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Surf-Swash Interactions on a Low-Tide Terraced Beach

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ABSTRACT

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Through an integrated approach, this paper investigates the role of coupled surf-swash dynamics on outgoing waves using data collected at a low-tide terraced beach, Grand Popo, Benin (Gulf of Guinea, West Africa). Observed reflection is 8 %. Analyses are conducted from deep water directional wave spectra measurements, daily beach surveys and remote video measurements. Our results show that the swash can be a non-negligible component of the nearshore energy balance (14% of total dissipation) and is closely tied to reflection. Reflection thus depends on waves at swash inception (offshore waves and surf zone saturation), and shoreface slope varying with tide and morphological evolution. An outgoing cut-off frequency (shortest reflected waves) can be linked to swash saturation with a strong dependence on shoreface slope. A phase-resolving Boussinesq model was validated and used to investigate the influence of terrace width, upper shoreface slope and tidal elevation over the terrace. This papers puts forward the role of the coupled system surf-swash and underlines potential key interactions between a rapid shoreface evolution and surf zone hydro-morphodynamics.

ADDITIONAL INDEX WORDS: *Grand Popo, Benin (Gulf of Guinea), reflection, standing wave, incoming and outgoing waves.*

INTRODUCTION

There is a potential for substantial wave reflection at the coast depending on hydrodynamic and morphological conditions. Understanding the mechanisms at the origin of such reflection and the nature of reflected waves is crucial for various aspects of coastal science including energy balance, standing and edge wave patterns and feedback with incoming waves, and resulting shoreface evolution. Pioneering studies based on laboratory experiments showed a link between reflection and the ratio of wave steepness to beach slope, hence vertical acceleration versus gravity, which can be summarized by the surf-similarity parameter (Battjes *et al.*, 1974).

Field observations have shown that these predictions are poor for irregular waves and complex bathymetric profiles Elgar *et al.* (1994). More recent studies, although mainly focused on engineering structure design (Sutherland *et al.* (1998), among others), have underlined the key role played by swash zone dynamics in controlling the phase and energy of reflected waves. Reflection is linked to a parameter comparing swash "wavelength" with horizontal excursion originally developed by Hughes *et al.* (1995).

Significant research effort has been devoted to energy saturation in the nearshore, the surf zone saturation being linked to the height-to-depth ratio and describing the limit between non-breaking and breaking waves, and the remaining energy being transferred to larger frequencies and non-oscillatory dynamics (*i.e.* setup). Sallenger *et al.* (1985) observe that the height-to-depth ratio might increase with local slope and can be rather independent of deepwater wave steepness. It has been extensively observed that wind- and swell-waves (T<20 s) are generally saturated whereas longer infragravity waves (T>20 s) rarely saturate Ruessink *et al.* (1998) although recent observations have shown that saturation could extend to the infragravity band (Ruggiero *et al.*, 2004; Senechal *et al.*, 2011 and that infragravity wave can be dissipated through breaking (de Bakker *et al.*, 2014). This high-frequency band saturation reflects surf-zone transformations but is also thought to result from non-linear swash zone processes such as swash-to-swash interaction Brocchini *et al.* (2008), bottom friction and infiltration. Supposedly crucial, the link between swash characteristics and reflection has not yet been clearly established, in particular the role of swash saturation for broadband spectra.

In this paper we revisit the link between surf and swash dynamics and reflection from field observations collected at a low tide terraced beach, Grand Popo beach, Benin, in the Gulf of Guinea (West Africa), where largest reflections on earth have been reported (Ardhuin and Roland, 2012). We show that reflection is mostly governed by surf zone saturation over the terrace, whereby the reflected spectrum essentially depends on swash slope.

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METHODS

An intensive field experiment was conducted during March 2014 at Grand Popo, Benin (Gulf of Guinea, West Africa), a sandy coast exposed to South Atlantic long swells (Almar *et al.*, 2014). Grand Popo beach is an intermediate-reflective (Ω>2), micro-tidal, wave-dominated (annual mean, Hs=1.4 m, Tp=9.4 s, SW, RTR~1), medium grain-sized $D50$=0.6 mm, alongshore uniform, low-tide terraced beach (Figure 1). Incoming and reflected waves and tide were measured in 10-m depth, The terrace was instrumented with 2 lines which included pressure sensors, Accoustic Doppler Velocimeters, and two cross shore arrays of 20 video-poles (every m) for measuring at high frequency (25 Hz) wave transformation across surf and swash zones.

