Large-scale Barrier Dynamics Experiment II (*BARDEX II*): experimental design, instrumentation, test programme and data set

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ABSTRACT

Despite the increased sophistication of numerical models and field techniques for investigating wave-induced nearshore sediment transport and ensuing beach morphological response, there remains a significant demand for large-scale laboratory experiments to address this research topic. Here, we describe the Barrier Dynamics II experiment (*BARDEX II*), which involved placing a near prototype-scale sandy barrier in the middle of the Delta Flume in the Netherlands and subjecting the structure to a range of wave, tide and water level conditions. A unique aspect of the experiment was the presence of a lagoon behind the barrier, as often occurs in natural barrier settings, providing a convenient means to experimentally manipulate the groundwater hydrology within the barrier. The overall aim of the *BARDEX II* was to collect a large-scale data set of energetic waves acting on a sandy beach/barrier system to improve our quantitative understanding and modelling capability of shallow water sediment transport processes in the inner surf, swash and overwash zone. In this paper we introduce *BARDEX II* and provide a detailed description of the experiment, including the experimental design, instrumentation, test programme and data set, as well as presenting some examples of the morphological and hydrodynamic data set. We also reflect objectively on the strengths and weaknesses of the data set. This paper serves as an introduction to a special issue of Coastal Engineering, solely devoted to the results of *BARDEX II*.

1. INTRODUCTION

Despite the increased sophistication of numerical models (e.g., Falchetti et al., 2010) and field techniques (e.g., Puleo et al., 2013) for investigating wave-induced nearshore sediment transport and ensuing beach morphological response, there remains a significant demand for large-scale laboratory experiments to address this research topic (Sanchez-Arcilla et al., 2011). In the EU large-scale wave flume experiments, funded through Hydralab (http://www.hydralab.eu/), are regularly conducted in the GWK flume in Hannover, Germany (e.g., Lopez de San Roman-Blanco et al., 2006), the CIEM flume in Barcelona, Spain (e.g., Stratigaki et al., 2011) and the Delta Flume in Vollenhove, the Netherlands (e.g., Williams et al., 2012a).

The large-scale experiment described in this paper took place in the Delta Flume and the setting modelled by this experiment is a sandy barrier system backed by a lagoon. Barrier systems are natural means of coastal protection against flooding, whilst at the same time representing porous boundaries that connect the terrestrial groundwater table with sea level.

Two key processes that are of particular relevance to these two functions, and for which our understanding is far from complete, are swash/overtopping/overwash processes during extreme wave and water-level conditions, and cross-barrier groundwater fluxes. Accurate prediction of the occurrence and morphological consequence of overtopping and overwash is of obvious importance for coastal flood risk assessment and management (Matias *et al.*, 2008). Equally apparent is the relevance of being able to quantify and model cross-barrier groundwater fluxes, for example for assessing the dispersal of pollutants from coastal aquifers into the sea and saline intrusion as a result of sea-level rise (Andersen *et al.*, 2007). A less obvious, but potentially significant and related process is the effect of interactions between the beach groundwater table and swash motion on sediment transport processes on the upper beach (Turner and Masselink, 1998) and, therefore, beach stability. These interactions are strongly controlled by the elevation of the beach groundwater table relative to sea level, and it is often considered that a low water table promotes beach stability, while a high water table has a destabilising effect on the beach.

In 2008, the large-scale Barrier Dynamics Experiment (*BARDEX*), funded under the Hydralab III programme, was carried out in the Delta Flume to investigate swash, overtopping and overwash processes, cross-barrier groundwater fluxes and the role of the beach groundwater table on beach stability (Williams et al., 2012a). *BARDEX* involved placing a near prototype-scale gravel barrier (height 4.5 m; width 30 m) in the middle of the flume and subjecting the structure to a range of wave, tide and water level conditions. A unique aspect of *BARDEX* was the presence of a lagoon behind the barrier, as commonly occurs in natural barrier settings, providing a convenient means to experimentally manipulate the groundwater hydrology within the barrier. The main results of this experiment have been published in a 6-paper special Issue of Coastal Engineering (Masselink and Turner, 2012; Matias et al., 2012; Thompson et al., 2012; Turner and Masselink, 2012; Williams et al., 2012a, 2012b). The main *BARDEX* partners considered it appropriate and timely to carry out a second experiment in the Delta Flume, but this time on a sandy barrier. Funding was obtained under the Hydralab IV programme and the project, named *BARDEX II* to acknowledge its pedigree, was carried out from May to July 2012.

The data set collected during *BARDEX II* is not only relevant in providing direct comparison with the gravel barrier data set (thereby providing added value to *BARDEX*), but the sandy barrier data are also important in their own right by providing fundamental new information on cross-shore sediment transport processes in the nearshore zone of sandy beaches. Specifically, in addition to explicitly addressing the effect of swash/groundwater interactions to sediment transport and morphological development in the swash zone, the project also investigates the sediment exchange between the swash and surf zone and, related, the dynamics of nearshore bar systems. It is generally accepted that mean offshore-directed flows are responsible for beach erosion and offshore bar migration under energetic wave conditions, but there is considerable debate in the literature as to what causes beach accretion and onshore bar migration under calm wave conditions. There have been a number of processes proposed that may be implicated in onshore sediment transport, berm construction and bar migration, including: (1) onshore mass flux due to cell circulation (Aagaard *et al.*, 2006); (2) sediment stratification (Conley *et al.*, 2008); (3) turbulence associated with breaking waves and bores (Butt *et al.*, 2004); (4) cross-shore velocity skewness ('wave skewness'; Marino-Tapia *et al.*, 2007); (5) cross-shore velocity acceleration skewness ('wave asymmetry'; Hoefel and Elgar, 2003); (6) ventilated boundary layer (Conley and Inman, 1992); and (7) plug flow due to horizontal pressure gradients (Foster *et al.*, 2006). These different processes are not necessarily mutually exclusive and all, except (1), are addressed during *BARDEX II*.

2. ORGANISATION, AIM AND OBJECTIVES

BARDEX II took place over a 3-month period from May to July 2012 in the Delta flume, the Netherlands. A total of 58 project days were allocated to the project, comprising 30 days for barrier construction and installation of instruments and pumps, 20 experiment days and 8 days for decommissioning the experiment. The project was funded under Hydralab IV at a total cost of €353k and the project was coordinated by Deltares. The academic lead was provided by the University of Plymouth (Gerd Masselink, UoP) and, in addition to the technical staff at the facility, 13 academics, 6 post-docs, 5 PhD students, 4 MSc students and 6 technicians from 8 institutions and 6 countries participated in the project. The following universities were involved with *BARDEX II*: Algarve (UAlg), Bordeaux (UB), Delaware (UoD), New Hampshire (UoNH), New South Wales (UNSW), Plymouth (UoP), Southampton (UoS) and Utrecht (UU).

The overall aim of *BARDEX II* was to collect a near proto-type data set of energetic waves acting on a sandy beach/barrier system to improve our quantitative understanding and modelling capability of shallow water sediment transport processes in the inner surf, swash and overwash zone. The project was structured through 6 work packages (WPs), each with their own set of objectives:

- *WP1 – barrier hydrology*: to observe, quantify and model the dynamic groundwater conditions within the barrier, subject to varying wave, water-level and back-barrier lagoon conditions (Lead: Ian Turner, UNSW).
- *WP2 – swash and berm dynamics*: to examine the relative roles of advected bore-generated turbulence *versus* local boundary layer processes in the full column sediment transport processes in the swash zone; to resolve the role of barrier hydrology in controlling equilibrium morphological response at the beachface (Lead: Daniel Conley, UoP).
- *WP3 – swash-surf zone exchange and bar dynamics*: to determine and quantify the dominant hydrodynamic and sediment transport mechanisms responsible for swash-surf zone sediment exchange; to identify key processes responsible for onshore and offshore bar migration (Lead: Gerben Ruessink, UU).
- *WP4 – barrier overwash*: to quantify overwash threshold for different wave and water-level conditions; to investigate the effect of groundwater gradients on overwash processes; to compare overwash processes on sand and gravel barriers (Lead: Ana Matias, UAlg).
- *WP5 – Sediment resuspension and bed morphology*: to observe and measure vortex resuspension processes and bedform dynamics under shoaling and breaking waves; to quantify changes in the magnitude and direction of sediment transport (bedload and suspended load) in the region just outside the surf zone (Lead: Charlie Thompson, UoS).
- *WP6 – numerical modeling*: to further develop and rigorously test advanced process-based cross-shore hydro-morphodynamic models that address bar and barrier dynamics, and barrier destruction through overwash (Lead: Bruno Castelle, UB).

This paper provides a description of the experiment, including the experimental design, instrumentation, test programme and data structure, and provides an introduction to 7 subsequent papers, covering the *BARDEX II* WPs. An important deliverable of this project is the collection of a comprehensive and state-of-the-art dataset on sandy beach response to changing wave and water level conditions, and to ensure that this data set is available to the international coastal research community. Therefore, considerable effort was expended on collating all the data collected as part of *BARDEX II* in a NetCDF database that contains all the necessary data and metadata to enable data analysis. This paper therefore also serves to 'advertise' and provide context to the *BARDEX II* data set to facilitate its wider use.

3. EXPERIMENTAL SET-UP

Figure 1 shows a CAD drawing of the experimental design during the *BARDEX II* experiment, and includes the along-tank cross-section, the planform view and the across-tank cross-section. The origin of the coordinate system is the rest position of the wave paddle at the back of the flume (x = 0 m), the centre line of the flume (y = 0 m) and the flume floor (z = 0 m). Positive x is from the paddle to the front of the flume, positive y is towards the left of the positive x-axis and positive z is upward from the flume floor.

A 4.5-m high and 75-m wide sandy barrier was constructed in the Delta Flume with the crest of the barrier located at 1.5 m above the default mean sea level (MSL) of 3 m and a lagoon situated to the landward. The sand barrier was separated from the lagoon by a permeable wall constructed out of a steel mesh (grid size = 0.05 x 0.05 m) shrouded on both sides with two layers of 180 micron geotextile cloth (Geolon PE180) to allow water to move freely between back-barrier slope and lagoon, but prevent the ingress of sand into the lagoon during overwash tests. Landward of the lagoon, and separated by an impermeable gate, a reservoir was located which was used as a water buffer to help regulate the water level in the lagoon.

A total of 1365 m^3 of sand was used to construct the barrier at a cost of just over 10% of the project budget. The sand was introduced into the flume in small batches and compacted regularly (c. 0.5-m layers). The barrier represents a cross-sectional area of 220 m^2 and considering a flume width of 5 m the total amount of compacted sand in the flume was 1100 m^3. This represents a compaction of 20%.

