SEDIMENT TRANSPORT AND BEACH PROFILE EVOLUTION INDUCED BY BICHROMATIC WAVES WITH DIFFERENT GROUPING PERIODS.

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The experimental conditions and preliminary results of the CoSSedM (Coupled High Frequency Measurement of Swash Sediment Transport and Morphodynamic) Hydralab IV access project have been introduced. Large scale mobile bed experiments were performed at the CIEM/UPC wave flume aiming to obtain detailed measurements of the hydrodynamics, sediment transport and bed evolution at the inner surf and swash zones. Bichromatic wave conditions were generated with different group periods but similar energetic content. Preliminary results have shown that the measured profiles display a different beach evolution as a function of the wave group period increasing the breaker bar cross-shore position respect to the initial SWL and reducing the shoreline erosion as the wave group increases. New conductivity (CCM+) based sediment concentration measurements at the swash zone sheet flow layer have been presented for a specific bichromatic wave condition. The CCM+ system also allowed wave group averaged bed level measurements. The new obtained data suggest an important influence of sediment exchange between the lower and upper parts of the swash zone with quick erosion during the wave group uprush and a slower accretion during the wave group backwash.

1. INTRODUCTION

The swash zone is notoriously difficult to instrument (Masselink et al., 2009) because its flows occur within a highly transient, shallow region which changes at wave frequency. Moreover, not only the large size of the sediment fluxes makes measurements difficult but also the various possible modes of transport (e.g. bed load, suspended load, sheet flow). Therefore, suitable characterization of the swash zone sediment transport, is not available as yet.

Sediment traps and Optical Backscatter Sensors (OBS) are, typically, used to measure the sediment transport rate or concentration at different levels down the water column or cross-shore positions. The collected data, together with different methods of bathymetric surveys (rods, mechanical surveys), have been used to gain knowledge on the physics of the swash zone sediment transport. However, these techniques are affected by some serious restrictions, which significantly limit the understanding of the controlling physics. OBSs need a minimum water depth to work in. Therefore, most of the reported findings of swash zone sediment transport come from the suspended load component far from the bed, even though bed-load or sheet-load transport may be a dominant component and its exclusion can add significant errors in the predictions of swash zone sediment transport. Sediment trap data obtained in the field, on the other hand, are still far from being fully reliable. Masselink et al. (2009) performed sediment trap field measurements and compared them with the net flux derived from bed level changes (considered the most reliable). They found the transport rates derived from bed level changes to be on average three times larger than the data derived from the sediment traps. Sediment trap data have been also obtained in experimental condition (Alsina et al., 2009) by overwash during the uprush swash stage, limiting the knowledge to only one phase of the problem. Finally, bathymetric surveys are, usually, taken after one or a good number of wave groups (during emergence periods) or, even, after hours/days and do not improve the knowledge on the short-term hydrodynamic/beachface response. Net sediment transport over individual swash events (Baldock et al., 2005) indicates that bed-level changes over individual swash events can be significant and that relatively few swash events can be responsible for most of the net morphological change. In summary, it is clear that, at present, there is no reliable method to obtain direct measurements of the total swash zone sediment transport rates.

The limited measuring capabilities on sediment transport in the swash zone mentioned above also limit the understanding of the swash morphodynamics and the numerical modelling skills in the swash zone. Therefore a technological upgrade is needed to obtain more detailed sediment transport and bed level evolution information largely demanded by the swash zone research community.

The main aims of the CoSSedM experiments were to take this challenge of undertaking novel measurement in the swash zone by obtaining detailed intra-wave measurements of bed level changes and sediment transport in the swash zone. Another important aim of the project was to evaluate the influence of wave groups and associated long waves in the inner surf and swash zones.

2. EXPERIMENTAL SETUP

During October-November 2012 the experiments of CoSSedM access were carried out in the large scale wave flume CIEM at Universitat Politecnica de Catalunya (UPC), Barcelona. This is a wave flume 100 m long, 3 m wide, and 4.5 m depth (Fig1). The working water depth was at around 2.5 m over the horizontal flume section and modified around that depth depending on the wave test. A beach was installed made of commercial well sorted sand ($d50 = 0.25$ mm, $d10 = 0.154$ mm and $d90 = 0.372$ mm) with an overall mean beach gradient of approximately 1:15. The measured sediment settling velocity is of 0.034 m/s. The beach commenced 33.3 m from the wavemaker with the toe of the beach at an elevation of around −2.5 m relative to the SWL and approximately 42 m seaward of the SWL.
The range of instrumentation utilized in the CoSSedM experiments (Fig. 1) included wire wave gauges (WG) along the length of the flume, Pore Pressure Transducers (PPT) in the surf zone and acoustic wave gauges (AWG) in the inner surf and swash zone. A series of Acoustic Doppler Velocimeters (ADV) and Optical Backscatter Sensors (OBS) were distributed in the surf and swash zones. Instruments measuring water surface elevation (WG, AWG and PPT) were calibrated during changes of water level in the flume (approximately once every two days).