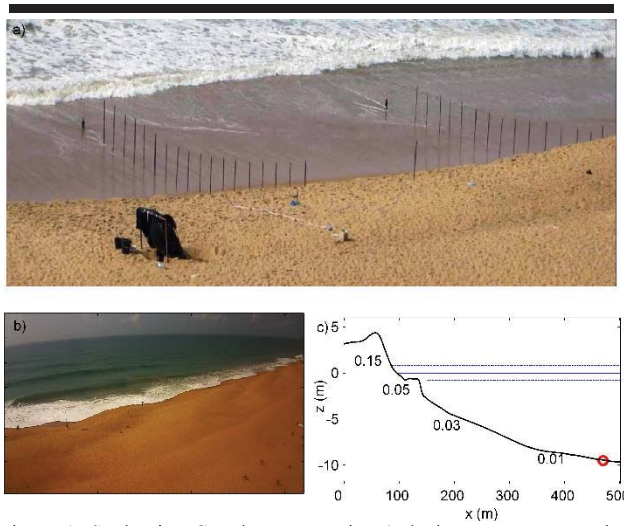

Figure 1. Study site, Grand Popo, Bénin. a) deployment setup on the terrace, b) image from video camera and c) bathymetric profil. Red circle shows ADCP location.

The 10-day experiment included daily differential GPS topographic surveys, deep water (11-m) directional wave measurements using an Acoustic Doppler Current Profiler (ADCP), and shore-based video swash monitoring.

Timeseries of runup were computed from 2-Hz cross-shore video spatio-temporal images collected during daylight hours, and extracted using a Radon Transform method (see Almar *et al.*, 2014a). The 3-colourband timestacks are first converted into grayscale and the Radon Transform is applied to detect motion. This methods offers a reasonable proxy of instant runup motion, although the thin backswash layer can sometimes be missed.

In Results Section, swash zone energy E_{swash} is approximated from the commonly used formula (Guedes *et al.*, 2013):

$$E_{swash}=4\sigma\ S\ \tan\alpha \qquad (1)$$

where S is runup timeseries derived from video and αlocal swash slope. The surf zone dissipation due to breaking $D_{breaking}$is estimated from the roller characteristics following Haller *et al.*, (2009):

$$D_{breaking} = \rho\ gA\sin\theta\cos\theta/T \qquad (2)$$

where g is the gravitational constant, θ a free parameter accounting for roller inclination (taken as ~6° from literature), and T the roller period, and $A= 0.11(L_r/\cos\theta)^2$ with L_r the roller length estimated from cross-shore video spatio-temporal images.

Numerical computations are conducted using the phase resolving fully non-linear 4th-order finite volume Boussinesq model SERR1D (Cienfuegos *et al.*, 2010). This model includes a parameterization for the wave-breaking energy dissipation.
The model has been previously validated with laboratory data for very non-linear conditions on a gently sloping beach (Michallet *et al.*, 2014). The model showed good performances in representing both short-wave dynamic and energy transfer to infragravity band.

RESULTS

Figure 2 shows timeseries of offshore hydrodynamic forcing (wave and tide), shoreface morphological and breaking over the terrace derived from video. Wave height has decreased over time, together with an increase of tidal range and a steepening of the

