Horizontal ADCP measurements of waves and currents in the very nearshore

Matthieu A. de Schipper, R.C. de Zeeuw,
S. de Vries and M.J.F. Stive
Section of Coastal Engineering
Delft University of Technology
Delft, the Netherlands
M.A. de Schipper@TUDelft.nl

Jarno Terwindt
Nortek B.V.
Badhoevedorp, the Netherlands

Abstract— **Hydrodynamic measurements of the very nearshore are valuable, but often difficult to obtain. Large amounts of bubbles due to wave breaking and complex installation complicate the use of acoustic instruments in this zone. This paper presents measurements obtained by a horizontal looking ADCP (hADCP) installed in the very nearshore to measure waves and wave currents. The observations are separated into the various timescales ranging from high frequency orbital motion to very low frequency oscillations and mean flow. Results reveal the presence of significant very low frequency oscillations and the potential of a hADCP to capture wave transformation in the nearshore.**

Keywords-component; ACDP; surfzone; waves

I. INTRODUCTION

The hydrodynamics of the very nearshore have been subject of several decades of research. Not without reason, since they have a large impact on the morphology and sediment transport on a daily scale. Morphology in this zone is far from uniform and the formation (and destruction) of nearshore (rhythmic) patterns such as beach cusps, sand bars, erosion hotspots and sand waves along the coast remains unclear until present. Moreover, currents in the surfzone are of importance to swimmer safety and the transport of nutrients and bacteria in the coastal zone.

The majority of the surfzone flow is induced by wave breaking and variations therein. The dissipation of wave energy generates strong currents of *O* (1 m/s) in both cross and alongshore direction. These wave induced currents are can be characterized by different timescales. Distinction can be made into 4 different timescales: 1) short wave high frequency motion, 2) infragravity low frequency motion, 3) very low frequency motion and 4) mean flow fluctuations. The perceived current in the surfzone is a superposition of all these elements.

The first category, the short wave high frequency motions, have periods less than 25 s. These rapidly varying motions are governed by the orbital motion of individual waves. The next category, infragravity low frequency motions, have periods in the range of 25 to 250 s. These infragravity motions are generated by the wave height variations over time. High waves are often clustered in wave groups and these wave groups are accompanied by infragravity waves [1]. Although the velocities and amplitudes of these infragravity waves are very little outside the surfzone, inside the surfzone they become of greater relative importance. Third category, Very Low Frequency (VLF) fluctuations have wave periods in the range 250 s to 30 minutes. Velocity fluctuations with such large wave periods can be generated by instability of the alongshore current or wave group induced surfzone eddies [2]. These slow motions have been hypothesized to be important for the initiation or development of nearshore rhythmic patterns [3] as well as the exchange of transported material between the surfzone and the inner shelf [4]. The fourth category is the mean flow pattern with wave periods larger than 30 minutes. This flow pattern is typically governed by tidal currents.

The objective of the measurements reported in this paper is to investigate the presence and magnitude of VLF motions at the Dutch coast. There is evidence that the magnitude of VLF velocities and especially the surfzone eddies is influenced by the characteristics of wave field (i.e. wave period, directional and frequency spreading) [3,5]. Since the waves are mostly generated inside the shallow (20-80 m) North Sea, the Dutch wave climate is characterized by low wave periods (*O* (5s)) and wide banded wind seas. As these wave conditions are quite different from the field observations of VLFs as presented previously [2], it is unknown if VLF motions are to be found.

The opportunity is taken to test a horizontal looking ADCP (hADCP hereafter) in the surfzone. Similar to any other ACDP, the Doppler effect is used to measure current velocity in bins along the beam. Each beam measures velocity parallel to the beam and by using 2 (or more) beams pointed in different direction it is possible to obtain a 2D (or 3D) velocity field. As the velocities of different beams are combined to compute the orthogonal velocity vectors, it is assumed that the velocity is uniform across the beams. Horizontal looking ADCPs typically have all beams aligned in a horizontal plane to prevent beams to intersect with the bottom or waterlevel. Profiles range between 20 m and 100 m, depending on the instrument.

Obtaining velocity measurements in the nearshore is very cumbersome, especially in water depths just under the low tide

M.A. de Schipper and S. de Vries are funded by
Building with Nature, EcoShape, Burgraadt Building, Dordrecht, 3311 JG, The Netherlands (http://www.ecoshape.nl)

978-1-4577-0022-4/10/$26.00©2010 IEEE

level. Installation of instruments in this zone is not possible with boats due to the limited water depth. A hADCP looking in cross shore direction installed at low tide can provide a solution in these situations. First tests of a hADCP at a macro tidal beach in France showed promising results especially for the mean flow velocities, revealing strong shear in flow in the vicinity of a rip channel [6]. In the present study it will be tested if a hADCP is also capable to measure signals with timescales smaller than 30 minutes (i.e. VLF, infragravity and short wave orbital motions).

II. Field Experiment

A. Field site

The measurements are obtained as part of field campaign *REDNEX10* in June 2010. The field site, Vlugtenburg beach, is close to the town of Hoek van Holland on the west part of the Dutch coast (Fig. 1).

