

Response to Anonymous Referee #1

Review of the manuscript nhes – 2017-165 “Variations in return value estimate of ocean surface waves a study based on measured buoy data” written by T. Muhammed Naseef and V. Sanil Kumar. My recommendation is that the paper is accepted but with major changes. In my view this paper is very interesting and the topic is of special interest for the scientific and engineering communities. However, there are a few outstanding points to mention. In the first instance, with only 8 years of wave data, the uncertainty is too great to estimate extreme values for a 100 year return period. Did you perform any sensitivity analysis? Waves were measured in a water depth of 9 m. In principle the data collected is strongly influenced by the wave period. I am almost sure that in the case of very severe storms there is a high probability that some waves arrive very steep or broken. Did you take into account these processes for the characterization of extreme values? For the most extreme conditions, in addition to H_s , it is also very important to consider the wave period and the duration of the storm. It is not explained in the paper how the Sea and Swell were separated from the original records. Very useful work has been carried out recently (see references) which does not seem to have been consulted. I strongly suggest the author check the state of the art. Why was the criteria used to separate the seasons that of months? It might be more reliable to use the atmospheric pressure values, as the Monsoon season is not always the same. It is the first time that I have read in a paper (Acknowledgements) that a contract is xxxx. My major concerns with the paper are: the length of the wave record, the fact that the analysis does not consider the physical processes involved, nor the effect of the wave period, direction of incidence of the waves and duration of the storms.

References Solari, S., & Losada, M. A. (2011). Non-stationary wave height climate modeling and simulation. *Journal of Geophysical Research: Oceans*, 116(C9). Solari, S., & Losada, M. A. (2012). Unified distribution models for met-ocean variables: Application to series of significant wave height. *Coastal Engineering*, 68, 67-77. Solari, S., Egüen, M., Polo, M. J., & Losada, M. A. (2017). Peaks Over Threshold (POT): A methodology for automatic threshold estimation using goodness of fit χ^2 value. *Water Resources Research*, 53(4), 2833-2849. Solari, S., & Losada, M. A. (2015). Statistical Methods for Risk Assessment of Harbor and Coastal Structures. In *Design of Coastal Structures and Sea Defenses* (pp. 215-272). Folgueras, P., Solari, S., Mier-Torrecilla, M., Doblaré, M., & Losada, M. A. (2016). The extended Davenport peak factor as an extreme-value estimation method for linear combinations of correlated non-Gaussian random variables. *Journal of Wind Engineering and Industrial Aerodynamics*, 157, 125-139

Reply:

Thanks for the suggestions. We have now revised the manuscript considering all the suggestions and the corrected manuscript in track-changes is attached. Since the measured buoy data is for a period of 8 years only, the H_s data from the ERA-Interim (Dee et al. 2011), the global atmospheric reanalysis product of the European Centre for Medium Range Weather Forecast (ECMWF) for 38 years (from 1979 to 2016) is now used to evaluate the wave height with different return period in the shallow (water depth ~20m) and the deep water. The shallow region is close to the buoy location and the deep water location is at a water depth of ~4000 m (Table 1). ERA-Interim used in the study has a spatial resolution is $0.125 \times 0.125^\circ$ and a temporal resolution of 6 h.

Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M. A., Balsamo, G., Bauer, P., Bechtold, P., Beljaars, A. C. M., van de Berg, L.,

Bidlot, J., Bormann, N., Delsol, C., Dragani, R., Fuentes, M., Geer, A. J., Haimberger, L., Healy, S. B., Hersbach, H., Hólm, E. V., Isaksen, L., Kållberg, P., Köhler, M., Matricardi, M., McNally, A. P., Monge-Sanz, B. M., Morcrette, J.-J., Park, B.-K., Peubey, C., de Rosnay, P., Tavolato, C., Thépaut, J.-N., and Vitart, F.: The ERA-Interim reanalysis: Configuration and performance of the data assimilation system, *Q. J. Roy. Meteor. Soc.*, 137, 553–597, 2011.

A section on "influence of length of wave data on estimated significant wave height return value" is now added (section 3.3). Since the data is collected at 9-m water depth, most of the time it is in intermediate wave regime. The data on mean wave period and the peak wave period are now added. A table is now added to show the percentage of time the waves are in intermediate, shallow and deep water regime based on relative depth (ratio of the water depth and the wave length) and the results are discussed. The wave breaking aspects are now covered.

The methodology on wind-sea and swell separation is also added (section 2.1).

The waves in the west coast of India are strongly season depended. Hence, we have considered seasons based on months. For the study location, the storm induced wave heights during the non-monsoon period are less than the monsoon induced waves. June first week is the onset of Indian summer monsoon and the maximum H_s in the study area is due to monsoon influence and in all years it is during June to September. These are now added in the manuscript under section 3.3.

The recent works as suggested are now cited.

Now we have added a wave rose plot showing the wave direction of measured data and the ERA-Interim data and discussed in the paper (Figure 12).

Other minor correction related to contribution number is corrected.

Response to Anonymous Referee #2

This paper provides an extreme value analysis of the significant wave height (H_s) in a buoy of India spanning for 8 years (2008-2016). It includes a detail comparison on the estimation of return levels using different extreme distributions (GEV vs GPD) and maxima selection (block maxima and peak over threshold), a set of statistical test to analyze threshold selection and model fit, and a sensitivity analysis considering different spanning periods. The analysis is performed to the total H_s , Wind Sea and swell, and, in the temporary scale they consider the annual and seasonal wave climate. The paper carries out a detailed but conventional analysis of extreme wave climate comparing different methods and tools. The main drawback is that the analysis is performed to an 8-year record of data, which is a very short period of time to analyze extreme behavior.

I miss a discussion about that in the manuscript and comments/references/analysis of interannual and decadal variability which can influence wave climate in such short periods of time. I find very cheeky and uncertain to obtain 100-year return levels extrapolating from an 8-year record. Besides nothing is told about the influence of water depth (9 m) that can also condition the extreme wave climate. For me it is not clear if the aim of the paper is to show a statistical analysis with a set of test, tools and comparisons or if it tries to provide useful information and knowledge about the extreme wave climate in India. In the first case,

although a complete EVA is posed, I do not consider it in the cutting edge. In the second case (which I consider the really interesting thing for the NHESS topics), I consider the use of an 8-year record buoy not appropriate for providing conclusions about extreme wave climate. I encourage the authors to carry out a similar analysis over a longer record buoy, satellite or reanalysis data. Extra explanations about how Wind Sea and swell are considered, the influence of water depth, influence of wave direction in wind sea and swell, or interannual variability in the area should be considered.

I recommend that the manuscript only be considered for publication after major revision

Reply:

Thanks for the suggestions. We have now carried out a major revision of the manuscript considering all the suggestions and the corrected manuscript in track-changes is attached.

Since the measured buoy data is for a period of 8 years only, the Hs data from the ERA-Interim (Dee et al. 2011), the global atmospheric reanalysis product of the European Centre for Medium Range Weather Forecast (ECMWF) for 38 years (from 1979 to 2016) is used to evaluate the wave height with 100 and 50-year return period in the shallow (water depth ~20m) and the deep water. The shallow region is close to the buoy location and the deep water location is at a water depth of ~4000 m (Table 1). ERA-Interim used in the study has a spatial resolution is $0.125 \times 0.125^\circ$ and a temporal resolution of 6 h.

Now we have added a Figure showing the inter-annual variations in the annual mean and annual maximum Hs based on the ERA-Interim data covering 38 years (Figure 11) and discussed the inter-annual variations.

Influence of water depth is studied based on the relative depth (ratio of water depth to wave length) in section 3.4.

Extra explanations about how Wind Sea and swell are considered, the influence of water depth, influence of wave direction and the inter-annual variability in the area are now included. A figure showing the inter-annual variability is also added (Figure 11). We have discussed the influence of storm on the 100-year Hs value (section 3.3).

Variations in return value estimate of ocean surface waves - a study based on measured buoy data and ERA-Interim reanalysis data

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Abstract. An assessment of extreme wave characteristics during the design of marine facilities not only helps to ensure its safety but also the economic aspects. In this study, return levels of significant wave height (Hs) for different periods are estimated using Generalized Extreme Value (GEV) and Generalized Pareto Distribution (GPD) based on the waverider buoy data spanning for eight years and the ERA-Interim reanalysis data for 38 years. The analysis is carried out for wind-sea, swell and total significant wave heights Hs separately for buoy data. Seasonality of prevailing wave climate is also considered in the analysis to provide return levels for short-term activities in the location. The study shows that Initial Distribution Method (IDM) underestimates return levels compared to that of GPD. Maximum return levels estimated by GPD corresponding to 100 years is 5.10 m for monsoon season (JJAS), and corresponding pre-monsoon (FMAM) and post-monsoon (ONDJ) values are 2.66 m and 4.28 m respectively. Intercomparison of return levels by block maxima and r-largest method for GEV theory shows that maximum return level for 100 years is 7.20 m by r-largest series followed by monthly maxima (6.02 m) and annual maxima (5.66 m) series. The analysis is also carried out to understand the sensitivity of the number of observation for GEV annual maxima estimates. It indicates that the variations in the standard deviation of the series caused by changes in the number of observation are positively correlated with the return level estimates. The 100-year return levels of Hs by using GEV method give comparable results for short-term (2008 to 2016) buoy data (4.18 m) and the long-term (1979 to 2016) ERA-Interim shallow data (4.39 m). The 6-h interval data tend to miss high values of Hs and hence there is a significant difference in the 100-year return level Hs obtained using 6-h interval data compared to data at 1/2-h interval. The study shows that a single storm can cause large difference in the 100-year Hs value.

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Keywords: surface waves, return period, Extreme value distribution, design wave height, north Indian Ocean

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1. Introduction

Coastal zones are relatively dynamic than rest of the regions due to numerous natural as well as anthropogenic activities. Events such as extreme waves, storm surges, and coastal flooding make large catastrophes in the coastal region. The long-term (climate) behavior of sea state variables can be studied using non-stationary multivariate models that represent the time dependence of the variables (Solari and Losada, 2011). Various marine activities like the design of coastal and offshore facilities, planning of harbor operations, and ship design require detailed assessment of wave characteristics with certain return periods (Caires et al., 2005; Menéndez et al., 2009; Goda et al., 2010). Generally, Extreme Value Theory (EVT) is used for determination of return levels by adopting statistical analysis of historic time series of wave heights obtained from various sources such as in-situ buoy measurements (eg.: Soares and Scotto, 2004; Mendez et al., 2008; Viselli et al., 2015), satellite data (eg.: Alves et al., 2003; Izaguirre et al., 2010), and hindcasted or reanalysis data by numerical models (eg.: Goda et al., 1993; Caires and Sterl, 2005; Teena et al., 2012; Jonathan et al., 2014). EVT consists of two type of distributions viz. Generalized Extreme Value (GEV) family which includes Gumbel, Frechet, and Weibull distributions (Gumbel, 1958; Katz et al., 2002) and Generalized Pareto Distribution (GPD) which incorporates Peak Over Threshold (POT) approach (Pickands, 1975; Coles et al., 2001).

