tool and trapping protocol

In recent years, sediment transport studies have generally focused on large areas and relied on modifications of coastal morphology. Using a Streamer Trap sand trapping method to evaluate sediment transport flux remains an effective approach for assessing transverse, longitudinal, and vertical sediment flow. Indeed, the Sand Trap is a device designed to quantify the rate of sand transport in the wave breaking zone (surf zone). This apparatus consists of long, sieve-like fabric bags that capture sediments while allowing water to pass through (Kraus, 1987). The method employed here is inspired by the research conducted by Kraus and his American research team at the U.S. Army's Coastal Engineering Research Center. It involves trapping sand using a device comprising six bags arranged vertically within the water column. These traps are 15 cm in length, 9 cm in height, and there is 10 cm interval between collector bags. The fabric mesh size is less than 0.05 µm to capture only sandy materials (Fig 4 (b)). The morphological units measured include the last breaker, trough, and the first breaker point (Fig 4 (d)). The trapping duration is set at 5 minutes for each measurement point, consistent with previous studies on various beaches (Nielsen, 1983; Cartier et al., 2012; Payo et al., 2020). This

Figure 2. The beaches studied: (1) beach at Sidi Ouassai; (2) beach at Sidi Rbat; (3) beach at Tifnit bay; (4) beach at North of Tifnit; (4) beach at Sidi Toual

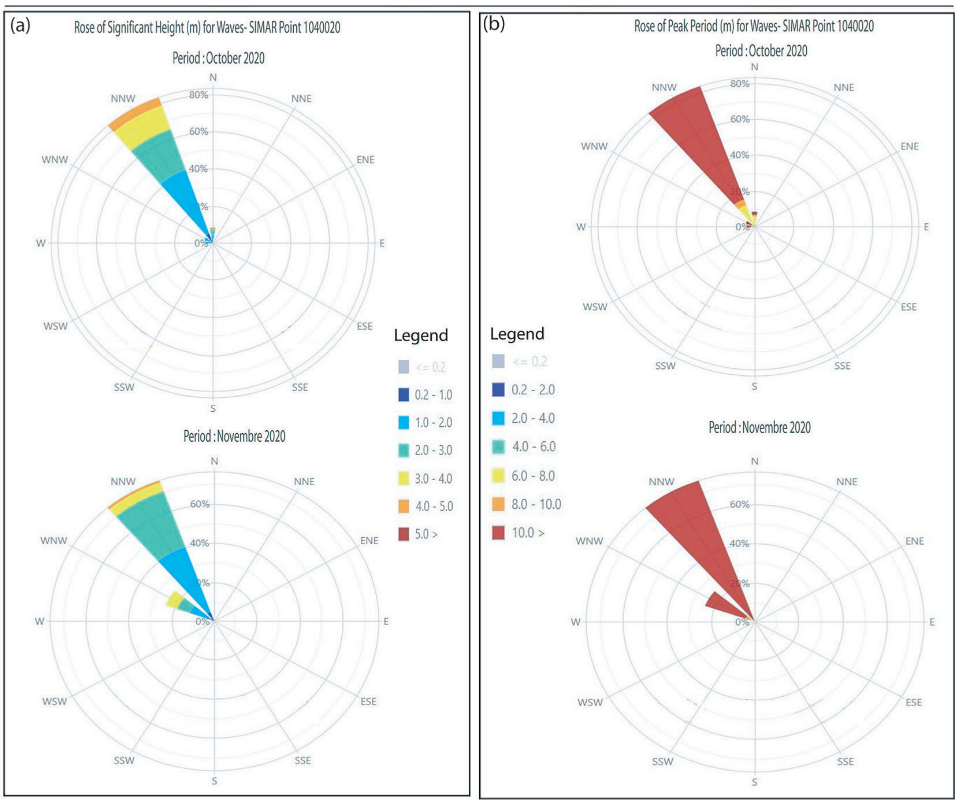

Figure 3. Wave characteristic roses, based on daily forecasts from the offshore point SIMAR 44, spot 1040020 (refer to Fig. 1b), were supplied by the Spanish Port Authorities (http://www.puertos.es). Plots (a) and (b) display offshore wave characteristic (heights; periods) in relation to wave directions