This part of the Dutch coast is a long open sandy coast with structural erosion. To mitigate the erosion (and create a new nature reserve) Vlugtenburg beach has been subjected to an extensive beach and shore face nourishment in spring 2009, moving the coastline approximately 300 m seaward. Since then the profile is adjusting to a new 'natural' equilibrium [7], Vlugtenburg beach can be classified as a meso tidal beach with neap and spring tidal range in order of 1.2 and 2.2 m respectively. Mean wave height H_{m0} is 1.2 m, mean wave period T_{m0} is 5 s and the waves are predominantly approaching shore obliquely from the southwest and north-northwest directions [8].

The bottom topography is characterized by a single subtidal bar with a crest at -2 m NAP and an offshore location of app. 70 m from the low water line (NAP is the Dutch Ordnance Datum, close to mean sea level). Mean slope of the beachface around the waterline (+2 to -2 m NAP) is around 1:20. An overview of the bottom topography at Vlugtenburg beach is depicted in Fig 2. Bottom topography is surveyed during the field campaign using jetski surveys [9] complemented with RTK GPS backpack surveys on the sub aerial beach on the day the instruments were deployed.

B. Instruments

Waves and currents in the very nearshore are measured during the experiment using a horizontal ADCP (hADCP) and a High Resolution upward looking ADCP (HR profiler) on a single measurement frame installed around the low water line, around -1 m NAP (Fig. 3).

In front of the frame the nearshore wave spectrum was measured with a surface tracking ADCP (*Nortek AWAC*) at -2 m NAP. Next to the instruments, surface currents were measured using Lagrangian GPS drifter buoys [10]. The latter two will not be elaborated upon in the present paper.

The horizontal looking ADCP was a *Nortek Aquadopp* 600 kHz. It records velocities in 9 bins along the beam axis with a bin size d_{bin} set at 5 m. The two transducer beams have a separation angle θ of 50 degrees (Fig. 4). Velocities of bin i are hence obtained at the following coordinates ($x_{SLD\,i}$, $y_{SLD\,i}$) with respect to the instrument:

$$x_{SLD\,i} = \pm \{(i\text{-}1/2)d_{bin} + d_{bl}\} \sin(\theta/2)\,, \quad (1)$$

$$y_{SLD\,i} = \{(i\text{-}1/2)d_{bin} + d_{bl}\} \cos(\theta/2)\,, \quad (2)$$

Where ($x_{SLD\,i}$, $y_{SLD\,i}$) are defined from the transducer head, and direction y_{SLD} is the viewing direction of the instrument (exactly in between the 2 beams). Blanking distance d_{bl} equals 0.5 m. As can be seen from (1) and (2), the farthest velocity points (i = 9) are located at (+/- 18.2, 39.0) meters from the instrument. Consequently, if cross and alongshore velocities are to be derived from the beam velocities, relatively uniform conditions are required in direction parallel to the instrument.

Individual beams fan out with a total beam angle of 4 degrees. As a consequence of this beam angle, if the transducer is mounted 1 m under the water level, the beam will intersect the water level if the profile exceeds 28 m. At mid tide this will affect the velocity measurements in the bins farthest from the

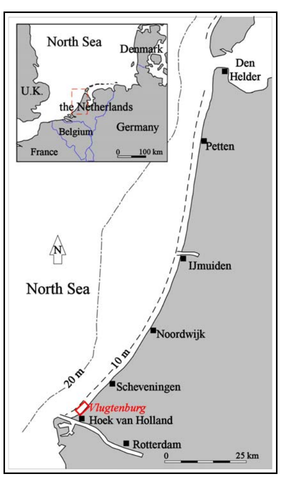

Figure 1. Location map of Vlugtenburg beach.

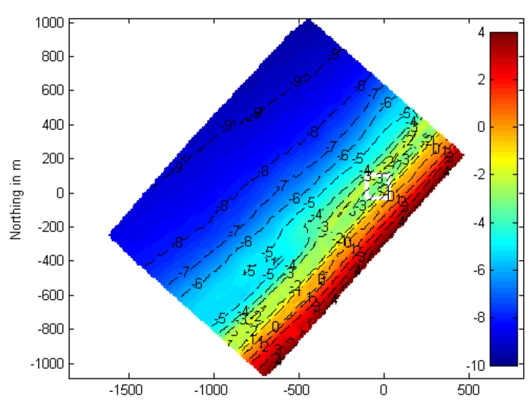

Figure 2. Bottom topography at Vlugtenburg beach, colors indicate evelation in m with respect to NAP. White box is the measurement area (Fig. 4).

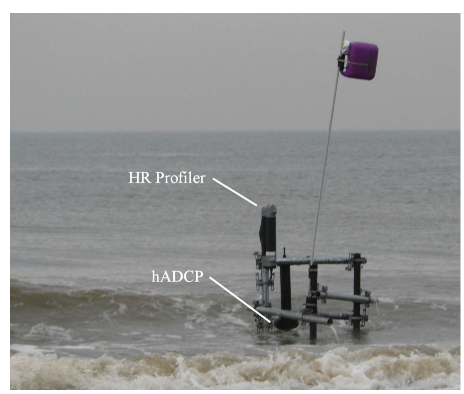

Figure 3. Measurement frame on Tuesday June 8th. The purple can serves as a buoy, mounted slightly outside the beams of the HR profiler.

apparatus.

The High Resolution upward looking ADCP (HR profiler) was a *Nortek Aquadopp HR* 2000 kHz. It was set up to measure in 44 bins of 1 cm in the upper part of the water column around high tide. The blanking distance is set at 10 cm. Its internal pressure sensor was used to record the waterlevel above the instrument.