GEV distribution by annual maxima (AM) observations (Goda et al., 1992) is one of the widely used methods in the Extreme Value Analysis (EVA). The main difficulty with using this method is that the unavailability of a reliable observation at a location of interest. To overcome the data scarcity, different alternatives has been used by various authors such as Initial Distribution Method (IDM) in which the distribution of data as such is used (Alves and Young, 2003), r-largest approach (Smith, 1986), where a number of largest observation from a block of period are considered rather than one observation used in AM method. POT method (Abild et al., 1992) gives a good number of observations available for the analysis. GPD are Although there have been various proposals to automate threshold selection, threshold estimation for the application of the POT method to a single sample is still not resolved (Solari and Losada, 2012; Solari et al., 2017). GPD is another class of distribution introduced by Pickands (1975) and is used by several authors like Caires and Sterl (2005) and Thevasiyani et al. (2014). Teena et al. (2012) and Samayam et al. (2017) have carried out the EVA of ocean surface waves in the northern Indian Ocean based on wave hindcast data and ERA-Interim reanalysis data.

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Most reliable source of ocean wave data is buoy measurements, and it can be used for EVA (Panchang et al., 1999). In this paper, data from a directional waverider buoy located in the central western shelf of India is used. Seasonality is one of the important aspects of climate data and therefore, it should be incorporated in the EVA of waves especially in a region like the Arabian Sea. Seasonal analysis of the extremes helps for the planning of short-term marine activities like offshore explorations, maintenance of coastal facilities, etc. In the present paper, the EVA is carried out by following both the GEV and GPD methods considering wind-sea, swell and total significant wave height (Hs) separately. The IDM and POT methods are used for total wave height analysis, and block maxima (annual and monthly maxima) and r-largest method are used in wind-sea and swell height analysis. Since the measured buoy data is for a short period of 8 years, the ERA-Interim reanalysis data from 1979 to 2016 is also used for comparing Hs value with 100-year return period.

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The paper is organized as follows. Section 2 deals with data and methodology used in the analysis. It also presents the threshold selection adopted in the study and Sect. 3 explains the results obtained in the analysis categorized into seasons using total Hs data and comparison of return level estimation by different GEV approaches using wind-sea and swell height data. A case study is also included in the section for realizing the uncertainty related to observations in AM approach when limited number of observations are available. The influence of length of wave data on estimated Hs return value is also covered under this section. Section 4 provides the concluding remarks.

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2. Data and Methodology

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2.1 Data

Data used in the analysis is ~~obtained~~ from Datawell directional waverider buoy deployed off Honnavar (14.304°N, 74.391°E) at a water depth of ~~9m~~ 9 m. The half hourly sampled data covers the period from March 2008 to February 2016. The waves at the location show strong intra-annual variations due to the prevailing wind system during monsoon and non-monsoon seasons (Sanil Kumar et al., 2014). To understand the local and remote influences on the design wave characteristics, we ~~did analysis on~~ analyzed Hs of wind-sea, swell and total waves separately. The season wise study is also carried out since it will provide insight to the design wave heights for short-term coastal activities.

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The Hs data from the ERA-Interim (Dee et al. 2011), the global atmospheric reanalysis product of the European Centre for Medium Range Weather Forecast (ECMWF) from 1979

to 2016 (38 years) is also used to evaluate the 100 and 50 year return period wave height in the shallow (water depth ~20m) and deep water. The shallow region is close to the buoy location and the deep water location is at a water depth of ~4000 m (Table 1). ERA-Interim used in the study has a spatial resolution of 0.125° X 0.125° and a temporal resolution of 6 h.

2.2 Methodology

EVA is carried out by following GEV Distribution model and POT method in which exceedance over a reliable threshold wave height can be fit into GPD. In POT method, distribution of excess, x , over a threshold u is defined as:

$$F_u(y) = \Pr\{x - u \leq x | x > u\} = \frac{F(x) - F(u)}{1 - F(u)} \quad (1)$$

Where $y=x-u$. Pickands (1975) shows that distribution function of excess, $F_u(y)$, for a sufficiently high threshold u converges to GPD having CDF as:

$$G(x; k, \alpha, \beta) = \left\{ 1 - \left(1 - k \frac{x-\beta}{\alpha} \right)^{1/k} \right\} \quad k \neq 0 \quad (2)$$

$$= 1 - e^{-(x-\beta)/\alpha} \quad k = 0$$

GEV has cumulative distribution function (CDF) as:

$$F(X) = \exp \left\{ - \left(1 - k \left(\frac{X-\beta}{\alpha} \right)^{1/k} \right) \right\} \quad k \neq 0 \quad (3)$$

$$= \exp \left\{ - \exp \left(- \frac{X-\beta}{\alpha} \right) \right\} \quad k = 0$$

Where α is scale parameter in the range of $\alpha > 0$, β is the location parameter with possible values of $-\infty < \beta < \infty$ and k is the shape parameter in the range of $-\infty < k < \infty$. GPD can be further categorized into three distributions based on its tail features. When $k=0$, GPD corresponds to an exponential distribution (medium-tailed or Pareto I type) with mean α ; when $k>0$, GPD is short-tailed also known as Pareto II type; when $k<0$, distribution takes the form of ordinary Pareto distribution having long-tailed distribution (also known as Pareto III type). Parameter estimation and statistical distribution fitting are carried out by using WAFO (Brodtkorb et al., 2000) developed by Lund University, Sweden.

The analysis is carried out by using the wind-sea, swell and total H_s data covering ~ 8 years (2008-2016). ~~GPD method is used for seasonal analysis of different time~~ From the measured data, to separate the wind-seas and swells, the method proposed by Portilla et al. (2009) is used. The

separation algorithm is on the assumption that, the energy at the peak frequency of a swell cannot be higher than the value of a Pierson-Moskowitz (PM) spectrum with the same frequency. If the ratio between the peak energy of a wave system and the energy of a PM spectrum at the same frequency is above a threshold value of 1, the system is considered to represent wind-sea, else it is taken to be swell. A separation frequency f_c is estimated following Portilla et al. (2009) and the swell and wind-sea parameters are obtained for frequencies ranging from 0.025 Hz to f_c and from f_c to 0.58 Hz, respectively. GPD method is used for seasonal analysis of different period data series. GEV method is used for inter-comparison of return level estimation among wind-sea, swell and resultant data sets by extracting different block maxima series viz. seasonal maxima which contain highest observations from each season; monthly maxima contain one highest observation from each month, and annual maxima. The parameters are estimated using PWM method since the data set duration ~~are~~ is very limited, and PWM method holds good results compared to other methods such as Maximum Likelihood (ML) method (Hosking et al., 1985).

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To study the uncertainties related to the length of the observation, we extracted 3, 6, 12 and 24 h data series from the half hourly original data and carried out EVA. Since the wave climate in the study location strongly characterized by the prevailing seasonal behavior of wind system, we took further consideration of uncertainties related to a seasonal aspect of wave climate by extracting three seasonal data, viz., pre-monsoon (FMAM), monsoon (JJAS) and post-monsoon (ONDJ) seasons.

2.1 Threshold selection

The major drawback of EVA using block maxima method, especially the annual maxima (AM), is that it ~~dedoes~~ does not consider the significant amount of observations which are closely related to storm features of the data set. Those omissions of observation would make variations in the final results of EVA to a great extent especially in the case when EVA is done for a very limited data set. EVT is based on one of the hypothesis that the observations under consideration are independent and identically distributed (Coles, ~~et al.~~ et al., 2001). In the case of ocean wave observations, we can expect its identical status for a large extent. Since POT approach re-samples the data over a threshold value, establishing identical and independence among the re-sampled observation is a tedious task. A suitable combination of threshold and minimum separation time between the re-sampled observations must be taken into account to establish independence among the observations.

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The average duration of tropical storms in the Arabian Sea is 2-3 days (Shaji et al., 2014). So, in the present analysis, we fixed minimum 48 hours of separation time in between two consecutive storm peaks to ensure the independence of data points for the analysis. Then selected a tentative threshold value in such a way that there must be at least 15 peak values per year on average. That resulted at least 120 data points in each sub data sets used for the seasonal analysis. The resulting data series are used in further POT analysis. Further adjustment of the threshold is carried by Sample Mean Excess (SME) plots and Parameter Stability plots (PS plot). From these plots, we selected probable four thresholds and fitted corresponding GPD. A final threshold value is chosen by analyzing results obtained in different Goodness of Fit (GOF) tests such as Kolmogorov-Smirnov (KS) test, Anderson-Darling (AD) test and Cramer-von Mises (CM) test (Stephens, 1974; Choulakian ~~et al.~~ and Stephens, 2001).

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The distributions used in the analysis is validated using graphical tools like Quantile-Quantile (Q-Q) plots and CDF plots. In addition to above graphical tools, we checked the reliability of chosen thresholds for POT method by using different GOF tests such as KS, AD and CM tests (Table 42). $p\text{-value} > 0.05$ indicates the selected distribution does not show a significant difference from the original data within 5 % significance interval.