Figure 2 shows the relative and cumulative frequency distribution of the grain size of sediment used. The distribution was obtained by averaging the sieve analysis results of 4 separate sediment samples that were each sub-sampled (using a riffle box) from a large sub-sample that was collated from many (> 100) small samples taken at 2-m intervals from the active part of the beach after each test series. The sediment size distribution is thus considered representative of the spatially- and temporally-averaged sediment characteristics of the *BARDEX II* barrier. The sediment can be classified as a moderately-sorted, coarse-skewed, medium sand with a small amount of gravel (c. 1%). The median and mean sediment size is 0.43 mm and 0.51 mm, respectively, and the sorting and skewness is 0.81ϕ and -0.24 ϕ, respectively. A very large number (> 100) of sediment samples were also taken to investigating the spatial and temporal changes in the sediment fall velocity during the experiment. Analysis of 30 samples sub-sampled from a bulk sediment sample collated from all sediment samples collected indicate that the *BARDEX II* sediment has a mean sediment fall velocity of 0.046 m s^{-1}.

The sediment used in the experiment was selected to provide sufficient hydraulic conductivity K and porosity P for significant horizontal (through-barrier) and vertical (through-bed) groundwater flows (K = 0.0005–0.001 m s^{-1}; P = 0.37–0.42; analysis by Deltares), but not too large a grain size as to inhibit sediment re-suspension and nearshore bar formation. It should be mentioned here that the sediment size obtained was significantly finer than originally requested. It was the intention to construct the barrier out of sand with a D_{50} of 0.6–0.8 mm; however, the high cost associated with such sediment (> €100k) was prohibitive.

The barrier was composed of a number of distinct profile sections (Figure 3: (1) a 1:10 seaward-sloping concrete toe at x = 24–29 m; (2) a 20-m wide, horizontal section with a 0.5-

m thick sand layer at x = 29–49 m; (3) a 60-m wide, 1:15 seaward-sloping section at x = 49–109 m; (4) a 5-m wide crest at x = 109–114 m; and (5) a 10-m wide, 1:5 landward-sloping section at x = 114–124 m. A 5-m high retaining wall was used to separate the back-barrier slope from a 10-m wide lagoon at x = 125–135 m. The lagoon was separated from a large water reservoir that extended from x = 135 m to the end of the Delta Flume at x = 240 m by an impermeable gate.

To regulate the water levels in the Delta Flume, four computer-controlled pumps were used (Figure **1**): (1) sea to lagoon; (2) lagoon to sea; (3) reservoir to lagoon; and (4) lagoon to reservoir. Each pump had a maximum capacity of 50 l s^{-1} and the discharge of the pumps between sea and lagoon was recorded to enable quantification of across-barrier water fluxes. Unfortunately, the gate between the lagoon and reservoir leaked by a significant, but poorly constrained quantity and this will make an accurate assessment of the across-barrier fluxes difficult.

4. INSTRUMENTATION AND DATA ACQUISITION

A suite of instruments and sampling devices were deployed during the experiment. An overview of the position of the instruments provided by the Delta Flume facility and the project partners is provided in Figures **3** and **4**, respectively. A photo record of the experiment is given in Figure **5**, while Figure **6** shows the very densely instrumented section of the scaffold rig for measuring swash dynamics.

The instrumentation provided by the Delta Flume included 28 buried and unburied pressure transducers (PTs) for recording water levels in the sea, lagoon, reservoir and within the barrier itself (groundwater levels), 10 wall-mounted electromagnetic current meters (EMCMs), 3 optical backscatter sensors (OBSs) for measuring suspended sediment concentrations, 3 ARGUS-style video cameras to monitor overwash, swash and breaking waves, 4 discharge recorders for the pumps and a high-resolution mechanical bed profiler mounted off the carriage to record morphological change. All these data were collected at 20 Hz by the central Delta Flume computer. Beach profiles along the centerline of the flume (y = 0 m) were recorded nominally every 30 minutes (more frequent at the start of the simulations) and a total of 135 profiles were surveyed.

To complement the Delta Flume equipment, a large number of additional instruments were deployed by the Project Partners:

- **Within the barrier** – Electric conductivity probes and thermistors were deployed in the sand to measure through-barrier movement of both an environmentally inert groundwater tracer and of heat. In addition, 4 pairs of high-precision PTs, deployed in piezometer tubes, were used to resolve instantaneous groundwater fluxes at the beachface. Data from these instruments contributed mainly to WP1 and were installed and maintained by UNSW.
- **Swash zone and barrier crest** – Equipment for recording swash and overwash flows, suspended sediment fluxes and bed-level changes were deployed from a large scaffold rig comprising 6 EMCMs, 6 acoustic Doppler velocimeters (ADVs) for point measurements, 4 acoustic Doppler velocity profilers referred to as Vectrinos (VECs), 6 OBSs, 8 PTs, 45 acoustic bed-level sensors (BLSs; Turner et al, 2008) and 6 conductivity concentration probes (CCPs; Lancriet et al., 2013). In addition, a thermal camera and 2 LiDARs were used to remotely monitor swash motion. These instruments were looked after by UoP, UoD, UNSW and UoNH; their data contributed mainly to WP2 and WP4.

- **Surf zone** – Equipment for measuring surf zone flows, breaking waves, turbulence and suspended sediment concentrations were deployed from a 3 wall-mounted rigs, each comprising 1 EMCM, 1 PT and 3 OBSs, and one rig comprising 3 ADVs, 1 PT and 7 OBSs. In addition, a 3D sector scanning sonar (SONAR) was deployed to monitor bedforms in the surf zone and a cross-shore array of 9 self-logging PT were deployed across the entire seaward slope of the barrier to record water levels and wave propagation. UU was responsible for the surf zone instrumentation and the data contributed mainly to WP3.
- **Shoaling wave zone** – A single measurement rig was deployed just beyond the zone of breaking waves to measure hydrodynamics, sediment re-suspension and bedforms under shoaling waves. The rig comprised solely of acoustic devices and included 2 ADVs, 2 sand ripple profilers (SRPs), an acoustic backscatter sensor (ABS) and a SONAR. The data contributed mainly to WP5 and were collected by UoS.

Data collected with these additional instruments were logged at frequencies ranging from 4 to 64 Hz using a suite of laptops and data loggers.

All data were recorded in GMT. The data collected by the Project Partners were recorded on a bank of laptop computers all time-synched using GPS clock and a local network (one of the laptops operated as a time server). Except on 14 and 15 June 2012, the time server worked throughout the experiment and the data collected by the partners are therefore on the same time. Unfortunately, the time synching with the Delta Flume computer did not work and these instruments are on their own time. To time-synch both data sets on an *ad hoc* basis, co-located instruments (e.g., some BLSs were located at very similar *x*-coordinates to the Delta Flume PTs) can be used. The video data were time-synched with the other data collected by the Delta Flume computer using a strobe light that was triggered at the start of the image collection. This trigger signal was also logged as a voltage with the other Delta Flume instruments allowing synching the video images with the hydrodynamic data.

5. EXPERIMENTAL PROCEDURE

5.1 Test programme

The test programme consists of 19 distinct ‘tests’ with different wave and water level conditions making up 5 ‘test series’ (Table **1**).

- **Test series A –** The objective of this test series was to determine the effect of high and low lagoon level, and therefore high and low beach groundwater table, on swash sediment transport processes and beach profile development. Two different wave conditions (accretion and erosion) and three different lagoon levels (low, medium and high) were used.
- **Test series B** – During this test series the effect of lowering the sea level on nearshore bar development was addressed. Erosive wave conditions were used and the sea level was lowered by 0.5 m relative to the default sea level.
- **Test series C** – To investigate tidal effects on beach profile development, the beach was subjected to a low-high-low tide cycle with erosive wave conditions. The tidal cycle, which had a range of 1.5 m and a period of 12 hours, was segmented in 30-min tide steps (refer to **section 5.3**). To enhance the effect of beach groundwater table generally lagging behind the tidal water level, the rising tide was executed with a low lagoon level and the falling tide with a high lagoon level.
- **Test series D –** During this test series, the water level was incrementally raised by 0.15-m intervals for 7 different wave conditions (constant height, but variable period) to achieve a

sequence of swash – overtopping – overwash. For each test condition, 20-min of wave action was used. Figure 7 shows a sequence of photos taken during overwash conditions.

- **Test series E –** During this final test series of the experiment, the sea level was set just beyond the overwash threshold and the barrier was exposed to consecutive 13-min segments of energetic overwash conditions. These conditions resulted in progressive lowering of the bar crest and sediment transport across the barrier crest into the back-barrier region.

Figure 8 shows the wave and water level conditions encountered during all tests. The different test series were sequenced such that they represent an increased level of complexity. Test series E continued until the barrier was lowered so much that unidirectional flow occurred across the barrier crest into the lagoon because the lagoon-to-sea pump could not keep up with the overwashing.

The beach-barrier morphology was not reshaped between the different test series because, as well as requiring valuable test time, this was impossible without removing most of the instrumentation. Reshaping of the back of the barrier did take place after each of the tests during test series D because during overwash a distinct channel developed in the center of the flume. This channel was manually filled in to avoid affecting the flow conditions during the next test condition. During test A7, a channel developed in the swash zone, possibly related to the high-lagoon level enhancing groundwater outflow, and the swash was distinctly three-dimensional. It was attempted to straighten this morphology using a short period of regular wave forcing (only partly successful). The swash flow pattern during tests with erosive wave conditions was overwhelmingly two-dimensional, but the accretionary test conditions (tests A6-A8) had a significant three-dimensional swash flow component.

5.2 Wave steering

For irregular waves, the wave paddle steering signal was a JONSWAP spectrum specified using significant wave height H_s and peak wave period T_p with a peak-enhancement factor γ of 3.3. The Automated Reflection Compensator (ARC) was deployed at all time to avoid seiching in the flume. To enable comparison between different tests within the same test series, for tests with the same wave forcing (H_s and T_p), the identical wave steering signal was used. The wave steering signals were segmented into separate 'runs' to allow frequent interruption of the wave forcing for beach profile measurement, and also for instrument maintenance to ensure that near-bed measurements were being made.

