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# Runup estimations on a macrotidal sandy beach

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ABSTRACT

This paper presents a methodological approach to calculate runup from the analysis of morphodynamic conditions on a macrotidal sandy beach. The method is based on measurements of the elevation of high-tide deposits and on the analysis of morphological and hydrodynamic changes. A series of measurements has been carried out on the beach of Vougot (Brittany, France) under different wave conditions. This allowed to assess runup formula effectiveness on a macrotidal sandy beach and to determine the best slope parameters to estimate runup. The results suggest that on that macrotidal sandy beach the slope of the active section of the upper beach should be used instead of the entire slope of the foreshore, the latter resulting in an underestimation of runup elevations when used in predictive equations from the literature. Results obtained with widely used equations are relatively well correlated with observed values ($r^2=0.63$). An analysis of the relationship between observed runup elevations and various variables has enabled the establishment of a runup estimation formula with a relatively good fit to the study site ($r^2=0.86$).

## 1. Introduction

Runup, defined as the difference between discrete water elevation maxima and still water level, is a process that can generate extreme water levels (Bellomo et al., 1999; Benavente et al., 2006; Komar, 1998; Matias et al., 2012; Ruggiero et al., 2001). Runup is a key factor during coastal erosion processes, when swash reaches the toe of the dune (Erikson et al., 2007; Fisher and Overton, 1984; Larson et al., 2004; Van de Graaff, 1986) or barrier (Ruggiero et al., 2001; Sallenger, 2000; Stockdon et al., 2007). Wave overtopping over a barrier (Donnely et al., 2006; Orford et al., 1991; Sallenger, 2000) or a coastal structure (De Rouck et al., 2005; Van der Meer and Janssen, 1995) depends widely on runup processes too. Many studies based on laboratory and in-situ measurements of runup have shown that runup is a function of beach steepness ($tan\beta$) deep water wavelength ($Lo$) and significant wave height ($H_{mo}$), and thus Iribarren number (Battjes, 1974; Hunt, 1959). The first relation found by I.A. Hunt in 1959 was:

$$R = H_{mo}\xi_o \tag{1}$$

where $R$ is the runup (in m) and $\xi_o$ is the Iribarren number with

$$\xi o = tan\beta/(H_{mo}/Lo)^{1/2} \tag{2}$$

where $H_{mo}$ is the significant wave height, $Lo$ is the deep water wavelength and $tan\beta$ is the beach steepness.

A constant $C$ has been added by Battjes, 1971. This constant varies according to the morphodynamic context, defined by Iribarren number ($\xi_o$):

$$R = CH_{mo}\xi_o. \tag{3}$$

From this basic relation, several equations have been proposed to estimate runup on different types of beaches. These studies have been carried out exclusively in micro or mesotidal environments (Table 1).

Many authors have taken into account runup process to estimate extreme water levels on macrotidal sandy beaches (Sabatier et al., 2009; Stéphan et al., 2010; Suanez, 2009; Suanez and Cariolet, 2010; Suanez and Stéphan, 2006). However, without any available in situ measurements in macrotidal sandy beaches, runup was estimated with equations parameterised in micro or mesotidal environment (Table 1).

As explained previously, runup is partially a function of beach slope (Komar, 1998). On a natural beach, the meaning of the term «beach slope» is fuzzy (Holman and Sallenger, 1985; Nielsen and Hanslow, 1991; Stockdon et al., 2006). For instance it is difficult to define a single slope value on concave beaches and beaches with sand bars (Stockdon et al., 2006). Some authors suggest using the slope of the surf zone (Holman and Sallenger, 1985; Nielsen and Hanslow, 1991). Nevertheless, the use of such parameter is not easy because breaking waves dynamic is still not completely known, especially where bathymetry is complex (Nielsen and Hanslow, 1991). For this reason, it is recommended to use the

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**Table 1**
List of the principal equations used to calculate runup, beach type for the use of each equation and tidal range of the study sites where equation were parameterised.

| Study | Equation | Beach type | Tidal range of the study site(s) |
|---|---|---|---|
| Holman (1986) and Nielsen and Hanslow (1991) | $R_{2\%}=0.92\ H_{mo}\xi_o$ (4) | $0.026<tan\beta<0.14$ | Microtidal |
| | $R_{max}=1.07\ H_{mo}\xi_o$ (5) | | |
| Mase (1989) | $R_{2\%}=1.86\ \xi^{0,71}H_{mo}$ (6) | $0.03<tan\beta<0.2$ | Microtidal |
| Ruggiero et al. (2001) | $R_{2\%}=0.27(tan\beta H_{mo}L_o)^{½}$ (7) | $0.005<tan\beta<0.025$ | Mesotidal |
| Stockdon et al. (2006) | $R_{2\%}=0.043(H_{mo}L_o)^{½}$ (8) | $\xi_o<0.3$ | Microtidal and mesotidal |
| | $R_{2\%}=1.1\left(0.35\beta(H_{mo}L_o)^{1/2}+\frac{\left[H_{mo}L_o\left(0.563\beta_f+0.004\right)^{1/2}\right]}{2}\right)$ (9) | $0.3<\xi_o<1.25$ | |
| | $R_{2\%}=0.73tan\beta(H_{mo}L_o)^{1/2}$ (10) | $1.25<\xi_o$ | |

foreshore slope, that is to say the slope of the intertidal zone (Nielsen, 2009; Nielsen and Hanslow, 1991; Stockdon et al., 2006).