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3. Results and Discussion

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3.1 Long-term statistical analysis of total Hs

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The mean wave climate at the study location is characterized by annual mean Hs of 1.04 m. Maximum Hs of the data during 2008-2016 is 4.70 m and the next highest Hs is 4.34 m (Figure 1), whereas the highest wind-sea, and swell Hs are 4.29 m and 4.28 m respectively. Statistical analysis of Hs was carried out by considering the seasonal characteristics of the wave climate. In order to study the seasonal aspects of the return level estimation, the data is grouped into three different seasonal series, viz. FMAM, JJAS and ONDJ seasons in addition to full-year data. Since the study location is located off the central west coast of India, the wave climate shows distinct variability throughout a year. Previous studies like Anoop et al. (2015) reported that average Hs attains its peak around 3 m during JJAS and FMAM season is relatively calm (0.5-1.5 m) compared to that (1.5-2 m) in ONDJ. The seasonal analysis is carried out using Hs data following both the GEV and GPD methods. Here, Initial Distribution Method (IDM) is considered in GEV method rather than block maxima (Mathiesen et al., 1994). One of the challenging tasks for GPD modeling is the selection of a

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suitable threshold value. The threshold should be high enough for observations to be independent and data after POT must have enough number of observations left ~~in order in order~~ to converge POT into GPD. SME plots and PS plots are used to select a range of initial thresholds. On analyzing the resultant GPD fit for those thresholds, final thresholds are chosen by the help of GOF tests which are presented in Table 42, Figure 42 and Table 23 shows the estimated parameters using PWM method for both GEV and GPD. It is clear that shape parameters in both cases are negative indicating the models are Type III distribution for GPD and Weibull distribution for GEV respectively. Table 23 also shows the RMSE in the chosen model for each data series with estimated CDF. It is evident that JJAS season has lesser RMSE (~0.07 m on average) when considering GPD model. While in the case of GEV model, full year data series has lesser RMSE (~0.02 m on average). ONDJ season shows a higher discrepancy in both cases resulting ~~an in~~ average RMSE of 0.31 m and 0.54 m for GPD and GEV respectively. Figure 23 shows a typical SME and PS plots used for choosing a range of thresholds before fixing final threshold for POT analysis on each series. In this particular case (6 h data series of FMAM season) a range of thresholds from 1.10 m to 1.32 m were selected, and the final threshold of 1.19 m was fixed on analyzing the GOF test results (Table 42).

3.1.1 Full year

Here, we considered full year data series without dealing with seasonality and both the GEV and GPD are used in the analysis. Initially, a range of thresholds from 2.5 to 3.4 m was selected, and further adjustment of ~~the~~ threshold is carried out by analyzing the GOF test results. Table 42 shows the selected thresholds and corresponding GOF test results for each series in the full year data analysis. It is clear that the selected thresholds are in good agreement with GOF test results. Both KS test and CM test gives p-value > 0.32. Moreover, both CDF plots and Q-Q plots (see Figure 34; first and second rows, respectively) show selected GPD models made a good performance for the particular POT series. After acquiring best fit model, return levels (Table 34) were estimated for 10, 50 and 100 years. The GPD model estimates 10-year return level smaller than that of ~~the~~ maximum measured total Hs value by an extent of 5 to 15 %. Underestimation of 10 to 25 % from the maximum measured value was reported by Samayam et al. (2017) compared to the 36-years and 30-years return levels based on ERA-Interim reanalysis data for deep waters around Indian mainland. The initial distribution approach ~~clearly~~ underestimates the return levels such a way that even 100 years return level does not cross the highest observation (4.70 m) in the data and the largest

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100 years return level is reported as 4.26 m when dealing with half-hourly data series. (Table 4). The large number of observations having very low Hs in the data series used in the analysis leads to the underestimation in the initial distribution method. Whereas, GPD model estimated 4.73 m and 4.96 m as 50 and 100 years return levels respectively which is comparable with Teena et al. (2012) estimation at a location in the eastern Arabian Sea. When considering different time interval data, both 612 and 1224 h data series estimates lower return levels compared to other series by GEV model. It is evident that there are uncertainties related to the sampling interval adopted for the return value estimation. The standard deviation for GPD estimation when considering different time intervals is 0.57 m which is are highest among the other seasonal data. GEV estimation reports even lesser spreading of return levels with 0.16 m standard deviation.

3.1.2 Pre-monsoon season

The data of February to May constitute the pre-monsoon data set. This Pre-monsoon is the calmest season in the study location with maximum and average Hs of around 1.94 m and 0.73 m. Using SME and PS plots, a range of thresholds from 1.19 m to 1.32 m are is selected for each time series and fitted corresponding GPD by using resultant POT. The final threshold selected by the help of GOF tests is presented in Table 42. KS and CM tests gives give p-value more than 0.43 and 0.45 respectively on an average (Table 42). Since the p-values are more than 0.05, the chosen POT is not significantly different from the time series data. CDF plots and Q-Q plots (Fig. 45) for the different data series of the season illustrate the reliability of the chosen model. Return levels for different return periods using a particular GPD are presented in Table 34. GEV estimation exhibit same characteristics of underestimation as shown in the full year analysis. Average 100 years return levels estimation using different time interval data using GEV model attained only 1.77 m which is are less than the highest observed data point in the season, whereas, GPD reports average 100 years return level of 2.49 m. Time interval analysis for the season exhibits least discrepancies among the return level estimations compared to other seasons. Standard deviations of 0.11 m and 0.08 m for GPD and GEV estimations respectively were observed for 100-year return levels considering different time series data.

3.1.3 Monsoon season

Monsoon season data set covers observations from June to September and this season is characterized by rough wave climate at the study location. Hs of 4.70 m and 1.77 m are recorded as maximum and average during the season. A range of thresholds (2.778 to 3.49 m)

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are selected for preliminary GPD fitting as a result of interpreting SME and PS plots of each data series, and corresponding final thresholds were selected after clarifying with GOF test results (Table 42). Both KS and CM tests report p-value > 0.56 indicating that the resulting POT for selected threshold converges into GPD. CDF and Q-Q plots in Fig. 56 shows the credibility of the adopted threshold value. Return levels for distinct return period were estimated using resultant POT. Table 34 provides 10, 50 and 100 years return period values estimated using GPD and GEV models. For half hourly data, GPD projects 4.80 m as 100-year return level, whereas GEV underestimates to 4.29 m. While considering different time interval data, GPD model shows 0.36 m standard deviation among the return levels for different time interval data. Both the 612 and 4224 h series gave lower return levels compared to other series.

3.1.4- Post-monsoon season

Post-monsoon season constitutes data from October to January months of the year and the observed maximum Hs in this season is 2.41 m. The majority of observations during this season lies below the average value of Hs. Only 32 % of the observations lies above 1.13 m and 8 % of the data are above 1.5 m. Hence, selecting the best threshold for the season was more difficult. GPD was fitted for a range of thresholds (0.7 to 1.3 m) selected from SME and PS plots corresponding to each series. Most suitable thresholds were selected after checking the goodness of GPD (Table 42). The GOF test results show that the ONDJ series holds maximum uncertainties on threshold selection due to lower p-values for KS test ranges from 0.13 to 0.48 and 0.19 to 0.45 for CM test respectively. Figure 67 shows the CDF and Q-Q plots. GEV and GPD estimation for post-monsoon season show very large difference among return levels (Table 34). The average percentage difference between 100 years return values obtained from GEV and GPD estimations is more than ~60%. It shows that GEV model clearly underperforms during ONDJ season when initial distribution methods were adopted. Highest return level reported by GPD model is 4.28 m, whereas GEV estimated about 2.3 m for the season. ONDJ accounts standard deviation of 0.30 m and 0.13 m for GPD and GEV estimation, respectively, while using different sampling intervals.

3.2- Long-term statistical analysis of wind-seas and swells

In this section, we relayed on GEV method based on block maxima. For that purpose, we extracted total, wind-sea and swell Hs data into different block maxima viz. monthly, seasonal and annual maxima series. Two seasonal maxima series is considered in such a way that one includes highest two observations in a season and another one consist of highest

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observation from each season. So monthly maxima series includes 96 data points. Both seasonal maxima series (seasonal maxima 1 and 2) consist of 24 and 48 data points respectively. Annual maxima series covers 8 data points. Table 45 shows the estimated return levels corresponding to various return periods. It is clear that both seasonal maxima series provides highest return levels for total Hs (6.56 m and 7.20 m) and swell Hs (5.95 m and 6.35 m), whereas wind-sea Hs is 6.16 m when annual maxima series is considered. ~~But the annual maxima series provides an abnormal result for 100 years return level estimation (Figure 7).~~ The GEV-AM model ~~also~~ shows underestimation of 10-year return level compared to the maximum measured data. The annual maxima series resulted in 5.66 m as the 100-year return level for the total Hs (Figure 8), which is comparable with Teena et al. (2012) estimation for the location off the central west coast of India.

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We did a separate analysis of the annual maxima series to get insight into the abnormal results observed for wind-sea data series. Here, we considered four unique series of different length by taking annual maxima observations from 2008 to 2016. That is, first series (S1) consist of 5 data points (2008-2012) and second series (S2) ~~consist~~consists of 6 data points (2008-2013) and so on. The density plots showing the probability for different wave height class is presented in Fig. 89 along with the corresponding GPD fit. We calculated the standard deviation for each series and the percentage difference between each series with the parent series (S0). The result shows that return levels are positively correlated with standard deviation (Table 56). In the case of total Hs, the correlation between the changes in standard deviation and the corresponding changes in 100-year return levels are 0.997, whereas for wind-sea and swell, it is 0.964 and 0.647 respectively. Annual maxima of wind-sea (4.29 m) for the year 2015 made an abrupt change in the standard deviation of the series by about 0.46 m which ~~is~~are more than 17 % of the average of the series excluding 2015. So, the 100 years return level for wind-sea overshoot for about 6.16 m making 66 % difference from return value obtained for S3 series. In this case study, the length of the special series under consideration does not influence on the estimated return levels. That is, in the case of total Hs series, 100 years return levels for S1 series is greater than both S2 and S3 series. Same characteristics can be seen in the case of swell Hs also. Therefore, return levels for annual maxima by GEV model have greater influence over how a single data point, i.e., the annual maxima, alter the standard deviation of the series rather than the changes in the length of the series.

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3.3 Influence of length of wave data on estimated significant wave height return value

An analysis is carried out to check uncertainties in return level estimation related to the length of the wave record. From the 1/2 h buoy measured data, data at 6-h interval are extracted and used for the analysis and the return levels obtained by using 6-h measured buoy data are compared with the return level obtained from the 6-h ERA-Interim data at shallow and deep locations (Figure 8). Six hourly ERA-Interim reanalysis data for 38 years (1979-2016) is used in this analysis. Buoy data consists of 11479 data points and ERA-Interim data consists of 55520 data points (Table 1). The highest observed Hs in the 6 hourly buoy data is 4.11 m followed by 4.03 m, while maximum Hs in the ERA-Interim shallow is 5.45 m and in the ERA-Interim deep is 7.13 m. The Hs values at deep location is ~1.4 times the values at the shallow location and it resulted in higher return level of Hs at the deep location. Sanil Kumar and Naseef (2015) observed that ERA-Interim overestimates the Hs for shallow water locations along the west coast of India due to swell height overestimation and the difference between the ERA-Interim Hs and the buoy Hs is up to 15%. For the study location, the storm induced wave heights during the non-monsoon period are less than the monsoon induced waves. June first week is the onset of Indian summer monsoon and the maximum Hs in the study area is due to monsoon influence and in all years it is during June to September. The 100-year return levels by using GEV method give comparable results for buoy data (4.18 m) and ERA-Interim shallow data (4.39 m), while that for ERA deep is 5.67 m (Figure 8). It is clear that the 100-year Hs return level using GEV for ERA-Interim data is lower than the maximum Hs in the data, while in the case of buoy data, 100-year return level is slightly higher than the highest Hs value. The return levels obtained by GPD method shows significant discrepancy among 100-year estimates. The 100-year return level obtained for buoy data is 4.46 m, but that using ERA-Interim shallow data is 6.18 m and that for ERA-Interim deep is 7.28 m. The Hs return level for 100-year for deep water has closer values following GEV and GPD, while in the shallow water, a significant difference is obtained. The 6-h interval data tend to miss 18 values of Hs between 4.11 and 4.70 m and hence there is a significant difference in the 100-year return level of Hs based on GEV-AM obtained using this data compared to that based on the data at 1/2-h interval.

