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Extreme wave analysis methods in the gulf of Cagliari (South Sardinia, Italy)

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ABSTRACT

The aim of the present paper is to compare the results of the most commonly used extreme wave analysis methods applied to a 20 year (1994–2013) wave hindcast record at a grid point in the Gulf of Cagliari (South Sardinia, Italy). This analysis is a part of a large activity to support design, maintenance and repair of the jetty of the SARAS oil terminal in the inner part of the gulf. The paper shows some merits and hindrances of these methods. While conventional distributions recommended by Goda (*e.g.* the Gumbel and Weibull distribution) represent nowadays the most common methods in those engineering applications, accurate results in the paper indicate that the coastal engineering community should consider the Generalized Pareto Distribution (GPD) as one of the most performing credible candidates. Particular attention should be paid to the large uncertainty in the return level of extreme significant wave height when predicting a reference value for structures operating in a severe marine environment.

1. Introduction

Many marine structures such as oil jetties and offshore platforms are susceptible to severe marine environment; *e.g.*, waves, currents or storm surges. Wave and current patterns induce large impact force on the structures and increase the local sediment transport capacity. Because of the extreme conditions to which it is exposed, an Extreme Wave Analysis (EWA) is the first step in the jetty design, maintenance and repair by providing the basis of selecting return levels of extreme significant wave heights (H_s). Fundamentally, the purpose of EWA is to define a relationship between large wave heights and their return periods. A variety of statistical distributions and methods for distribution fitting to the data have been proposed for EWA. Goda (2010) presented an extensive in-depth state-of-the-art review of this topic. In this paper, the comparison was made using the 20-year (1994–2013) wave hindcast record at a location in the Gulf of Cagliari (9.5° E; 39° N) offshore the South-East coast of Sardinia (Italy) in a water depth of 150 m (Fig. 1). In particular, return levels for H_s were estimated by fitting the Gumbel distribution, Fisher-Tippet (FT) type II (FT-II), the Weibull distribution with different shape parameter values and the Generalized Pareto Distribution (GPD). The Fisher-Tippet distribution can be synthesized into the Generalized Extreme-Value (GEV) distribution. Each distribution (namely, Gumbel, FT-II, Weibull and GPD) was fit to data above a given threshold (Peak Over Threshold – POT). While POT assures a larger dataset than the annual maxima method (Hawkes et al., 2008), the latter decreases statistical errors associated with the threshold selection (Jonathan and Ewans, 2013). Consequently, threshold selection is considered as a critical aspect in EWA (Sartini et al., 2015) particularly in the case of covariate effects (Jonathan and Ewans, 2013). Among the several available fitting methods, the least squares method in the form presented by Izumiya and Saito (1997), the maximum likelihood method (Coles, 2001) and the L-moments method (Hosking, 1990) are currently the standard practice in mainstream extreme statistics.

Despite the fact that extreme wave analysis has received a large attention in the scientific community, there is a growing need for reliable data sets for maritime design in the Gulf of Cagliari. In this paper, we make an attempt to consolidate the results from a number of recent studies in EWA. The main aim is to rigorously compare the above EWA methods that are commonly used in coastal engineering community and to suggest the GPD as one of

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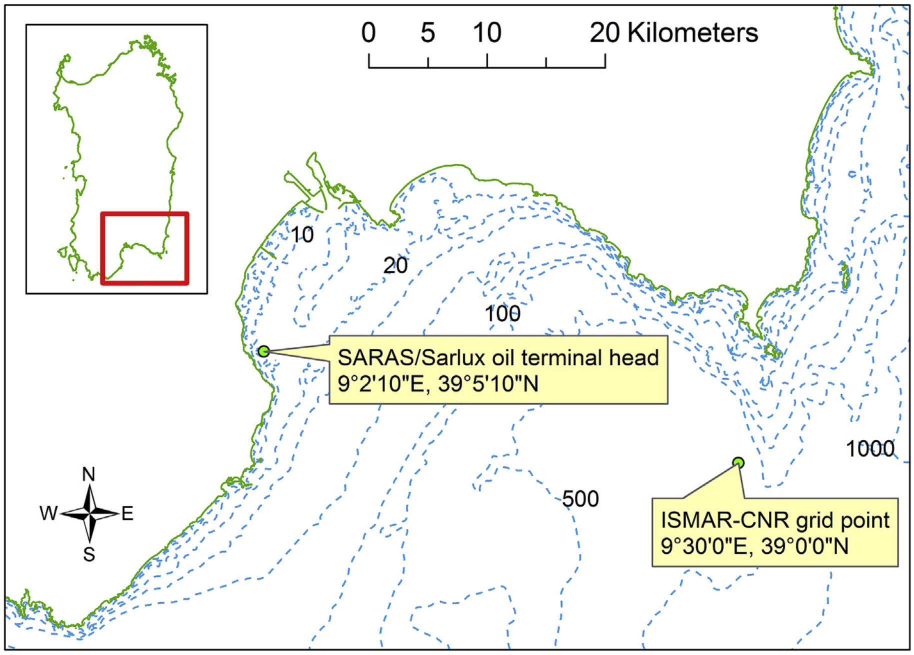