All instruments recorded at 1 Hz.

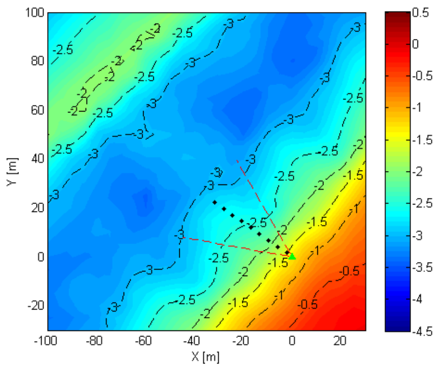

Figure 4. Bottom topography near the measurement frame on June 8th. Colors and contours show elevation in meters NAP. Red dashed lines show the two beams of the hADCP, black dots show the location of computed cross and alongshore velocity points in the profile.

C. *Field days*

The field campaign spanned 6 days in total, of these two days are shown here. The offshore wave and wind conditions as well as heights of the instruments are listed in Table 1.

TABLE I. INSTRUMENT SETUP AND OFFSHORE CONDITIONS

Selected days		
	June 8th	***June 13th***
High water Scheveningen	12:20 0.92 m NAP	16:40 1.08 m NAP
Bottom level at frame	-1.30 m NAP	-0.61 m NAP
Transducer height hADCP	-0.75 m NAP	0.30 m NAP
hADCP orientation	Looking cross shore	Looking alongshore
Transducer height HR	0.09 m NAP	0.48 m NAP
Wave height H_s	0.60 m	1.4m
Wave period T_{m02}	5 s	6 s
Wave direction	North	North
Wind	Up to 15:00 5 m/s South After 15:00 2 m/s North	3 m/s Northwest
Position	*Outside the surfzone*	*Inside the surfzone*

The first day of observations presented here is Tuesday June 8th. The offshore wave station (55 km to the North) recorded waves with a significant wave height H_s of 0.60 m. arriving from the north (40 degrees oblique with respect to shore normal). The measurement frame was installed close to the -1.5 m contour. As such, at high water on Tuesday June 8th, the instruments were in a water depth of over 2 meters. Based on the water depth and wave height, the instruments were positioned outside the surfzone.

During the first part of the field campaign the hADCP was looking approximately cross shore. Its profile spanned 39 m towards the -3 m NAP depth contour in between the beach and the subtidal bar (Fig. 4).

On the second day presented here, June 13th, waves were quite large (H_s of 1.4 m) and instrument frame is placed higher up the profile. As a result the measurements are inside the surfzone. The hADCP was mounted looking alongshore across a small rip channel.

III. PROCESSING THE TIMESERIES

The recorded time series of the hADCP are first transformed from the beam coordinate system to the instrument coordinate system, including a compensation for pitch and roll of the instrument. The signals from the orthogonal instrument coordinate system are then rotated to an orthogonal coordinate system perpendicular to the coastline giving cross and alongshore velocity timeseries. HR profiler velocities where rotated in the horizontal plane to match the coordinate system of the hADCP.

In this shore perpendicular coordinate system alongshore velocities are positive to the south and cross shore velocities are positive offshore.

The measurements are filtered on two aspects. Since the instruments are in the very nearshore, measurements are possibly corrupted by bubbles and falling dry of the instrument. Both instruments record the signal strength (or amplitude) of the signal. Good velocity measurements are characterized by a high signal strength which monotonously decreases in the bins further from the instrument. Points are removed with: 1) low signal strength or 2) increasing signal strength with respect to the bin closer to the apparatus. Simply removing only these points with poor velocity measurements creates a bias (towards low velocity periods). Therefore velocity data within 10 seconds of a removed velocity measurement are also removed.

Heading and tilt recordings were checked for movement of the instruments. During the last day of the experiment, Sunday June 13th, the instruments were subject to heavy wave impact, while being partly submerged at mid tide. Recordings showed a slight rotation of the instrument during that period. Since the data was already removed for signal strength reasons, this had no effect on the final data. Apart from this period, changes in tilt or heading remained in the order of 0.1 degrees.

Velocity signals are separated into 4 different timescales;

1) *mean flow velocity patterns (tide), T > 30 min*
2) *very low frequency (VLF) motions, 30min > T > 250s*
3) *infragravity velocities, 250 s > T > 25 s*
4) *and short wave orbital motion. T < 25 s*

To observe these, the measurements where filtered with Butterworth filters with cutoff frequencies at 0.00055, 0.004 and 0.04 Hz corresponding to the periods above.

Velocity spectra for the wind wave band are calculated by performing a Fast Fourier Transform. Non-grassy spectra are obtained by averaging 24 spectra over 2 hours, each representing 5 minutes. Influence of the mean flow on the velocity spectra is removed by detrending the 5 minute input.

Since the waves are not travelling exactly shore normal, total velocity spectra are computed in both cross and alongshore and combined.

IV. RESULTS

Results are shown for two days of the field campaign (Table 1), the first with small waves, causing the instruments to be just outside the surfzone. Next a day is shown with high energy wave conditions, with the instruments inside the surfzone.

A. Outside the surfzone

On Tuesday June 8th the instruments are mounted well under the high tide level (Table 1), resulting in observations over a large part of the high tide period.

