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Observations of wave run-up and groundwater seepage line motions on a reflective-to-intermediate, meso-tidal beach

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ABSTRACT

Swash (SW) and ground water seepage line (GWSL) motions have been recorded at an exposed, meso-tidal, reflective-to-intermediate beach, using a coastal video monitoring system, during a 15-month period. The monitoring period allowed the collection of imagery under a wide variety of wave and beach-morphological conditions and SW and GWSL velocities were extracted on a wave-by-wave basis. The continuous, double-bounded Kumaraswamy (Kw) probability distribution is proposed to parameterize the SW and GWSL height distributions and since the distribution shape of the latter was shown to be influenced by the tidal elevation, generic, tidal elevation-dependent Kw PDFs are proposed. The beach-face slope, more than any other factor tested, was found to apply certain control to the mean uprush, backwash and GWSL velocities. The results also indicate that in reflective-to-intermediate beaches, the GWSL lies between the mean and 2% exceedance swash elevation; with the occurrence of swash running above a saturated beach-face being controlled by the tidal gradient and the significant wave height.

1. Introduction

The swash zone is probably the section of highest interest for engineers, geologists and managers working on the coastal zone; being the most frequently accessed part of the beach, where morphological changes can be frequent (e.g. Houser and Barrett, 2010; Vousdoukas et al., 2012a), 3-dimensional (Vousdoukas, 2012; Poate et al., 2013) and tidally modulated (e.g. Masselink et al., 2009; Puleo, 2009). At the same time, wave runup is a common hazard factor for beaches and barrier islands through overwash (e.g. Baldock et al., 2005; Lindemer et al., 2010) and an essential factor to be considered for the effective design of coastal protection works (e.g. Briganti et al., 2005; EurOtop, 2007), beach nourishment projects (e.g. Dean, 2001), the prediction of storm wave, surge and tsunami effects (e.g. Korycansky and Lynett, 2007) and the planning of efficient coastal management schemes (e.g. Munoz-Perez et al., 2001; Xue, 2001; Kroon et al., 2007).

Given that uprush events typically result in onshore sediment transport, an effect contrasting to backwash, the net sediment transport is influenced — among other factors — by the statistical properties of the swash velocities (Hughes et al., 2010) and in particular the skewness (Masselink and Russell, 2005; Pritchard and Hogg, 2005). At the same time, interactions between swash events are very important not only in controlling the distribution of the swash maxima (Guedes et al., 2011), but also in entraining sediment and affecting the swash zone morphodynamics (Cáceres and Alsina, 2012).

Knowing the probability density function (PDF) of swash heights is important for predicting the total run-up height, especially in studies based on scenarios and statistical approaches to predict vulnerability (Callaghan et al., 2008; Hinkel and Klein, 2009; Almeida et al., 2012; Vousdoukas et al., 2012b). Similarly, such knowledge is required for stochastic simulations of beach morphological response (Baldock et al., 2008), given that phase-resolving numerical approaches remain computationally expensive and are still restricted to academic use and/or small scales (del Jesus et al., 2012; Higuera et al., 2013; Torres-Freyermuth et al., 2013). Therefore, it is not surprising that several decades ago researchers started to study and propose theoretical run-up height distribution models initially for idealized linear profiles or structures (e.g. Saville, 1964; Ahrens, 1979; Ryu and Kang, 1990) and later also for natural beaches (Sawaragi and Iwata, 1984; Nielsen and Hanslow, 1991; Holland and Holman, 1993; Hughes et al., 2010). Most of the previous studies support the Rayleigh distribution earlier proposed by Battjes (1971).

The proposed PDFs are based on the early assumption of Cartwright and Longuet-Higgins (1956) that the water level time series can be

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formed from the linear superposition of sinusoids of random phase and that the water level variations can be expressed by a Gaussian distribution (Ochi, 1998); however, Holland and Holman (1993) have demonstrated that the nonlinearities are responsible for the deviation of real distributions from the theoretical ones. Moreover, several previous studies have identified parameters affecting the shape of measured run-up height PDFs, including the spectral width (Ryu and Kang, 1990; Holland and Holman, 1993) and the tidal elevation (Guedes et al., 2011), while Guza and Feddersen (2012) using numerical modeling recently demonstrated that run-up heights can be strongly affected by the wave period and directional spread.

There is consensus among the coastal community that swash zone hydro- and morpho-dynamics are interacting with groundwater dynamics, with the latter affecting among others, the swash water mass and momentum, boundary layer processes, and sediment mobility (Turner and Masselink, 1998; Butt et al., 2001; Elfrink and Baldock, 2002; Horn, 2006). The above interactions are expected to play a more important role at — more porous — coarse grained beaches and/or barrier islands (Austin et al., 2013), but despite ongoing efforts there are substantial knowledge gaps. From that perspective, the relative position of the swash with the interface between the unsaturated and saturated beach face is an important parameter, controlling the percentage of time that swash is taking place over a saturated bed and consequently sediment dynamics (Turner, 1995; Baird and Horn, 1996).

Coastal imagery from stationary or portable video monitoring systems has been established as a standard way to track the swash extrema position through timestack images (Aagaard and Holm, 1989) and knowledge of the beach-face topography during the image acquisition allows the extraction of the horizontal and vertical swash positions and velocity components. At the same time, coastal imagery, even though not providing measurements inside the porous sediment body, can allow the tracking of the interface between the unsaturated and saturated beach face, known as 'swash water table exit point' (Puleo, 2009), or 'groundwater seepage line' (Huisman et al., 2011); referred to as GWSL hereinafter. The above studies allowed the finding of dependencies between the swash and GWSL, as well as the waves, tides and rainfall and have highlighted that coastal imagery offers great potential for studying, understanding and quantifying several of the above interesting interactions.

