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Measurements and three-dimensional modeling of nearshore circulation on a South Carolina beach

By

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ABSTRACT
A numerical modeling system for simulating nearshore surf zone conditions and tidal processes is presented and evaluated with in situ data. The modeling system is comprised of the Regional Ocean Modeling System (ROMS v 3.0), a three-dimensional numerical ocean model, coupled with Simulating Waves Nearshore (SWAN), a spectral wave propagation model. The system has been modified with a new vertical distribution of radiation stress terms for applications in very shallow waters. The model performance is evaluated by comparing simulations to hydrodynamic data (wave height, direction, longshore and cross-shore currents) collected in the surf zone in northern South Carolina. U.S. Model results have been analyzed to discern the variability in three-dimensional and depth-averaged cross-shore and longshore velocities due to changing wave height, wave direction and tidal stage. Overall, the model shows good correlation to observed data and it is found to be capable of reproducing typical flow patterns observed due to depth-induced wave breaking. An implication for sediment transport applications on beaches with tidal variability is also discussed.

The nearshore region of the coastal zone serves an important role for both commercial and recreational purposes. Wave activity and nearshore circulation determine movement of heat, nutrients and sediment in the surf zone. Wave and current parameters have been related to entrainment of nutrients (e.g., Grant et al. 2005), development of hypoxic conditions (e.g., Gregory et al. 2009), morphological changes due to gradients in cross-shore and longshore sediment transport (e.g., Hoefel and Elgar 2003) and dispersal of riverine masses (e.g., Uchiyama et al. 2000). Thornton and Guza (1986) developed one of the first surf zone longshore current models for obliquely incident waves. New models with inclusion of more complex physical processes gradually evolved, for example Church and Thornton (1993), Stive and DeVriend (1994), Feddersen et al. (1998) and Ruessink et al. (2001) amongst many others. These models are usually based on depth-averaged, steady state Navier-Stokes equations to resolve the longshore flow across the surf zone.

Most of these models assume alongshore uniformity and do not allow for alongshore bathymetric variations, identified to be an additional important forcing mechanism contributing to the creation of longshore currents (Feddersen et al. 1998; Ruessink et al. 2001). Two-dimensional, depth-averaged models (e.g. Yu and Slinn 2000) allow for alongshore bathymetric variations, but do not provide vertical structure of the flow field.

Recognizing the limitations of one- and two-dimensional (depth-averaged) models, great effort has been placed in developing quasi three-dimensional models like SHORECIRC (Svendsen et al. 2002) that extend the depth integrated 2-D horizontal equations in the vertical through the use of analytical solutions. These models have been previously applied to study rip current (Haas et al. 2003) and surf beat (van Dongeren et al. 1995) processes in the nearshore. It was not until very recently that full three-dimensional models have been developed (Groeneweg and Klopman 1998; Walstra et al. 2000; Mellor 2003, 2008; Newberg-
er and Allen 2007; Uchiyama et al. 2010) with varying degrees of complexity and applicability to practical situations.

Mellor (2003, 2005, 2008) developed depth dependent formulations for radiation stress terms, which have been implemented in ROMS by Warner et al. (2008) and more recently by Kumar et al. (in review). These previous efforts have focused on studying the currents generated by obliquely incident waves on a planar beach and rip currents formed on longshore bar trough morphology (Kumar et al., in review; Haas and Warner 2009). In this contribution, we apply the recently modified ROMS-SWAN coupled model in the surf zone of Long Bay, South Carolina. We use the model results to investigate modulation of surf zone hydrodynamic processes by tidal variation and the impact these processes have on longshore sediment transport.

MODEL DESCRIPTION
ROMS is a three-dimensional, free surface, topography following numerical model, which solves finite difference approximations of Reynolds Averaged Navier-Stokes (RANS) equations using hydrostatic and Boussinesq approximations with a split-explicit time stepping algorithm (Shchepetkin and McWilliams 2005). ROMS includes several options for certain model components, such as various advection schemes (second, third and fourth order), turbulence closure.
models (e.g., Generic Length Scale mixing, Mellor-Yamada, Brunt-Väisälä frequency mixing, user provided analytical expressions, K-profile parameterization), boundary conditions, etc.