The hADCP was looking cross shore and at high tide the maximum waterlevel over the transducer was over 1.5 m. A full profile (39 m) with good signal strength was obtained at this time. At mid tide waterlevel was lower, and the farthest bins reflected against the waterlevel. HR profiler recorded 4 hours of velocities and pressure observations.

The low passed measurements are shown in Fig. 5. In these results all high frequency velocities and pressure due to waves and infragravity waves are filtered out, leaving only observations with periods of 250 s and larger. As such, purely the mean flow and VLF motions are visible.

Fig. 5 (top) shows the water level as calculated from the low passed pressure signal. Tidal amplitude corresponds well with the tidal gauge recordings at Scheveningen harbor, 13 km north of the field site. A small time lag can be observed in the observations, due to the northward propagation of the tidal wave along the coast.

The low passed alongshore hADCP velocities for closest, middle and farthest bin (resp. 3, 16 and 39 m from the frame, Fig. 4) are shown in Fig. 5 (middle). Alongshore velocities are negative (northward) during high tide, caused by the northward tidal current. During ebb the direction of the tidal current reverses and becomes southward oriented.

In the bins farther from the apparatus alongshore velocities are larger as the tidal flow becomes more important in the

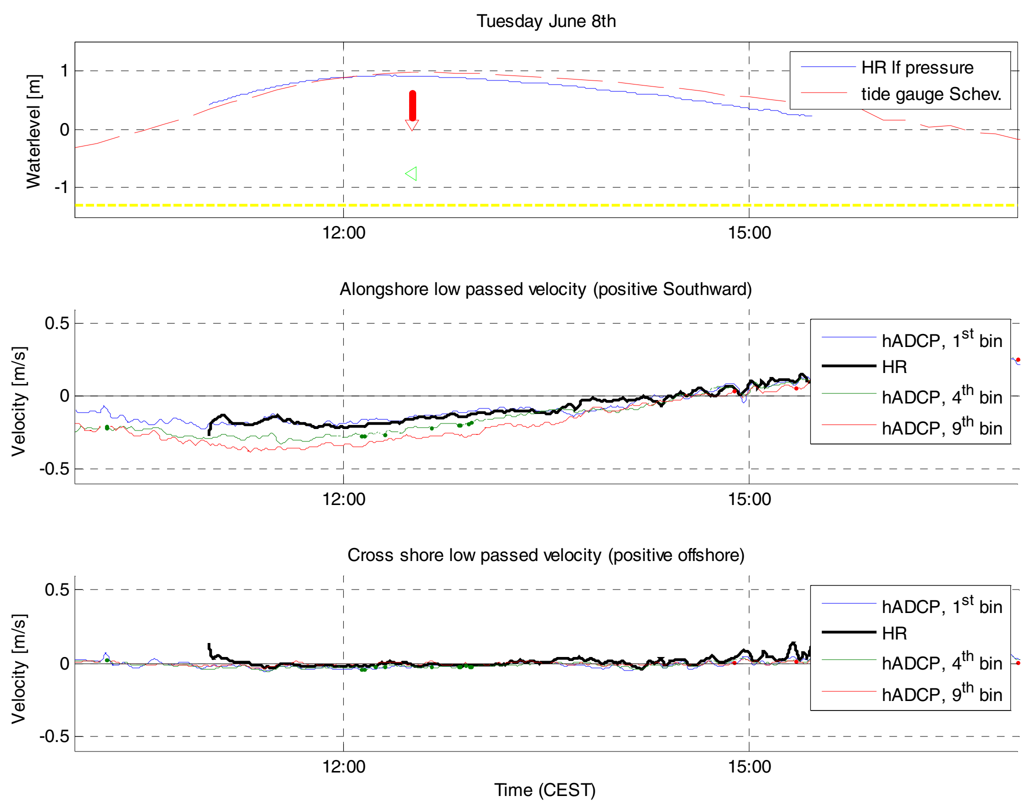

Figure 5. Low passed (T > 250s) measurements outside the surfzone on Tuesday June 8th. Top panel shows water level recorded at the frame in blue and the tidal recordings at the nearby harbor of Scheveningen. HR profile is given in red, hADCP transducer given by the green triangle. Approximate bottom level given by the yellow dashed line. Middle (bottom) panel shows alongshore (cross shore) velocities of the 1st,4th and 9th bins of the hADCP in blue, green and red and HR profiler in black. Note that measurements with poor quality are removed, causing the signal gaps towards the beginning and end of the recording.

trough between the beach and the subtidal bar. The shear in the alongshore current is substantial; flood current at the end of the profile at -3 NAP is up to 0.39 m/s, while close to the instrument at -1.5 m NAP the velocity is at maximum 0.2 m/s.

Cross shore velocities are very limited (< 0.1 m/s), indicating that the instrument was aligned well with the local alongshore flow.

The low pass velocities presented in Fig. 5 show velocity fluctuations with periods larger than 250 s (i.e. mean flow and VLF oscillations). Fluctuations on the VLF timescale (250 s < T < 30 min) are however very limited (u_{rms} < 0.1 m/s). At high tide the low passed velocities show no oscillations, and at mid tide (before 11:00 and after 14:00) small oscillations can be observed in the velocity signal. These oscillations could well be wave group induced VLF vortices generated in the surfzone, but due to the limited magnitude of the signal other explanations such as wind gusts cannot be excluded.

