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Spatial variability of extreme wave height along the Atlantic and channel French coast

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ABSTRACT

The knowledge of wave climate, and more particularly of the extremes and historical large wave events, is crucial for offshore infrastructure design as well as coastal applications such as defences design or submersion and erosion risks assessment. When it comes to analysing the spatial variability of extremes, a key issue is to ensure a uniform approach to get spatially comparable results. The present paper describes a new wave extreme values database for the French Atlantic and Channel coasts (BoBWA-X) relying on: (1) the wave hindcast BoBWA-10 kH (1958–2002; Charles et al., 2012. J. Clim. 25 (6), 2020–2039. doi:10.1175/JCLI-D-11-00086.1); (2) a POT/GPD method adapted to reduce the operator subjectivity in the threshold choice so as to ensure reproducible and comparable results along the coasts. The obtained extreme wave heights of 43 points distributed along the coast, exhibit a significant spatial variability delimiting 4 relatively homogenous areas, with 100-year return wave heights ranging between 3 m (East Cotentin) and 16 m (Western Brittany). These spatial distributions are analyzed in terms of spatial variability of the statistical parameters, using a depth-independent analysis and 7 quite homogeneous coastal segments are identified. The delimited segments are directly related to the wave climate and the exposure to classical storm waves. Therefore, they show similar repartition frontiers with the delimited areas by the H_{s100} spatial variations but with a higher degree of precision. The analysis of past events over the 1958–2002 period of the BoBWA-10 kH dataset shows 7 events characterized by wave heights with return periods larger than 50 years. The extent and intensity of these events vary greatly from one zone to another. For instance, the 1979 event affected 950 km of coast. Brittany is a particularly exposed region, with two events (1958, 1990) whose H_s return period ($R_p(H_s)$) ranges between 70 and 100 years. The highest return period is detected in the Dover Strait area ($R_p(H_s)=$ 107 years) during the Daria storm (January 25th 1990). The spatial variability of these large wave events is discussed regarding the atmospheric conditions and their similarities with classical weather types. Both databases (BoBWA-10 kH and BoBWA-X) are available at http://bobwa.brgm.fr.

1. Introduction

Accurate knowledge of extreme wave heights and their return periods is of critical importance for the design of offshore infrastructure, coastal defences or assessments of submersion and erosion risks. Large wave events are frequently associated with severe weather conditions such as storms circulating directly to the coast or occasionally far from the point of interest. When considering several sites, the definition and characterization of large wave events can vary widely, depending on the sites exposure and on average wave patterns.

Today, studies analysing significant wave height (H_s) extreme values at local scales are performed routinely, providing data on wave conditions for different return periods according to specific coastline characteristics (e.g. Méndez et al., 2006; Martucci et al., 2010). However, results are dependent on the initial data and the selected statistical methods (Mathiesen et al., 1994). Consequently, return values obtained for a same point but from different studies can vary widely (e.g. Bulteau et al., 2013a), making them difficult to interpret.

One approach to deal with this issue is the Regional Frequency Analysis (RFA). It consists in pooling together observations from several sites inside a homogeneous region, assuming that the highest observations in that region follow a common regional

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probability distribution, up to a local scale factor representing specific characteristics of each site (Bernardara et al., 2011). This approach can reduce uncertainties and was recently set up to estimate extreme marine water levels (Duluc et al., 2014; Weiss et al., 2014b) and extreme significant wave heights (Weiss et al., 2014a). It is especially useful when dealing with short times series as it artificially increases the duration of observation. However, this approach raises the issues of the definition of homogeneous regions and the inter-site dependency.

Another approach entails treating local points of a given dataset with a homogenous statistical method, enabling one to delineate *a posteriori* homogeneous areas in terms of extremes. A prerequisite to this method is the availability of long term and homogenous databases at regional or national scale to properly consider the variability of wave characteristics along the coasts (Neelamani et al., 2007; Méndez et al., 2011; Reguero et al., 2013). Such databases are now available thanks to the production during the last decade of global or regional wave hindcasts through wind wave numerical modeling based on meteorological reanalysis.

There are many parametric statistical laws that can be used to determine extreme values from a sample of data. Generally, the most relevant statistical law and method are selected according to the specific distribution characteristics. Those mainly used are the Generalized Extreme Value (GEV) distribution which is theoretically applied to a set of maximum values per block (BM sample) and the Generalized Pareto Distribution (GPD), applied to a sample of POT values (Peaks-Over-Threshold). The method most commonly recommended for wave distribution analysis uses the POT/GPD approach (Hawkes et al., 2008; Li et al., 2012). The advantage is that all the high values for the period under study are taken into consideration to adjust the parametric distribution, which is not the case with the BM/GEV approach where only one value per year is considered (for classic processing of yearly maxima). The POT/GPD approach therefore produces more accurate estimations of extreme values, especially when the data sample does not cover many years. It is based on choosing a threshold u above which the events are selected. The results obtained are thus highly dependent on the chosen threshold, this last being strongly influenced by the operator's subjectivity (Hawkes et al., 2008; Li et al., 2012). The variability of results obtained between two studied points can therefore be due not only to the characteristics of the data, but also to the way the threshold values are chosen (Neelamani, 2009; Thompson et al., 2009). To ensure that the results from the recording points are comparable, subjectivity in the choice of the threshold must be reduced as far as possible.