Against the foregoing background, the present contribution aims to discuss observations of swash (SW) and ground water seepage line (GWSL) motions, during 15 months, at an exposed, steeply-sloping beach. The continuous, double-bounded Kumaraswamy distribution is proposed, for the first time, to describe the SW and GWSL distributions, as well as their dependence on various parameters, such as wave forcing, tidal elevation and beach morphology. Moreover, the observations result in fresh knowledge on GWSL dynamics and the interactions with waves, tides, and SW on reflective-to-intermediate beaches.

2. Study area

Faro Beach is part of the Ancão Peninsula (South Portugal), a mesotidal, NW–SE-oriented sand barrier (Fig. 1), with semi-diurnal tides; average range of 2.8 m for spring-tides and 1.3 m during neap tides, with maximum range reaching 3.5 m (e.g. Ferreira et al., 2006). The offshore wave climate is moderate to high, with an average annual significant offshore wave height $H_s = 0.92$ m and average peak wave period $T_p = 8.2$ s (Ferreira et al., 2009). Waves are mostly west–southwest (occurrence 71%), while shorter period SE waves generated by regional winds are also frequent (23%) (Almeida et al., 2011). Storm events in the region are considered as those in which the significant offshore wave height exceeds 3 m (Vousdoukas et al., 2012a,b); such events typically correspond to less than 2% of the offshore wave climate (Almeida et al., 2011).

Faro Beach is characterized by a steep beach-face, with an average slope of around 10% and varying from 6% to 15% (Vousdoukas et al., 2011a, 2013), while part of the ocean front has been artificially stabilized with walls, which are often overwashed during spring tides, and/or storms (Almeida et al., 2012). The western part, discussed

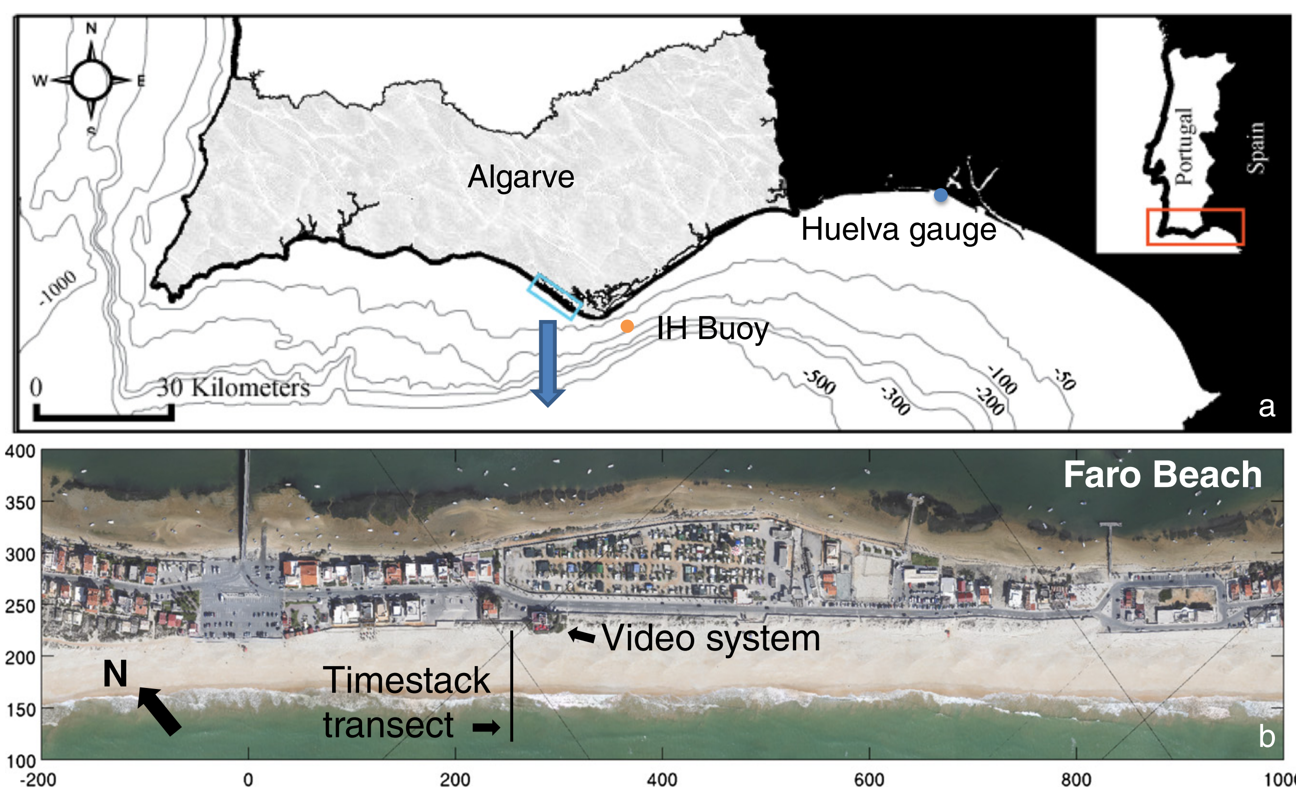

Fig. 1. Map of the study area showing Algarve (S. Portugal), the location of Faro Beach, as well as of the wave buoy and tidal gauge (a); aerial photograph of Faro Beach showing the locations of the ORASIS monitoring station, and the monitoring transect.