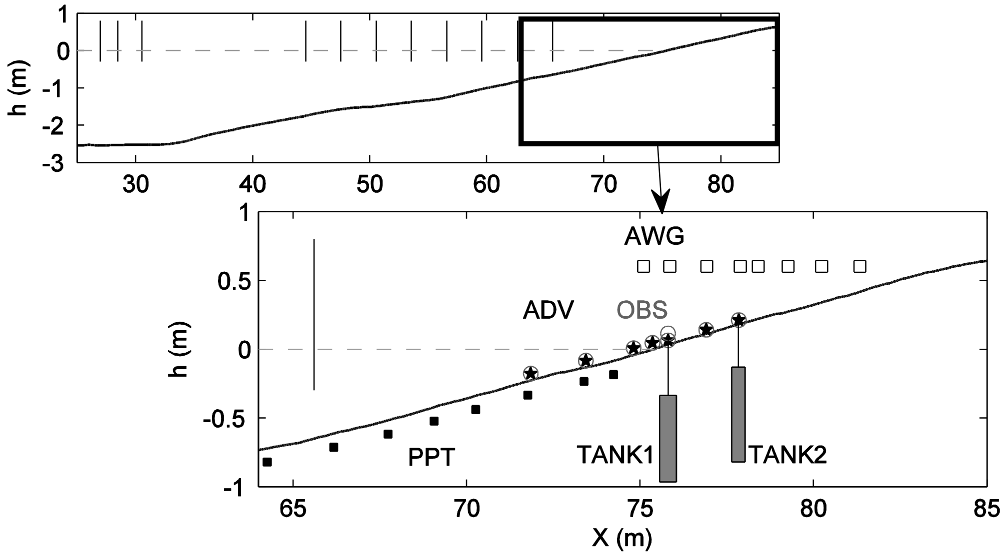

Figure 1 – Wave flume configuration with measured bathymetry. General view with resistive wave gauge positions, and amplification of the beach-face area subject of interest with instrument locations. Solid squares are PPTs, open squares are AWGs, open circles correspond to OBSs and stars symbols mean ADVs.

A new Conductivity Concentration Meter (CCM+) system (van der Zanden et al., 2013) was installed in the wave flume within the swash zone. The new CCM+ system consisted of a total of four sensor probes that can move in the vertical direction and that are part of two large tanks, plus a control box and operating system. The tanks were buried in the beach so the probes moved up and down from underneath to measure water conductivity at a known vertical elevation and therefore minimizing flow disturbance. The tanks and probes were located at two different locations within the swash area (Figure 3), x = 75.81 m (CCM probes 1/2 and 3, tank 1) and 77.8 m (CCM probe 4, tank 2). Different tank cross-shore locations relative to the swash zone limits were obtained by slightly modifying the working water depth. This is the reason why we have repeated wave conditions with different water depths. This choice was preferred to burying the tanks at a different location each time (highly time consuming). The CCM tanks capabilities to measure at the swash zone and technical details have been investigated, preliminary results have been presented in van der Zanden et al. (2013) and a more detailed description is expected (van der Zanden et al. in preparation). Finally a system of cameras was set-up aiming to measure the beach-face morphological evolution during swash emergence period.

The experimental program was divided into two test series (erosive and accretive), and within each test series a number of different wave cases were generated (Table 1). The different bichromatic wave conditions were designed to have a similar flux of energy and spectral energy content. The dimensionless sediment fall parameter (H/w_sT) is also included in table 1. This parameter is generally used to classify beach states (Wright and Short, 1984), and as a descriptor of beach profile evolution and on/off-shore sediment transport dominance (Dean, 1973). The dimensionless sediment fall parameter ranges between 2.8-3.5 for erosive conditions and 0.8-0.9 for accretive conditions suggesting similar erosive and accretive behavior for the different test series.

