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Potential of Video Cameras in Assessing Event and Seasonal Coastline Behaviour: Grand Popo, Benin (Gulf of Guinea)

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ABSTRACT

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In this study, we explore the potential of a nearshore video system to obtain a long-term estimation of coastal variables (shoreline, beach slope, sea level elevation and wave forcing) at Grand Popo beach, Benin, West Africa, from March 2013 to February 2015. We first present a validation of the video system with field data over a 10-day experiment conducted on Grand Popo beach in 2014. Secondly, 2-years daily and monthly timeseries are extracted and their variability is described as a function of regional forcing and climatic modes. All variables show large monthly variability. The longshore sediment transport estimated locally from video is in agreement with that derived from Era-Interim wave data re-analyses. Results show that the shoreline responds predominantly to tides at the event scale and to waves. Overall, this study suggests that video stations are efficient tools to monitor coastal processes over the long term, in complement with other conventional approaches. Although no clear conclusions can be drawn on inter-annual variability, the results show that it is important to build up extended coastal observation networks to address coastline changes over a wide range of scales.

ADDITIONAL INDEX WORDS : *Bight of Benin, video remote sensing, shoreline, longshore sediment transport, sea level, waves, tide, regional climate*

INTRODUCTION

Description and understanding of the processes that link coastal dynamics and regional meteorological-ocean forcing is still an important challenge. This must provide insights on the temporal and spatial scales of coastal response and long-term trends in a changing climate. Specifically, the link between high frequency (short-term events, <30 days) and longer term (i.e. inter-annual) evolution remains unclear, due to the lack of appropriate modeling tools to describe these different temporal scales. This can now be partly addressed via shore-based video stations, which allows the important variables of the near-shore environment to be derived at high frequency and large spatial scales.

The Gulf of Guinea coastline, in West Africa, is exposed to South Atlantic high-energy oblique swells which drive strong longshore sediment transport (~500 000 m^{3}yr^{-1}, Almar *et al.*, 2015). This stretch of coast is currently affected by severe erosion that reaches up to 10 m/yr at Cotonou , Benin, attributed to the development of large harbours that trap sand transported alongshore (Dossou and Glehouenou-Dossou, 2007). Recent analysis of model based studies and open ocean altimetry data suggest a large temporal variability of longshore transport and local sea-level elevation with trends reaching -103 m^3/yr (1979-2012 period) and +4.6 mm/yr (1993-2012 period) respectively over recent decades (Almar *et al.*, 2015; Melet *et al.*, 2015). These findings need to be confirmed with direct observations. For this purpose, a permanent low-cost video system was deployed since February 2013 at Grand Popo, Benin.

In contrast with costly in-situ field measurements limited in both time and space, a low-cost video camera-based video system is advantageous in measuring nearshore hydrodynamics

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(waves, tides, setup, currents) and morphology (shoreline, bathymetry and topography) (see Almar *et al*., 2012b; Holman and Haller, 2013). In addition, this video imagery technique offers an interesting alternative to coastal tidal gauges or spatial altimetry, because it can give an estimation of waterline elevation.