Although both instruments measure at different locations in the horizontal (2.7 m apart) and vertical (0.95 m apart), The low frequency flow observations of the first bin of the hADCP in Fig. 5 show a good correspondence with measurements of the HR profiler.

The behavior on the timescale of short waves (T < 25 s) is investigated using the measured velocity spectra. Spectra measured in the first bin of the hADCP and the HR profiler are horizontally 2.7 m apart. Vertically the measurements are about 1 m apart. Especially this vertical offset makes direct comparison of the velocity spectra impossible. Therefore the velocity spectra are transformed into variance density spectra of the surface elevation [11]. Velocity spectra are multiplied with a transfer function to attain surface elevation per frequency bin f_i :

$$\eta_{fi} = \{ 2\,\pi f_i \sinh(k_i h) / \cosh(k_i (h - z_{td})) \}\; U_{fi} \qquad (3)$$

Where k_i is the wave number corresponding to each frequency, h the waterdepth as extracted from the topographic survey and z_{td} the height of the transducer with respect to the water level.

Calculated surface elevation spectra from the velocity measurements are shown in Fig. 6. All hADCP bins show a similar shape and distribution. Spectral density increases in the

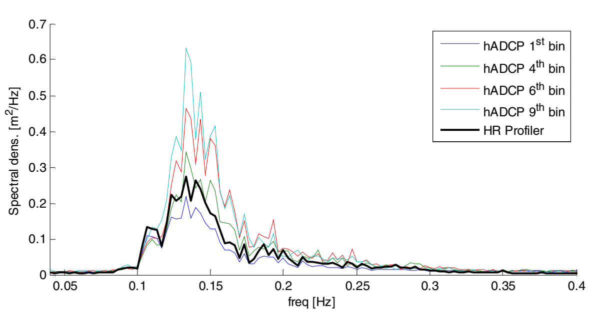

Figure 6. Variance density spectra of the short wave surface elevation spectra as measured on Tuesday June 8th between 12:00 and 14:00 by the hADCP and HR profiler (thick black line).

bins further from the apparatus, indicating a larger wave height further offshore. When the spectra of the HR profiler and the first (closest) hADCP bin are compared, it can be seen that the hADCP underestimates the short wave motion. Most likely these short waves cannot be resolved by the hADCP due to the large bin size of 5 m.

Mean period T_{mo2} based on the measurement of the hADCP and HR profiler are 5.0 and 5.4 s respectively, corresponding well to the wave period measured offshore (Table 1).

B. *Inside the surfzone*

On Sunday June 13th the instruments are mounted higher in the watercolumn (Table 1). The hADCP was oriented looking alongshore, across a small rip channel.

The alongshore orientation of the hADCP proved not beneficial in the surfzone. As the waterdepth is limited, only the first bin of the profile contained good quality data. Further away from the apparatus, beams intersected with the water level or the bottom and the observations were degraded.

Waveheights are approximately 1 m at the frame near high tide. Pressure sensor of the HR profiler showed 1 hour undisturbed measurements around high tide. Outside this period wave troughs were occasionally reaching the transducer level, and corrupting the measurements. Best quality data was measured in the first (lowest) bins of the profile.

The low passed velocities (T > 250 s) for the first bin of the hADCP and lowest HR profiler bin are shown in Fig 7. Once again, all high frequency velocities and pressure due to waves and infragravity waves are filtered out, leaving only observations with periods of 250 s and larger (mean flow and VLF motions).

The alongshore velocity observations fluctuate around zero near high tide. The northerly waves generate a southward wave induced current in the surfzone and near high tide this southward wave induced current and the northward tidal flow are in balance, leading to a negligible longshore current. As the tide level decreases the mean alongshore flow increases. This indicates a decrease in the northward flood current and the southward wave driven current becomes dominant.

Measurements of alongshore currents of the HR profiler and the hADCP show a very good correspondence.

The orientation of the hADCP (looking alongshore) leads to a mismatch in cross shore velocities. The two transducer beams fan out in the cross shore and the computed cross shore velocity is based on these two beam velocities measured at different water depths. Alongshore flow is believed to be more uniform, yielding to a better comparison of both instruments.

The velocity signals also reveal oscillations with timescales of O (10 min). To assess the magnitude of these oscillations with respect to the short wave energy, the velocity signals for the period around high tide (16:00 to 17:00) are separated into the different frequency bands and shown in Fig. 8.

Fig. 8 clearly shows the presence of the very low frequency oscillations during the experiment. Strikingly, their magnitude in this part of the surfzone is of the same order of magnitude as