Table 1 – Performed wave conditions with wave height obtained from spectral moment at sensor located closer to the wave paddle (x = 7.72 m shoreward from the toe of the wavemaker). * BE4 data not shown because the resistive wave gauges close to the wave paddle failed for this condition.

Wave Conditions	Component 1		Component 2					
	H_1 (m)	f_1 (Hz)	H_2 (m)	f_2 (Hz)	Δf (Hz)	H/w_sT	Iribarren	d (m)
Erosive Conditions								
BE1	0.29	0.303	0.25	0.237	0.066	3.089	0.429	2.53
BE1_2	0.30	0.303	0.25	0.237	0.066	3.121	0.427	2.48
BE2	0.28	0.30	0.26	0.240	0.060	2.827	0.448	2.5
BE3	0.30	0.295	0.28	0.245	0.050	3.518	0.402	2.5
BE4*		0.288		0.252	0.036			2.5
BE4_2	0.29	0.288	0.28	0.252	0.036	3.272	0.417	2.46
Accretive conditions								
BA2	0.11	0.234	0.10	0.175	0.059	0.871	0.831	2.5
BA3	0.10	0.227	0.08	0.181	0.046	0.846	0.844	2.5
BA4	0.11	0.2197	0.10	0.188	0.032	0.905	0.816	2.5

A typical test series (BE1, BE2,…) started from the same plane 1:15 sloping bed manually reshaped beach profile and a series of 8 (7 for BE1 case) hydrodynamics runs. Each run consisted of approximately 30 minutes of wave action (240 minutes in total, 210 BE1 case). The beach profile is measure after each run, having a total of 9 measured beach profiles per test (8 for BE1 case).

3. RESULTS AND DISCUSSION

As explained in the Introduction, the main aims of the CoSSedM experiments were to obtain coupled intra-wave measurements of hydrodynamics, sediment transport and beach evolution at the swash zone, and to investigate the influence of the wave grouping and associated long-waves in sediment transport. Both aims have been accomplished in terms of the quality of the obtained data. The measured information is being currently analyzed, preliminary results have been shown already (van der Zanden et al., 2013) and more information will be released in the future. A full description of our present results is beyond the space of this joint user HYDRALAB IV proceeding and/or some of the information is still being analyzed. Therefore, only a resume on how the project is meeting the main objectives will be detailed here.

3.1 INFLUENCE OF WAVE GROUP PERIOD IN SEDIMENT TRANSPORT AND BEACH PROFILE EVOLUTION

The four erosive generated bichromatic conditions aimed to have the same energetic content and flux of energy. They were designed to have the same primary wave variance-based bichromatic wave height H_{bi} of 0.4 m and a primary short wave group frequency $f_p = (f_1+f_2)/2 = 0.21$Hz. In reality, the measured water surface elevation showed slight differences from the designed ones due mainly to some discrepancies in the empirical wave paddle transfer function for different mean water surface elevations and periods. As a result the measured H_{bi} showed slight differences among the different tests. This is illustrated by the differences in the computed dimensionless fall velocity (H/w_sT) in table 1 which shows for example small variation between different erosive tests.

The mean initial and final measured beach profiles for each wave condition are illustrated in figure 2. It is evident from figure 2 that the four tested bichromatic wave conditions resulted in beach erosion, shoreline retreat and the development of a bar at around the wave breaking location (breaker bar). The shape of equilibrium foreshore slopes, the states of physical (laboratory) modelling of natural beaches, and shoreline erosion rates are often parameterized using the dimensionless fall velocity (Dalrymple and Thompson, 1976). However, in our experiment the differences observed in the measured final profiles between different test cases are not reflected in the small differences in the dimensionless fall velocity observed between the different erosive tests, (table 1). On the contrary the location of the breaker bar showed a direct relationship with the wave group period, increasing the distance to the initial SWL location with increasing wave group period. The breaker bar position is measured by taking the maximum local elevation at the bar. The different wave group period is also shown to influence the beach evolution close to the shoreline, increasing the shoreline erosion inversely with the increase of the wave group periods. Finally, there are some evidences of the influence of the wave group period in the development of a swash-berm, although this relation is not as evident due to the difference in berm shape formation observed.