Accretionary and erosive wave conditions were used. It was the intention to start with accretionary wave conditions (H_s = 0.8 m; T_p = 8 s), followed by erosive wave conditions (H_s = 1 m; T_p = 4 s). However, due to the sediment size being significantly finer than planned, the 'accretionary' wave condition (tests A1–A4) resulted in beach erosion; therefore, the second wave condition, which was supposedly erosive (tests A6–A8), was modified (H_s = 0.6 m; T_p = 12 s). Example spectra and time series of the two wave conditions are shown in Figure 9. The deep water wave steepness values H/L for the accretionary and erosive conditions are 0.003 and 0.008, respectively. Assuming a sediment fall velocity of 0.046 m s^{-1}, the accretionary and erosive wave conditions represent dimensionless fall velocities $\Omega = H_s/w_sT_p$ of 1.1 and 2.2, respectively.

During test series A, a several hour long erosive and accretionary wave steering signal was made for a water depth of h = 3 m. During the tests, this long wave steering signal was divided in periods of variable length to allow for beach profiling and instrument adjustment between the periods of wave forcing. During most tests of test series A, irregular wave action was followed by 5 minutes of monochromatic waves and 15 minutes of bi-chromatic waves. Except for the first mono- and bi-chromatic tests, which were too energetic, the mono- and bi-chromatic wave heights were selected to ensure that the wave energy associated with these signals was the same as that for the random wave signal.

For test series B, the erosive wave signal was used, but wave steering was adjusted for reduced water depth during test B2. During test series C the sea level was varied to simulate a tidal cycle (refer to **section 5.3**). The 12-hr tidal signal was subdivided into 25 x 30-min segments with constant water depth during the segments. For each segment the erosive wave steering signal was used, but adjusted for water depth. So, an identical sequence of waves occurred during each segment.

During test series D, each segment had 20 min of wave action and water depth was increased in 0.15-m intervals until overwashing occurred. The wave sequence was identical for each run, but the wave steering signal was adjusted for changing water depth and wave period. During test series E, the barrier was subjected to overwash conditions with a constant water level and wave forcing. The erosive wave steering signal was used during test series E, but only in 13-min segments.

5.3 Tidal signal

During test series C a tidal cycle was simulated. The tidal signal was a 'proper' sinusoid with an amplitude of 0.75 m and a period of 12 hrs, but the signal was 'cut' into 30-min segments, each with a constant water depth (Figure **10**). This was required because otherwise the ARC cannot be engaged with a slowly changing water level, and this would have resulted in significant seiching in the tank (this problem occurred during the first *BARDEX*). The maximum difference in water level between two consecutive 30-min segments was 0.2 m. The JONSWAP wave steering signal for each segment was identical, although adjusted for water depth, to ensure that any recorded morphological changes were not due to changing wave conditions. It was observed that as high tide was approached, overtopping started to occur; therefore, H_s was decreased from 0.8 m to 0.6 m, and the four planned segments at and around high tide were not executed. Some wave breaking off the paddle occurred during the lower water levels (also during test B2).

5.4 Maintenance of instrument elevations

Positional control of the instrumentation was critical, especially when measurements are aimed at collecting near-bed data (refer to Figure **6_swash_rig**). The instruments that remained fixed in position throughout the experiment include all Delta Flume instrumentation (PTs in the groundwater wells and wall-mounted EMCMs, PTs and OBSs), the self-logging PTs across the surf zone and the instruments on the offshore rig (VECs, ABS, SRPs and SONAR). The BLSs also remained in position, but between test series C and D, the lower 15 BLSs were moved from the seaward side of the scaffold rig to the lagoon side (refer to Figure **4**). Regular total station surveys were also carried out to ensure that the scaffold rig did not settle over the course of the experiment.

The surf zone rigs were fixed to the flume wall and their *x* and *y* coordinates remained constant; however, between runs the rigs were winched up and lowered to make sure that the elevation of the instruments (ADV, EMCM, PT and OBS) above the bed remained the same at the start of each run.

The swash and overwash instruments (VECs, ADVs and EMCMs and OBSs, buried PTs) were deployed to record near-bed hydro- and sediment-dynamics and within-bed pressure gradients, and required frequent manual adjustments (mainly in the vertical, but also in the horizontal). These adjustments were carefully noted and are included in the NetCDF files as metadata (refer to **section 6**).

6. ORGANISATION OF DATA FILES

The instrumentation deployed along the wave flume facility measured a range of hydrodynamic, morphodynamic and atmospheric parameters. These devices were logged to different PC platforms and data were collected using separate software packages usually distributed by the instrumentation companies who manufacture the individual sensors. As a result, a heterogeneous dataset made up of different format files was collected.

In order to provide an accessible and easy-to-use dataset to a wide user-community, the experimental raw data were homogenized and converted into a unique data format. The NetCDF (Network Common Data Form) standard was chosen for this purpose. The main reasons behind this choice was that NetCDF is a self-explanatory and platform-independent format which has been widespread adopted by a large community of geophysical scientists such as climatologists, meteorologists and oceanographers. Moreover, NetCDF is an open standard ensuring that its specifications are available and can be implemented without the need to pay royalties or license fees.

BARDEX II data are stored in NetCDF files organised in several groups mainly reflecting the collecting systems used during the experiments. Table **2** describes the dataset structure. These data include extensive metadata and, accompanied by the associated documentation, are self-explanatory. Positions of the instrumentation including the x, y and z coordinates in the adopted reference system are included in the metadata. Moreover, it is worth notifying that the time series in the original raw data have been split up into shorter time segments, each one containing data from a particular data segments, thus making ease of identifying and working with data from the individual segments. Although NetCDF is a widely adopted data format, potential users of the data are most likely to use Matlab for the data analysis. Therefore, the *BARDEX II* data set includes Matlab scripts to read in the NetCDF files and convert the data into data structures.

7. MORPHOLOGICAL DEVELOPMENT

Figure **11** provides a summary of the morphological development during *BARDEX II* and indicates 5 main morphological responses:

- **Bar formation –** Erosive conditions prevailed during tests A1–A4. After c. 16 hours of erosive wave action, a small berm developed above MSL at x = 90–100 m (berm volume Q_{berm} = 0.5 m^3 m^{-1}), but the prevailing morphological development was the formation of a nearshore bar around x = 70 m. The bar formed mainly as a result of offshore sediment transport in the lower swash and surf zone, and remained the focus of wave breaking throughout these tests.
- **Berm formation –** Accretionary conditions during tests A6–A8 caused onshore sediment transport, resulting in the disappearance of the pre-existing nearshore bar and the formation of a very pronounced berm at x = 90–105 m. After 11 hours of accretionary wave action, the height of the berm above the original profile was c. 1 m, the beachface gradient had increased from 1:15 to 1:6 and Q_{berm} was 7 m^3 m^{-1}.

- **Profile stability –** During test series B and C, when erosive waves were used and the sea level varied between 2.25 and 3.65 m, the beach profile was relatively stable. Hardly any change occurred in the subtidal area; test series B was of insufficient duration (6 hours) to re-establish a nearshore bar and the lack of a consistent breakpoint position during the tidal test series C also precluded development of bar morphology. The pre-existing berm did undergo some further development, especially at the end of the rising tide when wave runup overtopped the barrier crest and induced vertical accretion. The sediment for this berm accretion was sourced from the lower beachface, where erosion prevailed.
- **Overtopping followed by overwash –** Almost 12 hours of wave conditions around the overtopping/overwash threshold were simulated during test series D. Over this period, a subdued nearshore bar developed at x = 80–85 m, but, more importantly, the shoreline retreated by c. 6 m and a large amount of sediment was transferred from the beachface to the back of the barrier by overtopping and overwash processes. Test D1, with the shortest wave period (T_p = 4 s), was somewhat anomalous: as the sea level was progressively raised from 3.15 to 4.2 m, rather than transitioning from swash to overtopping to overwash, the beach developed a scarp and a subaqueous bar, whilst progressively retreating. During the other D tests, the beach prograded and demonstrated net accretion of the berm crest, whilst also showing transfer of material to the back of the barrier and into the lagoon.
- **Persistent overwash** – During test series E, the overwash condition for T_p = 8 s was maintained for just over an hour (5 runs of 13 min each). Continuous and energetic barrier overwash occurred under these conditions (refer to Figure 7) and resulted in c. 3 m shoreline retreat, lowering of the barrier crest and the transfer of 6 m^3 m^{-1} of sediment from the crest of the barrier to the backbarrier region. Similar to observations during the first *BARDEX* (Matias *et al.*, 2012), barrier crest lowering was enhanced by positive feedback through the positive link between the reduction in barrier freeboard and the increase in overwash frequency.

As a measure of the rate of morphological response, Figure 12 plots the change in sediment volume of the upper beach ('berm') region of the beach (x = 90–110 m) Q_{berm} relative to the volume at the start of the experiment, and the gross rate of volumetric change over this region Q_{berm}/dt for each run. Values for Q_{berm}/dt range from 0 to 0.1 m^3 m^{-1} min^{-1} and are highest during the overwash test series. The accretionary conditions (tests A6–A8) are characterised by larger Q_{berm}/dt values than the erosive wave conditions (tests A1–A4; test series B and C), and the small spikes in the Q_{berm}/dt time series are related to mono- and bi-chromatic wave action. From a relaxation and morphological equilibrium point of view it is interesting to note that there is practically a linear build-up of the berm over the 12-hour period (t = 900–1700 min) during the accretionary wave conditions of test series A.

8. EXAMPLE OF HYDRODYNAMIC DATA

Figures 13 and 14 show 6-min example time series of hydrodynamics measured along the wave flume for run #2 of test A2 (swash; A2_02) and run #4 of test series E (overwash; E_04) data segments, respectively. In the first and second panels the evolution of the free surface elevation estimated from 2 PT signals at separate cross-shore locations is plotted. The third panel displays the water elevations as well as the bed level detected by a swash BLS. In these upper three panels an individual wave event found approximately in the middle of the time series is marked by a down-facing triangle in order to spotlight the propagation along the flume. The fourth and the lower panels show the groundwater level fluctuations measured by a buried PT and the time stack of swash motions on the beach face (in which the dashed line indicates the position of the BLS sensor used in the third panel). Altogether, these 2 figures highlight the propagation of waves as groups evolve approaching the shoreline eventually forcing runup oscillations and groundwater fluctuations on the beach face and in the barrier. The figures also demonstrate differing morphological responses: the BLS time series for A2_02 shows bed accretion by swash processes, whereas the BLS time series for E_04 shows bed erosion by overwash processes.

9. CONCLUDING THOUGHTS AND LESSONS LEARNED

Overall, *BARDEX II* was very successful, and a comprehensive and high-quality data set was collected. However, there is always room for improvement and this concluding section reflects objectively on the project and highlights some aspects that were particularly successful, as well as pointing out some aspects that could have been done better.