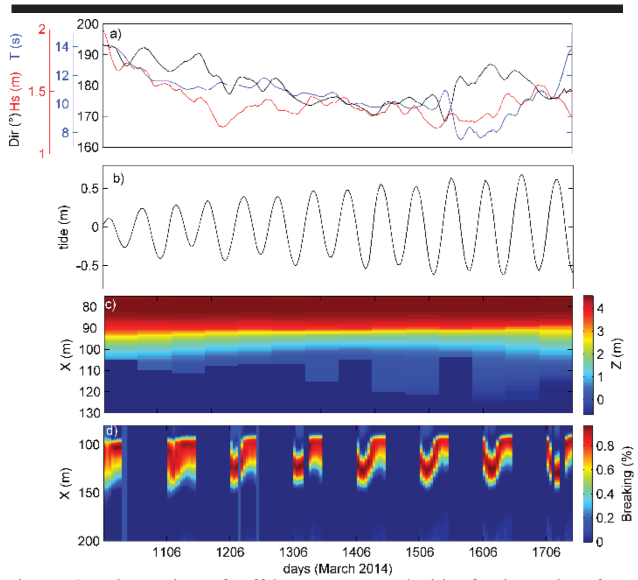

Figure 2: Timeseries of offshore wave and tide forcing, shoreface evolution and breaking over the terrace from video.

upper beach. Breaking over the terrace was largely affected by tidal modulation. Reflection R reaches 8% on average, through varying substantially over time from 4 to 12% (Figure 4).

Influence of surf and swash processes on reflection

The relative contribution of surf and swash zones in the dissipation of wave energy is shown in Figure 3. $D_{breaking}$, E_{swash} and R vary with offshore wave, tide and morphological evolution. A multiple linear regression shows that $D_{breaking}$ and E_{swash} dissipate 71 and 14 % of E_{inc} respectively, though varying substantially over time (from 3 to 12 %, Figure 4.a). E_{swash} can even be predominant at some specific moments, ***e.g.*** at high tide when breaking is weak over the terrace. In the meantime, E_{swash} contribution to R rises up to 62%. This is in line with what has

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been observed elsewhere at dissipative beaches (*i.e.* intense breaking over the terrace), where the surf zone saturation may extend to the infragravity band (de Bakker *et al.*, 2014; Senechal *et al.*, 2011), resulting in a weak dependence of R on the shoreface slope and swash dynamics. For such conditions, the swash could be scaled only through deep-water parameters (Guza *et al.*, 1982), and the beach only introduces more scatter in the regression. The role of swash in modulating the reflected spectrum is investigated in the next section.

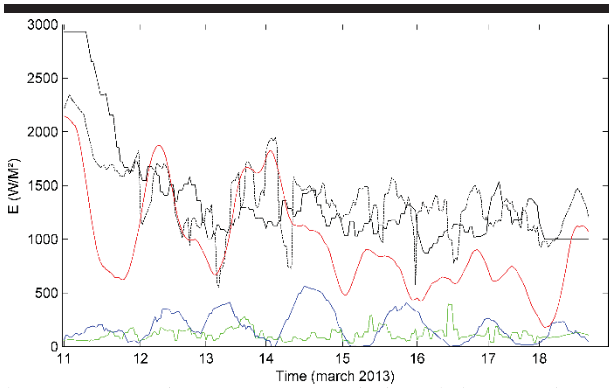

Figure 3. Nearshore wave energy budget during Grand Popo experiment. Incoming energy at 11-m depth (solid black), energy dissipated by the breaking (red), swash energy (blue), reflected energy (green) and reconstructed incoming energy from multiple linear regression (black dashed line).

Reflection cut-off frequency

Swash energy spectra are computed from 20 min of video-derived timeseries. It is noteworthy that the saturation extends into the infragravity band (T>20 s) at dissipative beaches whereas the swell-band might be unsaturated at reflective beaches such as Grand Popo. With the idea of linking swash saturation extent with reflection, and following the method described in Ruessink *et al.* (1998), the lowest saturated frequency is extracted from the spectra (Figure 5) as a swash cut-off period fc_{swash} (Figure 4). The highest reflected frequency $fc_{offshore}$ is also computed from offshore wave directional spectra. A reasonable fit (r^2=0.42, significant at the 95% level) is obtained between fc_{swash} and $fc_{offshore}$ with only a minor bias, $fc_{offshore}$ =0.89 fc_{swash}. This link shows evidence of a feedback between swash dynamics and the whole nearshore domain, which includes incoming and outgoing wave interaction and resulting standing waves.