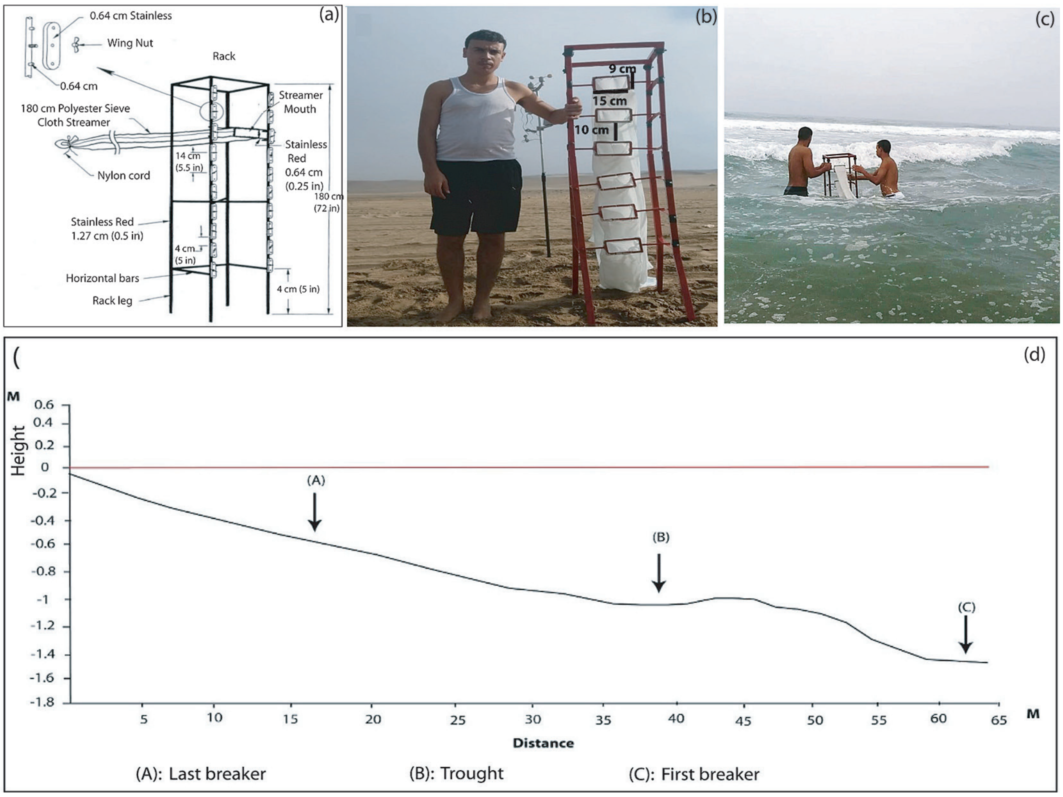

Figure 4. Field measurement methodology: (a) streamer trap device developed by kraus (1987); (b) schematic representation illustrating the use of a streamer trap during the experiments; (c) on-site trapping practical; (d) deployment locations of sediment traps along a transect perpendicular to the shoreline

duration represents an average of 18 to 30 waves, depending on the wave period.

During sediment trapping, the device used is manipulated by hand, which presents a number of advantages and disadvantages. The advantages of this trapping method manifest in its ability to obtain punctual, instantaneous, and absolute measurements of the transport rate. It allows for understanding transport over time intervals ranging from a few seconds to several minutes. This helps establish a direct connection between sediment movement and the waves and currents that drive it. Additionally, it makes it possible to measure the longshore, crosssshore, and vertical distribution of sediments at various levels, including rolling, saltation, and suspension. Subsequently, it also allows for the collection of materials actually mobilized in the wave breaking zone, such as sand, shell fragments, and other particles that exceed the mesh size of the traps. Finally, this method is relatively less costly than other sediment transport measurement methods, and it can be used simultaneously at multiple locations in the wave breaking zone. Although sand trapping offers many advantages, it comes with several drawbacks and limitations. Firstly, disturbance of the seabed (scouring) by the device manipulator and the support structure of the instrument can generate turbulence that produces an artificially elevated transport rate near the bottom. Additionally, sand trapping (Streamer Trap) may disrupt the flow field and, consequently, accelerate or decelerate local flow, which may cause a perceived increase or decrease in the recorded transport rate. Finally, the measurements are conducted under conditions of average to low wave energy.

Sediment flux calculation

A sediment flux, F(i), is calculated at each net (F1, F2, F3, F4, F5, F6) (Rosati et al., 1989):

$$F(i) = \frac{\mathrm{P}}{\mathrm{w} \times \mathrm{h} \times \mathrm{t}} \quad (1)$$

where: $F(i)$ – sediment flux at height i ($\mathrm{kg \cdot s^{-1} \cdot m^{-2}}$); P – dry weight of sediment (g); w – Width of the net opening (m); h – height of the net opening (m); t – sampling duration (s).

To integrate the fluxes over the entire water column, an intermediate flux between two consecutive fluxes is calculated using linear interpolation:

$$FE(i) = 0.5 \times (F(i) + F(i+1)) \quad (2)$$

where: $FE(i)$ – intermediate flux between two consecutive nets at height i ($kg \cdot s^{-1} \cdot m^{-2}$)

The fluxes are then integrated over the entire water column and as a function of the number of nets:

$$F = h \times \sum_{i=0}^{N} F(i) + \sum_{i=0}^{N} a(i) \times FE(i) \quad (3)$$

where: F – integrated flux in the water column ($kg \cdot s^{-1} \cdot m^{-1}$); N – number of nets; $a(i)$ – distance between two consecutive nets (m).