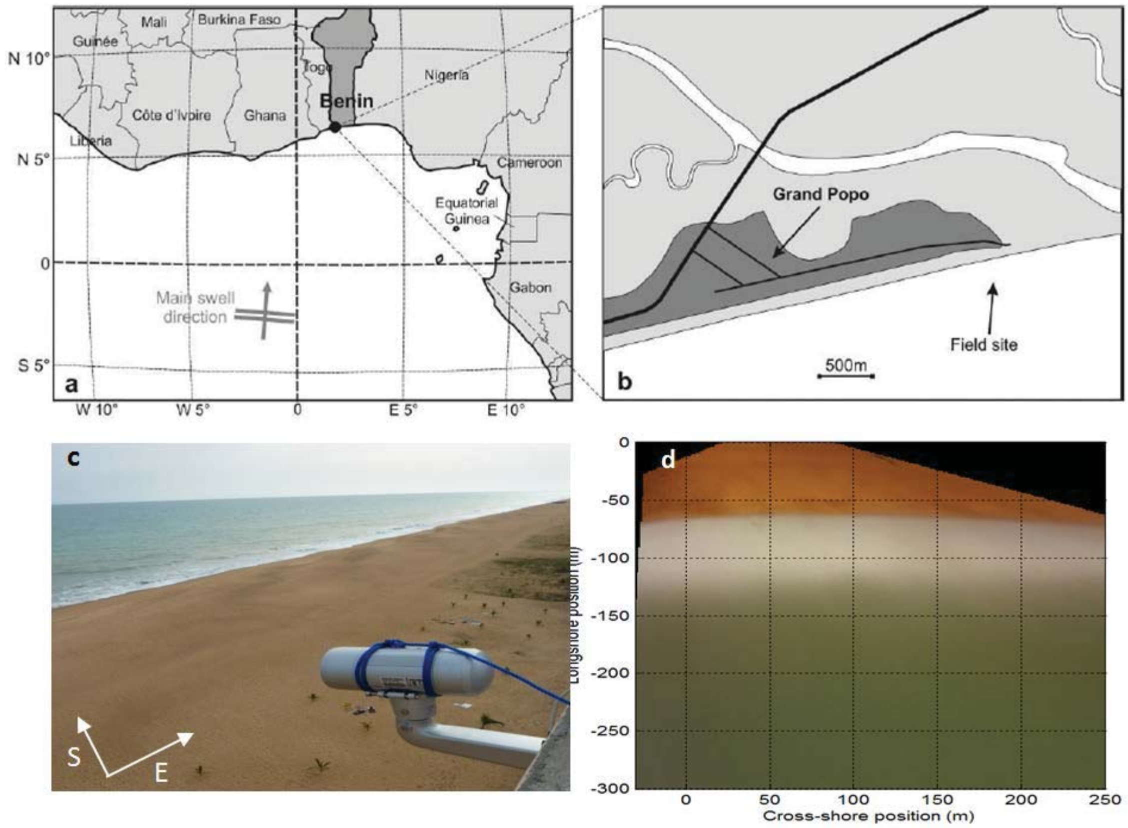

Figure 1.Study site, (a-b) Grand Popo beach in Benin, (Gulf of Guinea, West Africa), facing the South Atlantic.(c) video camera system deployed on a tower made available by the Beninese Navy, and (d) plan shape timex showing the camera field of view. White part is breaking zone and shoreline clearly appears as transition between white to red-band dominated sandy beach.

In this study we explore the potential of nearshore video systems in describing and linking the long-term variability of waves, alongshore currents, sea level elevation and the shoreline. This study includes a comparison with field data over a short period (10 days), which allowed for properly extrapolating the variables over the full observation period. The modes of variability of waves, sea level and shoreline position over the observation period (2.5 years) are analyzed and positioned in a regional climate context.

Site description

The beach of Grand Popo, Benin, is located in the Bight of Benin (Gulf of Guinea, West Africa), an open sandy stretch of coast facing the South Atlantic Ocean. Grand Popo is hardly affected by human presence, hosting only a few fishermen, and far enough (80 km) from the influence of Cotonou and Lome harbours. The beach dynamics are dominated by the influence of waves of moderate energy (mean significant wave height H_s = 1.36 m, mean peak period T_p = 9.4 s) coming from mid-latitude with a S-SW incidence (Laibi *et al*., 2014, Almar *et al*. 2015). Tides are semi-diurnal with a micro to meso-tidal range, from 0.8 to 1.8 m for neap and spring tides, respectively. Sediment size is medium to coarse, 0.4 to 1 mm, (D_{50} = 0.6mm). According to the classification proposed by Wright and Short (1984), Grand Popo is an intermediate Low Tide Terrace (LTT) to reflective beach.