Warner et al. (2008) improved ROMS for nearshore applications through the incorporation of the Mellor (2003) and Mellor (2005) radiation stress forcing methods. Following Ardhuin et al. (2008), Mellor (2008) developed a modification to his original formulation for the radiation stress tensor, which was coded into ROMS and evaluated against analytical solutions of rip-current flows by Kumar et al. (in review). We have further modified this coupled model for application in very shallow water depths (surf zone environment) by vertically distributing the radiation stresses using a scale proportional to the wave height. This modified model has been tested extensively through simulations of several cases that include: (a) obliquely incident spectral waves on a planar beach; (b) alongshore variable offshore wave forcing on a planar beach; (c) alongshore varying bathymetry with constant offshore wave forcing; and (d) nearshore barred morphology with rip-channels. These qualitative and quantitative comparisons (Kumar et al., in review) show that the updated model along with the modification for vertical distribution of radiation stresses, is more accurate in replicating surf zone recirculation patterns (onshore drift at the surface and undertow at the bottom, for example, Garcez-Faria et al. 2000) than any of the previous versions. In addition to the above modifications, the version of the model utilized here has been updated by including the effect of wave rollers, an effect important in distributing wave energy in the surf zone. The wave roller is included by solving the evolution equation of roller action density (Reniers et al. 2004). The results shown here include roller effects; however, no detailed description of the roller module is presented here as this is the subject of a subsequent publication.

The wave field required to compute the radiation stress terms are provided by SWAN (Booij et al. 1999), a third generation, spectral, phase averaged, wave propagation model, which conserves wave action density (energy density divided by relative frequency). The details of coupling ROMS to SWAN can be found in Warner et al. (2008) and are not discussed in this paper.

EXPERIMENTAL DATA

In this section, hydrodynamic data collected in Long Bay, SC, as a part of the U.S. Geological Survey and South Carolina Sea Grant sponsored South Carolina Coastal Erosion Study (SCCES) are described. Field data were collected in Long Bay, SC, at two different locations during the period 11-18 December 2005 (Work et al. 2005; Obley et al. 2005). These constitute one of the few detailed measurements of surf zone hydrodynamics in this region of the southeastern U.S.

Data Collection

Long Bay extends 100 km along the northeastern coast of South Carolina, located between Cape Fear, North Carolina, and the tidal estuary of Winyah Bay, South Carolina (Figure 1). Nearshore circulation in the coastal areas of the South Atlantic Bight (extending from Cape Hatteras, NC, to West Palm Beach, FL) including Long Bay is predominantly influenced by the local winds and the passage of low pressure synoptic fronts (Austin and Lentz 1999), while the impact of swell is minimal and limited only on periods associated with the passage of tropical storms. The low pressure synoptic fronts can be further categorized into cold and warm fronts (Austin and Lentz...
During the passage of a cold front, atmospheric pressure drops, wind speed increases and the wind direction changes from northeast to southwest. The passage of a warm front is characterized by a decrease in atmospheric pressure and change in wind direction from southwest to northeast. Despite the local extent of the synoptic fronts, their predominant directions (from NE or SW) result in highly energetic wave events with high oblique angles of approach, which drive strong longshore and cross-shore velocities in Long Bay (Voulgaris et al. 2008).

Data collection was carried out simultaneously at two locations (hereafter referred to as Transect 1 and 2, respectively) approximately 18 km apart. Results from only one location (Transect 1, see Figure 1) are discussed in this paper, as the work for the other location is still in progress. The beach morphology is characterized by a mean foreshore slope of 0.05, and an alongshore linear bar system. The median value of sediment grain size is 250μm, and the mean tidal range is approximately 1.4 m. The beach profile of the experimental site location is shown in Figure 1. Hydrodynamic data were collected at three locations at Transect 1 hereafter called A1, B1, and C1, respectively. Instrumentation used consisted of acoustic current meters programmed to resolve both mean and wave-induced flow by measuring flow condition in bursts of 1,024 seconds at 2 Hz every 30 minutes (Obley et al. 2005; Work et al. 2005). An Acoustic Doppler Velocimeter (ADV) was positioned in a mean water depth of 1.4 m (Station C1, Figure 1b), with its measuring volume located 0.4 m above the bed. Two upward-looking Aquadopp profilers (2MHz) were installed at mean water depths of 2.9 and 2.0 m, which correspond to Stations A1 and B1, respectively (see Figure 1). Since the main focus of this experiment was measurement of both mean current speeds and wave parameters, the aquadopps were configured in the wave measuring mode that allows high frequency noise ratio through the use of a large size bin (0.50 m). Thus the aquadopps provided measurements of pressure and orthogonal velocity components \((p, u, v, \text{ and } w)\) at a single location approximately 0.70 m above the sea bed. Finally, an upward looking Acoustic Doppler Current Profiler (ADCP) equipped with the WAVES® option was deployed at a mean water depth of about 7.3 m, well beyond the breaker zone, to obtain the offshore wave and current information. The ADCP was configured with a 0.50 m bin size with the first bin located approximately 1.5 m above the sea bed. Daily profile surveys were conducted at three locations: north, along and south of the instrumented transect using a Sokkia SET610 Total Station and a Zodiac® inflatable vessel. Each profile started above the high tide line on the beach and extended to about -2.35 m (from MWL). Detailed description of beach morphology surveys can be found in Work et al. (2005). Beach profiles further offshore have been obtained from the surveys conducted by Coastal Carolina University and U.S. Geological Survey (http://gis.coastal.edu, Harris et al. 2007).