Hydrodynamic forcing and trapping protocol

Hydrodynamic forcing significantly influence the transverse, longitudinal, and vertical transport of sediments along sandy beaches. To measure these forcings, it is essential to conduct in-situ measurements of hydrodynamic characteristics, especially wave proprieties including height, period, and angle of incidence, before proceeding with sand trapping. Subsequently, approximate bathymetric profiles should be conducted to determine the underwater morphology of different measurement sites. Lastly, it is crucial to determine measurement points in the same manner for each profile to enable comparison between different sites.

Wave conditions, including height (H) and significant period (T), were measured on-site using a graduated column in centimeter scale inserted into the wave breaking zone, following previous studies (Horikawa, 1988). Wave direction and angle of incidence were determined visually in the field. The slope was approximately determined through the creation of bathymetric profiles. Hydrodynamic forcing data during the measurement campaigns (wave height, period, direction and angle of incidence, slope) are presented in the table below (Table 1). During various field missions, it was observed that meteorological and marine conditions were favorable for implementing measurements. The recorded wave heights varied between 1.20 m and 1.96 m, with a period ranging from 10 to 16 s. The observed wave directions in the field were NNW, WNW. Additionally, an incidence angle of 20° to 50° was noted, along with beach slopes ranging from 2.1% to 3.3%. To validate the wave characteristic values, we relied on the daily forecasts managed by the port authorities of Spain from SIMAR point 1040022 (coordinates 30.500 N, -10.000 E) (Fig 5).

Characterization of the sandy material

In this study, 84 samples were gathered from 10 different measurement sites, providing a representative overview of the sedimentary characteristics of the studied beaches. The samples underwent granulometric assessment to examine the dimensions and distribution of sediments grains in the surf zone. The primary goal of this assessment is aimed to characterizing the granulometric organization pertaining to sediments gathered in relation to water depth. This organization allows for the examination of how sediments are redistributed and transported by marine currents at different depths, providing valuable information on sediment transport mechanisms opering on the various beaches south Agadir. Particles size distribution was performed by running a Rop-Tap sieve shaker for 15 min with AFNOR grid. Using version 8.0 of the GRADISTAT program, the statistical parameters – mean, sorting, and skewness – were analyzed. This tool allows for rapid computation of grain size statistics through both the

Table 1. Hydrodynamic and morphodynamic conditions at the measurement sites

Beaches	Studied sites	Measurement date	Significant wave height (m)	Significant wave period (s)	Wave direction	Slope	Wave angle of incidence
Sidi Ouassai/ Sidi Rbat	S1	09/11/2020	1.66	12	NNW	2.2	45°
	S2	09/11/2020	1.74	13	NNW	2.3	45°
	S3	25/10/2020	1.57	10	NNW	2.1	40°
	S4	25/10/2020	1.89	16	NNW	2.6	50°
Tifnit	S5	24/10/2020	1.97	13	NNW	3.2	45°
Nord Tifnit	S6	13/10/2020	1.73	10	NNW	2.3	40°
Sidi Toual	S7	10/11/2020	1.70	12	WNW	3.6	25°
	S8	10/11/2020	1.50	11	WNW	2.6	20°
	S9	11/11/2020	1.80	14	WNW	3.2	30°
	S10	11/11/2020	1.4	10	WNW	2.4	15°