The aim of this article is to build a new homogeneous extreme wave atlas allowing inter-comparisons of extreme values along the French Atlantic coastline including the Bay of Biscay and Channel coastline. The issue of threshold subjectivity is tackled with the implementation of an iterative method combining the double-threshold approach put forward by Bernardara et al. (2014) with several visual and statistical tests. The selected homogeneous wave dataset is the BoBWA-10 kH retrospective simulations database (Charles et al., 2012).

After presenting the data (Section 2) and the methodology (Section 3), the creation of the BoBWA-X database is detailed (Section 4). Section 5 provides an analysis of the spatial variability of extreme wave characteristics and past large wave events. The uncertainties associated with the method and the data are discussed in Section 6 before drawing the conclusion (Section 7).

2. Data

BoBWA-10 kH wave hindcast covers 44.7 years from January 1958 to August 2002 (Charles et al., 2012). This database was built up from the WaveWatch III model (Tolman, 2009) in a two-way nested configuration, with the parameters given by Ardhuin et al. (2009). The model was forced by ERA-40 wind reanalyses (Uppala et al., 2005) every 6 h at a height of 10 m across a 1.125° × 1.125° grid, and covers the North Atlantic (spatial resolution of 0.5°) and the French Atlantic and Channel coasts (spatial resolution of 0.1°). A calibration was carried out by varying the wind input height and comparing the simulated waves against the Biscay buoy measurements over the period 1998–2002. The optimal wind input height value was found to be 4.5 m. This calibration indirectly compensates the known underestimation of winds by ERA-40 reanalyses.

The validation performed by Charles et al. (2012) for 9 buoys (orange crosses, Fig. 1, Brittany buoy not shown) concurred well with observations ($0.76 < R^2 < 0.94$). Paris et al. (2014) showed that, in the Bay of Biscay area, BoBWA-10 kH had the lowest statistical errors compared to the other available regional wave hindcast databases (CERA-40, Caires and Sterl, 2005; ANEMOC, Benoit et al., 2006; ERA-INTERIM, Dee et al., 2011; Bertin and Dodet, 2010). Comparisons with 5 buoys data (purple circle, Fig. 1, plus Brittany buoy) show that the highest wave height values (above the 90th percentile) are reproduced more accurately (Fig. 2). For more details about BoBWA, see (Charles et al., 2012) and http://bobwa.brgm.fr.

To complete the validation for extreme statistics application, we compared BoBWA-10 kH data with observations made during large wave events. A large wave event is defined as an event for which the period in which H_s is larger than 2/3 of the maximum value reached during the entire record. Observations and model outputs are compared at two buoy locations (one offshore: Biscay; one nearshore: Minquiers, in the western part of the English Channel). We detected 9 events at the Biscay buoy (from 1998 to 2002), and 7 events at the Minquiers buoy (from 1992 to 1994 and from 1997 to 2002). Only the storm peaks (highest observed and

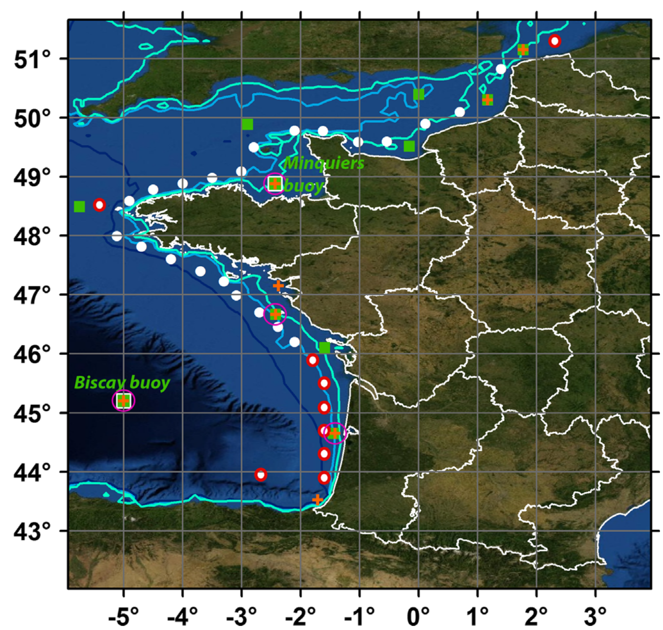

Fig. 1. Location of selected points for the statistical analysis: grid points with 6-hourly data (white circles) and data buoys (green squares). Red circles show points for dual analysis (hourly and 6-hourly data). In addition, BoBWA-10 kH validation points are identified (orange crosses) as well as points used for the comparison of BoBWA-10 kH with the other available regional wave hindcast databases (purple rounded squares). Last, squares with white edges identify the two buoys used in the present study to assess the ability of BoBWA-10 kH to reproduce the highest wave heights. The contour lines show the 30 m isobath (light blue), 50 m isobath (blue) and 100 m isobath (dark blue). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)