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# Long-term tidal level distribution using a wave-by-wave approach

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**Abstract**

Tidal analysis is usually performed in the time domain by means of the decomposition of the time series of the free surface in a number of harmonics, characterizing every single component along a shelf or inside an estuary. Although this kind of analysis has proven to be very useful in numerous studies, when it comes to characterizing the tide statistically (i.e., the long-term sea level distribution) this approach is inadequate. This paper presents a different approach. Instead of working with the complete time series, some statistical properties of the signal, such as the probability density function (pdf) of the tidal wave heights (TWH) are used. The tidal elevation (TE) pdf is obtained by means of a statistical procedure that consists of the definition of the compound pdf as a function of the TWH pdf and the U-shaped pdf for the elevations of a single wave. In order to have an analytical representation of the probability density functions, the use of kernel density functions is explored. An extension to account for asymmetries in the tidal elevations is also proposed. Both, the symmetric and the asymmetric models are applied to different tide gauge data along the World's coastline (symmetric and asymmetric – positive and negative skewed –). The results show that the symmetric approach is capable of representing the TE pdfs for roughly symmetric tides. However, in shallow areas where the distortion of the tide is more pronounced, the asymmetric model provides a better description of the TE pdfs.
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*Keywords:* Tidal elevation; Tidal range; Statistical analysis; Tidal asymmetry; Nodal cycle; Probability density function; Kernel density model

## 1. Introduction

Knowledge of sea level fluctuations in a bay or estuary has been the key stone of many scientific studies and estuarine restoration and protection projects. Designing a channel entrance with navigation criteria, establishing flood defences, preventing shoreline erosion and, in general, any man-made alterations to these systems require the determination of sea level. Sea level analysis in tidal dominated embayments, has traditionally been performed through the calculation and prediction of tides and currents. Usually, this has been done decomposing a tidal record into a number of harmonics constituents [7,3,6,8,12,24]. However, the study of tidal records from a statistical point of view is increasingly used in different applications.

Due to the increasing awareness of the ecological importance of wetlands and coastal aquifers, environmental studies, guidelines or even political strategies aimed at the restoration of these usually degraded habitats, are being developed in several countries [4,25,17,14,13]. Frequency and duration of flooding or soil saturation, water permanence and water regime are key factors in describing the hydrology of these systems [22,15].

Moreover, studies of extreme water levels using the joint probability of surge and tide require a proper determination of the probabilistic distribution of tidal elevations. Also, the importance of tidal asymmetries in the transport and accumulation of sediments in estuaries demands a statistical study of tide. Accordingly, the probability density function (pdf) of the tidal elevation (hereafter, TE) is

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increasingly used to statistically describe the tide at a specific location [23,19,26].

In this paper, the statistical distribution of tidal levels, hereafter also named long-term water level distribution, is examined in more detail. A statistical approach is presented to be applied in the study of areas with predominantly semidiurnal tides. The novelty here is that, instead of working with the complete time series, we will make use of some statistical properties of the signal. The main assumption is that a free surface tidal record can be represented as a consecutive series of waves with different wave heights (tidal range) and wave periods (tidal period). Therefore, although the time scales are very different, a parallelism between the short-term probabilistic description of the free surface in a sea state (1 h) and the analysis of a tidal record (years) is explored.

## 2. Tide gauge data

As an example of statistical analysis of tidal records, Fig. 1 shows the TE pdfs, relative to the mean sea level (MSL) for several semidiurnal tidal records located along the World's coastline: Santander and Bonanza in Spain, Newlyn and Sheerness in England, Delfzijl in the Netherlands, Bremen in Germany, New Brunswick in Canada, Boston in USA and Heywood Shoal in Australia. Data from Spanish tidal gauges are obtained from Puertos del Estado (Ministerio de Fomento, Spain) and the rest of the data are extracted from X-tide package (http://www.flaterco.com/xtide/). Table 1 summarizes the main characteristics of each tide gauge location.