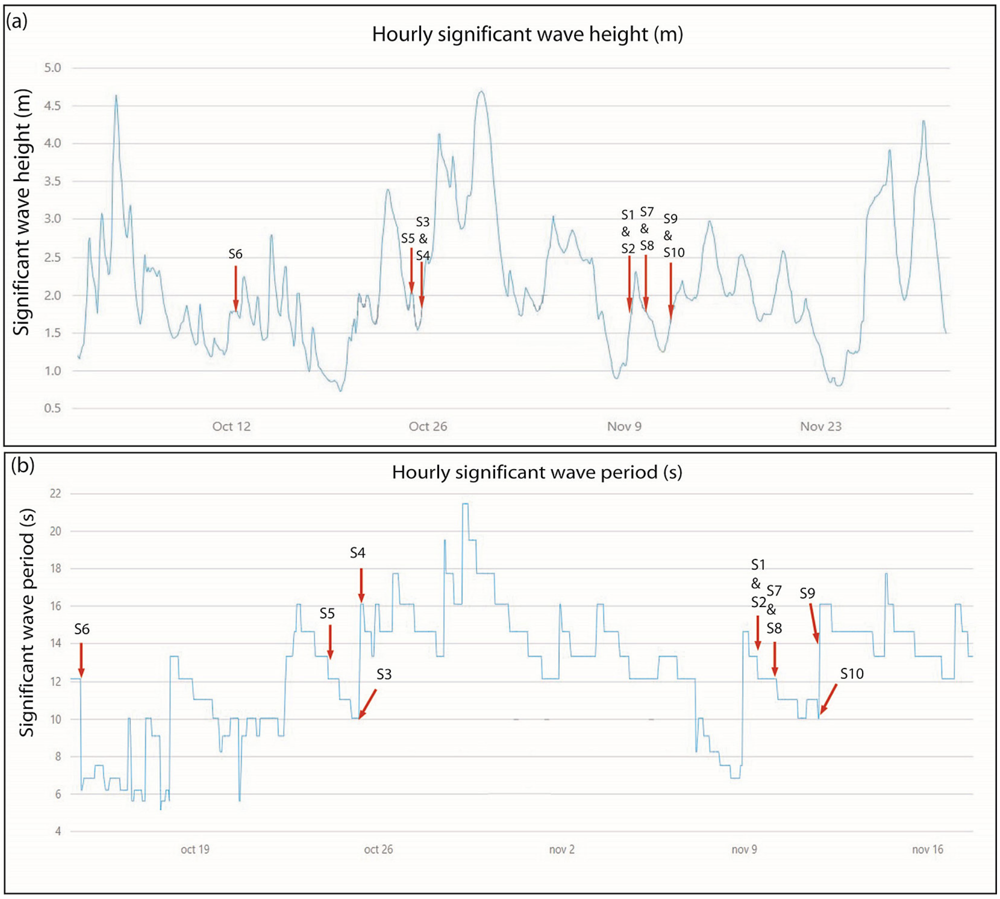

Figure 5. Hydrodynamic forcing data. Plots (a) and (b) shows offshore significant wave height and wave period recorded during the two month of field measurement in October and November 2020 of the 10 sites measured (S1 to S10) (http://www.puertos.es)

Folk and Ward (1957) approach and the moments method (Blott and Pye, 2001). Integrated within a Microsoft Excel spreadsheet, it provides results in both table and chart formats.

RESULTS

Analysis of sediment transport flux

The sediment transport flux corresponds to the sum of sediments trapped vertically and horizontally at each measurement site. The results obtained indicate varying rates across the different measurement sites, ranging from a maximum rate of 0.366 $kg \cdot s^{-1} \cdot m^{-1}$ to a minimum rate of 0.018 $kg \cdot s^{-1} \cdot m^{-1}$ (Table 2). This variability in sediment flux is due to variations in hydrodynamic and topographic conditions at the measurement sites. However, these results only correspond to the range of sediment flux measured under conditions of low to moderate agitation. The highest fluxes (> 0.366 $kg \cdot s^{-1} \cdot m^{-1}$) are absent due to the difficulty of measuring transport during excessively turbulent conditions. To comprehensively understand sediment transport across different coastal environments, it's essential to consider both vertical and horizontal trapping mechanisms at each measurement site. By correlating sediment transport rates with the dominant hydrodynamic conditions during various trapping missions, we can identify patterns and anomalies in sediment movement. The observed transport rates across the ten sites, ranging from 0.018 $kg \cdot s^{-1} \cdot m^{-1}$ at site 6 to 0.366 $kg \cdot s^{-1} \cdot m^{-1}$ at site 9, highlight significant variability driven by local hydrodynamic forces and topographic features. Sites with higher transport rates, such as site 9, likely experience stronger currents and wave actions, which enhance sediment mobility, whereas sites with lower rates, such as site 6, may be in more sheltered locations with gentler hydrodynamic conditions. These variations underscore the complex interplay between environmental factors and sediment dynamics. For instance, areas with steep bathymetric profiles or exposed to strong wave actions

Table 2. Summary of sediments transport flux at the measurement sites

Beaches	Studied sites	Measurement date	Sediment flux ($kg.s^{-1}.m^{-1}$)
Sidi Ouassai / Sidi Rbat	S1	09/11/2020	0.086
	S2	09/11/2020	0.118
	S3	25/10/2020	0.033
	S4	25/10/2020	0.212
Tifnit	S5	24/10/2020	0.141
Nord Tifnit	S6	13/10/2020	0.018
Sidi Toual	S7	10/11/2020	0.344
	S8	10/11/2020	0.203
	S9	11/11/2020	0.366
	S10	11/11/2020	0.125

tend to exhibit higher sediment fluxes. Conversely, protected areas or those with gradual slopes may experience lower transport rates. Moreover, the absence of data for the highest fluxes, greater than 0.366 $kg.s^{-1}.m^{-1}$, reflects the challenges in measuring sediment transport during extreme conditions, such as storms or high turbulence, where standard trapping methods might fail or become impractical. This gap in data suggests a need for advanced measurement techniques that can operate effectively in highly dynamic and turbulent environments to capture the full spectrum of sediment transport processes.