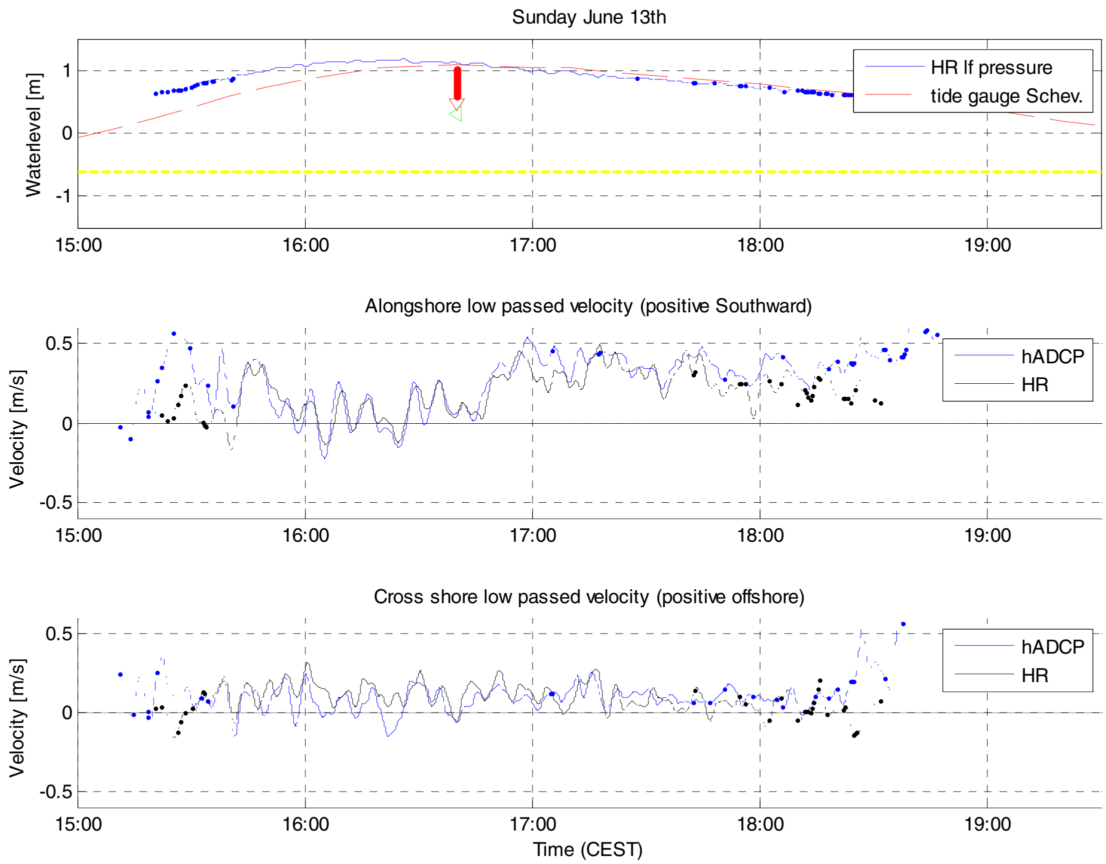

Figure 7. Low passed (T > 250s) measurements inside the surfzone on Sunday June 13th. Top panel shows water level recorded at the frame in blue and the tidal recordings at the nearby harbor of Scheveningen. HR profile is given in red, hADCP transducer given by the green triangle. Approximate bottom level given by the yellow dashed line. Middle (bottom) panel shows alongshore (cross shore) velocities of the 1st bin of the hADCP in blue and HR profiler in black. Note that measurements with poor quality are removed, causing the signal gaps towards the beginning and end of the recording.

the orbital motion and the infragravity waves. In the time period 16:00 to 17:00, the root mean square velocities (rms) velocities for the VLF, infragravity and short wave band are 0.31, 0.23 and 0.49 m/s respectively.

Oscillations in the VLF band of this magnitude are most likely forced by wave group action [2]. Wind gusts are unlikely, since the wind was very small during this day. Since the alongshore current was also small, shear instabilities of the alongshore currents are not expected to have this magnitude.

C. *Comparison hADCP vs HR profiler*

A direct comparison of the timeseries of both instruments is not possible, as the velocity measurements from the instruments are obtained at different locations. Instead, the statistical properties of the results above are compared.

First the difference in low pass filtered ($T > 250$ s) results of both instruments is quantified for both days (Fig. 5 and 7). Hereto the HR signal and the first bin of the hADCP are compared.

Two values are of interest, the mean difference between the two instruments and the Signal to Noise (SNR) ratio of the

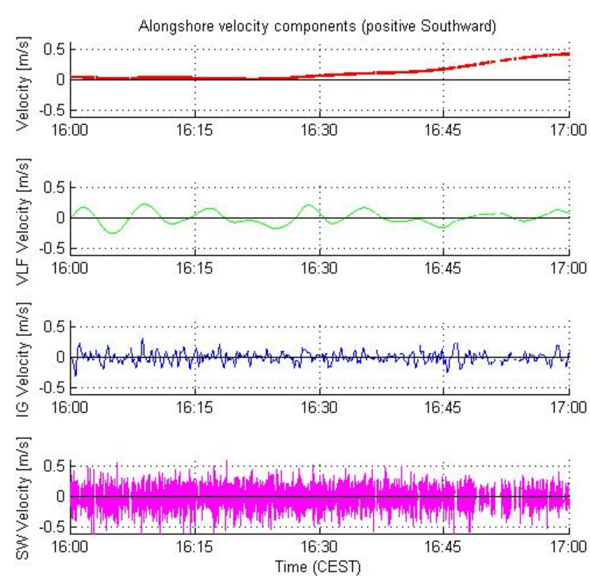

Figure 8. Alongshore flow on Sunday June 13 separated in four different velocity bands. Panels show from top to bottom; mean flow ($T > 30$ min), VLF flow (30 min $> T > 250$ s), Infragravity motion (250 s $> T > 25$ s) and short wave orbital motion ($T < 25$ s).