Meteorological conditions during the time of experiment (Figure 2a, b and c) were obtained from the NOAA Meteorological Station at Springfield Pier, SC (Station ID 8661070), which is located approximately 24 km south of the experimental site (see Figure 1). The atmospheric pressure (Figure 2b) shows a significant drop on 13 and 16 December, 2005, and the wind direction (Figure 2c) changes from northeast to southwest and vice versa on the 13th and the 16th, respectively. These two events are characterized by low pressure and changes in wind direction, which coincides with the passage of a cold front moving from west to east on 13 December 2005 (see light grey shaded area in Figure 2), and a warm front moving from south to north on 16 December 2005 (see dark grey shaded area in Figure 2).

### Data Processing and Analysis

The velocity data measured by the instruments were rotated to an orthogonal coordinate system aligned with the local coastline orientation (158°N). The coastline coordinate system is defined so that positive cross-shore velocity values indicate offshore directed flows while positive longshore velocity values are indicative of northeastward directed flow. Instantaneous pressure and horizontal velocity measurements from each burst were used to calculate power spectral and cross-spectral densities using Welch’s averaged modified periodogram method of spectral estimation (Welch 1967). The spectral analysis was carried out using the time series toolbox available in MATLAB®. The pressure spectra were converted to sea surface elevation spectra after correcting for pressure attenuation with depth using linear wave
Figure 3. Time series of (a) Significant Wave Height (m); (b) Mean Wave Period (s); (c) Water Depth (m); (d) Mean Wave Direction (°); (e) Longshore Velocities; (f) Cross-shore Velocities measured by the instruments at Station A₁ (solid black), B₁ (solid grey), and C₁ (dashed black). The vertical scale in Figure 3e and 3f are same, but shifted for clarity. The light and dark grey shaded areas correspond to passage of cold and warm fronts observed during the data collection period.

Experimental Results

The sea surface wave energy spectrum calculated from the pressure time series data (not shown here) suggests that for the entire period the wave energy occurred at the wind wave frequency range (>0.125 Hz). A small amount of energy is observed at the swell band only for the energetic conditions on 16th Dec. The significant wave height calculated by integrating the wave energy spectrum is shown in Figure 3a for all stations. Tidal variability in water depth appears to modulate the wave height at the various locations and shift the wave breaking location accordingly. At high water level (Figure 3c), offshore waves with intermediate wave height (0.5 m < $H_{sig} < 0.8$ m) do not break even at station $C₁$ in the shallower water depth. When the wave height is greater than 1 m at the offshore station $A₁$, a cross-shore variation in wave height distribution is observed, even at high water. At low water level, offshore waves with significant wave height less than 0.5 m do not break over the measurement locations and we observe similar wave heights at stations $A₁$ and $B₁$, while for wave height greater than 0.5 m, wave breaking occurs at all measurement positions.

The mean wave period oscillates between 4 and 8 seconds during the entire experiment, suggesting locally generated wind waves (Figure 3b). Time series of mean water depth measured at each measurement location are shown in Figure 3c. Periods with no data correspond to times when the sensor (ADV at $C₁$) located at the shallower location was out of the water. The mean wave direction with respect to the shore normal (Figure 3d) calculated for all the instruments, correlate to changes in wind direction (see Figure 2c). A negative value in this case denotes waves propagating from south/southeast while positive values denote waves approaching from east or northeast. The effect of wave refraction is noticeable as the angle of wave approach decreases toward the shore. During the period 11-13 December, waves are approaching the shoreline from the south/southeast, whereas during 14-15 December the wave propagation direction is east/northeast with respect to shoreline. The wave direction also reverses on 16 December, when waves approach from the southeast.