Fig. 1. Locations of ISMAR-CNR hindcast point and wave recorder on SARAS/Sarlux jetty head in the Gulf of Cagliari, South Sardinia (Italy) in the western Mediterranean Sea. At the SARAS/Sarlux jetty, waves from the south-east are favored, given the maximumfetch limited by the Libyan coasts (larger than 1200 km) and prevailing wind (Scirocco from the second quadrant).

the best models for the processing of return level estimates for maritime design in the Gulf of Cagliari. The manuscript is organized as follows. In Section 2, the 20-year wave dataset from which statistics have been derived is presented. Section 3 describes the application of the statistical methods and Section 4 shows obtained results and some relevant aspects are discussed. The final section gives some suggestions for future developments.

2. CNR-ISMAR wave data

Wave data of this analysis come from the wave hindcasting produced by ISMAR-CNR commissioned by SARAS/Sarlux (Cavaleri et al., 2014). The two basic sources of data have been the altimeters on board of the ERS-1/2 and TOPEX/Poseidon satellites, available respectively since 1991 and 1992, and the operational wind and wave results of the European Centre for Medium-Range Weather Forecasts (ECMWF) at 6-h intervals. The data have been combined providing a 20-year wave dataset from which statistics have been derived in the grid point of coordinates 9.5°E; 39.0°N located at the mouth of the Gulf of Cagliari about 8 km south of the Sardinia coast (Fig. 1). Notably, the use of low time resolution (such as a 6-h sampling interval) data could cause some bias in the definition of the design climate in a given site (Reale et al., 2013); however this is not relevant in the present research as demonstrated in previous investigation in the enclosed sea of the Gulf of Cagliari. A refined further investigation could be carried out to supply a local description of small-scale storm variations in time in the enclosed sea of the Gulf of Cagliari from the storms monitored by the oceanographic buoy deployed offshore from the Capo Carbonara Cape (latitude = 39°06′52″ N; longitude = 09°24′20″ E) being part of the Italian Data Buoy Network (RON) owned and managed by ISPRA (Italian Institute for Environmental Protection and Research).

Data are available from January 1994 to December 2013. To assure the independent and identically distributed conditions for the storm events, storm waves must exceed a storm threshold H_h and its duration, measured as the time recordings exceed H_h, must be longer than 24 h (Boccotti, 2000). The interval between two consecutive storms must be higher than 12 h (T_h); otherwise, the two storms were regarded as a single storm (Lemm et al., 1999; Boccotti, 2000). Regarding H_h, it depends upon the given location. For enclosed seas in the Mediterranean Sea, Boccotti (2000) proposed a H_h equal to 2.0 m. Each storm was represented by its peak wave height during the storm. Fig. 2 shows the peak wave heights during storms as provided by Cavaleri et al. (2014) and their basic statistical properties in the 20-year wave dataset. All distribution functions were fitted to data of Fig. 2.

3. Methods

Assuming a wave dataset **H** and a specific value of significant wave height H_s, the cumulative distribution function *F(H)*is defined to represent the probability of a storm-wave heights non-exceeding H_s:

$$F(H) = P_r[H \le H_s] \tag{1}$$

The present research employed the Fisher-Tippet (FT) type I (FT-I) or Gumbel distribution (2), the FT-II distribution (3), the Weibull distribution (4) and the Generalized Pareto Distribution (GPD) (5) expressed by:

$$F(H) = exp\left[-exp\left\{-\left(\frac{H-B}{A}\right)\right\}\right] \tag{2}$$

$$F(H) = exp\left[-\left\{1-\frac{H-B}{kA}\right\}^{k}\right] \tag{3}$$

$$F(H) = 1 - exp\left[-\left(\frac{H-B}{A}\right)^{k}\right] \tag{4}$$