- **Organization** – With over 30 staff involved with *BARDEX II* and an ambitious test programme, completing all planned tests within the allocated time (and budget!) was not trivial, and required not only the full participation of the partners, but also a clear organizational framework. *BARDEX II* was structured into 6 work packages, each led by a different institution and representing a different phase of the test programme and/or a different region on the barrier profile. This clear structure considerably simplified the logistics with respect to planning the attendance of participants, as well as the actual running of the experiments, because there was a clear line-of command and understanding of who was in charge of certain tests. Many *ad hoc* decisions were required during the experiment and due to time pressures there is not much opportunity for deliberation and discussion, especially if relevant partners are not on-site.
- **Time synching** – In any experiment, whether field or lab-based, it is crucial that all data are collected on the same time; therefore, considerable effort was spend to ensure all logging equipment was linked to a universal time server. Unfortunately, this was only partly successful. Practically all data collected by the Project Partners was on the same time, but the hydrodynamic data collected by the Delta Flume computer was not. In addition, some self-logging equipment was not linked to the time server either. Combining data sets collected on different times is very time-consuming and prone to error; this can seriously limit the use of the combined data set, especially when high-frequency phenomena, such as turbulence and wave propagation, are being investigated.
- **Location of instruments** – Positional control of the equipment is critical and a dedicated survey team was used to document instrument position changes during the course of the experiment. Even so, errors and/or omissions in the metadata did occur and it was not always possible to retrospectively correct these. The positional information for *BARDEX II* is fully contained in the metadata of the NetCDF data base, but this was an extremely time consuming, albeit necessary, task to accomplish.
- **Sediment characteristics** – In mobile bed tests the sediment size should be known well in advance of the experiments. Preparations for *BARDEX II* were made assuming that sediment with a D_{50} of 0.6–0.8 mm and a w_s of c. 0.8 m s^{-1} could be obtained. Two months before the start of the project it became known that the requested sediment was not available and the barrier was constructed out of significantly finer sediment (D_{50} = 0.43 mm; w_s = 0.46 m s^{-1}). Because the test programme was not modified to reflect the different sediment size, the erosive beach response during the first part of test series was not anticipated and *ad hoc* changes had to be made to the test programme. Moreover, computer simulations were carried out well before the experiment to help decide on the instrument positions; these simulations were also carried out using the coarser sediment size. It is difficult to have foreseen this issue, but a better consideration of the potential implications of the use of finer sediment would have been useful.

- **Research assistant** – The production of the final report and the collation of the complete data set for future use (both requirements of Hydralab) for a project of the scale of *BARDEX II* is a very significant task. In an ideal world, a dedicated person should be appointed to participate in the experiment, responsible for diarizing the experiment and ensuring the documentation is complete, as well as producing the final report and data set. For *BARDEX II* these tasks were carried out by the PI and a post-doc appointed after the experiment. The latter spent c. 6 months of their time collating and error-checking the NetCDF dataset. A dedicated person should ideally be funded through Hydralab, because it is difficult to get funding for this through national research councils.
- **Measuring pump discharge** – Water level control in the sea and lagoon was critical during *BARDEX II*, and the system comprising 4 pumps and 2 computers to control the pumps (based on that used during the first *BARDEX*) was excellent. However, there was a mismatch between the maximum pump volumes required to rapidly adjust the water levels between tests to avoid long waiting times due to water level adjustment (50 l s^{-1}) and the accuracy required for resolving cross-barrier flow during tests (1 l s^{-1}). The discharge measurements recorded during the tests are therefore unlikely to be of much use for quantifying cross-barrier groundwater flows. The problem is compounded by the leakage between lagoon and buffer which was of the same order as the cross-barrier flow rates. With the knowledge of hindsight, a separate pump system for moving large amounts of water and maintaining water levels should have been deployed.
- **Duration of tests** – Tests during *BARDEX II* were designed to ensure sufficient morphological change would occur during the tests to determine morphological trends; not to determine the equilibrium morphology. To save time (and money), the beach profile was not re-shaped between different tests, such that the morphology developed cumulatively and each test started with a different morphological boundary condition. In that sense the tests were rather different from the Large Wave Tank experiments carried out, e.g., in 1956–1957 and 1962 by the US Army Corps of Engineers (Kraus and Larson, 1988), which each test condition generally lasting more than 50 hours and each test starting with the same initial morphology. The *BARDEX II* tests are also quite different from those during the first *BARDEX* during which the tests were of similar duration, but where quasi-equilibrium did develop after only several hours of wave action (Masselink and Turner, 2012). This is because a gravel beach responds much quicker than a sandy beach.

As always with large projects, the associated cost (and in laboratory experiments time is directly equivalent to cost) is a key factor in making decisions about the experimental set-up and the test programme. The main shortcomings in *BARDEX II* due to the less-than-ideal sediment size, inadequate pump discharge measurements, absence of a dedicated research assistant during the experiment and different morphological boundary condition at the start of each test series, are all related to a limit to the amount of funding available. To some extent, these shortcomings could have been addressed by conducting far less, but better controlled tests. However, it was felt that it would be more useful to conduct a large number of tests using a wide range of wave and water level conditions, and accept the shortcomings. To conclude, a very comprehensive and high-quality data set has been collected in this large-scale laboratory experiment. It is hoped and expected that the BARDEX II team, as well as other researchers, will use these data to provide fundamental new information and understanding on cross-shore sediment transport processes in the nearshore zone of sandy beaches.

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REFERENCES

All papers in BARDEX II special issue

Aagaard, T., Hughes, M., Moller-Sorensen, R. and Andersen, S., 2006. Hydrodynamics and sediment fluxes across an onshore migrating intertidal bar. *Journal of Coastal Research*, 22, 247-259.

Andersen, M.S., Baron, L., Gudbjerg, J., Chapellier, D., Jakobsen, R., Gregersen, J. and Postma, D., 2007. Nitrate-rich groundwater discharging into a coastal marine environment. *Journal of Hydrology*, 336, 98-114.

Butt, T., Russell, P.E., Puleo, J., Miles, J. and Masselink, G., 2004. Influence of bore turbulence on sediment transport in the swash and inner surf zones. *Continental Shelf Research*, 24, 757-771.

Conley, D.C., Falchetti, S., Lohmann, I.P. and Brocchini, M., 2008. The effects of flow stratification by non-cohesive sediment on transport in high-energy wave-driven flows. *Journal of Fluid Mechanics*, 610, 43-67.

Conley, D.C. and Inman, D.L., 1992. Field observations of the boundary layer under near breaking waves. *Journal of Geophysical Research*, 97, C6.

Falchetti, S., Conley, D.C., Brocchini, M. and Elgar, S., 2010. Nearshore bar migration and sediment-induced buoyancy effects. *Continental Shelf Research*, 30, 226-238.

Foster, D.L., Bowen, A.J., Holman, R.A. and Natoo, P., 2006. Field evidence of pressure gradient induced incipient motion. *Journal of Geophysical Research*, 111, C05004.

Hoefel, F. and Elgar, S., 2003. Wave-induced sediment transport and bar migration. *Science*, 299, 1885-1887.

Kraus, N.C. and Larson, M., 1988. *Beach Profile Change Measured in the Tank for Large Waves, 1956-1957 and 1962*. Tech. Rep. CERC-88-6, U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS.

Lanckriet, L., Puleo, J.A., Masselink, G., Turner, I.L., Conley, D., Blenkinsopp, C. and Russell, P., 2013. A comprehensive field study of swash zone processes, Part 2: Sheet flow sediment concentrations during quasi-steady backwash. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 10.1061/(ASCE)WW.1943-5460.0000209.

Lopez de San Roman-Blanco, B., Coates, T.T., Holmes, P., Chadwick, A.J., Bradbury, A., Baldock, T.E., Pedrozo-Acuna, A., Lawrence, J. and Grune, J., 2006. Large scale experiments on gravel and mixed beaches: Experimental procedure, data documentation and initial results. *Coastal Engineering*, 53, 349-362.

Marino-Tapia, I., Russell, P.E., O'Hare, T., Davidson, M.A. and Huntley, D.A., 2007. Cross-shore sediment transport on natural beaches and its relation to sandbar migration patterns.

Part 1: Field observations and derivation of a transport parameterization. *Journal of Geophysical Research*, 112, C03001,

Masselink, G. and Turner, I.L., 2012. Large-scale laboratory investigation into the effect of varying back-barrier lagoon water levels on gravel beach morphology and swash zone sediment transport. *Coastal Engineering*, 63, 23-38.

Matias, A., Ferreira, O., Vila-Concejo, A., Garcia, T. and Dias, J.A., 2008. Classification of washover dynamics in barrier islands. *Geomorphology*, 97, 655-674.

Matias, A., Williams, J., Ferreira, O. and Masselink, G., 2012. Overwash threshold for gravel barriers. *Coastal Engineering*, 63, 48-61.

Puleo, J.A., Blenkinsopp, C., Conley, D., Masselink, G., Turner, I.L., Russell, P., Buscombe, D., Howe, D., Lanckriet, T., McCall and R., Poate, T., 2013. A comprehensive field study of swash-zone hydrodynamics, Part 1: Experimental design with examples of hydrodynamic and sediment transport processes. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 10.1061/(ASCE)WW.1943-5460.

Sanchez-Arcilla, A., Caceres, I., van Rijn, L. and Grune, J., 2011. Revisiting mobile bed tests for beach profile dynamics. *Coastal Engineering*, 58, 583-593

Stratigakia,V., Manca, E, Prinos, P., Losada, I.J., Lara, J.L., Sclavo, M., Amos, C.L., Caceres, I., and Sanchez-Arcilla, A., 2011. Large-scale experiments on wave propagation over *Posidonia oceanica*. *Journal of Hydraulic Research*, 49, 31-43.

Thompson, C.E.L., Williams, J.J., Metje, N., Coates, L.E. and Pacheco, A., 2012. Turbulence based measurements of wave friction factors under irregular waves on a gravel bed. *Coastal Engineering*, 63, 39-47.

Turner, I.L. and Masselink, G., 2012. Barrier Coastal gravel barrier hydrology – observations from a prototype-scale laboratory experiment (BARDEX). *Coastal Engineering*, 63, 13-22.

Turner, I.L., Russell, P.E. and Butt, T., 2008. A new instrumentation to measure wave-by-wave bed-levels in the swash zone. *Coastal Engineering*, 55, 1237-1242.

Turner, I.L. and Masselink, G., 1998. Swash infiltration-exfiltration and sediment transport. *Journal of Geophysical Research*, 103, 30,813-30,824.