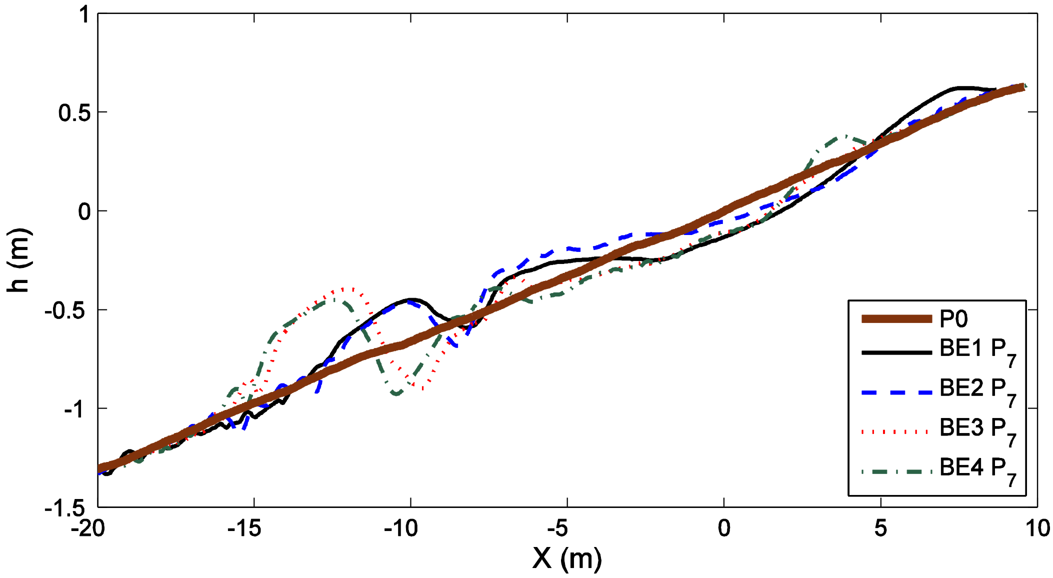

Figure 2 – Mean initial beach profile (P0) and final measured beach profile evolution (P7) for the four bichromatic conditions.

In summary, we find that increasing the wave group period tends to move the beach profile seaward, i.e. the final shoreline position and bar location for longer wave group periods are closer to the wave paddle than the for shorter wave group periods. However, the distance of the breaker bar to the final shoreline position was also shown to increase with the wave group period (except condition BE2) suggesting a more "erosive" tendency as the wave group period increases.

3.2 INTRA-WAVE GROUP MEASUREMENT OF BED EVOLUTION AND SHEET FLOW SEDIMENT TRANSPORT

The other important aim of the CoSSedM project was to obtain coupled high frequency measurements of swash sediment transport and bed evolution. Therefore, a new CCM+ system for simultaneous measurements of sheet-flow concentrations and bed level elevations in the swash zone (van der Zanden et al., 2013) was applied for the first time during the CoSSedM experiments.

A detailed explanation of the new CCM+ measuring technique and how sediment concentration and movable bed level are obtained can be found in van der Zanden et al. (2013). Conductivity probes are able to measure high concentration values very close to the bed level and of the order of the packed sediment in the stable bed. The new CCM+ concentration tracking system consists of a feedback loop between concentrations and sensor vertical movement, enabling the sensor to move vertically to the direction of a given target concentration. If the tracking system performs ideally, the system is able to keep the measured concentrations at all times at a target value by adjusting the sensor height continuously. However, due to the system's characteristics, such as delays and probe overshooting, but also due to the spiky nature of the measured concentration signal and the steep vertical concentration gradients when the sheet-flow layer is absent or small, the measured concentrations in practice fluctuate around the target value. van der Zanden et al. (2013) have shown the CCM system was not able to respond quickly enough to follow instantaneous concentration changes and was therefore not able to follow the target concentration during the complete wave group cycle, however the system is well able to follow the bed level on a time scale equal or larger than the wave group. Other probes that are either slowly moving or positioned at a fixed elevation, can be used to measure intra-wave sediment concentrations in the sheet-flow layer and to study intra-wave bed-level movements. Hence, two probes that are at the same cross-shore position yield complementary results (probe in 'quick' tracking-mode for wave-averaged bed-level measurements, and probe in 'slow' tracking-mode for intra-wave concentration measurements).