We have examined the difference in the return level of Hs by considering data in different blocks; i.e. 10, 20, 30 and 38 years using the ERA-Interim shallow water data. The study indicates a large underestimation (~18%) in the return level estimate if we consider only the

first 10 years (1979-1988) data in place of the 38 years (Figure 10). The large difference in the values of Hs return level is due to the occurrence of a tropical storm in the Arabian Sea during 9-12 June 1996, which resulted in a high wave heights, Hs up to 5.46 m, whereas the maximum Hs excluding this storm is 4.63 m. During the 1996 storm, Hs of 5.69 m is measured by a Datawell directional waverider buoy moored at 23-m water depth off Goa (Sanil Kumar et al., 2006), which is ~150 km north of the present study area. The data blocks containing this storm data i.e. the 20 years (1979-1998) and 30 years (1979-2008) data did not show much difference in the 100-year Hs value compared to the 38 years data. If we consider only the last 10 years (2007-2016), it resulted in 7% underestimation in the 100-year Hs value. The study shows that a single storm can create a large difference in the 100-year Hs value, compared to the differences in values resulted from different length of the data block.

The long-term and decadal trend of wave climate in the different parts of major oceans is studied (Young et al. 2011). We have examined the trend in Hs at the shallow location based on the ERA-Interim data from 1979 to 2016. The study shows that the annual maximum Hs shows a weak increasing trend (1.1 cm y^{-1}), whereas there is no significant trend in the annual mean value (Figure 11). Sanil Kumar and Anoop (2015) observed that during 1979 to 2012, the average trend of annual mean Hs for all the locations in the western shelf seas is 0.06 cm y^{-1} .

3.4 Influence of water depth on the measured buoy data

The relative water depth based on spectral peak period (d/L_p) indicates that most of the time (97.8 to 99.3%), the wave regime is in intermediate water (Table 7). Only during 0.1 to 0.8% of the time, the waves satisfy the deep water condition. Hence, the waves measured by the buoys are influenced by the bathymetry and the wave characteristics will be different in the deep water. The wave rose plots during March 2008 to February 2016 based on the measured buoy data and the ERA-Interim reanalysis data at shallow and deep water locations are presented in Figure 12. As the waves move from deep to shallow waters, the direction of high waves shifted from southwest to west. The limiting value of wave height based on breaker criteria is 0.6 to 0.78 times the water depth (Massel, 1966). The maximum Hs in the measured buoy data is 4.70 m and some of the waves containing this record will arrive very

steep or broken at 9-m water depth since the maximum wave height is 1.65 to 1.8 times the Hs.

4. Conclusion

Long-term statistical analysis of extreme waves is carried out based on GEV and GPD models using measured buoy data from March 2008 to February 2016, and the ERA-Interim data from 1979 to 2016. Return levels are calculated for resultant, wind-sea and swell Hs separately. The analysis is also conducted for data under three different seasons. The parent data are resampled into 3, 6, 12 and 24 hourly series and estimated the discrepancy in return level estimation. Selection of appropriate thresholds for POT method is justified using different GOF tests results. Analysis of the total Hs shows that IDM approach underestimates return levels for different seasons compared to corresponding GPD. The 100 years return level estimated by IDM are almost comparable with corresponding GPD estimation for ten years period, but there is a significant difference in the return level estimates when considering different sampling intervals. ~~Maximum return levels are obtained while considering half hourly series for different seasons except pre-monsoon season where 12 hourly data estimated highest return level.~~ IDM estimates largely underestimates return levels for the post-monsoon season since the majority of the observation in this season lies away from its tail of the distribution.

Long-term statistics of wind-sea and swell data are calculated by GEV model following block maxima and r-largest methods. Annual maxima and monthly maxima are considered for block maxima series, and two seasonal maxima series are considered for the r-largest method. It is shown that these methods give higher return levels than GPD models. The r-largest method provides 7.20 m as 100-year return level when compared to 5.27 m of GPD model. The sensitivity analysis of GEV-AM model shows that change in the standard deviation of data series under consideration makes discrepancies in the return level estimates rather than a change in the length of the series. Both GEV and GPD models ~~underestimates 10-year return levels compared to maximum measured data~~ underestimate 10-year return levels compared to maximum measured data. The 100-year return levels by using GEV method give comparable results for short-term (2008 to 2016) buoy data (4.18 m) and the long-term (1979 to 2016) ERA-Interim shallow data (4.39 m). The 6-h interval data tend to miss high values of Hs m and hence there is a significant difference in the 100-year return level Hs obtained using this data compared to data at 1/2-h interval. The ERA-Interim data shows that from 1979 to 2016, the annual maximum Hs shows a weak increasing trend (1.1 cm y⁻¹). The study shows that a single

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storm can create a large difference in the 100-year Hs value, compared to the differences in values obtained from different length of the data block.

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References

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Abild, J., Andersen, E. Y., and Rosbjerg, D.: The climate of extreme winds at the Great Belt, Denmark, J. J Wind Eng Ind Aerod., 41(1), 521-532, 1992.

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Alves, J. H G M., and Young, Ian R.: On estimating extreme wave heights using combined Geosat, Topex/Poseidon and ERS-1 altimeter data, Appl Ocean Res, 25(4), 167-186, 2003.

Anoop, T. R., Kumar, V. S., Shanas, P. R., and Johnson, G.: Surface wave climatology and its variability in the north Indian Ocean Based on ERA-interim reanalysis, J. Atmos. Ocean. Technol., 32(7), 1372–1385. <http://doi.org/10.1175/JTECH-D-14-00212.1>, 2015.

Brodtkorb, P.A., Johannesson, P., Lindgren, G., Rychlik, I., Rydén, J. and Sjö, E.: WAFO - a Matlab toolbox for analysis of random waves and loads, Proc. 10th Int. Offshore and Polar Eng. Conf., Seattle, USA., Vol III, pp. 343-350, 2000.

Caires, S., and Sterl, A.: 100-year return value estimates for ocean wind speed and significant wave height from the ERA-40 data, J Climate., 18(7), 1032-1048, 2005.

Choulakian, V. and Stephens, M.A.: Goodness-of-Fit Tests for the Generalized Pareto Distribution, Technometrics., 43, 478–484, 2001.

Coles, S., Bawa, J., Trenner, L., and Dorazio, P.: An introduction to statistical modeling of extreme values, Springer-Verlag, London., UK., 205pp, 2001.

Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M. A., Balsamo, G., Bauer, P., Bechtold, P., Beljaars, A. C. M., van de Berg, L., Bidlot, J., Bormann, N., Delsol, C., Dragani, R., Fuentes, M., Geer, A. J., Haimberger, L.,

[Healy, S. B., Hersbach, H., Hólm, E. V., Isaksen, L., Kållberg, P., Köhler, M., Matricardi, M., McNally, A. P., Monge-Sanz, B. M., Morcrette, J.-J., Park, B.-K., Peubey, C., de Rosnay, P., Tavolato, C., Thépaut, J.-N., and Vitart, F.: The ERA-Interim reanalysis: Configuration and performance of the data assimilation system, Q. J. Roy. Meteor. Soc., 137, 553–597, 2011.](#)

[Goda, Y., Hawkes, P., Mansard, E., Martin, M. J., Mathiesen, M., Peltier, E., and Van Vledder, G.: Intercomparison of extremal wave analysis methods using numerically simulated data, Proc. WAVES'93, New Orleans, USA, 963-977, 1993.](#)

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Goda, Y., Kudaka M., and Kawai.H.: Incorporation of Weibull distribution in L-moments method for regional frequency of peaks-over-threshold wave heights, Proceedings of 32nd international conference on coastal engineering., ASCE, 2010.

Goda, Y.: Uncertainty of design parameters from viewpoint of extreme statistics, J Offshore Mech Arct., 114(2), 76-82, 1992.

Gumbel, E. J.: Statistics of extremes, Columbia Univ. Press., New York, 1958.

Hosking, J. R. M., Wallis, J. R., and Wood, E. F.: Estimation of the generalized extreme-value distribution by the method of probability-weighted moments, Technometrics, 27(3), 251-261, 1985.

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Izaguirre, C., Mendez, F. J., Menendez, M., Luceño, A., and Losada, I. J.: Extreme wave climate variability in southern Europe using satellite data, J Geophys Res., 115(C4), doi:10.1029/2009jc005802, 2010.

Jonathan, P., Randell, D., Wu, Y., and Ewans, K.: Return level estimation from on-stationary spatial data exhibiting multidimensional covariate effects. Ocean Eng., 88, 520-532, doi:10.1016/j.oceaneng.2014.07.007, 2014.

Katz, R. W., Parlange, M. B., and Naveau, P.: Statistics of extremes in hydrology, Adv Water Resour., 25(8-12), 1287-1304, doi:10.1016/s0309-1708(02)00056-8, 2002.

[Massel, S.R.: On the largest wave height in water of constant depth, Ocean. Eng., 23, 553-573, 1966.](#)

Mathiesen, M., Goda, Y., Hawkes, P. J., Martín, M. J., Peltier, E., and Edward, F.: Recommended practice for extreme wave analysis, *J Hydraul Res*, 32:6, 803-814, 1994.

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Méndez, F. J., Menéndez, M., Luceño, A., Medina, R., and Graham, N. E.: Seasonality and duration in extreme value distributions of significant wave height, *Ocean Eng.*, 35(1), 131-138, 2008.

Menéndez, M., Méndez, F. J., Izaguirre, C., Luceño, A., and Losada, I. J.: The influence of seasonality on estimating return values of significant wave height, *Coast Eng.*, 56(3), 211-219, doi: 10.1016/j.coastaleng.2008.07.004, 2009.

