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Estimation of extreme wind speeds and wave heights along the regional waters of India

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ABSTRACT

A new Polynomial approximation method has been used for the estimation of the extreme significant wave heights and wind speeds from 33 years of hindcast data for six locations along the Indian coast. These return value estimates are compared with the values obtained from the well-known Generalised extreme value distribution and Generalised Pareto distribution methods. Further, the entire data is subdivided into three decadal time blocks to assess the time variability in model outputs of extreme values of significant wave heights and wind speeds. Although the comparison, in general, is found good, a closer examination of the results reveals that the present method based on polynomial approximation could be preferred for practical applications. The detailed analysis of the Polynomial approximation method, salient features and its fulfilment of consistency condition which overcomes the shortcomings of the other standard extreme value estimation methods are presented and discussed in this paper.

1. Introduction

India has a long coastline of about 7000 km with a vast exclusive economic zone that is conducive to exploration and exploitation of natural living and non-living resources. This has resulted over the years, a rapid progress in a variety of activities in the coastal and offshore areas that include fishing, development of fishing and commercial harbours, offshore exploration and exploitation of oil and gas, establishment of desalination plants, ocean energy, coastal tourism and also the conservation of the coastal environment. All these activities require a variety of structures to be constructed in the marine environment, the design of which is based on the design wave which is a dominating factor that ensures the safety of the structure. This calls for an in-depth investigation on the prediction of design wave associated with a certain return period. This information not only depends on the quality and quantity of data applied for the exercise but also the estimation method adopted.

Several researchers have studied the random behaviour of extreme wave heights predicted through extreme value distributions (Carter and Challenor, 1981; Morton et al., 1997). A state-of-the-art revision of models for the distribution of the highest wave in a sea state has been presented by Massel and Sobey (2000). The most widely adopted methods for return values assessment according to Lopatukhin (2012) are the initial distribution method (IDM) (Goda, 2000), the method of annual maxima method (AMM) (Castillo, 1988), and the method of overcoming the threshold (POT - Peak Over Threshold) (Ferreira and Guedes Soares, 1998). These methods could henceforth be termed as the standard ones. As an example, the IDM method has been applied to the Indian coast for the storm hindcasting at two locations in addition to extreme wave analysis by using Gumbel, lognormal and Weibull approach by Dubey and Das (2013).

All the extreme value estimation methods are based on executing the following procedure:

i Calculating the histogram, $H(H_i)$, for a considered time series of random variable, H, with a discrete ΔH [i.e., $H_i < H < H_i + \Delta H$]
ii .The probability provision function, $F(H)$, being defined as,

$$F(H) = 1 - \int_0^H P(H)dH \approx 1 - \sum_{H_i=0}^{H_i=H} H(H_i) = \sum_{H_i=H}^{H_i=H_M} H(H_i) \tag{1}$$

where $P(H)$ is the probability density function of the random variable, $H(H_i)$ is the histogram and H_M is the maximum value of the considered

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time series. Herein, it is useful to note that $F(H_M) = H(H_M)$.

iii Extrapolating provision function $F(H)$ beyond an existing maximum value H_M, by means of an analytical approximation, $F_{ap}(H)$ for the function $F(H)$.

The main problem in evaluating the return period values consists in the fulfilment of the requirements of uniqueness and authenticity for performing extrapolation $F_{ap}(H)$ beyond the maximum value H_M. It is clear that any uncertainty in the extrapolation would lead to an inaccuracy in the return value estimates. Therefore, the problem of constructing an extrapolation function turns often into a separate study, even for the mentioned standard methods as detailed by Lopatukhin (2010, 2012).

Typically, the above-mentioned problem needs a fixing and justification statistics defining the extreme of geophysical magnitudes considered. Traditionally (Lopatukhin, 2010, 2012; Caires and Sterl, 2005), the extreme value prediction methods have not considered the fact that the statistics of natural processes may vary with scales, due to different dynamics of geophysical processes on different scales as stated by Monin and Krasitskii (1985). Therefore, the unified probability distribution describing the statistics of some geophysical quantity H on all scales of variability may not exist. Hence, there are evidently many preferable ways of solving the problem with extrapolating provision function $F(H)$. Furthermore, the question of accuracy for approximation $F_{ap}(H)$ in general has not been discussed in the approaches to the present problem. Nilanjan and Sannasiraj (2012) estimated short term extreme values using the method of up-crossing from the Gumbel distribution. The authors through this paper have made an attempt to fill this gap.