Contrary to that found for peak swash frequency or outgoing peak frequency (fp), $fc_{offshore}$ appears to be relatively independent of incoming waves. The correlation of $fc_{offshore}$ is larger with α(0.51) than with $f_{offshore}$(0.32).This clearly indicates that $fc_{offshore}$ essentially depends on α and not the incoming waves.

Model validation

The skills of the Serr1D model in describing wave transformation over the terrace and reflection is tested here. The model is first compared to field observations over the full experiment duration. 20-min of surface elevation timeseries from ADCP are propagated over real bathymetry. Figure 4 shows that the model reproduces the frequency transfers that include secondary wave generation at high tide and infragravity at low tide. Reflection (computed using Radon Transform separation, see Almar *et al.*, 2014) is reasonably reproduced, together with breaking intensity over the terrace, estimated from the breaking index $\gamma=H_b/d$, H_b and d being breaker height and depth, respectively. Slope at waterline α values (accounting for tide and wave-induced setup) are similar, despite that bathymetric profile was chosen constant in the model and cannot reproduce the observed flattening trend. This, together with fc_{swash} and $fc_{offshore}$ that show largest discrepancies, need to be further investigated. The model is used in the next Section to investigate the influence of terrace width, upper slope and tide on reflection.

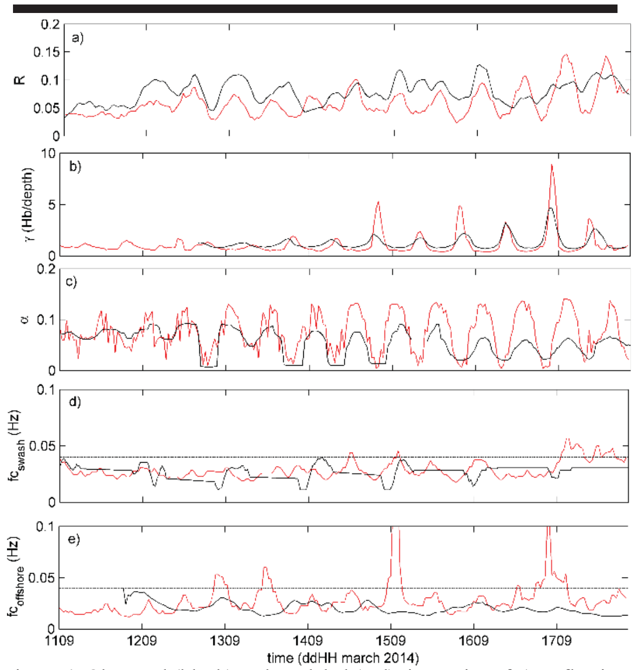

Figure 4. Observed (black) and modeled (red) timeseries of a) Reflection R, b) breaking index $\gamma=H_b/d$, c) shoreface slope α (at the waterline, taking into account for setup and tide) and cut-off frequency computed from d) horizontal runup fc_{swash} and e) offshore spectra $fc_{offshore}$.

DISCUSSION

Once validated, the model is used in Figure 6 to determine the modulation played by the terrace width, upper shoreface slope and tide on the interaction between outgoing and incoming waves in the surf zone. An increase of the terrace width moves the system toward a flatter beach and wider dissipative surf zone, which enhances wave frequency transfer to the infragravity band. Reflected energy increases with the upper shoreface slope, and the cut-off frequency shifts toward shorter periods. The control of outgoing component, through the enhancement/decrease of breaking, on incoming waves increases. As a result, incoming spectrum shifts toward the

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outgoing one and, interestingly, the overall trapped energy increases which is a resonant condition.