difference, given by the squared ratio of the standard deviation of the HR profiler signal and the standard deviation of the difference between the two instruments [6]:

$$SNR = \{\sigma(u_{HR}) / \sigma(u_{HR} - u_{ADCP})\}^2 \quad (4)$$

TABLE II. LOW PASSED VELOCITY COMPARISON

	Alongshore	*Cross shore*
Tuesday June 8th 12:00 to 15:00		
Mean deviation (hADCP-HR)	0.002 m/s	-0.020 m/s
Signal to Noise ratio	5.5	1.6
Sunday June 13th 16:00 to 17:00		
Mean deviation (hADCP-HR)	-0.001 m/s	-0.065 m/s
Signal to Noise ratio	4.7	1.1

Mean deviation and signal to noise values for the low passed signals are given in Table 2. Mean deviation between both signals is very low compared to the measured velocities. The. measurements inside (June 8th) and outside (June 13th) the surfzone show mean deviations and SNR values of the same magnitude. Inside the surfzone the SNR values are slightly lower, possibly due to the large spatial variations in velocity in this zone. Cross shore motions are less accurate.

On the timescales of the short waves ($T < 25$ s) the results are compared using waveheights calculated from the surface elevation spectra. Significant wave heights are calculated using:

$$H_s = 4\, m_0^{0.5} \quad (4)$$

Where m_0 is the zeroth-order spectral moment of the spectrum. Significant wave heights computed form the spectrum are shown in Table 3.

TABLE III. HIGH FREQUENCY WAVE HEIGHT COMPARISON

Tuesday June 8th 12:00 to 14:00						
	HR Profiler	***hADCP 1st bin***	***hADCP 4th bin***	***hADCP 6th bin***	***hADCP 9th bin***	***Offshore Station***
Wave height H_s [m]	0.52	0.49	0.58	0.66	0.69	0.68

Assuming wave height obtained with HR profiler is correct, the first bin value of the hADCP shows a small (6%) underestimation of the wave height. An underestimation could well be due of the large bin size (5 m) relative to the wave length (*O* (20 m)) in this region.

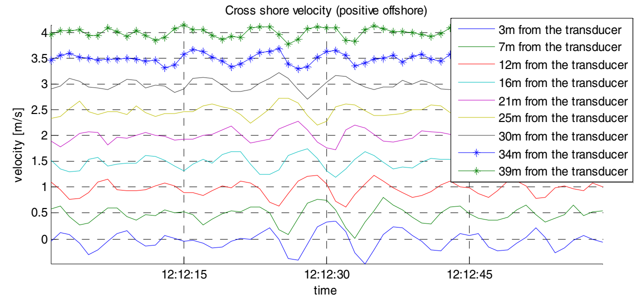

Figure 9. Cross shore velocities as measured by the hADCP. The figure represents 1 minute of raw data showing the arrival and shoaling of a group of waves from offshore (top lines) to close to the instrument (bottom lines). Note that to separate the different bins in the plot, subsequent time series are separated by 0.5 m/s.

D. *Depth Inversion*

On the timescale of several waves (*O* (1min)) the hADCP recordings show the wave transformation in the nearshore (Fig. 9). As can be seen from the figure, the orbital velocities increase as waves approach shore.

The pattern in the velocity signal (Fig. 9) is slightly shifted in time between adjacent signals. This is due to the propagation of the waves towards the shore.

The shift is not equal within the profile. When the waves travel in shallower water the wave celerity decreases and this shift or timelag between two signals increases.

By measuring the timelag, the wave celerity can be computed from the high frequency signals recorded by the hADCP. This is done by cross correlating individual timeseries of two velocity measurements at different locations in the cross shore.

Offshore, towards the end of the hADCP profile the wave celerity is in the range of 4 to 5 m/s. In the 1 Hz signals of adjacent timeseries, measured 4.5 m apart, it is difficult to accurately correlate a timelag. Therefore the timelags are calculated in between signals 2 cells apart (at *i-1* and *i+1*). The timelag $\Delta t_{lag,}$ with the largest cross correlation can then be used to estimate the wave celerity $C_{x\,i}$ as follows:

$$C_{x\,i} = \{ y_{SLD\,i+1} - y_{SLD\,i-1} \} / \Delta t_{lag} \quad (5)$$

The wave celerity in the nearshore is dependent on water depth and consequently the wave celerity can be used to estimate the bottom topography. This depth inversion can be done using the dispersion relation describing the wave celerity as a function of its wave number *k* and water depth *d*. In the nearshore region this water depth of wave propagation is usually taken as the water depth under the crest of the wave (*d+H/2*), yielding to a slightly adapted wave celerity formulation as proposed by Booij [12]:

$$C = \{g/k \tanh(k(d+H/2))\}^{0.5} \quad (6)$$

Given the wave speed $C_{x\,i}$ obtained from (5), a wave height of approximately 0.4 m and the wave number k (calculated using $k=2\pi/(T_{mo2}\,C)$), the depth can be solved iteratively.

The estimated depth profile is shown in Fig 10. Estimates of the depth profile using the cross shore velocity V_{cs} clearly underestimate the depth profile. Mean difference between the measured topography and the estimated depth points is 0.79 m.

As the waves approach the shore oblique, the wave celerity is underestimated using a cross shore profile. Therefore the depth estimate is also calculated using the most north beam of the hADCP, pointing more into the direction of wave propagation. The profile obtained using the beam velocities V_{bN} has a larger correspondence with the measured bottom profile (Fig. 10). Mean difference between the measured topography and the estimated depth points is 0.15 m.