The relationship between the overall rate of sediment transport and the predominant hydrodynamic forcing conditions across many measurement campaigns suggests that the quantity of displaced sands and wave properties, including height, period, and angle of incidence, are strongly correlated. (Fig 6). Specifically, when wave height increases,

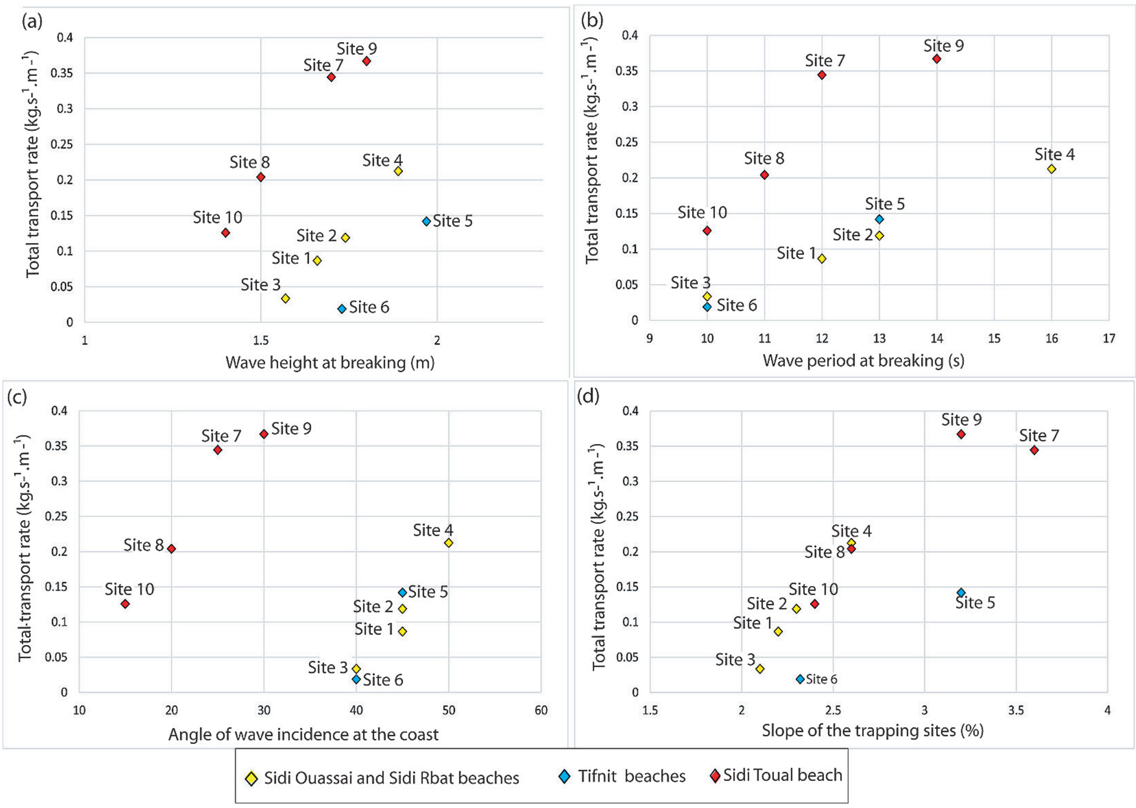

Figure 6. Total transport rates in relation to dominant local meteorological and topographic conditions during various measurement campaigns. (a): wave height, (b): wave period, (c): wave incidence angle at the coast, (d): slope of bathymetric profiles

period lengthens, and bathymetric profile slopes steepen, sedimentary flows rise. This suggests that more energetic wave conditions, with larger and more prolonged wave actions, are more effective at mobilizing and transporting sediments across the seabed. However, this relationship exhibits variability across different sites; low sediment transport is generally linked to low wave height, while even a slight rise in wave height can significantly boost sediment transportation. This variability may be influenced by local factors such as the type of sediment and the specific geomorphological features of each site. These findings confirm previous research like (Wright et al. 1984; Williams et al. 2000; Agbetossou et al. 2023) who demonstrated that sedimentary flows are closely related to wave hydrodynamic conditions and submarine topography. The alignment of these findings with previous research highlights the essential influence of wave dynamics on sediment transport processes. It also emphasizes the need to account for site-specific characteristics in sediment transport assessments, as local variations can greatly impact the observed patterns.

