14th International Symposium on Ultrasonic Doppler Methods for Fluid Mechanics and Fluid Engineering
Kobe, Japan (23.-25. October 2023)

Sediment Dynamics by Bistatic Ultrasonic Doppler Under Real Waves

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In order to improve sand transport models, the coastal engineering community needs data collected in natural conditions. In particular, sand transport processes in the wave boundary layer still need to be investigated, but the high temporal and spatial variability observed in this area makes it complicated to monitor it properly. In order to address this issue, the first worldwide in situ deployment of UB-Lab 3C, based on Acoustic Concentration and Velocity Profiler technology, took place at Porsmilin beach, in 2022. First data collected with this instrument are processed, and averaged in order to obtain intra-wave velocity, concentration and flux for two categories of waves in the shoaling zone: low and high orbital velocity waves. Sediment concentrations under higher orbital velocity waves are stronger than under lower orbital velocity waves. This preliminary data set is promising, and further analysis should allow to extend existing knowledge on sand concentration and transport under real in situ waves in shallow environments.

Keywords: Acoustic Profiler, ACVP, ADVP, Sediment Dynamics, Concentration, 3C Velocity Vector Profile

1. Introduction

Beaches are among the most dynamic areas on Earth. In order to predict beach morphodynamics, the coastal engineering community needs robust and reliable sand transport models, all the more so since water level rise due to climate change is bound to reshape the shoreline and to impact its dynamics in the years to come. Depending on the wave conditions and their initial state, beaches erode or accrete. While erosion mechanisms have been the focus of numerous publications in the last decade and are therefore quite well quantified in predictive models (van Rijn et al. 2011), mechanisms leading to accretion still remain poorly understood in comparison. Up until now, most data concerning sediment transport processes were collected in laboratory facilities (Ribberink et al. 2008; Nielsen et al. 2002 ; Hughes, 1993). It is known for instance that onshore-directed transport mainly occurs in the wave boundary layer via bed load, under moderate wave conditions (Mieras et al. 2019), but the relative contribution of different transport mechanisms leading to onshore-directed transport still needs to be clarified. Furthermore, understanding suspended sediment load as well as bed load is necessary in order to predict morphological changes of beaches (Aagaard and Jensen, 2013).

Technical difficulties accounting for the lack of in situ sediment transport data are twofold: first, the complex logistic needed to deploy instruments in the field in such energetic environments and second, the lack of appropriate means of colocalized velocity and concentration measurements. Indeed, in order to investigate boundary layer transport processes, high spatial and temporal resolution is needed for an accurate quantification of these highly variable processes. Likewise, the investigation of turbulence in this very area also requires high temporal resolution. Colocalized measurements of sediment velocity and concentration are necessary to compute transport. In this frame, the Acoustic Concentration and Velocity Profiler (ACVP) technology has been developed and allows obtaining high resolution profiles of velocity and estimations of concentration through an inversion model (O(ms), O(mm)) (Hurther et al. 2011). Since then, the instrument has been turned into a field prototype, the UB-Lab 3C, by Ubertone. This novel instrument, which has been made suitable for the marine environment, has been deployed for the first time in 2022 at Porsmilin Beach, Brittany, France, with the aim to better understand sediment conditions under waves. Targeting the observation of sand transport in the boundary layer, data collected with this instrument seem very promising and should allow improving predictive sand transport models.

First, the deployment site and methods are presented. Then, preliminary results are revealed, based on first observations of velocity, concentration and cross-shore flux in the boundary layer under waves in the shoaling zone.

2. Study sites and methods

2.1 Study area

UB-Lab 3C deployment took place on October 27th, 2022 at Porsmilin beach, Brittany, France. It is a pocket Beach located 15 km West of Brest. It is submitted to moderate south-west swell. It is a macrotidal sandy beach, with a median sand particle radius D50 = 320 micrometers (Dehouck, 2009). The long-shore dynamic observed on the beach is negligible compared to cross-shore dynamic.

2.2 UB-Lab 3C deployment method

UB-Lab 3C is part of a whole set of instruments deployed on a dedicated platform, (Fritsch et al. 2022) in order to study hydrodynamics and sediment transport in the water column (see Fig. 1). For instance three acoustic Doppler velocimeters (ADV) and concentration profilers are installed higher in the water column.