METHODS

In February 2013, a low-cost video system was deployed on a 15-m high semaphore of the navy of the Republic of Benin, 80 m from the shore (which is the approximate beach width). It comprises a VIVOTEK IP 7361 camera (1600 x 1200 pixels) that collects data continuously at 2 Hz. This autonomous system is powered by solar panels. An on-site computer processes the raw images and stores the data. Three types of secondary images are stored: instant, 15-min average and time stacks. Three time stacks are generated (two across-shore and one along-shore, Almar and *al*., 2014).

Two field experiments were conducted at Grand Popo beach, Benin, on February 2013 and March 2014. Field data collected during the Grand Popo 2014 experiment (Almar *et al*., 2016) are used in this study to validate the video system. Measurements included both sea and beach morphological surveys with Differential GPS and bathymetric sonar, while offshore forcing (waves and tide) was characterized using an Acoustic Doppler Current Profiler (ADCP) moored at 10-m depth.

ERAInterim re-analyses (Sterl and Caires, 2005) data were extracted over the 2013-2015 period at the daily scale to compute wave heights at Grand Popo (propagated from deep water to the breakpoint using the formula by Larson *et al*., 2010), and to compute 3 daily indexes standing as proxies of the dominant climatic modes of the South Atlantic. The Inter-Tropical Convergence Zone (ITCZ) and El Nino Atlantic (AMM) were computed from local wind and sea level off Grand Popo, and Southern Annular Mode (SAM) was computed from mid-latitude winds. Longshore Sediment Transport was estimated using the formula by Kaczmarek *et al*., (2005) (see Almar *et al*., 2015).

In this paper, several important nearshore parameters were estimated daily : cross-shore and longshore wave energy fluxes, surface elevation, shoreline location and beach slope. Several video methods were used to estimate the corresponding parameters: wave height (Almar *et al*., 2012a), period and surface elevation (inversed from celerity, see Catalan and Haller, 2008; Stockdon and Holman, 2000) were measured from spatio-temporal images; wave direction and shoreline location were estimated from average images (Almar *et al*., 2012). Determination of the intertidal beach profile involved the delineation of the shoreline at different tidal levels (Aarninkhof *et al*., 2003) and interpolation between low and high tides. Kaczmarek *et al*. (2005) formula is used to estimate longshore current within the surf zone.

RESULTS

Table 1 shows the RMSE errors and the mean error (ME) obtained during Grand Popo 2014 measurements for wave parameters (H_s, T_p and *Dir*), elevation, intertidal topography and bathymetry. The average RMS error of the beach profile is relatively low (0.28 m). The accuracy of the method is within the error range of existing methods (0.3-0.7 m reported in Plant and Kingston, 2007).

Figure 2 shows the comparison for hydrodynamics (wave and tide) using the ADCP data and Era-Interim wave estimates. Errors for H_s, T_p and *Dir* are reasonable though the correlations are rather weak, showing the difficulties in describing high-frequency behavior. The day-to-day dynamics are well captured. It must be noted that ERAInterim estimates show substantial discrepancies (more than 50 % overestimation of H_s and period shorter by 2-4s), which argues in favor of using local video-based measurements rather than hindcast products because of local unresolved effects of bathymetry hydrodynamics (or adverse conditions for the Larson *et al*., (2010) formula).

On the whole, this validation proves that video methods have reasonable errors and can be used in a stand-alone mode for longer-term estimates of waves, sea level and beach morphological evolution.

Beach and forcing evolution over the 2013-2015 period

The five following parameters: cross-shore and longshore wave energy fluxes, surface elevation, shoreline location and beach slope, were computed at daily and monthly scales over the 2-yr period, providing a long enough timeseries to determine the relative contributions of wave and tide forcing to beach response, using a multiple linear regression. In this analyze, waves and tide are considered independent, and the shoreline response approximated as linear, though it might slightly differ (see Davidson *et al*., 2013; Yates *et al*., 2009). Table 2 shows that short-term shoreline evolution is dominated by tidal range modulation (spring/neap tide cycle) while waves are rather steady at this scale (which is typical of a storm-free area). At the seasonal scale, the shoreline responds preferentially to the summer/winter modulation of waves, with larger waves during the southern hemisphere winter.