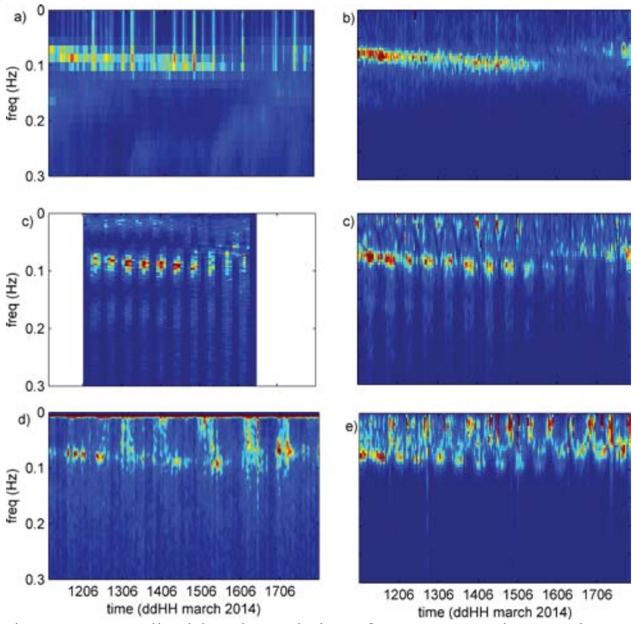

Figure 5. Normalized hourly evolution of spectra over the experiment duration for field (left) observation and (right) model at (upper panels) 11-m depth (ADCP), terrace (pressure sensors) and runup (from video).

CONCLUSIONS

In this paper we investigate the link between swash and surf zone dynamics at the low-tide terraced Grand Popo beach, Benin. Our observations, combining video imagery of swash and surf zone as well as deep water wave spectra, underline the key role played by swash in the reflection (8 % observed) mechanism and feedback on incoming waves which leads to quasi-standing wave or even resonance. Swash contributes to 14 % of nearshore energy dissipation and its link with reflection increases from low to high tide (when breaking is limited). A good agreement was found between a cut-off frequency *Fc* of reflected waves computed from deep water spectra and retrieved from swash saturation (r^2=0.42, $fc_{offshore}=0.89fc_{swash}$). Unlike reflection *R*, *fc* uniquely depends on shoreface slope *α*.

A Boussinesq model was validated with these challenging reflective conditions and showed good skills at retrieving key parameters. The model was later used to investigate the influence of the terrace width, upper slope, and tide on reflected component and its interaction with incoming waves. The most striking influence is played by the upper shoreface slope which closely controls the outgoing waves, but also incoming waves through a positive feedback when frequencies coincide which enhances breaking rate at particular frequencies.

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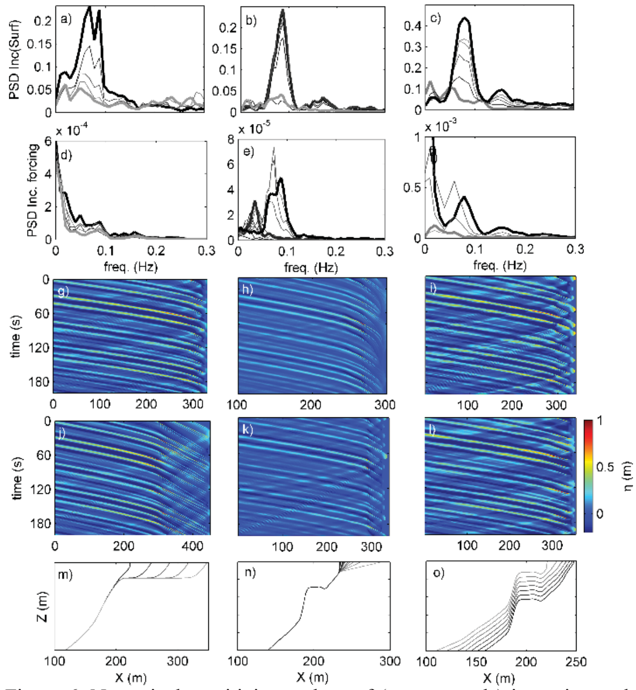

Figure 6. Numerical sensitivity analyze of (upper panels) incoming and (second panels) temporal form of the forcing parameter (see Ruju *et al.*, 2013) $\gamma(t)=\eta_{inc}/(tide+\eta_{out})$ (spectra at the breakpoint)for varying (left) terrace width (from 0 to 60 m), (centre) upper shoreface slope (from 0.01 to 0.15) and (right) tide (from 0.5 to 1.5 m). In upper panels, thick black and grey lines are lowest and largest values respectively of parameters, shown as Hovmoller surface elevation diagram in panels g-l. In lower panels (m-o) are shown bathymetric profiles.