Williams, J., Buscombe, D., Masselink, G., Turner, I.L. and Swinkels, C., 2012a. Barrier Dynamics Experiment (BARDEX): Aims, Design and Procedures. *Coastal Engineering*, 63, 3-12.

Williams, J.J., Ruiz de Alegria-Arzaburu, A., McCall, R.T. and van Dongeren, A., 2012b. Modelling gravel barrier profile response to combined waves and tides using XBeach: laboratory and field results. *Coastal Engineering*, 63, 62-80.

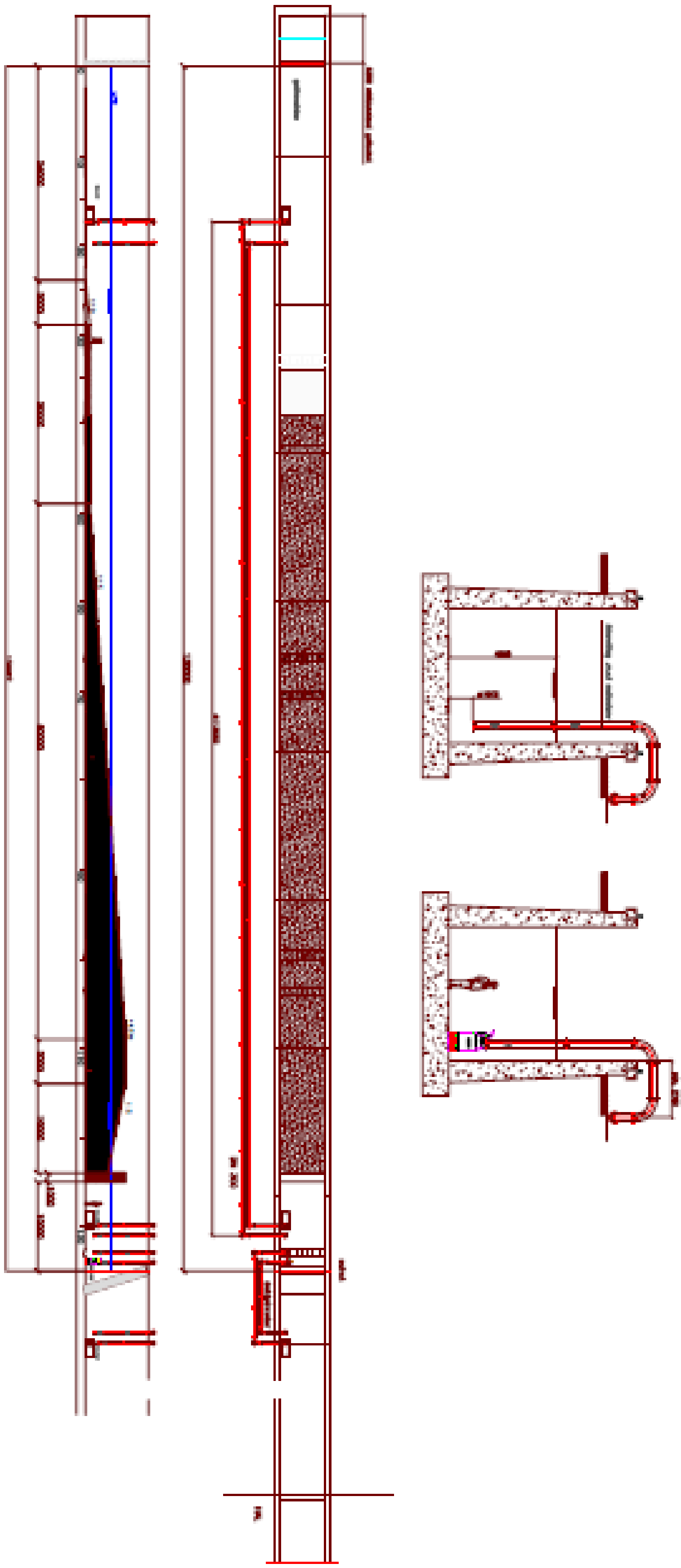

Figure 1 – CAD drawing of experimental set-up in the Delta Flume during the *BARDEX II* experiment.

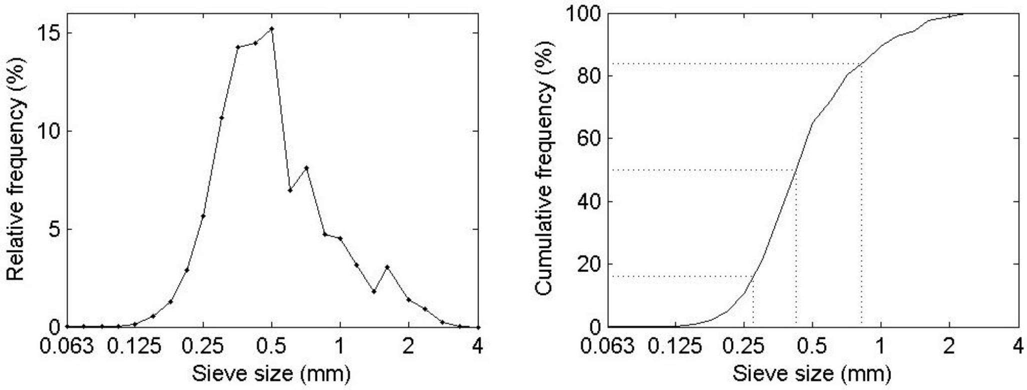

Figure **2** – Relative (left panel) and cumulative (right panel) frequency distribution of grain size of the sediment used in the *BARDEX II* experiment. The horizontal and vertical dashed lines in the right panel indicate the D_{16}, D_{50} and D_{84} sediment size, which are 0.28, 0.43 and 0.83 mm, respectively.

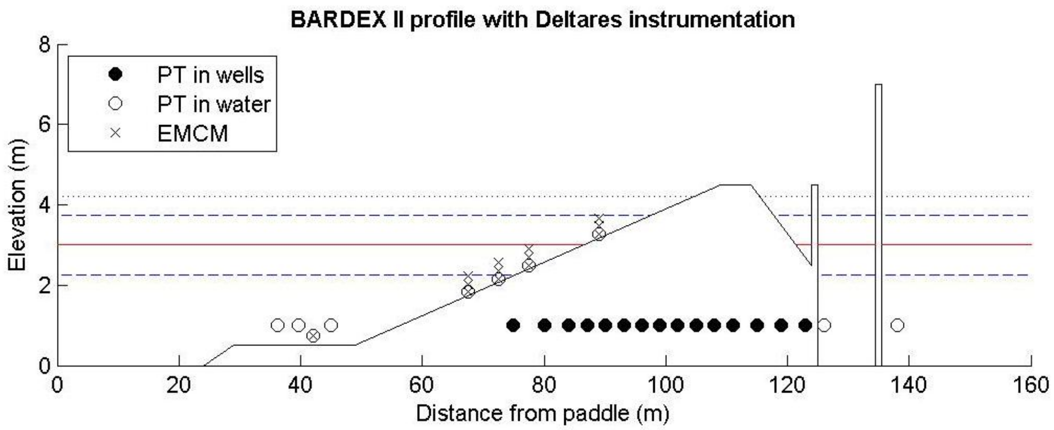

Figure 3 – Delta Flume cross-section with barrier profile at the start of the experiment and location of Deltares instrumentation. PT = pressure transducer; EMCM = electromagnetic current meter. Horizontal solid line shows the ‘default’ water level used (h = 3 m); horizontal dashed lines show the high and low tide ‘sea’ level and the high and low ‘lagoon’ level (h = 2.25 and 3.75 m). The horizontal dotted line represents the maximum sea level used for the overwash test series D (h = 4.2 m). Four separate water bodies or reservoirs can be distinguished: the area between the wave paddle at x = 0 and the barrier is referred to as the ‘sea’; the small region between the barrier crest and the retaining wall at x = 124 m is the ‘backbarrier’; the reservoir from x = 125 to 135 m is the ‘lagoon’; and the reservoir from x = 135 m to the end of the flume at 240 m (not shown) is the ‘buffer’.

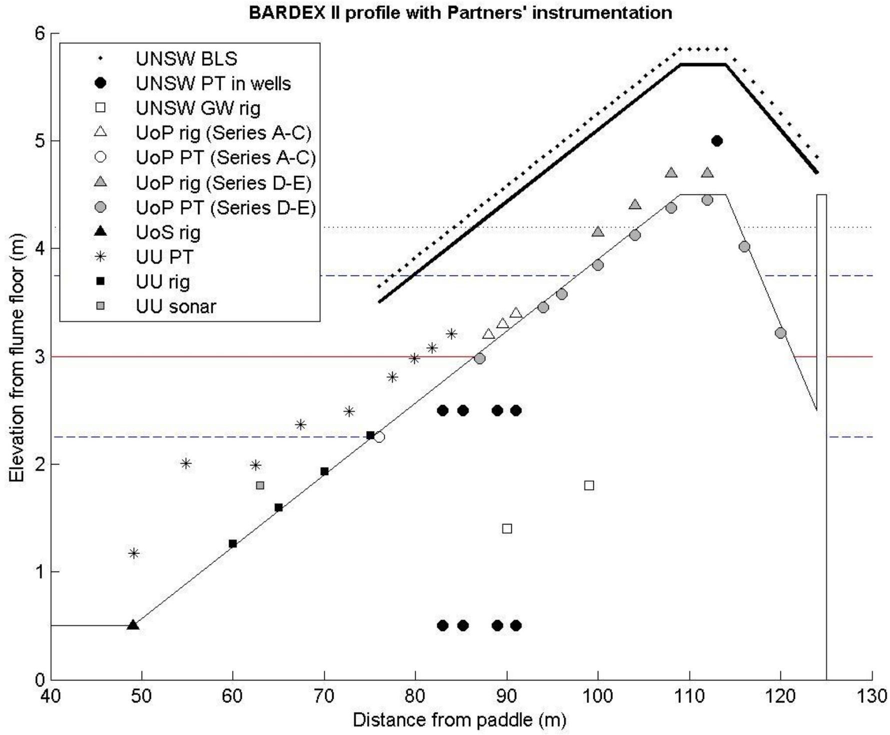

Figure 4 – Close-up of the barrier showing the locations of the instruments provided to *BARDEX II* by the Project Partners: UNSW = University of New South Wales; UoP = University of Plymouth; UoS = University of Southampton; and UU = Utrecht University. Horizontal solid line shows the 'default' water level used (h = 3 m); horizontal dashed lines show the high and low tide 'sea' level and the high and low 'lagoon' level (h = 2.25 and 3.75 m). The horizontal dotted line represents the maximum sea level used for the overwash test series D (h = 4.2 m). BLS = bed-level sensor; PT = pressure transducer; and GW = groundwater.