Figure 3 displays time series of CCM sensor 3 (in quick tracking mode) and 4 (corresponding to CCM tank 1 and 2 respectively) vertical elevation (left) and power spectrum of the vertical elevation (right). The test conditions correspond to BE1 and the cross-shore locations relative to the initial SWL are x = 0.56 m (tank 1) and x = 2.55 m (tank 2), shoreward of the initial SWL. The spectrum shows various bed-level fluctuations, but in this document we will focus on the intra-wave-group concentrations and bed-level movements. For this purpose, we first require an estimation of the elevation of concentration measurements of probe 1/2 (which is at the same cross-shore position) with respect to the bed. We define the bed here as the wave-averaged bed-level, which can be obtained by applying a low-pass Fourier filter on the positions of probe 3 and 4 (dash lines in Figure 3). The Fourier transform-based filter was applied with a cut-off frequency of 20 s. Therefore, we are focusing on bed level oscillations occurring at a time scale larger than the wave group (the wave group period for case BE1 was 15.15 s, table 1).

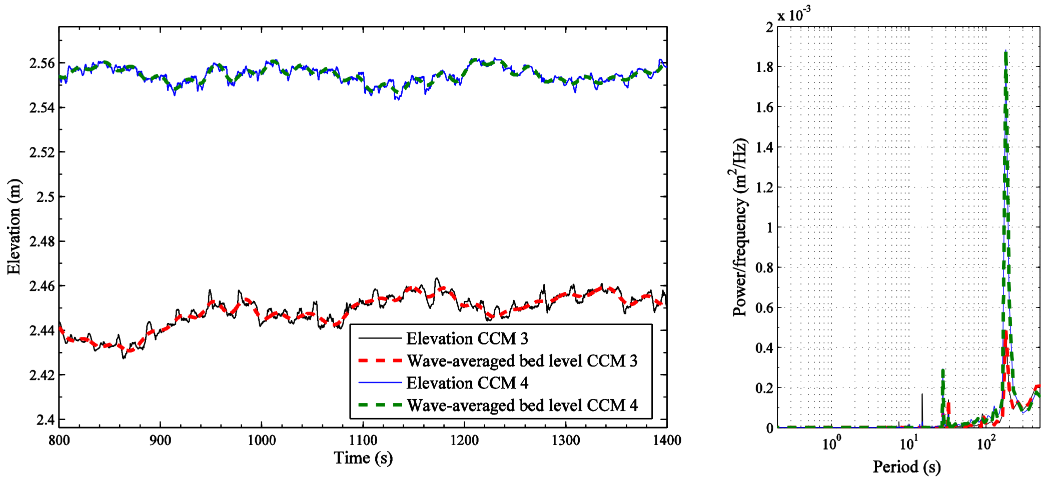

Figure 3 – Time series of vertical elevation measured with CCM3 probe with low-pass computed bed level (left); and computed vertical elevation power spectrum (right)

Bed levels during the intermittently emerged periods (between swash events) were also estimated using Acoustic wave gauge sensors (Turner et al., 2008). Bed exposure is identified as the Acoustic wave gauge (AWG) signal section where the signal variation does not exceed 2.5 mm during a time interval equal or longer than 2 s. Figure 4 illustrates a comparison of the obtained bed level computed using the CCM probe 4, (tank 2), the bed level estimated from the co-located AWG and the bed level measurements using the bottom bed profiler. The agreement is relatively good given the instruments accuracy (order of mm for the CCM and AWG and 10 mm for the bottom profiler) and the distance between the centre-line of the wave flume where the bottom profiler measure the bed level and the CCM and AWG located close to one of the flume walls (around 1m). When the emergence period increases the AWG-based bed level measurements become more reliable and better agreement with the CCM has been obtained (van der Zanden et al. in preparation).

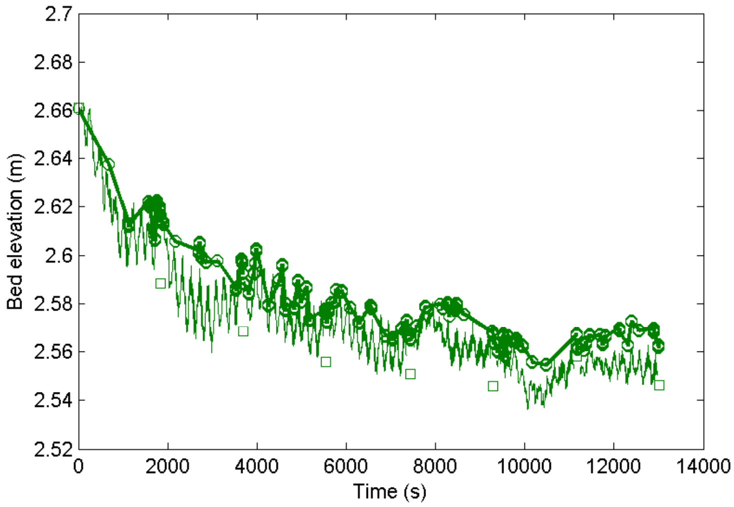

Figure 4 – Time series of bed level elevation measured using the CCM tank (solid line), AWG (circles) and the bottom profiler (squares) at a cross-shore location x = 2.55m respect to the initial SWL (onshoreward) and test BE1.