LITERATURE CITED

Ardhuin, F. and Roland, A., 2012. Coastal wave reflection, directional spread, and seismoacoustic noise sources. *J. of Geophysical Research,* 117, C00J20

Almar, R.; Du Penhoat, Y.; Honkonnou, N.; Castelle, B.; Laibi, R.; Anthony, E.; Senechal N.; Degbe, G.; Chuchla, R.; Sohou, Z.; Dorel, M., and 2014. The Grand Popo experiment, Benin, *Journal of Coastal Research*, SI 70, 651-656, ISSN 0749-0208

Almar, R.; Michallet, H.; Cienfuegos, R.; Bonneton, P.; Ruessink B.G., and Tissier, M., 2014. On the use of the Radon Transform in studying nearshore wave dynamics, *Coastal Engineering*, 92, 24-30

Battjes, J., 1974. Surf similarity. *14th Coastal Engineering Conference, Am. Soc. Of Civ. Eng*., Copenhagen, Denmark, 466-480

Brocchini, M., and Baldock, T., 2008. Recent advances in modeling swash zone dynamics: Influences of surf-swash interaction on nearshore hydrodynamics and morphodynamics. *Reviews of Geophysic,s* 46(3), RG3003

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Cienfuegos, R.; Barthelemy, E., and Bonneton, P., 2010a. A wave-breaking model 34 for Boussinesq-type equations including roller effects in the mass conservation equation. *J. Waterw. Port Coastal Oc. Eng.* 136, 10-26

de Bakker, A.; Tissier, M., and Ruessink, B., 2014. Shoreline dissipation of infragravity waves. *Continental Shelf Research,* 72(1), 73–82

Elgar, S.; Herbers, T., and Guza, R., 1994. Reflection of ocean surface gravity waves from a natural beach. *J. Physical. Oceanogr.* 24(7), 1503-1511

Guedes, R.; Bryan, K., and Coco, G., 2013. Observations of wave energy fluxes and swash motions on a low-sloping, dissipative beach. *Journal of Geophysical Research* 118(7), 1–19

Guza, R. and Thornton, E., 1982. Swash oscillations on a natural beach. *J. Geophys. Res.,* 87, 483–491.

Haller, M.C. and Catalan, P., 2009. Remote sensing of wave roller lengths in 325 the laboratory. *J. Geophys. Res.,* 114, C07022.

Hughes, S. and Fowler, J., 1995. Estimating wave-induced kinematics at sloping structures. *Journal of Waterway, Port, Coastal, and Ocean Engineering,* 121(4), 209–215.

Michallet, H.; Ruessink, G.; Rocha, M.V.L.; de Bakker, A.; van der A,D.; Ruju, A.; Silva, P.A.; Sénéchal, N.; Marieu, V.; Tissier, M.; Almar, R.; Abreu, T.; Birrien, F.; Vignal, L.; Barthélemy, E.; Mouazé, D.; Cienfuegos, R., and Wellens, P., 2014. GLOBEX: Wave dynamics on a shallow sloping beach, , *Proceedings of the HYDRALAB IV Joint User Meeting, Lisbon,* July 2014

Ruessink, B.; Kleinhans, M., and Van den Beukel, P., 1998. Observations of swash under highly dissipative conditions. *J.Geophys. Res.,* 103, 3111–3118.

Ruggiero, P. and Holman, R., 2004. Wave run-up on a high-energy dissipative beach. *J. Geophys. Res* C06025.

Ruju, A.; Lara, J.L.; Michallet, H.; Sénéchal, N., and Losada, I.J., 2013. Transient swash motions on a gently sloping beach. *Proceedings Coastal Dynamics,* 2013

Sallenger, A. and Holman, R., 1985. Wave energy saturation on a natural beach of variable slope. *J. Geophys. Res.,* 90-C6/11, 939–944.

Senechal, N.; Coco, G.; Bryan, K., and Holman, R., 2011. Wave runup during 355 extreme storm conditions. *Journal of Geophysical Research – Oceans,* 116, C07032.

Sutherland, J. and O'Donoghue, T., 1998. Characteristics of wave reflection spectra. *J. Waterw. Port Coastal Ocean Eng.,*124(6), 303–311.

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