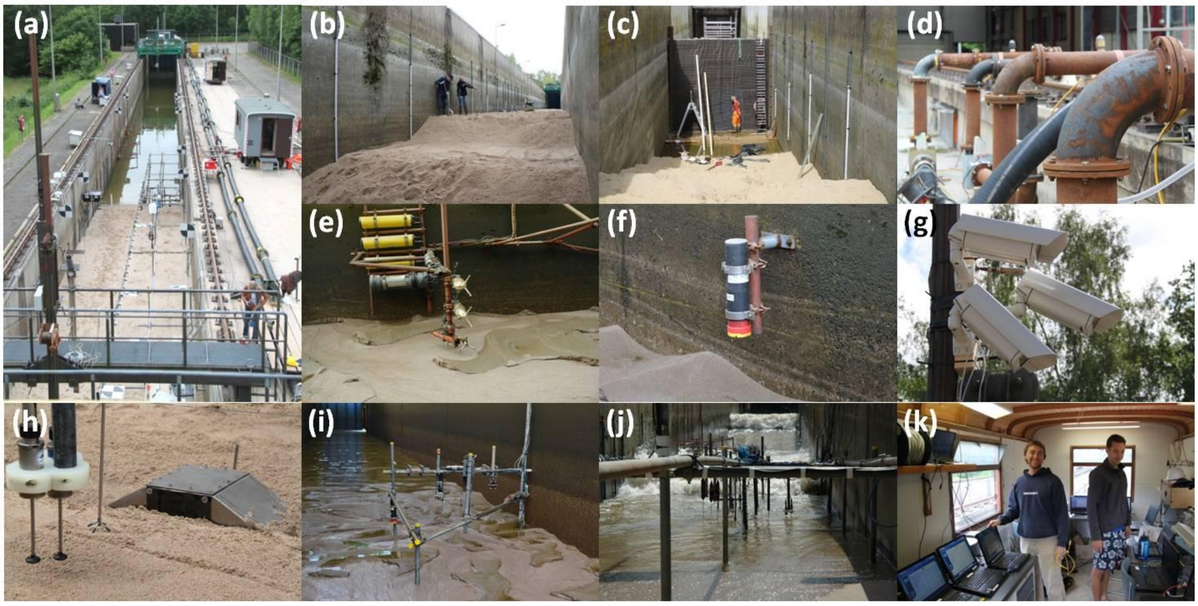

Figure 5 – Photos showing key elements of the experimental set-up during *BARDEX II*. (a) Overview of the Delta Flume looking from trolley above crest of the barrier towards the wave paddle, 120 m distant. (b) Barrier under construction showing several groundwater wells affixed to the flume wall. (c) Construction of retaining wall separating the back of the barrier from the lagoon. (d) Pump system showing all inlets/outlets to/from the lagoon. (e) Surf zone turbulence rig. (f) Self-logging pressure sensor for measuring surf zone water levels. (g) An Argus video system, comprising 3 cameras, was mounted at a height of c. 5 m above the barrier crest. (h) Underwater video camera flush mounted with the bed collocated with electromagnetic and acoustic current meters for making detailed measurements of hydro- and sediment-dynamics in the boundary layer. (i) Offshore rig with a range of acoustic instruments to monitor sediment re-suspension and bedform dynamics. (j) Photo taking through the scaffold rig showing numerous vertically-mounted electromagnetic and acoustic current meters. (k) View inside one of the measurement cabins with more than 15 laptops that were used simultaneously during the experiment to record the data.

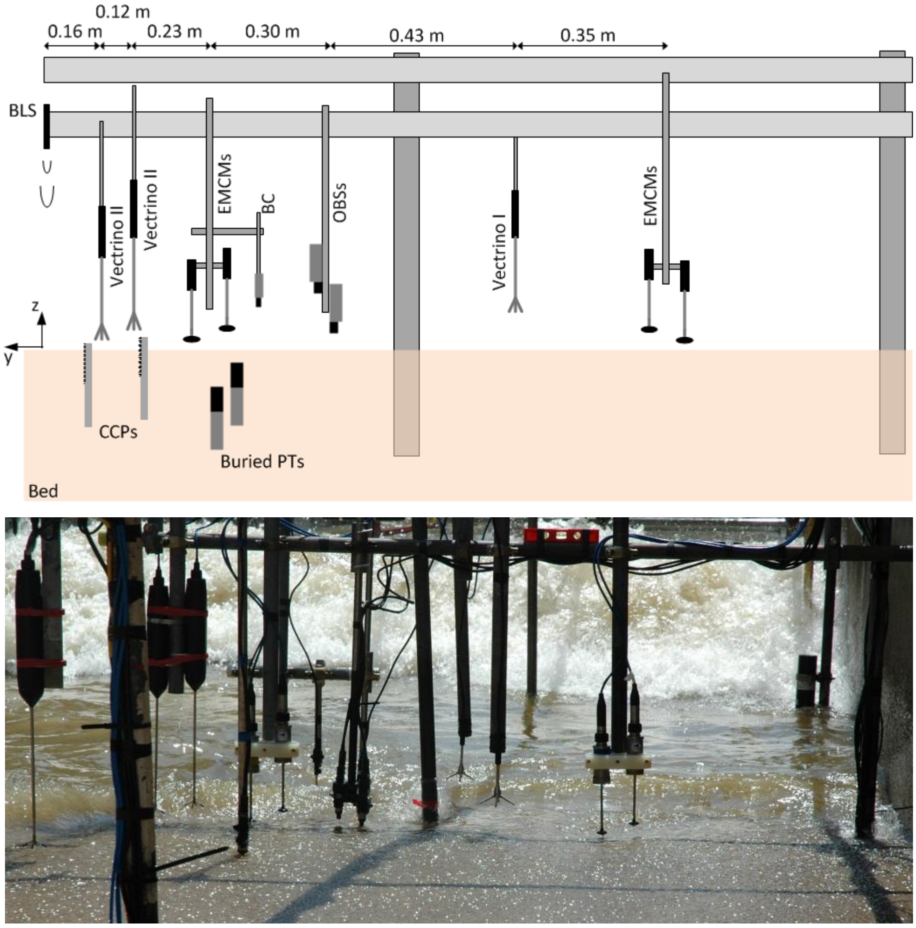

Figure 6 – Schematic and photo of the main swash instrumentation on the scaffold rig at x = 89.5 m. Instrumentation includes, from left to right, 1 bed-level sensor (BLS), 2 acoustic Doppler current meter profilers (Vectrino II), 2 partly buried conductivity concentration probes (CCPs), 2 pairs of mini electromagnetic current meters (EMCMs), 2 buried pressure transducers (PTs), 1 bed camera (BC), 2 optical backscatter sensors (OBSs), 1 acoustic Doppler current meter for point measurements (Vectrino I). There are three instruments in the photograph that are not present on the schematic: a Vectrino II in the far left of the photo is offset by 1.5 m 'landward' of the main swash rig (at x = 91 m); another Vectrino II is located between the Vectrino II and the central scaffold pole, and is offset by 1.5 m 'seaward' of the main swash rig (at x = 88 m); and the feature attached to a scaffold pole in the far right of the photo is a self-logging PT offset by 5.6 m 'seaward' of the main swash rig (at x = 83.9 m).

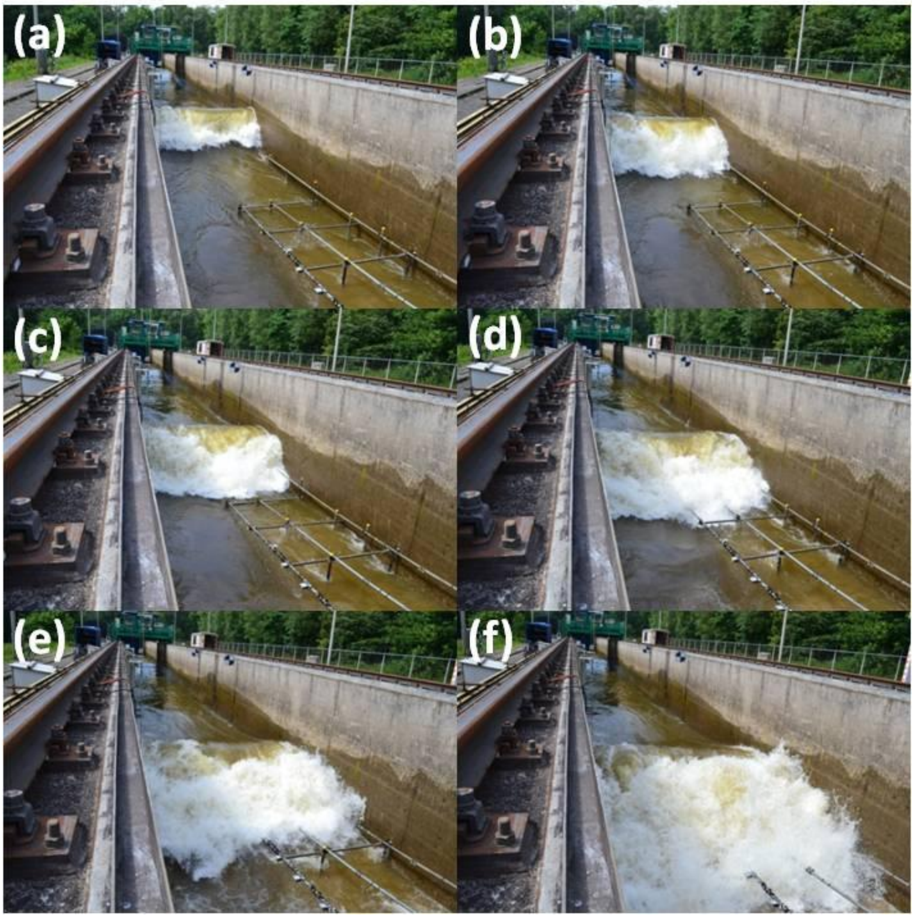

Figure 7 – Photo sequence showing turbulent bore going through the scaffold rig during overwash test series E.