To obtain these distributions, long tidal series are needed (at least 18.6 years to include nodal modulation) [10,5]. If a sea level record of this length is not available, harmonic analysis is usually applied to the tidal signal, taking into consideration the nodal corrections. According to this, Fig. 1 shows the corresponding TE pdfs associated to tide level records at 0.05 h intervals over a 19-year period for each location. The chosen locations exhibit different tidal ranges (varying between 3.5 m at Bonanza and more than 8.0 m at New Brunswick) and pdf shapes. Eight of the nine pdfs present a bimodal distribution with the most probable levels at mean high water neaps and mean low water neaps. Note that, while in Newlyn and New Brunswick it can be assumed that these two peaks are symmetric with regards to the MSL, in the rest of locations the tide asymmetry is more evident. Moreover, in Bonanza and Delfzijl, where the shallow water effects become important, the asymmetry can be also observed in the lowest and highest astronomical tide level. Also it is interesting to observe that these two locations have the skewed distribution peaking on a different side of the MSL. The TE pdf at Heywood

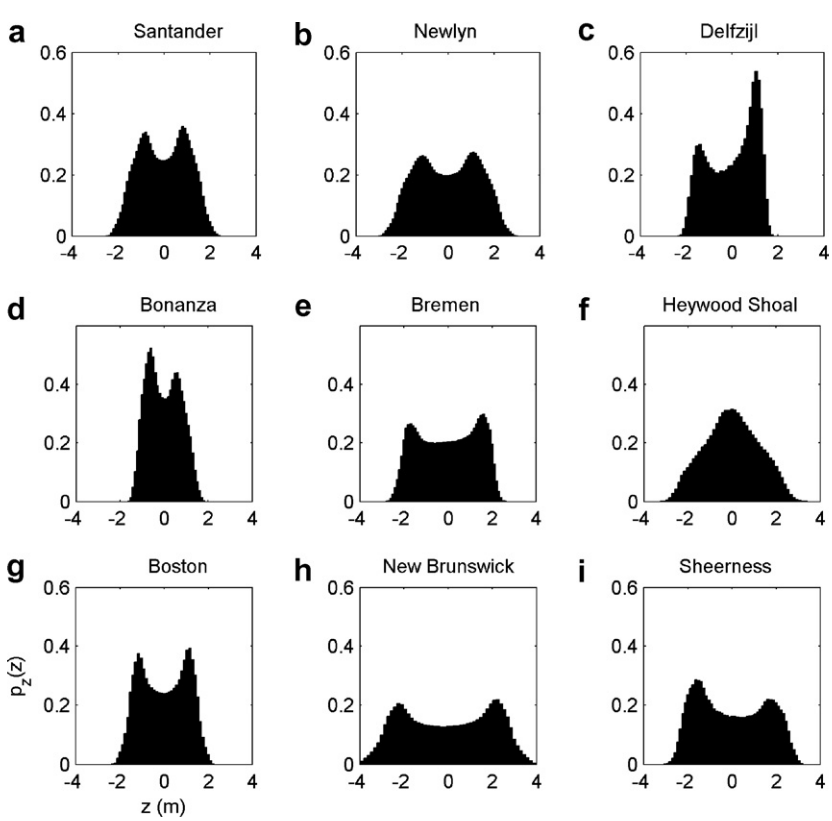


Fig. 1. TE pdfs at (a) Santander in Spain, (b) Newlyn in England, (c) Delfzijl in the Netherlands, (d) Bonanza in Spain, (e) Bremen in Germany, (f) Heywood Shoal in Australia, (g) Boston in USA, (h) New Brunswick in Canada, and (i) Sheerness in England. Tidal level above mean sea level. Data from Spanish tidal gauges are obtained from Puertos del Estado (Ministerio de Fomento, Spain); rest of data: from X-tide package (http://www.flaterco.com/xtide/).

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