In the present paper, three methods of estimating the return period with 33-year of historic time series for wind speed and significant wave height at a few locations along the Indian coast are analysed and compared. To be more practical, six salient coastal locations along the Indian coastline are chosen. The sites chosen off the coastline of India are Paradip, Kakinada, Krishnapatnam, Kalpakkam, Kochi, and Mumbai (Fig. 1).

Initially, the study focused on the application of Generalised Extreme

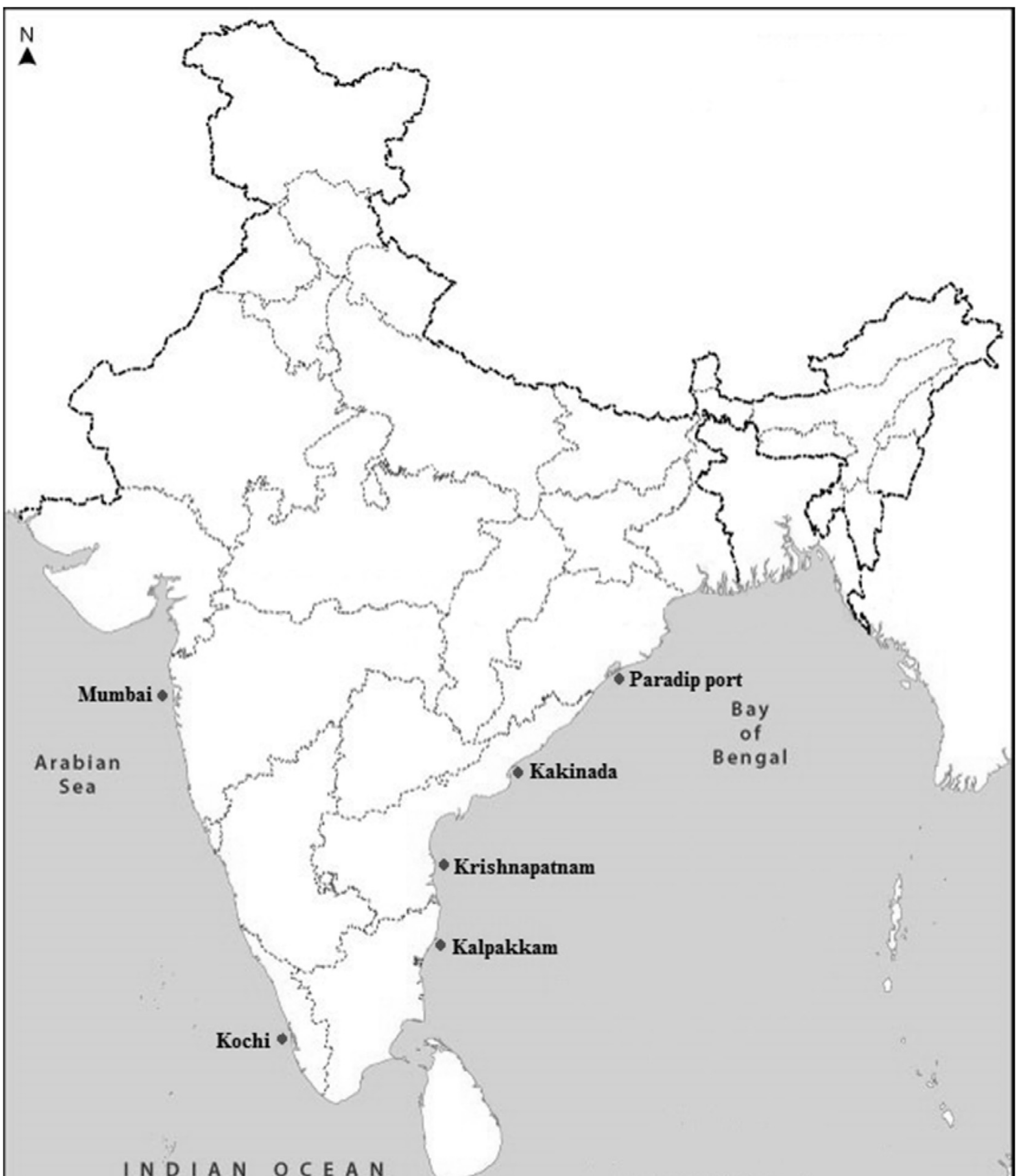

Fig. 1. Chosen major stations for extreme value estimation.

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