Figure 1: Mooring at low tide (top) and UB-Lab 3C (385 mm long with a central emitter and 4 surrounding receivers (bottom)

The mooring was deployed at low tide in the intertidal zone of the beach (1m high). Instruments then recorded hydrodynamic and sediment transport data during one tidal cycle, and the platform was retrieved during the following low tide. That day, the wave height was approximately 0.75 m at the beach and 1.25 m offshore.

2.3 UB-Lab 3C features

The UB-Lab 3C (Fig.1) is an ADVP - Acoustic Doppler Velocity Profiler (Hurther et al. 2011) and was developed by Ubertone. This bistatic velocity profiler works with one narrow beam emitter and four simultaneous wide beam receivers, each is 10 cm apart from the receiver. All transducers are wide band and centered at 1MHz. Profiles can be recorded at a sampling frequency up to 64 Hz and spatial resolution down to 2.2mm.

In this study, it simultaneously recorded the 3C velocity and backscattered echo amplitude profiles, up to 15 cm above ground. The instrument was set with a PRF of 1650Hz, each profile was calculated over 32 pulses. We applied acoustic inversion techniques on backscattered intensities (Thorne and Hanes, 2002), to estimate sediment mass concentration in the boundary layer. Since concentration and velocity are measured in the same volume, they can be regarded as colocalized measurements. Quasi instantaneous cross-shore fluxes were then computed by multiplying colocalized concentration and velocity profiles. The sand bed is defined as corresponding to the location of the maximum backscattered intensity.

2.4 Studied data

The water elevation above the mooring over high-tide is obtained through pressure data (collected at 5Hz rate). The water height reached 4.5m above the mooring during the deployment. The time series studied below were recorded in the shoaling zone. Those specific time series were chosen because separation between waves was possible. The first studied time series starts at 14h48min53s (UTC) and stops at 14h51min10s. The second studied time series starts at 14h54min5s and stops at 14h56min11s. The 'free stream' velocity time series on Fig. 2 corresponds to the cross-shore velocity average of the cells 30 to 35 (U_{rms}) in the profile recorded by the UB-Lab 3C (50 Hz) (among the 100 cells in a profile).

2.5 Data processing

Since measurements are quasi instantaneous, they are subject to noise problems. In order to remain consistent with previous studies realized under waves (Fromant et al 2019, Hurther and Thorne 2011), data were averaged on 15 waves which were cut with a zero-crossing method. Then, indices retrieved from this velocity cutting were applied on concentration and velocity profiles recorded by the UB-Lab 3C. This method is explained on Fig. 2. This way, concentration and velocity profiles under each studied wave were obtained. Then, those waves were divided into two groups based on the value of their orbital velocity.

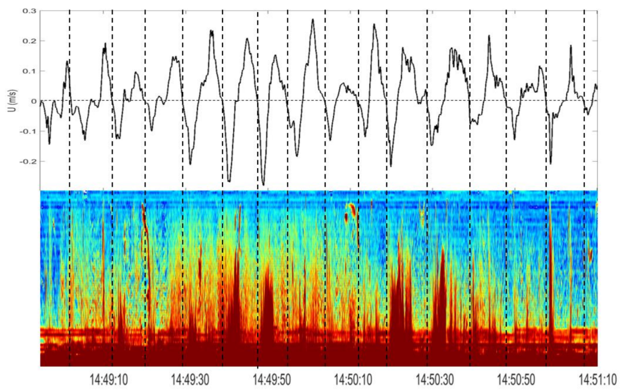

Figure 2: First line: free stream velocity of the first time series, and second line: corresponding concentration under the waves. The concentration profiles are cut following the indices retrieved after the wave cutting thanks to a zero-crossing method (vertical dotted thick black lines, arbitrary color range).