Variations in sediment transport flux

The results obtained indicate that most sediments transported in the wave breaking zone gradually decrease starting at the seabed and moving up through the water column. A considerable portion of sediment has been trapped at the bottom, mainly in the initial bags. This area consistently shows the highest levels of sediment transport across all measurement points. This finding underscores the essential role of rolling and saltation processes in transporting materials within the wave breaking zone. These processes involve sediment particles being lifted off the seabed and then bouncing or rolling along the bottom, driven by the kinetic energy of breaking waves. In contrast, the transport of sediments in suspension remains relatively low compared to rolling and saltation. Suspended sediment transport under wave involves particles being carried by the water column, but this mode of transport is less dominant than others modes. The lower levels of suspended sediment transport can be attributed to the reduced capacity of waves to keep particles in suspension due to the decreasing energy and turbulence as one moves upward in the water column.

The arrangement of transverse fluxes, indicating the horizontal transport of sediments across the coastline, is primarily governed by the dynamics of wave breaking. At different measurement points, wave breaking significantly influences sediment transport, particularly during the final stages of wave breaking. This phase of wave action results in very high levels of sediment transport, with the largest quantities of sand being trapped near the shore. This observation is supported by data indicating that sediment transport under wave energy reaches its maximum peak in the nearshore area, as illustrated in Figure 7. Futhermore, The vertical distribution of sediments is directly influenced by the energy and turbulence present in the wave breaking zone. The deeper sections of the water column exhibit significant turbulence, which is essential for the resuspension and transport of sediments. In contrast, the upper levels experience much less wave energy, resulting in lower sediment concentrations. This differential distribution of energy and turbulence across the water column helps explain the observed exponential decline in the transport of sediment from the bottom to the top.

Characterization of the sandy material trapped at measurement sites

The sandy material collected during various measurement campaigns primarily consists

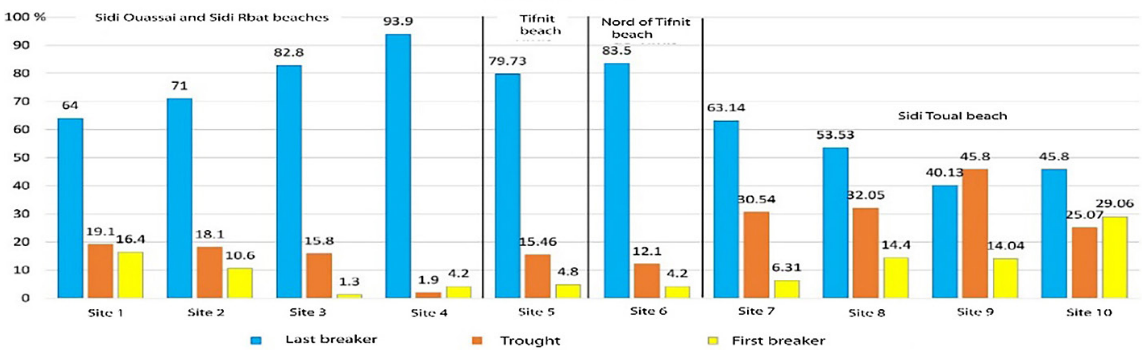

Figure 7. Cross-shore variation in sediment transport at different measurement points.

of uniformly graded sand with medium to fine grain sizes. Analyses conducted on samples taken in the wave breaking zone have revealed a trend of gradual decrease in the median size. This decrease is observed both vertically, starting at the seabed and moving up through the water column, and transversely, from the first measurement point (last breaking wave) to the third measurement point offshore (first breaking wave).In samples from the initial bags, a mixture of sandy materials with shell fragments is noticeable. The presence of these shell fragments in the wave breaking zone can be attributed to two main factors. Firstly, there is the energy released by the waves near the coast. Secondly, the sediments pattern on the continental shelf reveals a predominance of littoral shell sands, extending to depths below -20 m (Mattieu, 1977).

Median values range between 217 μm and 340 μm for the first measurement points (last breaking wave), between 205 μm and 350 μm for the second measurement points (trought), and between 187 μm and 370 μm for the third measurement points (first breaking wave) (Fig 8). The vertical grain size distribution presents more heterogeneous facies. The analyzed samples are well-sorted, with well-sorted coarse sand. For all analyzed samples, it is observed that the coarsest fraction is located at the lowest level, while the fine fraction is situated at the top of the water column (Fig 8). This situation was initially documented by Bascom (1951) on the United States beaches, where he noted that the largest sediments gathered at the break point just beyond the breaking line. This observation is explained by the finer sediments being eroded and transported by the dissipation of wave energy in both the breaking and swirling area. This erosion leaves behind the coarser materials, which accumulate on the seafloor.

DISCUSSION

The assessment of sand movement holds significant importance in the realm of coastal engineering and is a central challenge in advancing our comprehension of sandy beach dynamics. Coastal literature has extensively focused on the study of sediment transport fluxes in the longshore, cross-shore, and vertical distributions. This scrutiny is rooted in the fundamental role played by wave and current-driven sand movement within the littoral zone, as it profoundly influences the long-term sediment equilibrium of beaches and is integral to coastal processes.