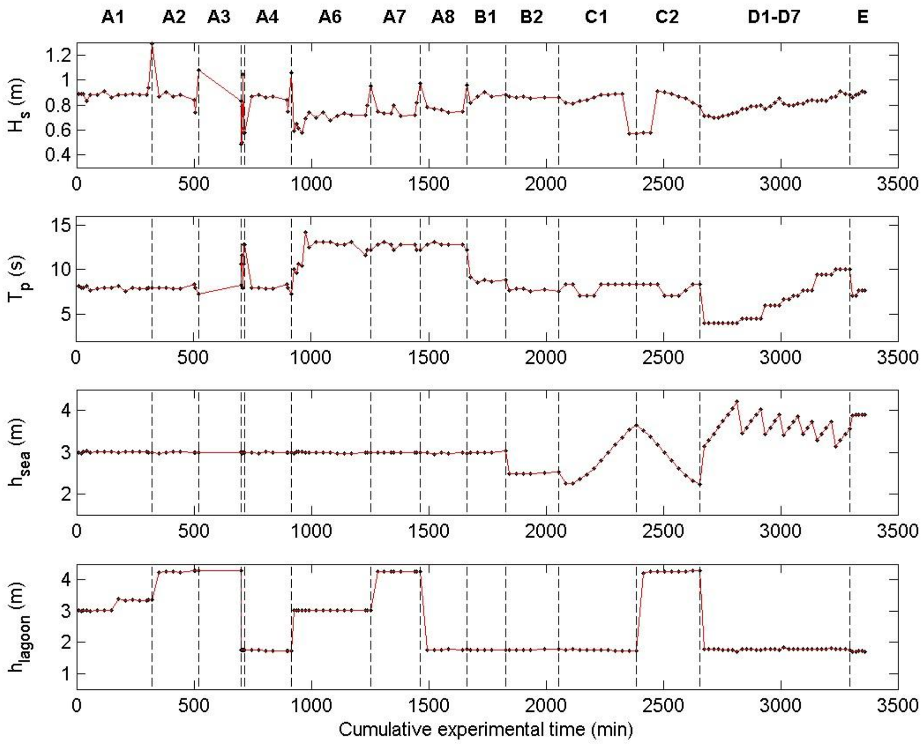

Figure **8** – Measured significant wave height H_s, peak wave period T_p, mean sea level h_{sea} and mean lagoon level h_{lagoon} for all *BARDEX II* tests. The measured wave conditions were based on the first 512 data points of every test (c. 8 min) of the PT sensor deployed at x = 36.2 m. The pressure data were corrected for depth attenuation using linear theory and a frequency cut-off based on the peak frequency and the water depth, but the signal was not separated into the incoming and outgoing signal. Significant wave height was simply determined as four times the standard deviation of the time series. The mean sea level and the lagoon level were computed over the complete test using the mean of the PT sensor deployed at x = 36.2 m and 140 m, respectively. Test A5, which involved 8 short sequences of mono- and bi-chromatic wave action (2 min each) was conducted between tests A3 and A4.

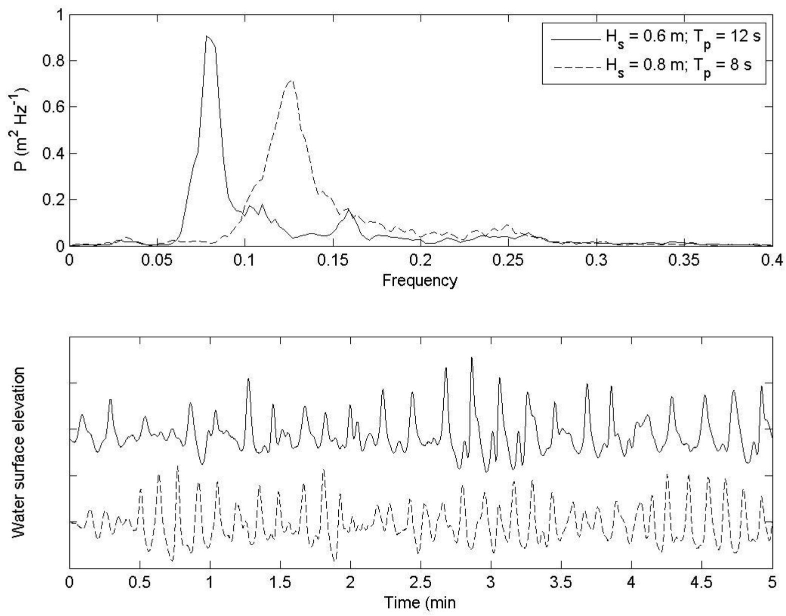

Figure **9** – Example wave spectra (upper panel) and 5-min time series (lower panel) of accretionary (H_s = 0.6 m; T_p = 12 s) and erosive (H_s = 0.8 m; T_p = 8 s) wave conditions. The data presented is (vented) pressure data recorded at x = 42 m and the data are not corrected for depth attenuation. In the lower panel, the time series are offset by 1 m for ease of comparison and the tick marks on the y-axis are at 0.5-m intervals.

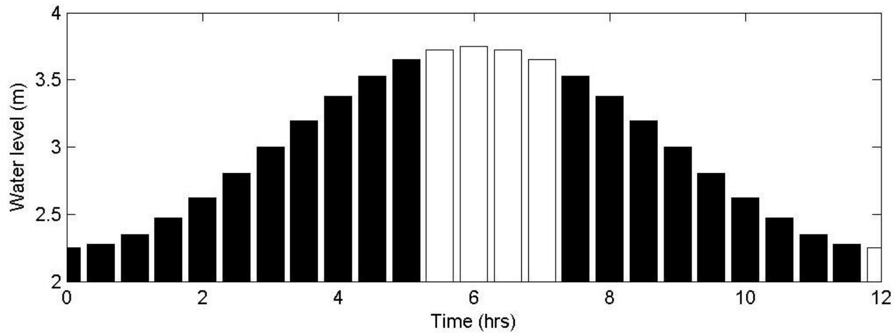

Figure 10 – Tidal signal used during test series C. Because overtopping of the barrier crest started to occur close to high tide, only the water levels presented by the black bars were carried out.

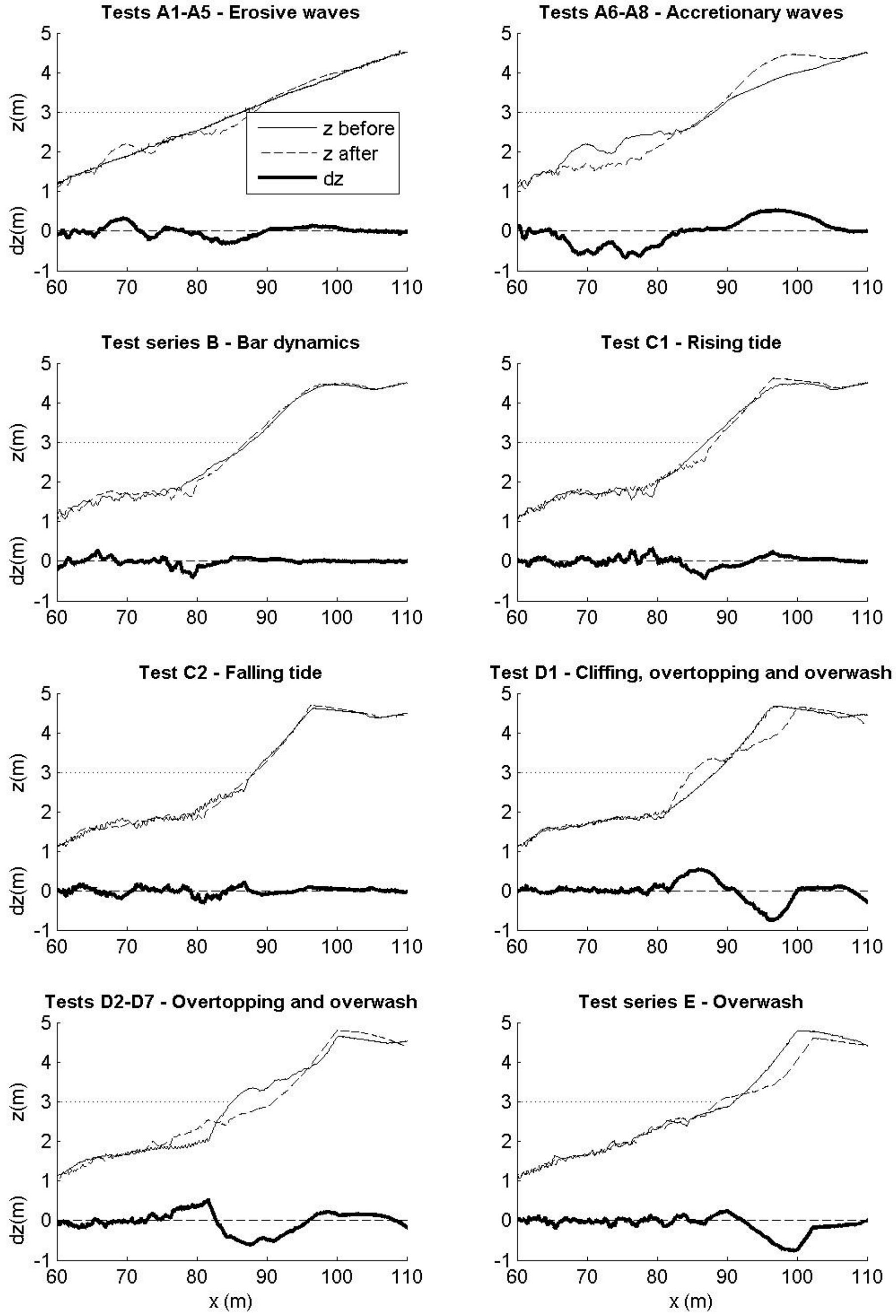

Figure **11** – Beach profiles and morphological change for distinct periods of the test programme.