Table 1. *Comparison of hourly hydrodynamic video estimates and Grand Popo 2014 field measurements. The root mean square error (RMSE) and the mean error (ME) are computed from the difference between the two sets of data. Intertidal profile error computed from 7 daily comparisons.*

Hydrodynamic parameters	RMSE	ME
H_s (m)	0.14	-0.02
T_p (s)	1.31	-0.18
Direction (°)	9.25	2.25
Elevation (m)	0.12	0.02
Intertidal profile	0.28	0.23

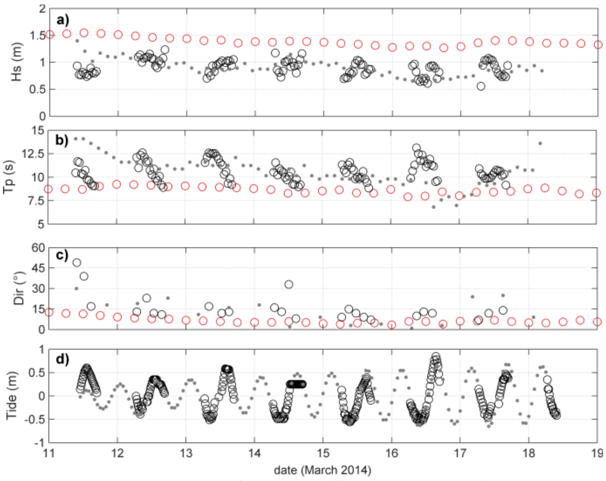

Figure 2. Comparison of 15-min video estimates with Grand Popo 2014 hourly field measurements for (a) H_s, (b) T_p, (c) Dir and (d) tide. Red circles stand for ERAInterim waves propagated to the shore using formula by Larson *et al*., (2010). Grey dots and black circles are in-situ data (ADCP) and video data, respectively.

Table 2. *Relative contribution (percent) of significant wave height and tide to the evolution of shoreline at monthly and event scale.*

Hydrodynamic forcing parameters	H_s (%)	Tide (%)
Monthly scale	72	28
Event scale	21	79

Figure 3 shows that all variables have substantial monthly variability. Wave flux (both cross and alongshore) peak in the southern hemisphere winter, while slope decreases and shoreline retreats. In the meantime, elevation and shoreline behavior seem linked and present a substantial trend, though it is too early to draw significant conclusions.

Since the dynamics of this coastline is dominated by longshore processes (Almar *et al*., 2015; Laibi *et al*., 2014), we computed Longshore Sediment Transport (LST) from locally video-derived wave parameters. Interestingly, results in Figure 4 shows that Era-Interim (from total swell and wind waves) and local estimates are in good agreement, both in average value (444397 and 496993 m^3/yr, respectively) and variability, though some discrepancies exist (RMSE=0.23).

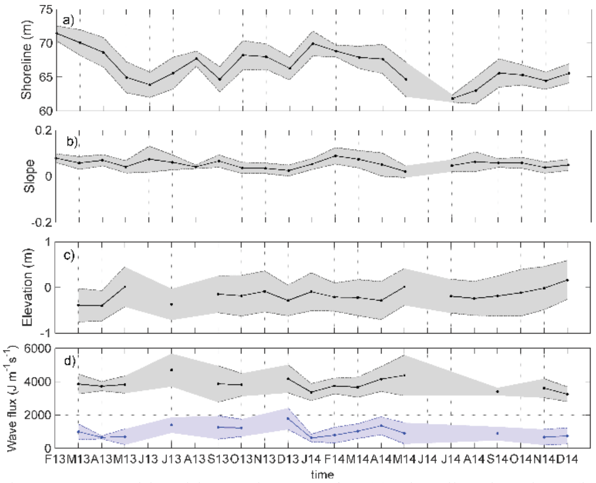

Figure 3. Monthly video estimates of : (a) shoreline location, (b) beach slope, (c) surface elevation, and (d) wave energy flux, cross-shore in grey and longshore in blue. Shaded zones stand for day-to-day dispersion (standard deviation).