Analysis of sediment transport flux under wave breaking zone has enabled us to understand the transport mechanisms in the dynamic forebeach zone. The findings from this study have given us definitive insights into the rate of sediment transport by marine currents within the wave breaking zone. This zone plays a vital role in supplying sand to beaches, as it represents a reserve of sediments that are transported to beaches on a continuous basis. It is also part of a complex, constantly evolving coastal system, interacting with the intertidal and supratidal zones. In the field, two primary modes of sediment transport were observed: rolling and saltation. This finding was corroborated by quantifying sediment accumulation in collection bags, with most mobilized sand trapped in the initial three bags. Suspended transport, by contrast, proved less substantial. Numerous studies have explored this phenomenon using optical or acoustic devices (Osborne and Vincent, 1996; Tonk and Masselink, 2005; Miles and Thorpe, 2015) and sediment traps (Kraus, 1987; Williams et al., 2000; Guo et al., 2023), consistently demonstrating an exponential decline in sediment transport intensity from the bed upward.

Quantifying sediment transport on different sandy beaches reveals variations from one site to another, and even within the same site. These variations can be explained by several factors. Firstly, the topobathymetric profiles have different shapes and slope values. We found that as slope increases, so does the amount of sediment trapped. Secondly, the hydrodynamic forcing conditions prevailing during the various trapping missions also have an influence on the quantity of sand mobilized in the wave breaking zone. Field measurements of these conditions prior to manipulating the sand trapping allowed us to correlate them with actual sediment transport. The results reveal a strong correlation between sand displacement and hydrodynamic forcing conditions. Indeed, the amount of sand displaced increases considerably as wave height, period and angle of incidence increase. Nevertheless, variability in sediment fluxes is observed even under similar wave height conditions. This variability can be attributed to the fact that comparable transport rates may correspond to different wave heights. This occurs even on the same beach and during identical field experiments. This indicates that sediment transport is influenced by factors beyond just wave characteristics.In addition, the specific morphology of each measurement site