Panchang, V., Zhao, L., and Demirebilek, Z.: Estimation of extreme wave heights using GEOSAT measurements, *Ocean Eng.*, 26(3), 205-225, doi:10.1016/s0029-8018(97)10026-9, 1999.

Pickands, J.: Statistical inference using extreme order statistics, *Ann Stat.*, 3, 119-131, 1975.

[Portilla, J., Ocampo-Torres, F. J., and Monbaliu, J.: Spectral Partitioning and Identification of Wind Sea and Swell, *J. Atmos. Oceanic Technol.*, 26, 107-122, 2009.](#)

Samayam, S., Laface, V., Annamalaisamy, S. S., Arena, F., Vallam, S., and Gavrilovich, P. V.: Assessment of reliability of extreme wave height prediction models. *Nat. Hazards Earth Syst. Sci.*, 17, 409-421, 2017.

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[Sanil Kumar, V., Pathak, K.C., Pednekar, P., Raju, N.S.N. and Gowthaman, R.: Coastal processes along the Indian coastline. *Curr Sci* 91; 530-536, 2006.](#)

Sanil Kumar, V., Shanas, P. R., and Dubhashi, K. K.: Shallow water wave spectral characteristics along the eastern Arabian Sea, *Nat. Hazards*, 70(4), 377-394, doi:10.1007/s11069-013-0815-7, 2014.

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[Sanil Kumar V., Anoop, T.R.: Spatial and temporal variations of wave height in shelf seas around India. *Nat. Hazards*, 78, 1693-1706. doi: 10.1007/s11069-015-1796-5, 2015.](#)

[Sanil Kumar, V., Muhammed Naseef T.: Performance of ERA-Interim wave data in the nearshore waters around India. *J Atmospheric and Oceanic Technology*, 32, 6, 1257-1269. doi:10.1175/JTECH-D-14-00153.1, 2015.](#)

Shaji, C., Kar, S.K., and Vishal, T.: Storm surge studied in North Indian Ocean: A review, Indian J Geo-Mar Sci., 43(2)125-147, 2014.

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Smith, R. L.: Extreme value theory based on the r largest annual events, J Hydrol., 86(1-2), 27-43, doi:10.1016/0022-1694(86)90004-1, 1986.

Soares, C. G., and Scotto, M.: Application of the r-largest-order statistics for long-term predictions of significant wave height, Coast Eng., 51(5-6), 387-394, doi:10.1016/j.coastaleng.2004.04.003, 2004.

Solari, S. and Losada, M. A.: Non-stationary wave height climate modeling and simulation, J. Geophys. Res., 116, C09032, doi:10.1029/2011JC007101, 2011.

Solari, S. and Losada, M. A.: Unified distribution models for met-ocean variables: Application to series of significant wave height. Coastal Engineering, 68, 67-77, 2012.

Solari, S., Egüen, M., Polo, M. J. and Losada, M. A.: Peaks Over Threshold (POT): A methodology for automatic threshold estimation using goodness of fit p-value. Water Resources Research, 53(4), 2833-2849, 2017.

Stephens, M. A.: EDF Statistics for Goodness of Fit and Some Comparisons, J Am Stat Assoc., 69(347), 730-737, doi:10.1080/01621459.1974.10480196, 1974.

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Teena, N. V., Sanil Kumar, V., Sudheesh, K., and Sajeev, R.: Statistical analysis on extreme wave height. Nat Hazards., 64(1), 223-236, doi:10.1007/s11069-012-0229-y, 2012.

Thevasiyani, T. and Perera, K.: Statistical analysis of extreme ocean waves in Galle, Sri Lanka. Weather Clim. Extrem., 5-6, 40-47, doi:10.1016/j.wace.2014.07.003, 2014.

Viselli, A. M., Forristall, G. Z., Pearce, B. R., and Dagher, H.J.: Estimation of extreme wave and wind design parameters for offshore wind turbines in the Gulf of Maine using a POT method. Ocean Eng., 104, 649-658, doi:10.1016/j.oceaneng.2015.04.086, 2015.

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Young, I.R., Zieger, S. and Babanin, A.: Global trends in wind speed and wave height. Science 332(6028); 451-455, 2011.

Figure captions

Figure 1: Time series plot of the significant wave height measured by buoy and from ERA-Interim data at shallow and deep water.

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Figure 2: Estimated shape parameters for different seasonal data with different sampling intervals used in a) GEV and b) GPD model.

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Figure 3: A Typical (a) SME and (b) PS plots used for selecting a range of thresholds required for POT analysis. In this particular case, a range of 1.19 m to 1.32 m was selected.

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Figure 4: Figure corresponding to full year analysis. (a) to (e) is CDF plots for ½ hourly to 24 hourly data respectively, sub-figures, (f) to (g) are corresponding Q-Q plots and (k) to (o) are corresponding return levels estimated using GPD model.

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Figure 5: Same as in Figure 4- Same as in Figure 3 but corresponding to pre-monsoon season.

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Figure 6: Same as in Figure 4 but corresponding to monsoon season.

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Figure 7: Same as in Figure 4 but corresponding to the post-monsoon season.

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Figure 8: Return levels estimated of significant wave heights for different return periods based on buoy data (2008-2016), ERA-Interim shallow and deep water (1979-2016) at 6-h interval by GEV model using annual maxima series.

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Figure 9: Density plots showing the probability for different wave height class. Total, wind-sea and swell Hs are presented in rows wise. Columns correspond to selected number of data points (5 to 8 years). The solid curve is the corresponding GPD fit.

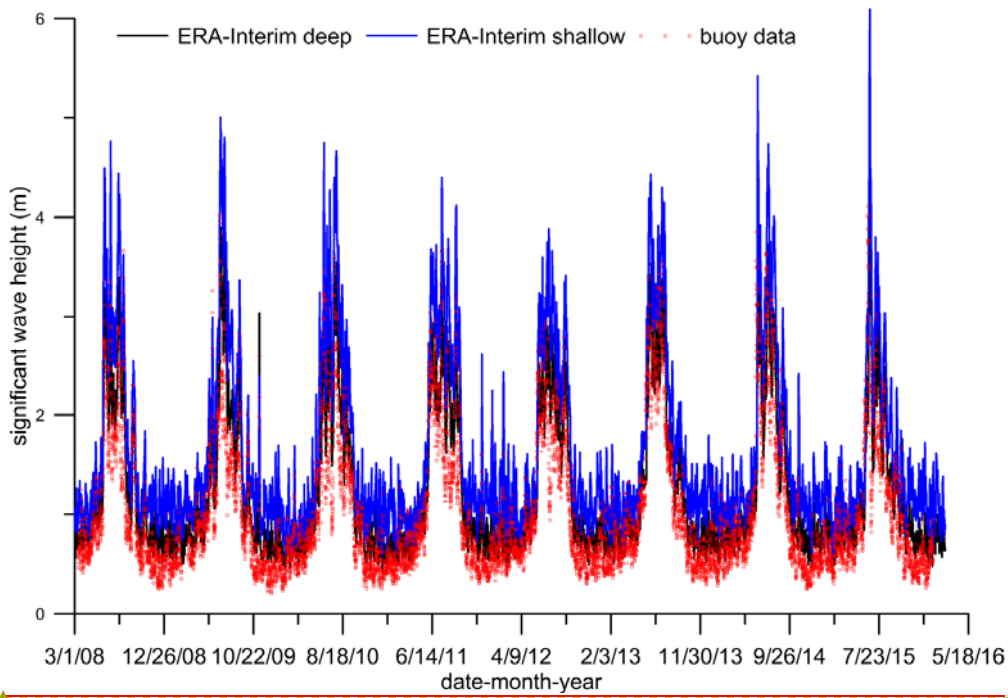
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Figure 10. Return levels of significant wave heights for different return periods based on ERA-Interim shallow water data in different block years by GEV model using annual maxima series

Figure 11. Variation of (a) annual maximum and (b) annual mean Hs at the shallow locations based on ERA-Interim data. The solid line indicates the trend in Hs during 1979 to 2016

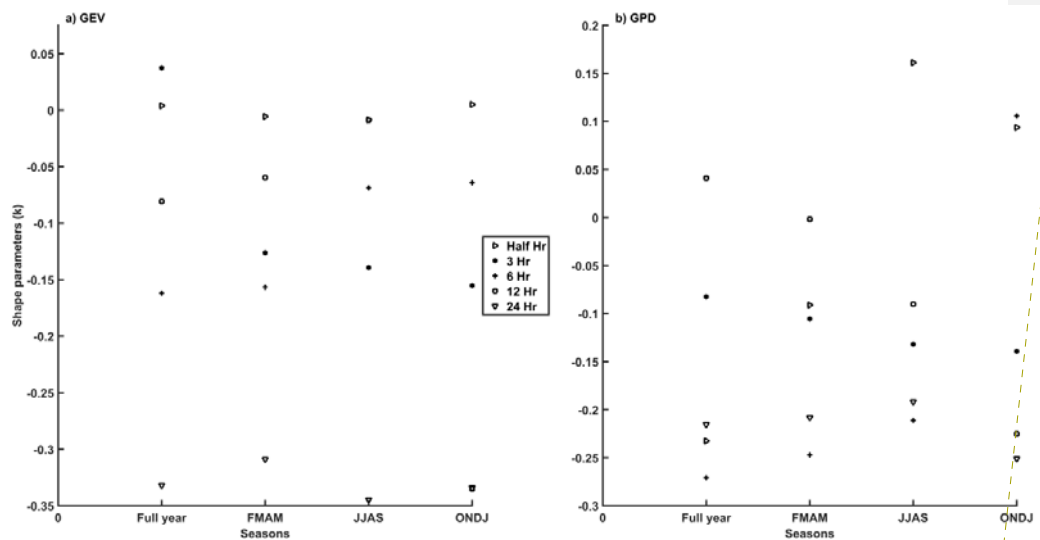
Figure 12: Wave rose plots during March 2008 to February 2016 based on the measured buoy data and the ERA-Interim reanalysis data at shallow and deep water locations