Figure 5 represent a wave group ensemble averaged plot of measured water surface elevation (Figure 5a), horizontal velocity (figure 5b), sediment concentration at different vertical elevations relative to the wave averaged bed level within the sheet flow layer (figure 5c) and a contour plot of sediment concentrations at different relative vertical elevations (figure 5d). The line in Figure 5d indicates the vertical elevation where concentrations are equal to 0.30 m3/m3, it is obtained by linear interpolation and serves as an estimate for the vertical position of the sheet-flow layer’s centre or the intra-wave bed level.

BE1 hydrodynamics condition has a modulation of 15.15 s of group period and consisting of around of 3-4 short waves per group. This wave group structure repeats in the time series with slight differences between successive wave groups due to the wave generation. As the wave groups propagate to the shoreline, energy transfer to the wave group frequency occurs plus energy dissipation of high frequency harmonics due to wave breaking. Therefore, the wave group frequency dominates the ensemble averaged water surface signal and velocity measured at the at the tank 1 cross-shore location (figure 5a and b). The swash event induced by the wave group structure is evident and the individual waves can be recognized but are hardly evident, due also to the ensemble process that smooth the water surface elevation signal.

The first wave of the group arrives at t/Tgr=0.1 with high velocities, a second wave arriving at t/Tgr=0.25 can be noticed and interacting with the previous wave in a wave-uprush type of interaction, i.e. the second wave arrives during the uprush of the previous wave adding momentum to the swash event (Hughes and Moseley, 2007). A third wave can be identified at t/Tgr=0.52 during the backwash of the previous waves, this third wave cannot invert the velocity signal which remains negative and therefore this wave-swash interaction can be regarded like a strong wave-backwash interaction (Cáceres and Alsina, 2012). The third wave is washed seaward with the backwash.

During the wave group uprush, a rapid sediment concentration reduction at most of the vertical relative elevations is noticed (figure 5c) and a bed-level drop with an erosion depth of an estimated 5 mm (figure 5d). During the remainder of the uprush phase and the beginning of the backwash, the bed level position and vertical gradients in concentration are more or less constant. This means that the sediment that was mobilized in the uprush phase is horizontally advected towards the upper swash (erosion). The backwash phase associated to the wave group is characterized by a gradual accretion of the bed level, which is especially evident at the end of the backwash. This is likely due to sediment being advected from the upper to the lower swash, deposited as water levels and velocities drop.