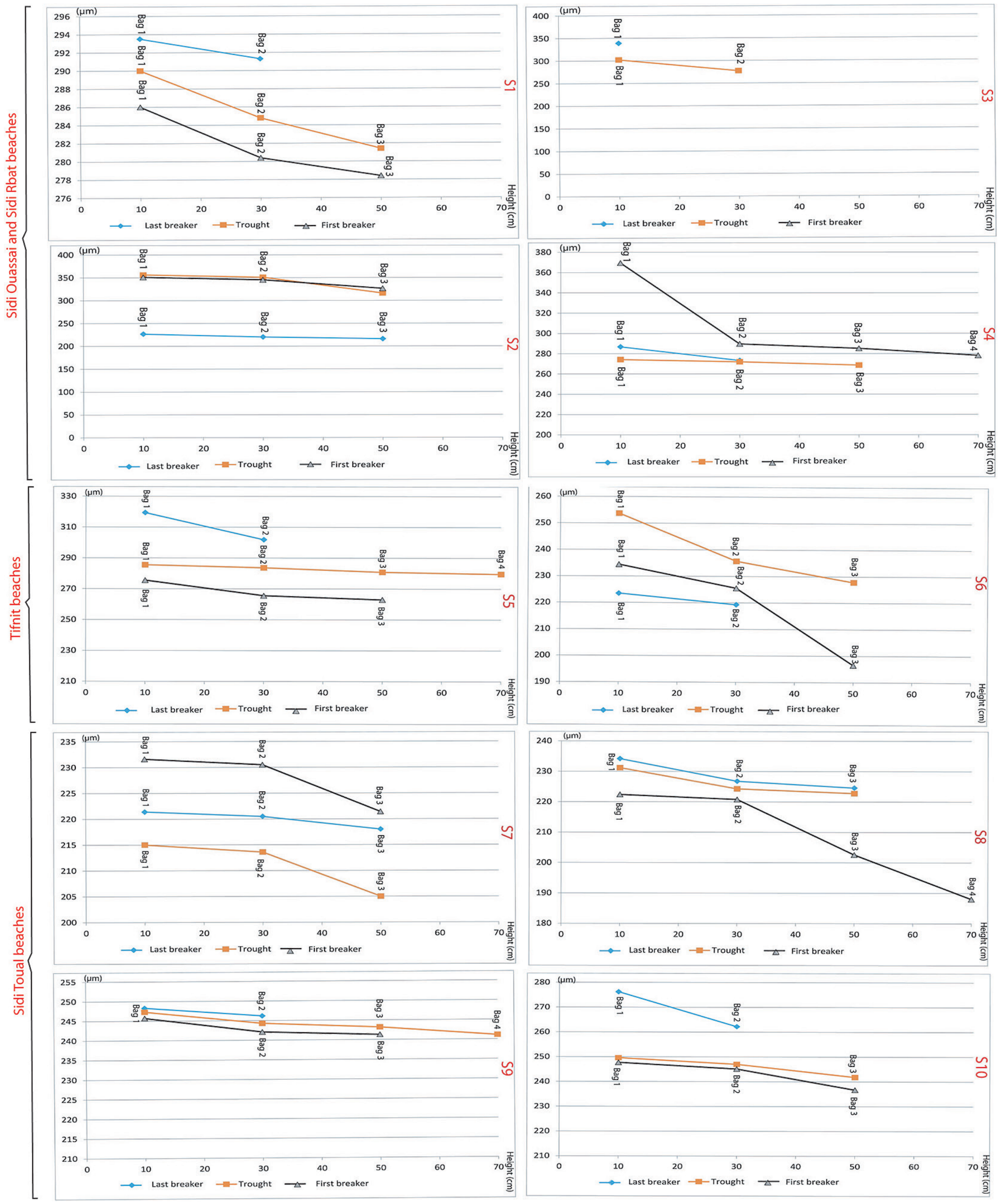

Figure 8. Evolution of median (D_{50}) in relation to water column height

influences the amount of sand mobilized in the wave breaking zone. Overall, we can see that the greatest quantity of trapped sediment is recorded at the last wave breaker. By contrast, the other measuring points show lower percentages. It is therefore at the pre-ripple level that a significant quantity of sediment is mobilized (Fig. 8).

These results are in line with previous work carried out in other regions (Kraus, 1987; Kraus et al., 1989; Greenwood et al., 1990; Beach et al., 1996; Corbau et al., 2003; Cartier et al., 2011; Lasgaa, 2018). These studies have shown that maximum sediment transport rates are generally recorded at the level of the last break-up. These zones correspond to the release of considerable wave energy due to friction on the seabed (Kraus et al., 1989). In the investigated zone, friction between waves and seabed generates a vertical movement of sand materiel within the water column. This phenomenon leads to the displacement of substantial amounts of sediment along the seabed, occurring through both bedload and saltation transport modes of transport.

Understanding sediment transport processes in beach morphology hinges on comprehending the arrangement of grain sizes in the wave breaking zone. The characterization of sandy material in the wave breaking zone has enabled us to better comprehension of sediment transport processes in connection with granulometric characteristics. Generally speaking, the materials collected using Streamer Trap sand trapping are medium to fine sands, well classified for all samples analyzed. Granulometric analysis of the various trapped samples reveals a vertical and horizontal evolution of the sandy material. This evolution is closely linked to local conditions at each measurement site, such as submarine morphology and the hydrodynamic forcing prevailing during the various sediment trapping campaigns. Examining the vertical distribution of sediment grain sizes offers valuable insights into sediment transport processes. Earlier research (Kraus et al., 1987, 1988, Rosati et al., 1990; Wang et al., 1998) founded that mean grain size remained nearly uniform in wave breaking zone. Along the Atlantic coast beaches south of Agadir, the results obtained show an evolution of mean grain size from bottom to top through the water column. In fact, the coarse fraction is located at the bottom, at the level of the first bags. The sediments collected at this depth are rich in shell fragments, reflecting the importance of the energy released by the waves, especially at the bottom. Gradually, the size of the median decreases in high water column, with a preponderance of finer fraction. A comparison of sediments collected at the bottom, at the lower level, and those trapped at the top, suggests that the level of upwelling energy near the bottom is high.

CONCLUSIONS

The study of sediment transport in the wave breaking zone with a streamer trap allowed us to quantify the transverse and vertical transport of sediment flow. The results reveal a high degree of variability in sediment flux, mainly attributable to various physical hydrodynamic, sedimentological and topographical processes. Indeed, total sediment transport is intrinsically linked to wave height and period, the angle of incidence of swells at the coast, and the slope of the surf zone. This shows that transverse sediment transport is heavily affected by the underwater morphology of each measurement site. We also note a certain logical organization of sediment transport from the first break to the coast. Generally speaking, the maximum transport rate is calculated at the last break, which confirms that it is near the shore where a large quantity of sediment is mobilized. Granulometric analyses of the trapped samples show an evolution of the sandy material, both vertically and transversely. The average grain size decreases starting from the seabed to the upward of the water column. Coarse fractions are trapped at the bottom in the first bags (rolling and saltation transport), indicating that a large quantity of sand is moved to the bottom. Fine fractions, on the other hand, are located at the top (suspension transport). We also conclude that there is a transverse trend from the coast to the open sea for most of the measurement sites.

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