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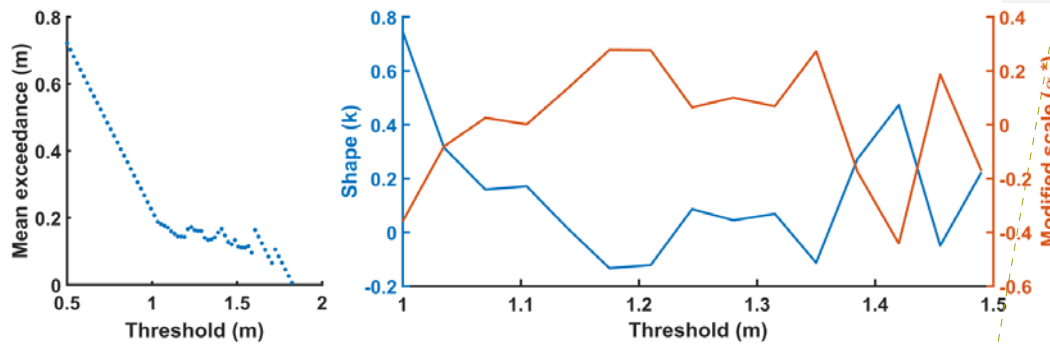
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Figure 2: Estimated shape parameters for different seasonal data with different sampling intervals used in a) GEV and b) GPD model

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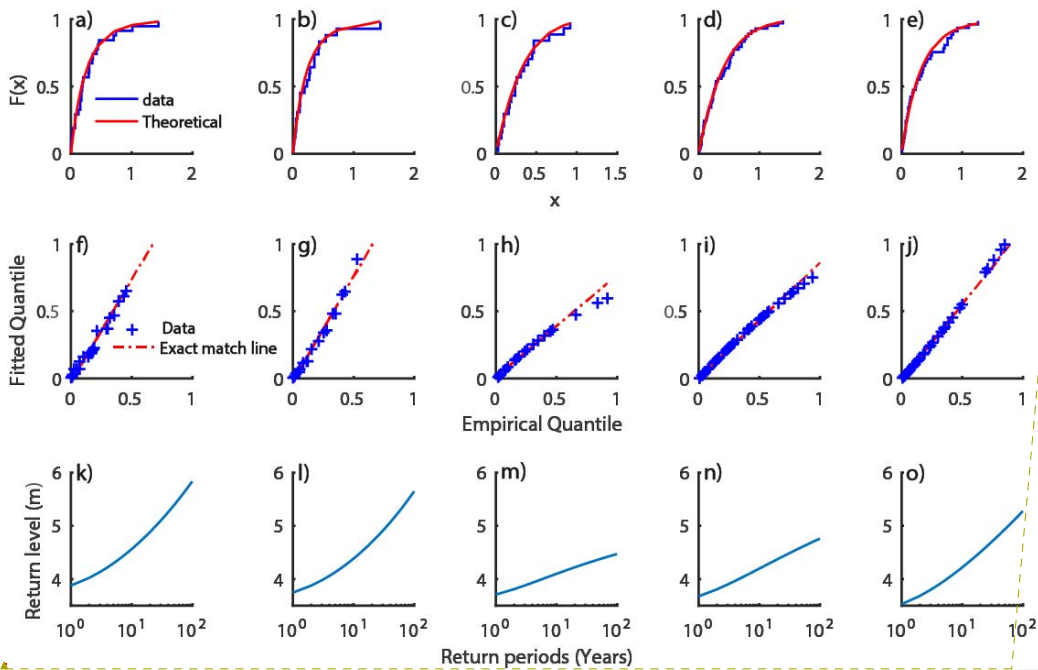
Figure 23: A Typical (a) SME and (b) PS plots used for selecting a range of thresholds required for POT analysis. In this particular case, a range of 1.19 m to 1.32 m was selected

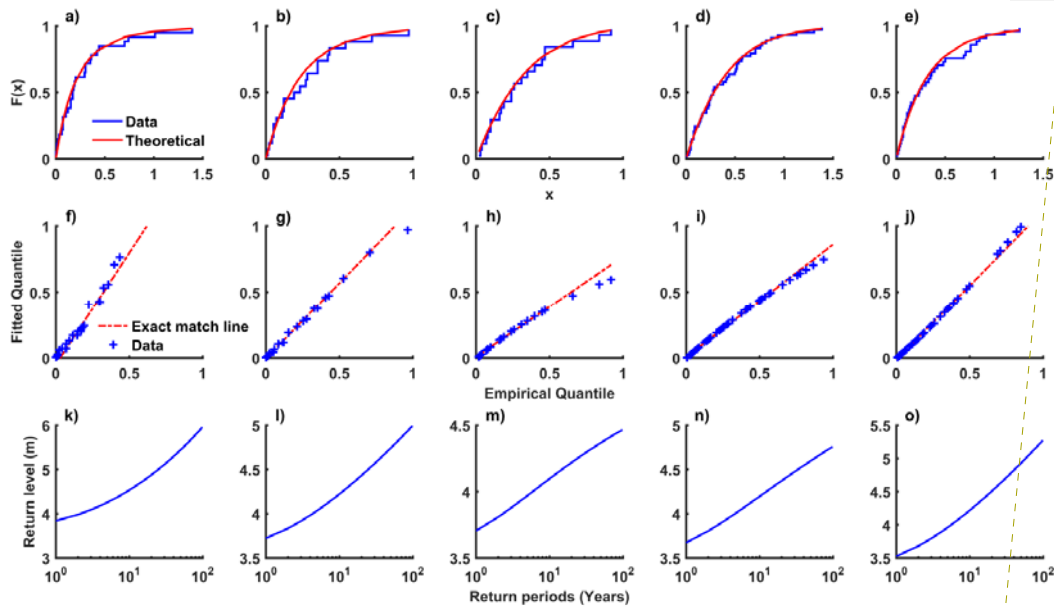
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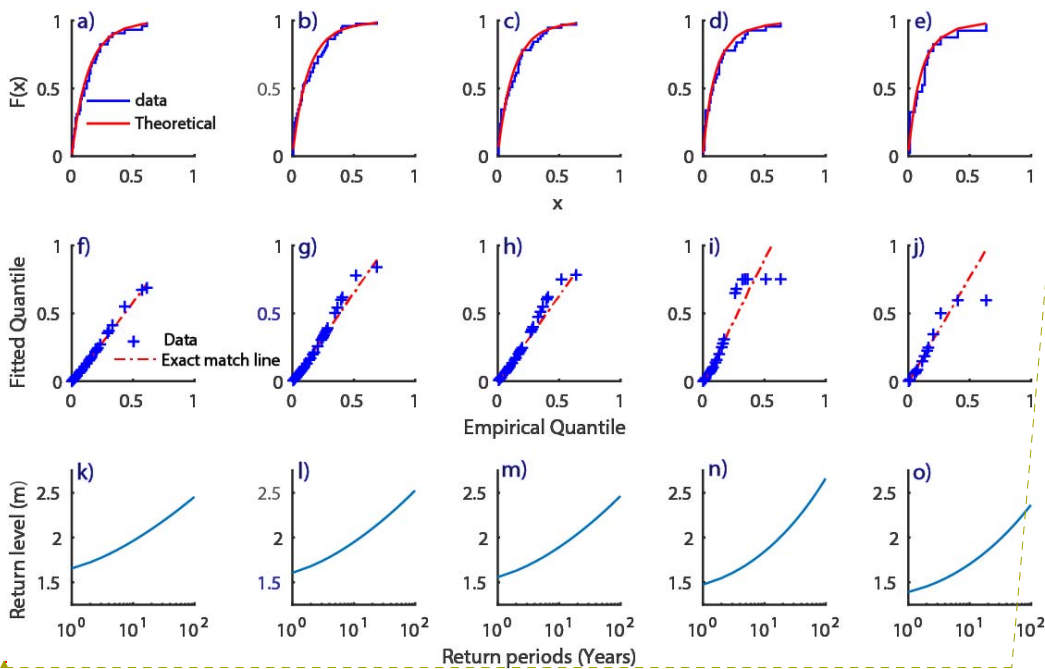


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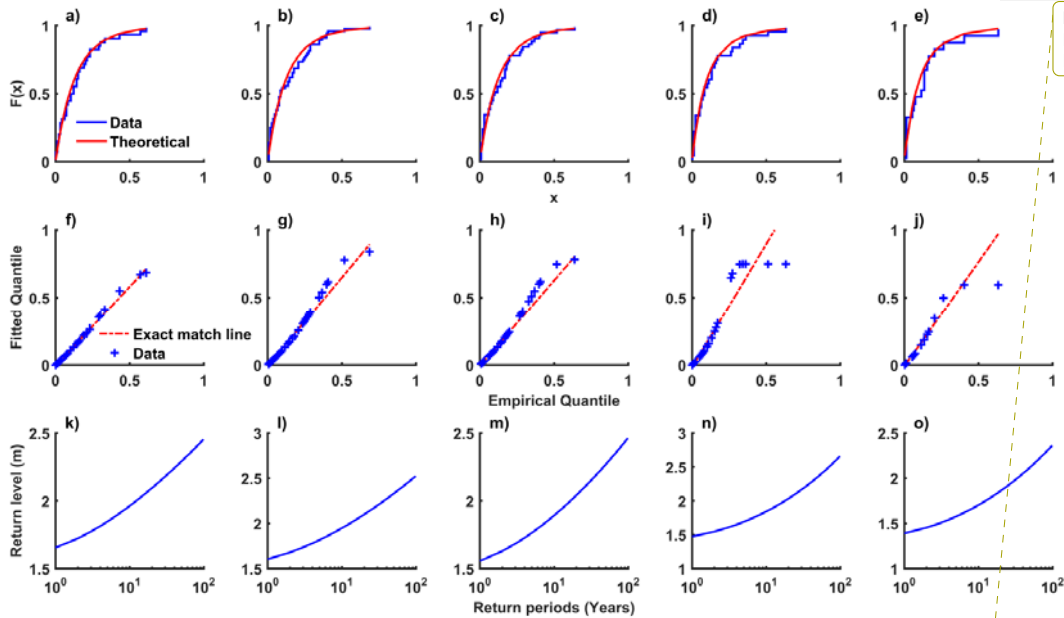
Figure 34: Figure corresponding to full year analysis. (a) to (e) is CDF plots for 1/2 hourly to 24 hourly data respectively, sub-figures, (f) to (j) are corresponding Q-Q plots and (k) to (o) are corresponding return levels estimated using GPD model