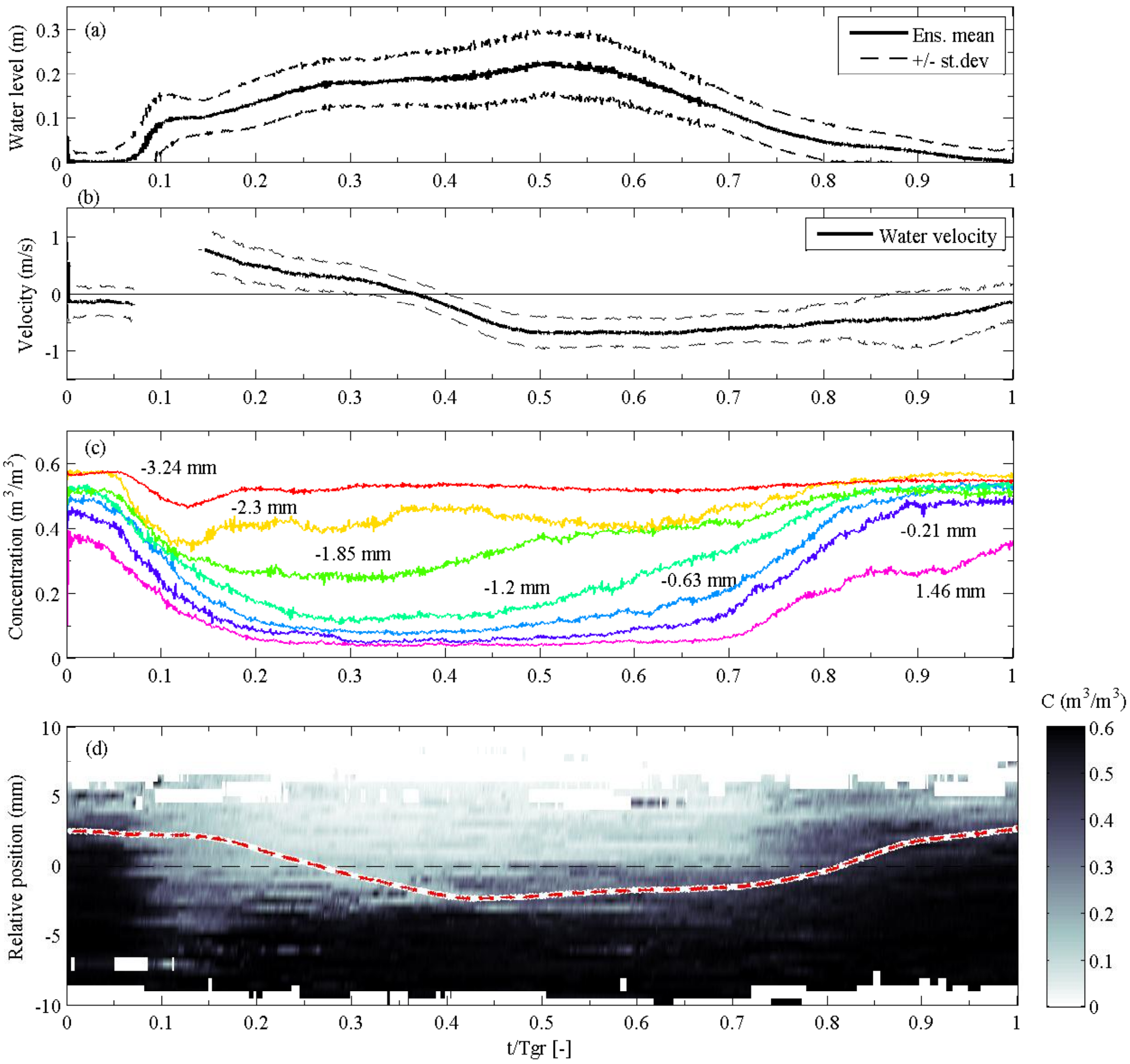

Figure 5 – Ensemble averaged plots of: (a) water surface elevation, (b) horizontal velocity, (c) sediment concentration at different relative vertical elevations and (d) concentration contour plot at different relative wave group phases and relative vertical elevations.

The overall bed level at this location was found to be erosive although this location reached a quasi-equilibrium condition after approximately 60 minutes of experimental test (the ensemble averaged plots on figure 5 were obtained with the last 120 minutes of a total of 210 minutes of experimentation time). Under successive wave groups, the opposing bed level changes within the wave group (accretion during the backwash and erosion during the uprush) add up to a net offshore transport of sediment. The observed erosion and accretion pattern differs from observations in previous sheet-flow studies, including flume studies with wave groups (Dohmen-Janssen and Hanes, 2005), during which it was usually found that the concentration profile was pivoting around a fixed position point (O'Donoghue and Wright, 2004). For the swash conditions presented here, the vertical position of the pivot point is non-stationary (van der Zanden et al. in preparation) within the wave group cycle. Also the measured concentrations of CCM 1/2 (Figure 5c) do not show the typical sheet-flow behavior, i.e. a pick-up layer for the higher concentration bin classes and an upper sheet-flow layer showing a mirrored image for the lower concentration bin classes (see e.g. Ribberink and Al-Salem, 1995). This is due to the advection nature within the swash but also partly due to the fact that the probe was always close to the bed, and the higher and lower elevations were not well captured.

4. CONCLUSION

A summary of the Coupled High Frequency Measurement of Swash Sediment Transport and Morphodynamic (CoSSedM) project has been presented in the present work. The main aims and preliminary results obtained from CoSSedM are highlighted. So far we can say that the CoSSedM project successfully met the main goals of obtaining coupled measurements of sediment transport, suspended sediment concentration and sediment concentration occurring in the sheet flow layer, and bed level measurements at a wave frequency scale as already illustrated in the present work. The obtained measurements have been also used to highlight the influence of the wave group periods in the sediment transport and beach profile evolution. The link between the detailed hydrodynamic, sediment concentration measurements and the illustrated bed evolution with different wave group period are being currently analyzed.