2.6 Wave characteristics

The first group of waves corresponds to the 'low orbital velocity' waves (category 1), and the second group the 'high orbital velocity' waves (category 2). The characteristics of the mean free stream of each category are displayed in Table 1. T is the wave period in seconds, A_{sy} is the wave asymmetry computed as:

$$A_{sy} = \frac{a_{max}}{a_{max} - a_{min}} \quad (1)$$

with a_{max} the maximum acceleration value during the studied wave cycle, and a_{min}, the minimum acceleration value. S_k is the wave skewness computed as:

$$S_k = \frac{u_{max}}{u_{max} - u_{min}} \quad (2)$$

with u_{max} the maximum velocity value during the studied wave cycle and u_{min} the minimum velocity value. A_{orb} is the orbital velocity, computed following Ribberink et al. (2008):

$$A_{orb} = \frac{\sqrt{2}Urms\,T}{2\pi} \quad (3)$$

with U_{rms} the root mean square of the wave velocity .

Table 1: Wave parameters for both categories (see eq. 1, 2 & 3).

	Category 1		Category 2	
Parameter	Average	Standard deviation	Average	Standard deviation
T (s)	9.2	1.4	9.0	1.4
A_{sy}(1)	0.52	0.11	0.51	0.07
S_k (1)	0.53	0.12	0.53	0.13
A_{orb} (m)	0.12	0.05	0.27	0.07

For each category of waves, velocity, concentration and flux data are studied. Those quantities are represented on Figures 3, 4 and 5 for the category 1 (waves with low orbital velocity) and on Figure 6 for the category 2 (waves with high orbital velocity).

3. Results

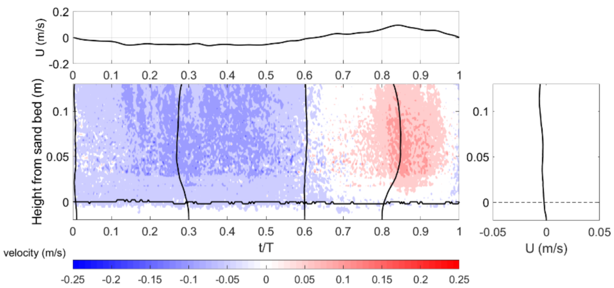

Figure 3: Free stream wave velocity (first line), intra wave mean velocity color plot (middle graph) and mean wave-averaged velocity profile (right panel) for the low orbital velocity waves.

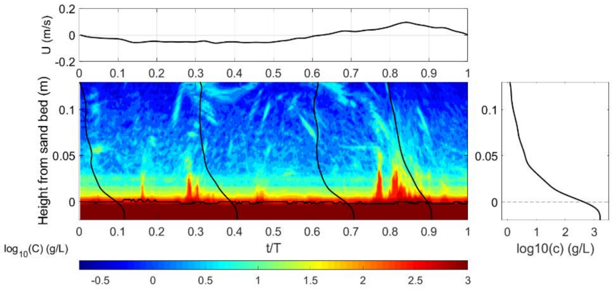

Figure 4: Free stream wave velocity (first line), intra wave mean concentration color plot (middle graph, in logarithmic scale) and mean wave-averaged concentration profile (right panel) for the low orbital velocity waves.

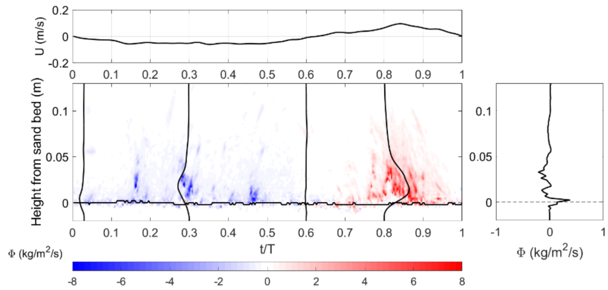

Figure 5: Free stream wave velocity (first line), intra wave mean flux color plot (middle graph) and mean wave-averaged flux profile (right panel) for the low orbital velocity waves.