theory (Bishop and Donelan 1987). The sea surface power spectral density and cross-power spectral density values were then used to calculate wave height, wave direction, and mean wave direction using standard formulations (Herbers et al. 1999).
Formation of longshore current depends on wave height as well as direction. When waves approach from the south/southeast, they generate longshore current directed towards the northeast direction (Figure 3e). From 11 to 13 December, we observe positive (northward) longshore velocities at all the stations, as shown in Figure 3e. The fluctuation in velocity strength occurs due to variability in the tidal stage which is discussed later in this paper. From 14 to 16 December, waves approach from the east/northeast and generate a southwest (negative) directed longshore current. On 16 December, the wave propagation direction is from the southeast and longshore current is towards the northeast.

Cross-shore velocities at the deep water station (Figure 3f) are either zero or offshore directed for the majority of the data collection period. On 16 December, when the wave height exceeds 1 m, an increase in cross-shore velocity at station A1 is observed. The stations located in shallower water (B1 and C1) measure stronger cross-shore velocities, which also show a tidal modulation. At high water level, the cross-shore velocity weakens, while it increases at low water level. On 16 December, cross-shore velocity ~0.4 ms\(^{-1}\) is observed at Station B1. This occurs due to intense wave breaking at these locations, creating a strong offshore directed undertow. The velocity decreases moving further onshore to Station C1 as the waves have already broken (see Garcez-Faria et al. 2000).

MODEL APPLICATION AND EVALUATION

A two-dimensional computational grid for both ROMS and SWAN was created by repeating the observed beach profile in the alongshore direction, forming an alongshore uniform grid (350 m × 400 m, x × y). The grid resolution is 4 m and 25 m in the cross-shore and alongshore directions, respectively. Wetting and drying of the computational domain due to tidal variability is taken into account by activating this option in ROMS. The minimum depth (wet/dry criterion) is set to 5 cm. The domain is distributed into eight equally distributed vertical sigma layers. Neumann boundary conditions are used at the shoreline and offshore boundary, while periodic boundary conditions are used at lateral boundaries. The bottom friction parameterization used for this simulation accounts for wave-current interaction within the bottom boundary layer (Styles and Glenn 2000) and is described in Warner et al. (2008). The physical roughness length associated with grain size (skin friction) is used to estimate the kinematic bottom stress due to pure waves and currents, and for calculating eddy viscosity profiles and velocity in the boundary layer. The turbulence closure scheme used in this case is a generic length scale (GLS formulation) mixing with coefficients selected to parameterize the k-\(\varepsilon\) scheme.

The model system is forced at the offshore boundary with a time series of significant wave height, peak wave period, mean wave direction, and sea surface elevation measured at the site of ADCP location (Figure 4). The coupled ROMS-SWAN model system is run for approximately 3 days (14–16 December). Both models exchange wave and current information every 30 seconds. The results from the model simulation are first compared with the measurements and subsequently used to explore the variability in three-dimensional and depth-averaged...
longshore and cross-shore velocity caused by (a) changing wave height and wave direction for the same tidal stage; (b) effect of changes in tidal stage. Impact of tidal variability on longshore sediment transport is also investigated.

Model and Field Data Comparison

Overall, simulated and measured significant wave heights (Figure 5a) agree with a skill ($r^2 > 0.94$) at all sensor locations, demonstrating that the observed tidally modulated wave distribution in shallow waters is reproduced accurately by SWAN. Root mean-square errors ($\varepsilon_{rms}$) for individual sensors vary between 0.07 m and 0.10 m, with an average value of 0.08 m for all the sensor positions. Significant wave height at Station B1 is overestimated from 15.6-16.4 days (Figure 5a) by a mean value of 0.15 m, with a maximum difference of about 0.24 m at low tide (see t=15.7 days). These differences may occur due to discrepancies regarding the exact instrument position or due to lateral variations in morphology.

Modeled and measured mean wave direction (with respect to the shore-normal, see Figure 5b) agrees with a skill of $r^2 > 0.80$ for sensors A1 and B1. At the station closest to shoreline (C1), larger differences in modeled and measured wave direction are observed at low tide. In general, the model performance deteriorates during low tides in comparison to high tides because in very shallow waters, swash zone processes become important, which are not considered in the model simulations.