Within the preliminary results it has been shown that the wave group period has an effect on the beach profile evolution reflected in the breaker bar formation and shoreline evolution. It has been shown that increasing the wave period leads to an increase in the breaker bar position with respect to the initial SWL position. On the contrary, the shoreline retreat with respect to the same initial SWL was shown to reduce with the wave group period. It seems that by increasing the wave group period forces a seaward evolution of the beach profile, however the wave group period influence on the breaker bar location is larger than on the final shoreline position, suggesting a more erosive tendency with larger group periods.

The new CCM+ system has been, for the first time, applied to the swash zone. It has been briefly shown how the new CCM+ system achieves to measure the bed level at a wave group time scale. The space and scope of the present document do not allow a more detailed description but the reader is referred to van der Zanden et al. (2013) for more information on the new CCM+ system applied to the swash zone. Ensemble averaged hydrodynamics and sediment concentration measurements for one tested condition (BE1) have been shown. These measurements have shown that the measured sheet-flow layer in the swash presents important differences with respect to previous sheet-flow measures outside the surf zone. At the swash zone the typical pick-up and upper sheet-flow layer behavior is not evident and the different ensemble averaged concentration bins show a similar behavior within the wave group, suggesting horizontal sediment exchanges to be more important than vertical sediment movements (pick-up). Consequently, the intra-wave group bed level evolution showed quick erosion during the wave group uprush due to sediment being removed from this location and horizontally advected to upper parts of the swash area and a slower accretion during the wave group backwash conversely due to sediment coming from the upper part of the beachface.

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REFERENCES

Alsina, J.M., Falchetti, S. and Baldock, T.E., 2009. Measurements and modelling of the advection of suspended sediment in the swash zone by solitary waves. Coastal Engineering, 56(5-6): 621-631.

Baldock, T.E., Hughes, M.G., Day, K. and Louys, J., 2005. Swash overtopping and sediment overwash on a truncated beach. Coastal Engineering, 52(7): 633-645.

Cáceres, I. and Alsina, J.M., 2012. A detailed, event-by-event analysis of suspended sediment concentration in the swash zone. Continental Shelf Research, 41(0): 61-76.

Dalrymple, R.A. and Thompson, W.W., 1976. Study of equilibrium beach profiles. 15th International Conference on Coastal Engineering, Honolulu, Hawaii, United States, pp. 1277-1296.

Dean, R.G., 1973. Heuristic models of sand transport in the surf zone. Engineering Dynamics of the Coastal Zone: First Australian Conference on Coastal Engineering, Sydney, pp. 208–214.

Dohmen-Janssen, C.M. and Hanes, D.M., 2005. Sheet flow and suspended sediment due to wave groups in a large wave flume. Continental Shelf Research, 25(3): 333-347.

Hughes, M.G. and Moseley, A.S., 2007. Hydrokinematic regions within the swash zone. Continental Shelf Research, 27(15): 2000-2013.

Masselink, G., Russell, P., Turner, I. and Blenkinsopp, C., 2009. Net sediment transport and morphological change in the swash zone of a high-energy sandy beach from swash event to tidal cycle time scales. Marine Geology, 267(1-2): 18-35.

O'Donoghue, T. and Wright, S., 2004. Concentrations in oscillatory sheet flow for well sorted and graded sands. Coastal Engineering, 50(3): 117-138.

Ribberink, J.S. and Al-Salem, A.A., 1995. Sheet flow and suspension of sand in oscillatory boundary layers. Coastal Engineering, 25(3-4): 205-225.

Turner, I.L., Russell, P.E. and Butt, T., 2008. Measurement of wave-by-wave bed-levels in the swash zone. Coastal Engineering, 55(12): 1237-1242.

van der Zanden, J., Alsina, J.M., Caceres, I., Buijsrogge, R.H. and Ribberink, J.S., 2013. New ccm technique for sheet flow measurements and its first application in swash zone experiments. Proc. 6th International Short Course/Conference on Applied Coastal Research, 4-7 June, Lisbon, Portugal, pp.

Wright, L.D. and Short, A.D., 1984. Morphodynamic variability of surf zones and beaches: A synthesis. Marine Geology, 56(1-4): 93-118.