In macrotidal environment, the calculation of the foreshore slope is problematic because the intertidal zone is often vast and rarely homogeneous. Macrotidal foreshores are characterised by an overall concave-upward profile with a steep upper profile and a low-gradient dissipative low tide terrace. It appears that morpho-dynamic model or index such as the model of Masselink and Short (1993) or the Iribarren number ($\xi_o$) is unadapted for macrotidal beaches, the upper beach and the low tide terrace having different morpho-dynamic behaviours (Anthony et al., 2004; Masselink and Hegge, 1995; Sedrati and Anthony, 2007; Wright et al., 1982). Indeed the average foreshore slope does not reflect reality since it may vary greatly from the lower to the upper beach in macrotidal environment (Fig. 1). Runup values can thus be greatly modified.

A previous study on the macrotidal sandy beach of Porsmillin (Brittany, France) has been conducted (Cariolet, 2011). The foreshore of this cove beach is 200 m wide and composed of mid sands (median = 320 μm). With a maximal tidal range of 7.2 m, the mean foreshore slope has a value of $tan\beta=0.037$. This sandy beach may be considered, on morphodynamic grounds, as an intermediate type with a reflective upper beach ($0.05<tan\beta<0.08$) and a dissipative low tide terrace ($0.02<tan\beta<0.035$). This beach is characterised by the seasonal presence of a berm and intertidal bars (Dehouck et al., 2009). The active section of the beach – section where greatest altitudinal variability is observed – is located between the toe of the dune and a slope break sited at around 90 m from the dune toe. During the field campaign, $H_{mo}$ calculation has varied from 0.2 m to 3.1 m (average = 1.21 m), for a period between 6 and 16 s (mean period = 12.5 s.). The study has shown that runup values calculated with the foreshore slope underestimate reality. Calculation of runup using the slope of the active section of the beach resulted in more reliable results when compared with observed values. The results also show that on Porsmilin beach, $H_{mo}\xi_o$ is the best correlated morphodynamic variable with runup using the slope of the most mobile section of the beach ($r^2=0.72$). A new equation $R_{max}=1.09\ H_{mo}\xi_o$ has been calibrated for the beach of Porsmillin and gives better results than classic equations, with a mean deviation of −0.04 m, a root-mean-square error of 26 cm and a coefficient of determination that is equal to 0.72 (Cariolet, 2011).

The aim of the present study is to verify these first results with additional measurements on another macrotidal sandy beach. Another objective is to validate the method based on the study of statistical relationships between runup and morphodynamic variables. This method could help to better characterise this process on macrotidal sandy beaches and thus to propose adapted equations. For this study, a series of morphologic and water level in-situ measurements has been carried out on the macrotidal sandy beach of Vougot (Brittany, France).

## 2. Study site: morphologic characteristics

The beach of Vougot is located in the district of Guisseny (North coast of Brittany, France) and stretches over about 2 km facing north-west (Fig. 2). The foreshore is composed of mid sands (250 to 315 μm) and is bordered by a 13 m high dune (Suanez et al., 2012). During spring tides, the beach is 300 m wide and the maximal tidal range is 9 m. The morphological dynamic of the beach has been studied since 2004, with a monthly monitoring along a transect (Suanez and Cariolet, 2010).

The average foreshore slope is low ($tan\beta=0.016$) (Suanez et al., 2007). Along the studied transect, morphological changes decrease from the upper to the lower section of the beach (Fig. 3a and b). It

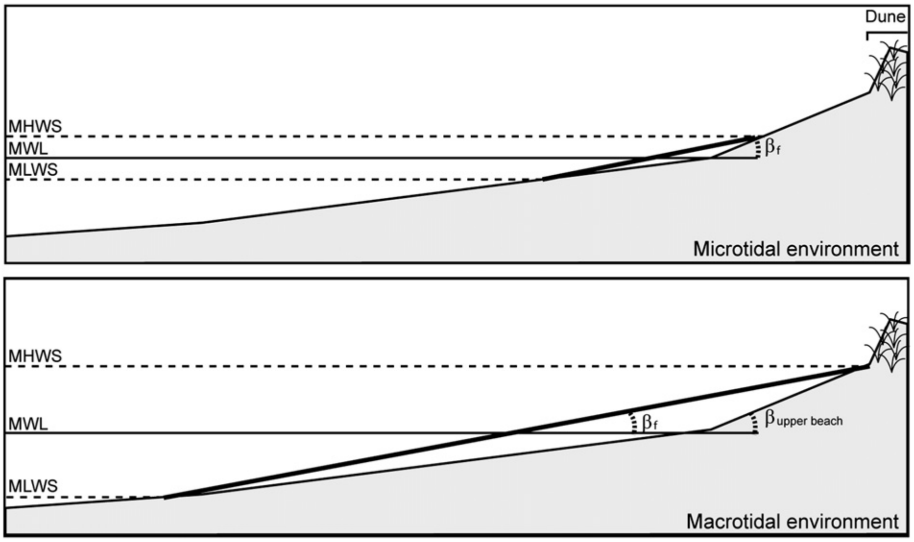

**Fig. 1.** Diagram representing the different types of slope on a beach regarding the tidal range. In microtidal environment, the foreshore slope ($\beta_f$) is calculated on a shorter distance than in macrotidal environment.