Even though it is too early to determine the influence of regional climatic modes, SAM, ITCZ and AMM (Almar *et al*., 2015) (Figure 5) on these coastal variables, our paper puts forward the potential of video-based techniques for such long-term oriented investigations.

DISCUSSION AND CONCLUSIONS

In this paper, 2 years of video observations at Grand Popo, Benin, analysed using recently developed methods, were employed to estimate the main nearshore parameters: wave height, period and direction, surface elevation, bathymetry and topography, as well as shoreline change. These estimates were compared to field observations collected during the 10-day Grand Popo 2014 experiment and showed reasonable agreement. This shows the ability of low-cost video imagery in continuously and quantitatively monitoring a large number of key coastal variables over long durations, pending substantial errors that need to be further quantified, and ultimately reduced. In particular, the measurement of sea level brings new

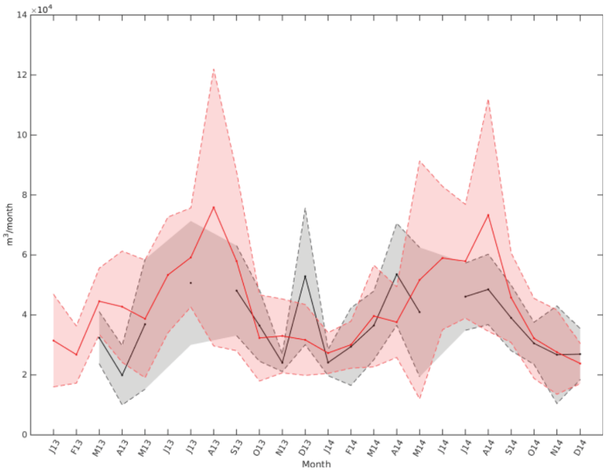

Figure 4. Monthly video estimates of Longshore Sediment Transport estimated using the Kaczmarek *et al*. (2005) formula, computed from (red) ERA-Interim re-analyses (using Larson *et al*., (2010) for wave propagation to the shore) and (black) video estimates. Shaded zones stand for day-to-day dispersion (standard deviation).

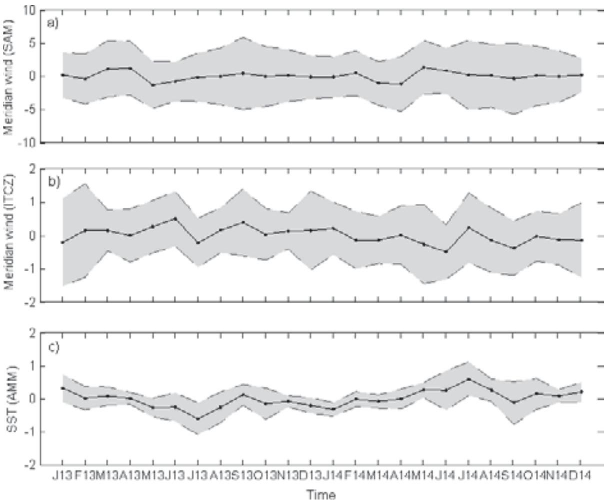

Figure 5. Monthly video estimates of proxies for regionally climatic modes : (a) meridian wind in the South Atlantic (SAM), and (b) meridian wind (ITCZ) and (c) Surface Sea Temperature (AMM) in the Bight of Benin computed from daily Era-Interim re-analyses. Shaded zones stand for day-to-day dispersion.

perspectives in the assessment of tidal harmonics in remote or hazardous areas where the deployment of buoys encounter difficulties. Also, it has to be pointed out that, in contrast with tidal gauges or spatial altimetry, this technique provides the actual shoreline elevation, which includes all regional and coastal components of sea level (including wave-induced setup and run-up), a key aspect in assessing coastal vulnerability.

All studied variables show substantial variability at the monthly scale, wave energy peaking in the southern hemisphere winter when waves are larger in the South Atlantic Ocean. Interestingly, shoreline and elevation behavior seem to be strongly linked. In this storm-free area, elevation preferentially controls shoreline response at the short-term scale while waves dominate monthly shoreline evolution.

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