A comparison between the observed and simulated longshore and cross-shore velocities is shown in Figure 5c & d. The simulated velocities shown here have been interpolated for the elevation above the bed at which the instrument measurements were obtained. The longshore current agrees with a skill of $r^2 > 0.89$, at all locations. The model performance deteriorates at station C1 which is located closest to the shoreline. Though overall the model compares well with the observations, some discrepancies are observed at station B1 from 15 to 16 December 2005. The maximum difference is approximately 0.3 m/s and occurs at low tide. The deterioration in model performance is attributed to differences in measured and modeled wave height corresponding to this period. The root mean square errors at all the sensors vary between 0.05 and 0.07 ms$^{-1}$.

The mean cross-shore velocities observed during this experiment are usually small with the exception of storm induced velocity on 15-16 December 2005. The cross-shore velocity agrees with a skill of $r^2 > 0.90$ at all the sensors. The root mean square errors at all the sensors vary between 0.03 and 0.05 ms$^{-1}$.

THREE-DIMENSIONAL CIRCULATION IN SURF ZONE

Longshore and cross-shore velocity profiles obtained for the time period of model simulation are used to discuss the three-dimensional structure of circulation for the study site. Model runs (see Figure 4) corresponding to low (L1 and L2), mean (L3) and high (L4) water levels are selected for discussion. It should be noted that periods L2 to L4 correspond to the period of passage of a warm front (see Figure 2).

Vertical structure of nearshore circulation as function of wave forcing

Longshore and cross-shore velocity from two different low tidal stages (L1 and L2 in Figure 4), corresponding to 15.21 days and 15.77 days, respectively are compared. The corresponding offshore wave heights / directions are 0.6 m / 20° and 1.2 m / 6°, respectively. During event L1, waves break shoreward of the bar crest at x=170 m, and generate a surf zone vertical circulation pattern (Figure 6a) with an undertow of 0.15 ms$^{-1}$.
event L2, larger waves break offshore of the bar crest at x= 220 m, and develop offshore directed undertow which has a magnitude 0.3 ms\(^{-1}\) near the bed (Figure 6c). The velocity at the surface during event L2 is onshore directed with a magnitude of 0.2 ms\(^{-1}\). Outside the wave breaking zone (i.e., x> 200 m), the cross-shore velocity is directed offshore with strength increasing from the surface to bottom boundary layer.

A longshore current maximum of 0.5 ms\(^{-1}\) is observed close to the shoreline (Figure 6b) during event L1, whereas for L2 the peak in longshore current (0.6 ms\(^{-1}\)) occurs at the bar crest (Figure 6d). Although the undertow strength observed during event L2, is double than that of L1, the longshore current strength is of similar magnitude in the entire water column for both cases. At L1, relatively smaller wave height and a higher wave angle with respect to shore normal generates strong longshore currents in the surf zone; while at L2, higher wave height and smaller wave angle from the shore normal also creates strong longshore flows. Also, the cross-shore position of the longshore current maximum depends on the offshore wave height.

**Figure 6. Vertical structure of cross-shore (left) and longshore velocities (right) corresponding to events L1 (a, b), L2 (c, d), L3 (e, f), and L4 (g, h) shown in Figure 4. The text in center provides the angle of wave propagation with respect to the shore normal. The heavy grey lines show the cross-shore profile of significant wave height, H\(_{\text{sig}}\) (m).**
The cross-shore velocity in Figure 6e corresponds to a mid-tide level time period (L3, Figure 4) and offshore wave forcing of 1.20 m in height, propagating at an angle of 3° from the shore normal. In this case, waves break initially at the location of bar crest and again closer to the shoreline. At both locations, offshore directed undertow is observed with that on the shoreward location being smaller in magnitude. Onshore flow occurs within the surface layer throughout the surf zone. Outside the surf zone, the velocity distribution is similar to that found during low tide conditions. At high water level (see L4, Figure 4), while the incident offshore wave height is the same as before, the waves propagate normal to the shoreline. Wave breaking occurs over the bar crest as well as close to the shoreline, but the strength of the undertow at the inshore wave breaking position is larger than that of the offshore breaking position (Figure 6g). Outside the surf zone, the velocity structure is similar to that of previous tidal conditions.