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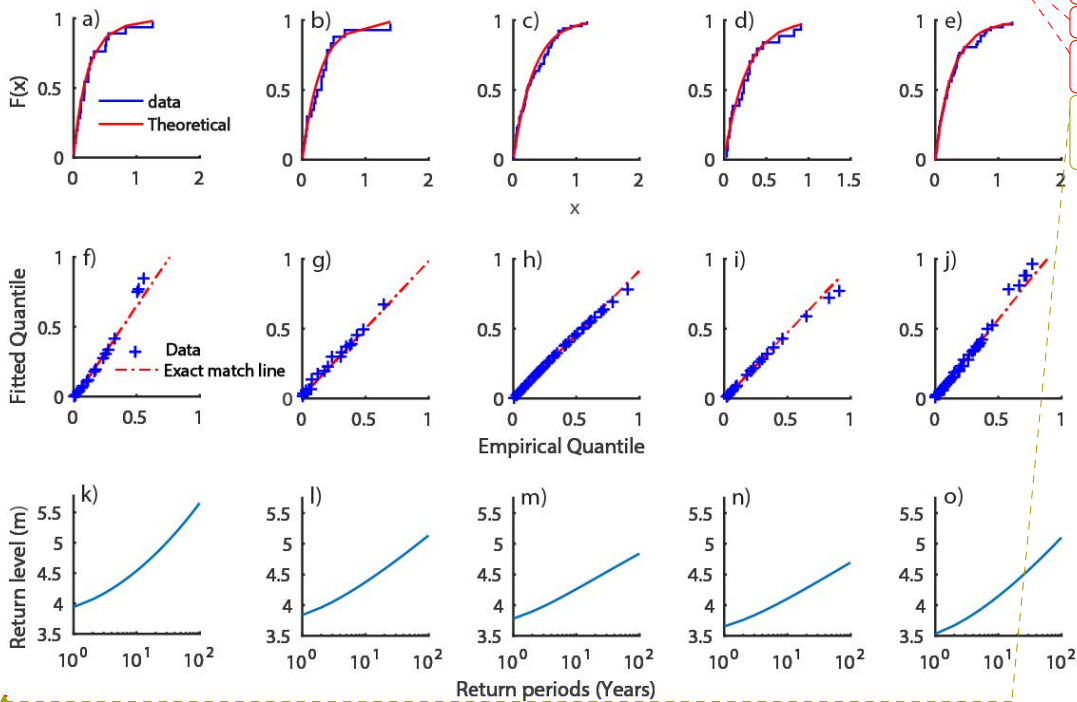


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Figure 45: Same as in Figure 34 but corresponding to pre-monsoon season



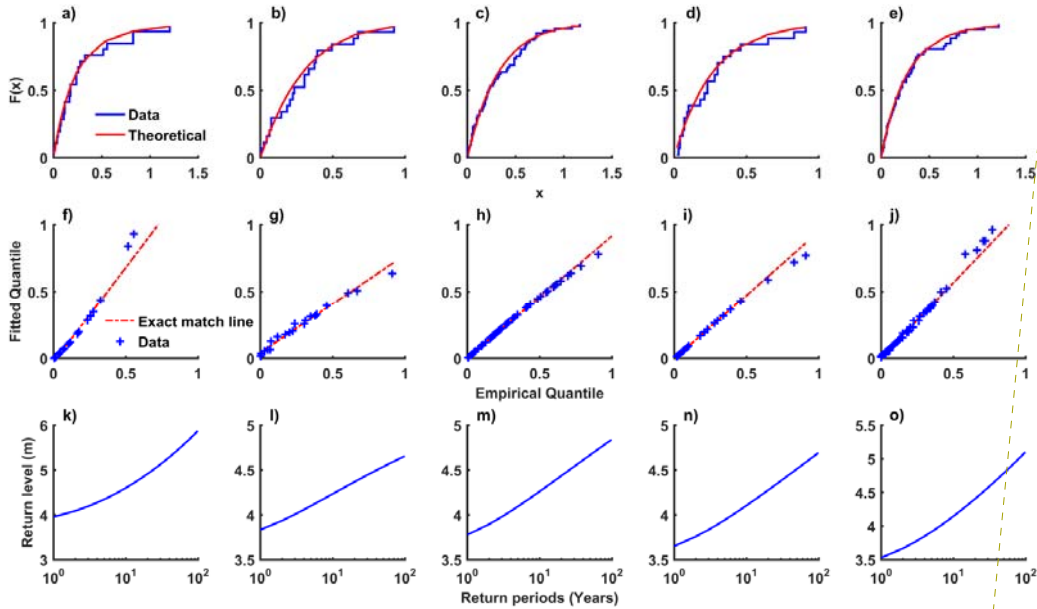
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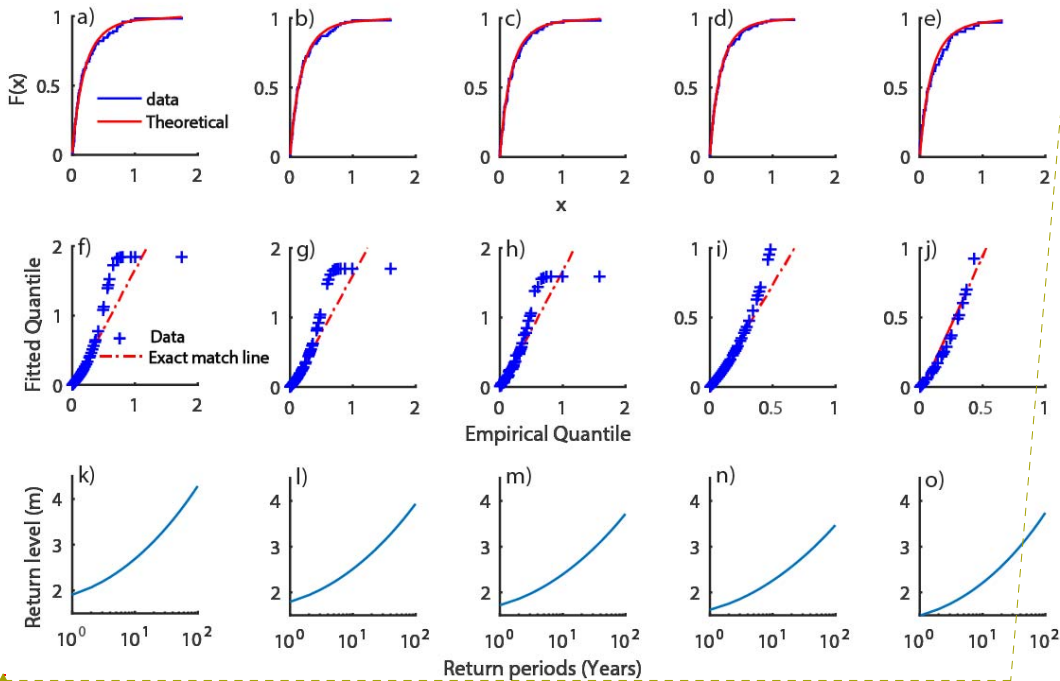
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Figure 56: Same as in Figure 34 but corresponding to monsoon season

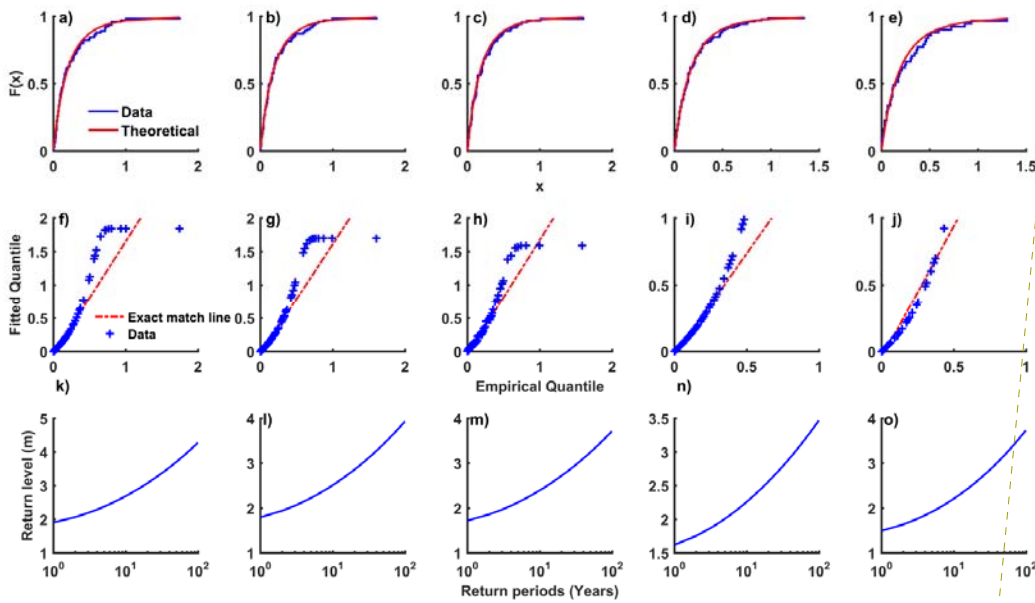
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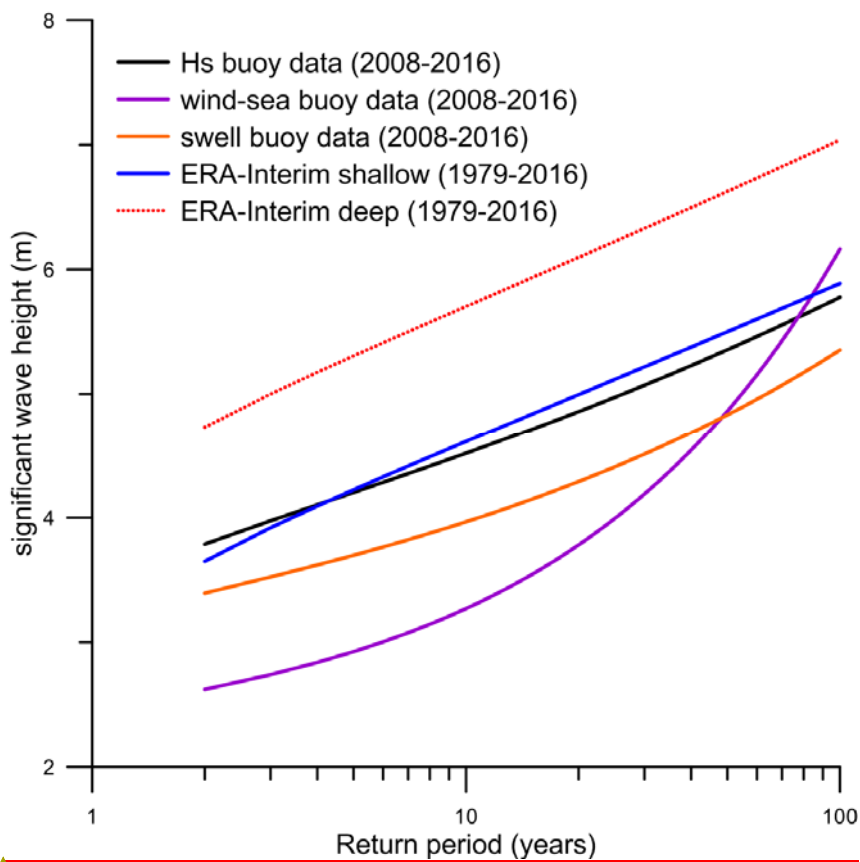
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Figure 67: Same as in Figure 34 but corresponding to the post-monsoon season