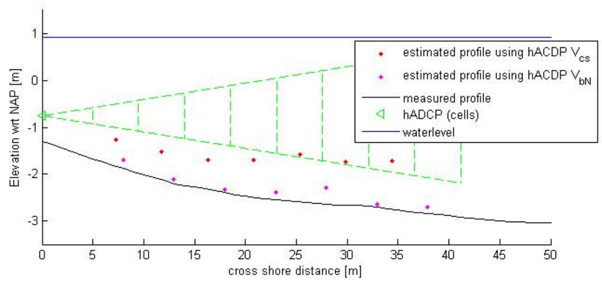

Figure 10. Depth profile reconstructed from 800 s timeseries on Tuesday June 8th around 12:12. Black line represents the profile as measured using the jetski. Red points are depth estimates from cross correlation of the cross shore velocity signals of the hADCP, magenta points are depth estimates using the northern beam velocity signals.

Discussion and Conclusions

The objective of the present study was twofold, first to investigate the presence and magnitude of very low frequency (VLF) motions at the Dutch coast and secondly to investigate the potential of a horizontal ADCP.

Measurements of both instruments showed the presence of substantial VLF oscillations on one of the field days. The observed root-mean-squared velocity of the oscillations in the VLF frequencies (30 min > T > 250 s) was 0.31 m/s, which is substantial compared the short wave motion. This finding implies that the VLF oscillations are not only reserved to ocean coasts with medium to high period ($T > 10$ s) waves.

On the field day when VLF motions were observed, waves were well aligned and long crested for the Dutch standards. Future research will have to show if under the more common short crested wind sea conditions the VLF velocities are of equal size.

Measurements of the hADCP corresponded well with the measurements of the HR profiler, especially for the low frequency part of the observations. The large bin sizes in the profile make it difficult to measure waves with short wave length inshore.

The large separation angle between the beams restricts the use to situations with shear perpendicular to the instrument. Horizontal vortical motions with a radius similar to the profile length (O (50 m)) will be poorly reproduced by the farthest cells of the profile, since the conversion from beam parallel velocities to a profile of alongshore and cross shore velocities will become troublesome.

A horizontal looking ADCP has shown to be of most value when deployed outside the surfzone, where 1) the flow is more uniform and 2) the beams intersect less with the water or bottom. In this region it a hADCP can reveal both the shear in alongshore current as well as wave transformation.

Acknowledgment

Nortek B.V. Netherlands is greatly acknowledged for providing the instruments as well as support during installation.

Thanks to the fluid mechanics laboratory personnel for the construction of the measurement frame and to the UNESCO-IHE students for their effort during the field campaign.

The current work is funded by Ecoshape, Building with Nature under Project codes NTW 3.2 and HK 3.2

References

[1] M.S. Longuet-Higgins and R.W. Stewart, “Radiation stress and masstransport in surface gravity waves with application to ‘‘surf beats’’,J. Fluid Mech., 29, 1962.

[2] J.H. MacMahan, A.J.H.M. Reniers and E.B. Thornton, “Vortical surf zone velocity fluctuations with 0(10) min period”, J. Geophys. Res., 115, 2010.

[3] A.J.H.M. Reniers, J.A. Roelvink and E.B. Thornton, “Morphodynamic modeling of an embayed beach under wave group forcing”, J. Geophys. Res., 109, 2004.

[4] A.J.H.M. Reniers et al. “Surf zone surface retention on a rip-channeled beach”, J. Geophys. Res., 114, 2009.

[5] M.A. de Schipper, R. Ranasinghe, A.J.H.M. Reniers and M.J.F. Stive. “On the initiation of nearshore morphological rhythmicity”. Proceedings of the International Confererence on Coastal Engineering, 2010.

[6] B. Castelle et al. “Rip current system over strong alongs non-uniformities: on the use of HADCP for model validation.” Journal of Coastal Research, Special Issue 56, 2009.

[7] S. de Vries, M.A. de Schipper, M.J.F. Stive and R. Ranasinghe. “Sediment exchange between the sub-aqueous and sub-aerial coastal zones.” Proceedings of the International Confererence on Coastal Engineering, 2010.

[8] K.M. Wijnberg and J.H.J. Terwindt. ”Extracting decadal morphological behaviour from high-resolution, long-term bathymetric surveys along the holland coast using eigenfunction analysis.” Marine Geology 126 (1-4), 301 – 330, 1995.

[9] S.T.J. Van Son, R. Lindenbergh, M.A. de Schipper, S. de Vries and K. Duijnmayer. “Using a personal watercraft for monitoring bathymetric changes at storm scale”. Proceedings of the International Hydrographic Conference, 2009.

[10] J. MacMahan, J. Brown and E.B. Thornton, “Low-cost handheld Global Positioning Systems for measuring surf zone currents.” J. Coastal Res., 2009.

[11] R. Guza, and E.B. Thornton, “Local and shoaled comparisons of sea-surface elevations, pressures and velocities”. Journal of Geophysical Research-Oceans, 1980.

[12] P. Catalan and M. Haller “Remote sensing of breaking wave phase speeds with application to non-linear depth inversions”, Journal of Coastal Engineering, 2006.