Longshore currents exhibit a similar variability throughout the tidal cycle as shown in panels d, f, and h of Figure 6. At low water level, the longshore current attains its maximum strength at the bar crest with a magnitude of approximately 0.6 m s⁻¹ directed toward the southwest. The velocity remains uniform for the entire water column and diminishes both shoreward and seaward. The strength of the longshore current maximum reduces with increasing water depth (see Figures 6d and f) while the location of the maximum longshore current moves slightly shoreward with increasing tide levels. Although the variation in location of maximum longshore current corresponds to change in tidal stage, the differences in longshore current strength between the different tidal stages is mainly due to differences in the wave angle of incidence. During low water level (Figure 6d), the waves approach at a small angle of 6° and generate strong longshore current, while at mid and high tide level, the waves are almost normally incident to the shoreline not creating strong longshore current. This modulation in wave direction corresponds to the change in wind direction observed during this period (see Figure 2).

**TIDAL VARIATION OF LONGSHORE SEDIMENT TRANSPORT**

The simulations clearly indicate the significant role of tidal variability on the vertical structure and location of cross-shore velocity within the surf zone. The secondary impact of tidal stage on longshore current is discussed in this section. The effect of tidal inundation on longshore sediment transport is further examined using a proxy for longshore sediment transport (Q) based on the principle that bottom orbital velocity mobilizes the sediment while mean longshore
The proxies shown in Table 1 have been calculated using the model results for the complete tidal cycle from L1 to L2 (see Figure 4). The cross-shore profile of the proxy $Q(x,t)$ during high water level suggests maximum transport at $x\sim100$ m, whereas at low water level (L1, Figure 4) the maximum transport occurs over the bar crest at $x\sim180$ m (see Figure 7a). Finally, by tidally averaging (period of 12.42 hours) the sediment transport proxy estimates, we take into account the inundation period for each point along the intertidal zone as well as tidal modulation of the hydrodynamics (as discussed previously). These averaged proxy values, $Q(x)$, show significantly different distribution of the longshore transport in comparison to high water (HW) or low water (LW) conditions. Overall, the distribution remains similar over the bar as for the LW conditions, but it increases significantly near the LW waterline mark, monotonically decreasing towards the HW line. Over the whole width of the simulated domain the total longshore sediment proxy, $Q$, is 9.58, 8.98 and 5.92 m$^3$s$^{-1}$ per meter width of nearshore profile for the full tidal cycle, HW and LW conditions, respectively. The variation of total instantaneous longshore sediment proxy, $Q$ over the tidal cycle is shown in Figure 7b. Higher values of $Q$ at the end of tidal cycle occur due to an increase in bottom orbital velocity (caused by higher waves) and longshore current (Figure 7b). Although more work is required over a variety of tidal cycles (e.g. spring and neap) and wave conditions to confirm this, the results described in here indicate that HW total sediment proxy estimates are similar in magnitude as those of tidally averaged ones, but the location of the transport maxima is shifted towards the LW waterline.

**CONCLUSIONS**

ROMS has been modified and implemented for surf zone applications using a depth dependent formulation of radiation stresses and a wave roller formulation. This updated model has been evaluated against field measurements of wave and current parameters measured in a surf zone environment, which was collected as a part of SCCES.

(a) Nearshore circulation in Long Bay, SC, appears to be developed in direct response to synoptic meteorological phenomena which for the study site are mainly cold and warm fronts.

(b) The nearshore three-dimensional numerical model performs well with root mean square errors of 8 cm, 6 cm$s^{-1}$, 3.5 cm$s^{-1}$ in wave height, longshore and cross-shore currents, respectively. The errors obtained are reasonably small and similar in magnitude to other longshore current models like Ruessink et al. (2001).

(c) The three-dimensional flow field obtained from model simulations provides an insight on vertical profile of cross-shore and longshore velocities obtained due to tidally modulated and depth-induced wave breaking. These velocity profiles qualitatively agree with field data of longshore and cross-shore velocities typically observed for barred beaches at environments with significantly higher energies (see Garcez-Faria et al. 2000).

(d) Finally, it should be mentioned that the implementation of modeling techniques as that described in here allow the accurate reproduction of surf zone hydrodynamic conditions as a function of tidal range. This approach leads to an improvement in estimation of tidally integrated processes that could not only help in developing more accurate engineering studies of coastal erosion, but also in the prediction of nearshore hazards as those of rip currents that appear to be dependent on tidal level (Voulgaris et al., in press).

Future work is focused on the inclusion of additional processes like wave breaking induced turbulence and wave induced bottom streaming, and further evaluation of the model against more field measurements. Determination of sediment transport and morphodynamic evolution in the surf zone also constitutes one of our future goals.

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