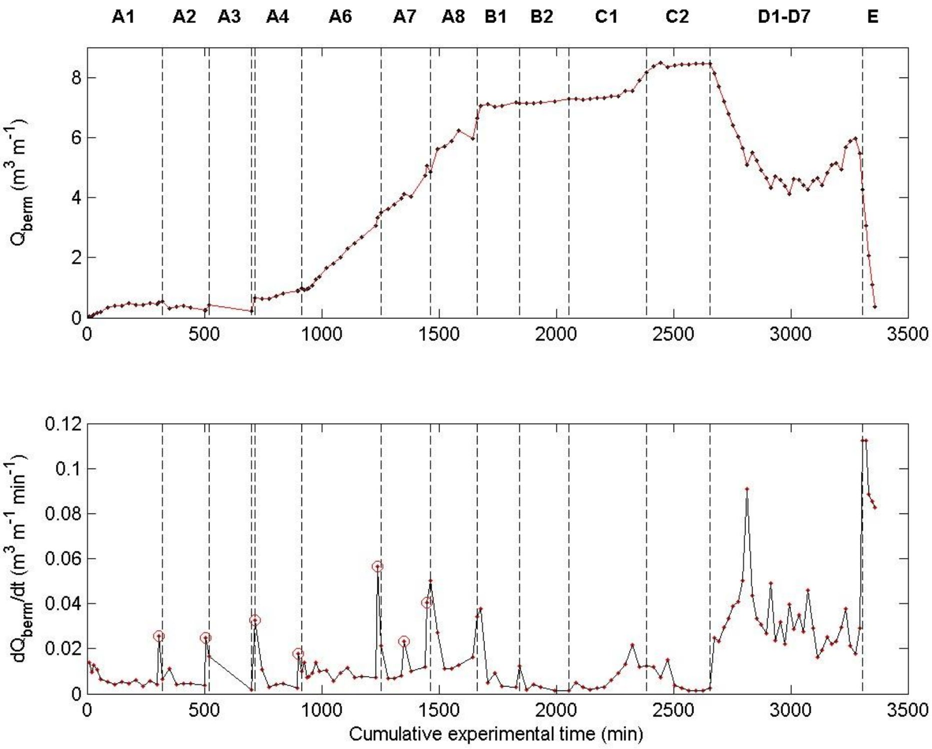

Figure **12_morph2** – Change in sediment volume of the upper beach ('berm') region of the beach (x = 90–110 m) Q_{berm} relative to the start of the experiment and the gross rate of volumetric change over this region Q_{berm}/dt for each test, over the experimental period. Circles in the lower panel represent tests with mono-chromatic waves. Test A5, which involved 8 short sequences of mono- and bi-chromatic wave action (2 min each) was conducted between tests A3 and A4.

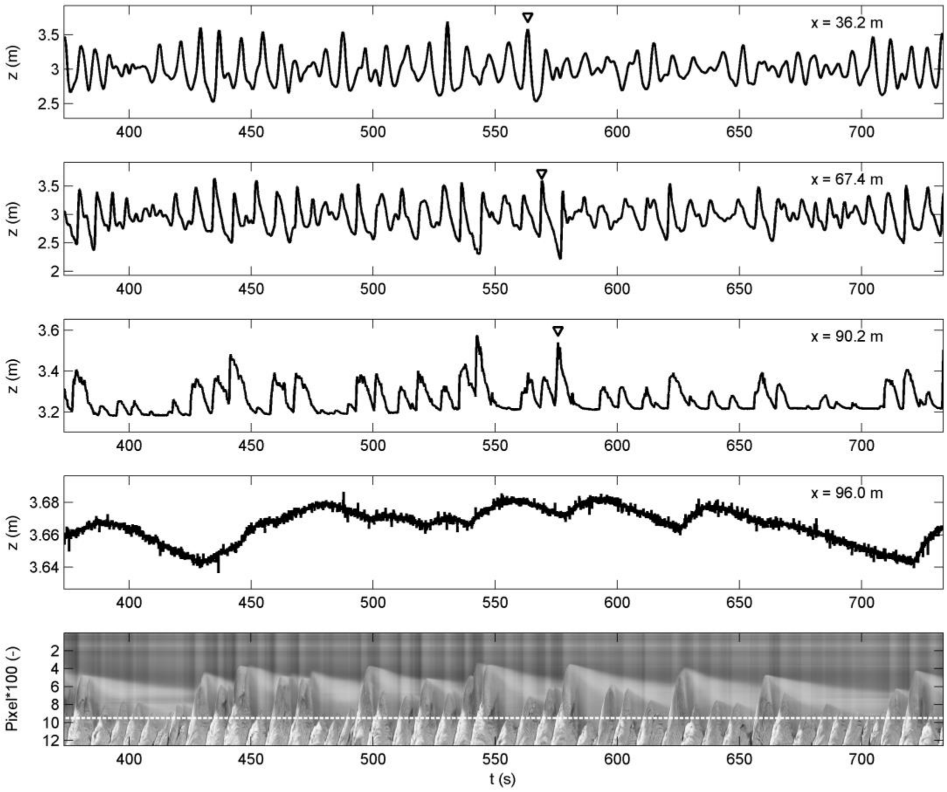

Figure 13 – Example of 6 minutes of data collected during run #2 of test A2 (A2_02) showing landward transformation of the wave signal. From top to bottom: shoaling waves at *x* = 36.2 m measured with Delta Flume PT; breaking waves at *x* = 67.4 m measured with UU PT; swash action at *x* = 90.2 m measured with UNSW BLS; beach groundwater table at *x* = 96.0 m measured with Delta Flume PT; and timestack showing swash action measured with Delta Flume video camera. The down-facing triangle marks the propagation of a wave through the instrument array, up to the top of the beach.

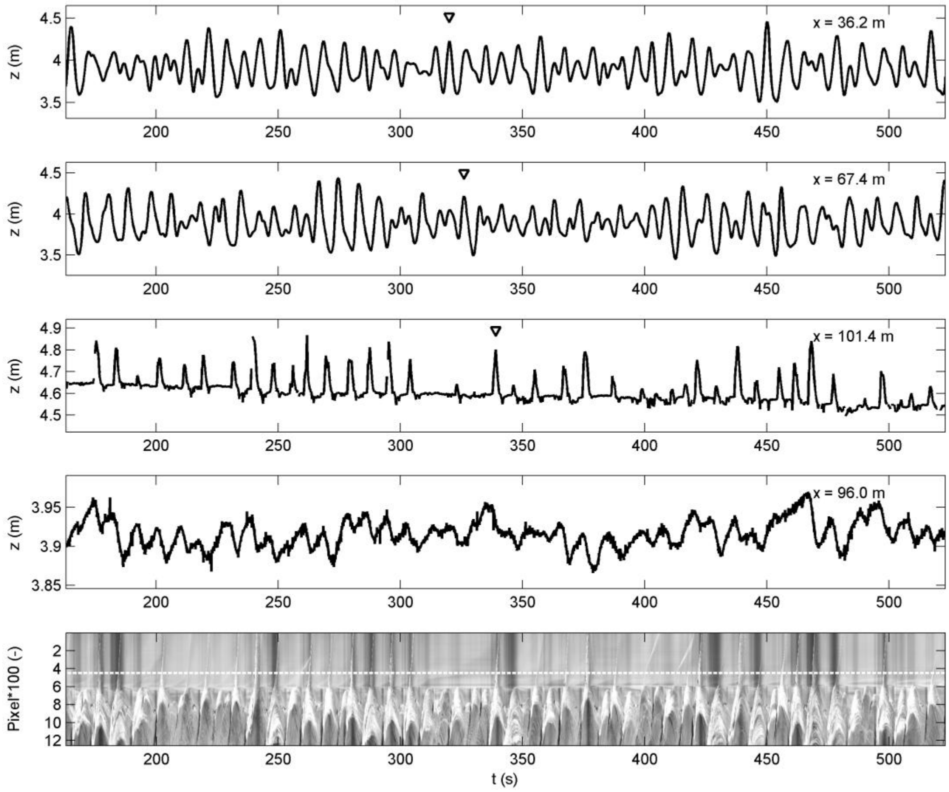

Figure **14** – Example of 6 minutes of data collected during run #4 of test series E (E_04) showing landward transformation of the wave signal. From top to bottom: shoaling waves at *x* = 36.2 m measured with Delta Flume PT; breaking waves at *x* = 67.4 m measured with UU PT; overwash at *x* = 101.4 m measured with UNSW BLS; beach groundwater table at *x* = 96.0 m measured with Delta Flume PT; and time stack showing overwash action measured with Delta Flume video camera. The down-facing triangle marks the propagation of a wave through the instrument array, up to the top of the beach.

Table 1 – Overview of the planned experimental programme during *BARDEX II*. H_s = significant wave height; T_p = peak wave period; h_s = sea level; h_l = lagoon level; and T_{test} is duration of the test. Note that these planned conditions are not identical to the conditions that actually took place (refer to Figure 8).

Test	H_s **(m)**	T_p **(s)**	h_s **(m)**	h_l **(m)**	T_{test} ***(min)***
Test series A: Beach response to varying wave conditions and different lagoon levels; no tide					
A1	0.8	8	3	3–3.4	320
A2	0.8	8	3	4.3	200
A3	0.8	8	3	4.3	180
A4	0.8	8	3	1.75	200
A5	0.3–0.8	8–12	3	1.75	17
A6	0.6	12	3	3	335
A7	0.6	12	3	4.25	213
A8	0.6	12	3	1.75	200
Test series B: Bar dynamics due to different sea levels; no tide					
B1	0.8	8	3	1.75	165
B2	0.8	8	2.5	1.75	225
Test series C: Beach response to varying wave conditions with tide (30-min data segments)					
C1	0.8, 0.6	8	2.25 → 3.65	1.75	330
C2	0.8, 0.6	8	3.53 → 2.25	4.25	270
Test series D: Identification of overtopping/overwash threshold; increase sea level until overwash occurs (20-min data segments)					
D1	0.8	4	3.15 → 4.2	1.75	160
D2	0.8	5	3.45 → 4.05	1.75	100
D3	0.8	6	3.45 → 3.9	1.75	80
D4	0.8	7	3.45 → 3.9	1.75	80
D5	0.8	8	3.45 → 3.75	1.75	60
D6	0.8	9	3.30 → 3.75	1.75	80
D7	0.8	10	3.15 → 3.6	1.75	80
Test series E: Barrier overwash (13-min data segments)					
E	0.8	8	3.9	1.75	65

Table 2 – Overview of the NetCDF data groups with the included instrumentation and measured parameters.

DATA GROUP	INSTRUMENTATION	MEASURED PARAMETERS
BLS (290 MB)	BLS	Water and bed levels in the inner surf and swash zone
DELTARES (5.69 GB)	PT EMCM OBS Wavemaker Pump Video strobe	Hydrodynamic and morphodynamic quantities along the wave flume (sea and lagoon)
PROFILES (12.9 MB)	Bed profiler	Subaerial and subaqueous beach profile
SOUTHAMPTON (9.35 GB)	ABS ADV SRP	Hydrodynamics, sediment resuspension and bedforms in the near-bed region extending offshore from the surf zone
SWASH (635 GB)	PT EMCM ADV VEC OBS	Velocities, turbulence, water levels, and suspended sediment concentrations in the swash zone
UTRECHT (433 MB)	PT EMCM ADV OBS	Mean flows, wave velocities, turbulence and sediment concentrations in the surf zone