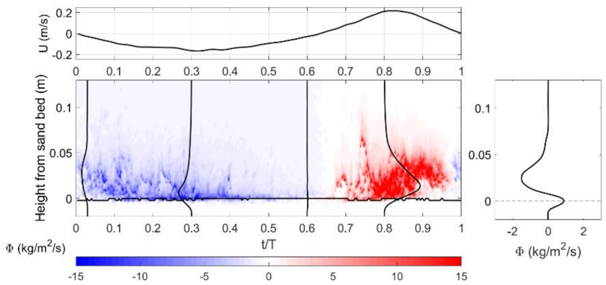

Figure 6: Free stream wave velocity (first line), intra wave mean velocity color plot (middle graph) and mean wave-averaged velocity profile (right panel) for the high orbital velocity waves.

3.1 Structure of the figures

On each of the above-displayed figures (Fig. 3 to 6), the free stream wave velocity cycle is displayed in the first line, then the color plot represents the intrawave velocity (Fig. 3), concentration (Fig.4) and cross-shore flux (Fig. 5 and 6). The vertical profiles on the color plots correspond to the phase-averaged profiles at specific wave events inside a wave cycle: the crest to trough flow reversal, the maximum offshore velocity, the trough to crest flow reversal and the maximum onshore velocity events. The thick black horizontal line corresponds to the bed, detected as explained earlier. Finally, the panel on the right corresponds to the wave-averaged profile of velocity, concentration or cross-shore flux.

3.2 Velocity data

In terms of velocity, it can be observed that in the 'high orbital velocity' case (not plotted), the intrawave velocity values are higher than in the 'low orbital velocity' case (Fig. 3).

3.3 Concentration data

The intrawave concentration dynamics under the category 2 mean wave (Fig. 4) are more important than under the category 1 mean wave (not plotted). Notably, there is a high concentration patch at $t/T = 0.8\text{-}1$ for the high orbital velocity waves, after the trough to crest flow reversal and during the onshore half cycle of the wave. In this case, since sediment did not have the time to resettle before the end of the onshore half cycle, phase lagging effects might be observed (Ribberink et al. 2008, O'Donoghue and Wright 2004). Sediment mobilized during the onshore half cycle might be advected offshore during the offshore half wave cycle. This phenomenon does not seem to be observed for the low orbital velocity case.

3.4 Flux data

The measured intrawave cross shore flux values are higher for the category 2 mean wave (Fig. 5) than for the category 1 mean wave (Fig. 6). This is consistent with the higher concentration values observed in category 2 than in category 1 (Fig. 4). On the mean flux profile (right panel of Fig. 6), it is clear that a strong wave-averaged onshore flux can be observed close to the sand bed, whereas an offshore-directed flux can be observed higher in the water column. This result is consistent with previous studies (Mieras et al, 2019; Brenner et al., 2018).

4. Discussion and Conclusion

The UB-Lab 3C is the first commercial version of a field ADVP and was developed by Ubertone. Its first deployments allowed obtaining colocalized high resolution measurements of velocity and concentration profiles in natural conditions. First data collected at Porsmilin beach, Brittany, France, show how promising this technology is in terms of boundary layer transport observations. For a better understanding of sand transport processes, UB-Lab 3C data should be processed in the light of the data recorded higher in the water column from the ADVs and the concentration profilers. Data set collected with the mooring (Fig. 1) should offer a complete overview of cross-shore sediment processes on sandy beaches.

Several deployments were done in the meantime, in particular in the winter 2022-2023 at Porsmilin Beach in Brittany, France. Those specific deployments aim at targeting the observation of seasonal accretive conditions that can be observed after stormy events on sandy beaches. It is hoped that data collected with this UB-Lab 3C, associated with data from other instruments deployed in the mooring will deepen knowledge on cross-shore sand transport in natural conditions, particularly under accretive conditions.

This field version of the UB-Lab 3C will soon be available also in lab version, with external transducers and splashproof case.

Acknowledgements

This work is part of ANR project WEST (ANR-20-CE01-0009), it was also supported by Geo-Ocean lab (UMR6538), ISblue project (ANR-17-EURE- 0015) and co-funded by a grant from the French government under the program "Investissements d'Avenir". Part of the equipment used in this experiment was funded by the French Government, the European Fund for Economic and Regional Development, the Regional Council of Brittany, and authorities of Finistère as part of the CPER project O3DO (2016-2020). Special thanks to ODYSC team for support on field experiments, P2I, Albert Lucas sailors and IUEM divers.

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