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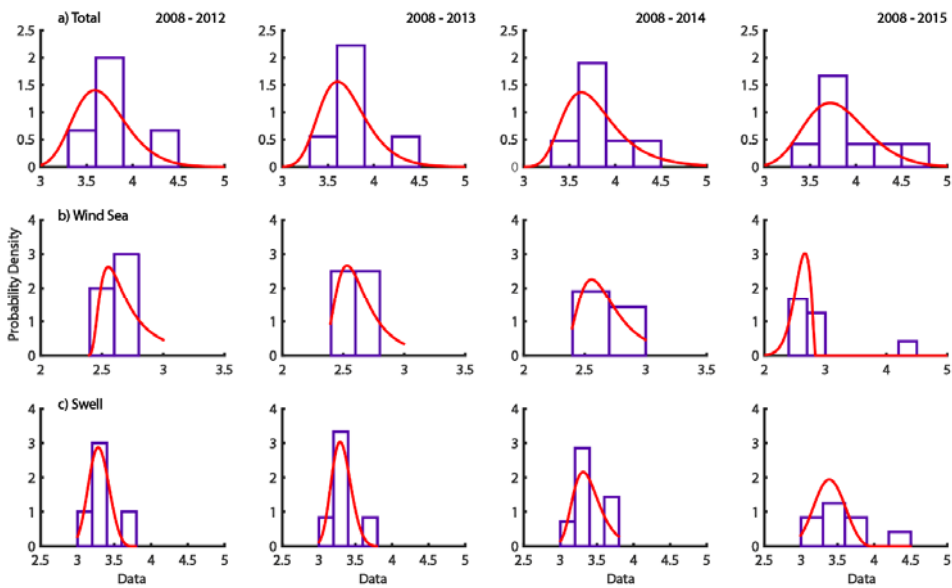
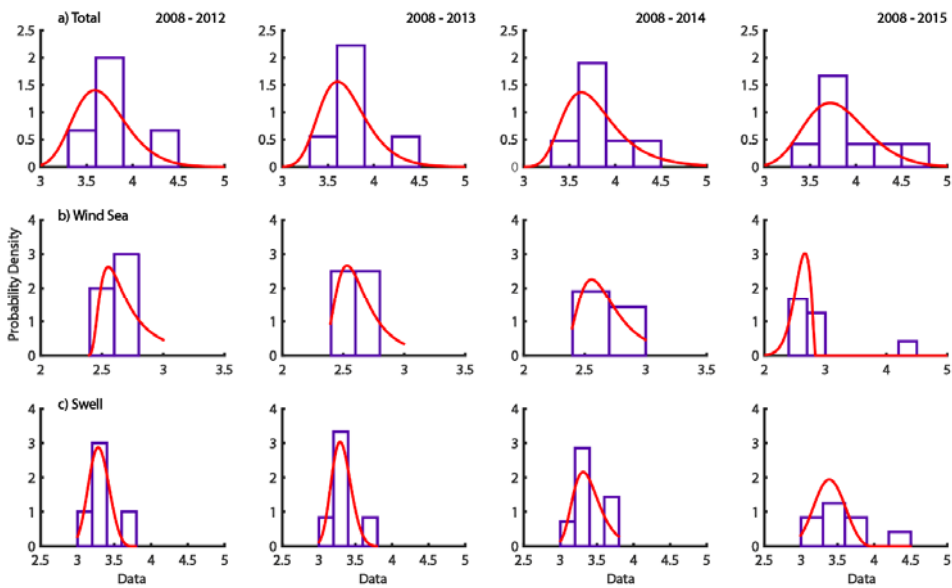
Figure 78: Return levels estimated of significant wave heights for different return periods based on buoy data (2008-2016), ERA-Interim shallow and deep water (1979-2016) at 6-h interval by GEV model using annual maxima series

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Figure 89: Density plots showing the probability for different wave height class. Total, wind-sea and swell H_s are presented in rows wise. Columns correspond to selected number of data points (5 to 8 years). The solid curve is the corresponding GPD fit

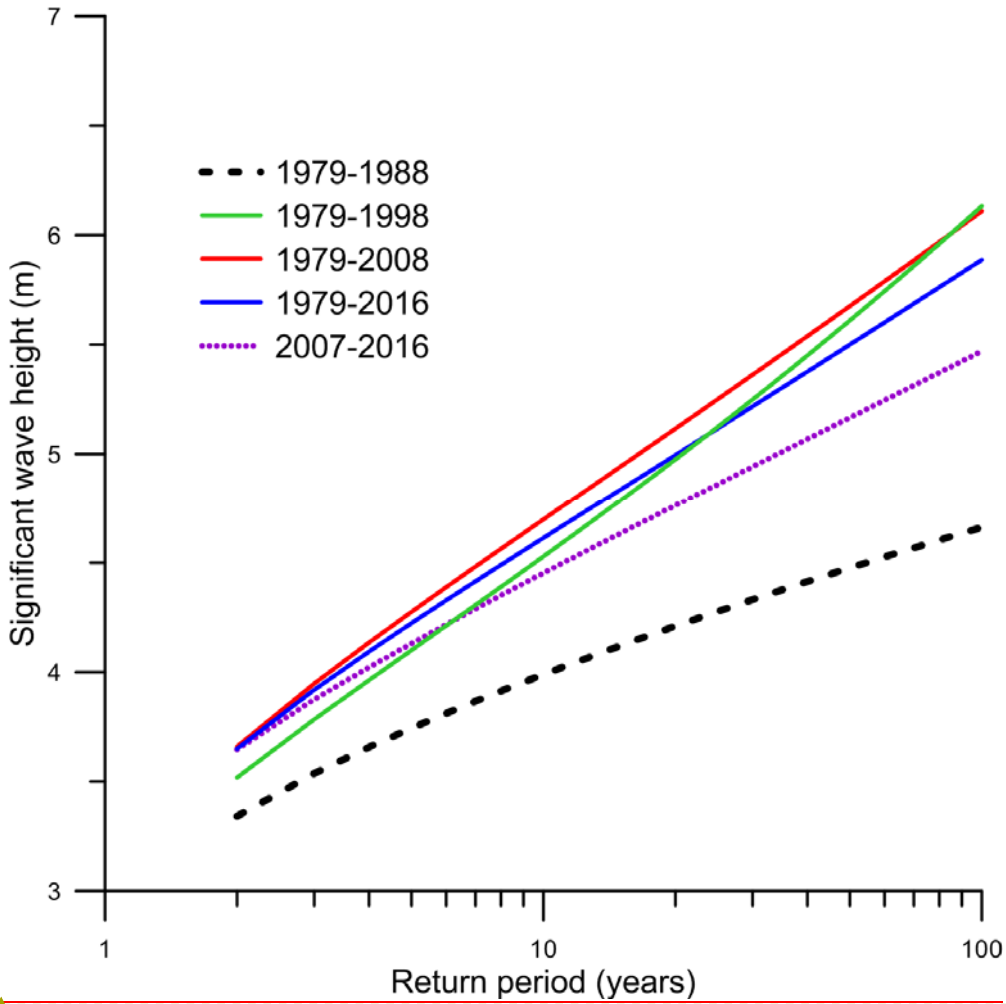
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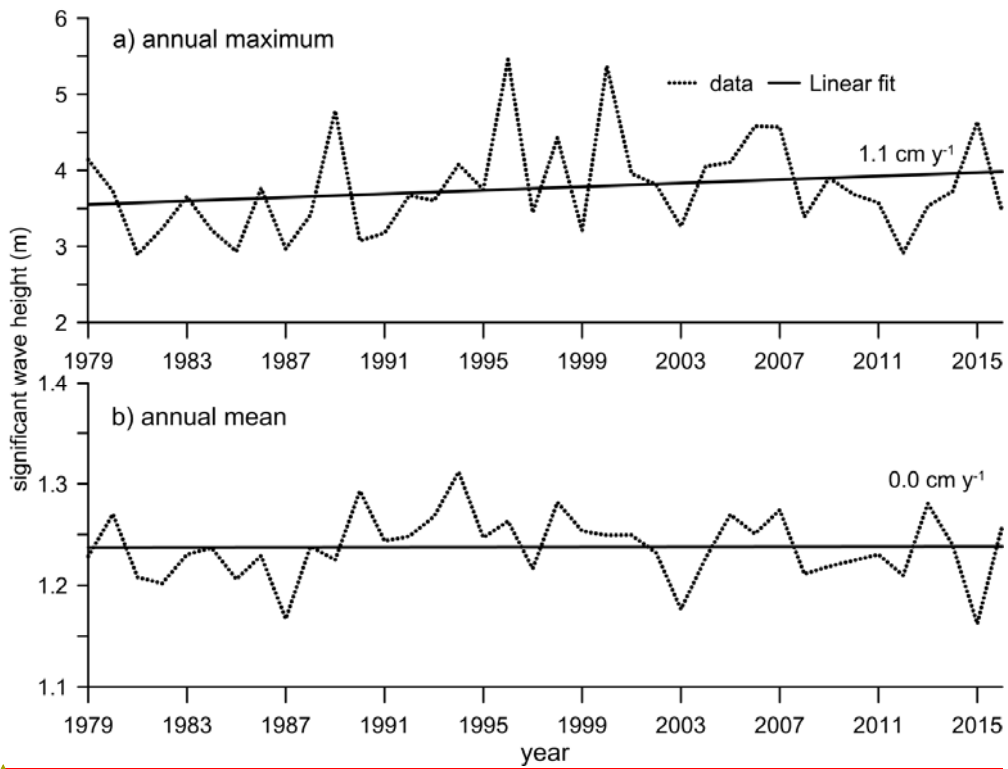
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Table 1



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Figure 10. Return levels of significant wave heights for different return periods based on ERA-Interim shallow water data in different block years by GEV model using annual maxima series



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Figure 11. Variation of (a) annual maximum and (b) annual mean Hs at the shallow locations based on ERA-Interim data. The solid line indicates the trend in Hs during 1979 to 2016

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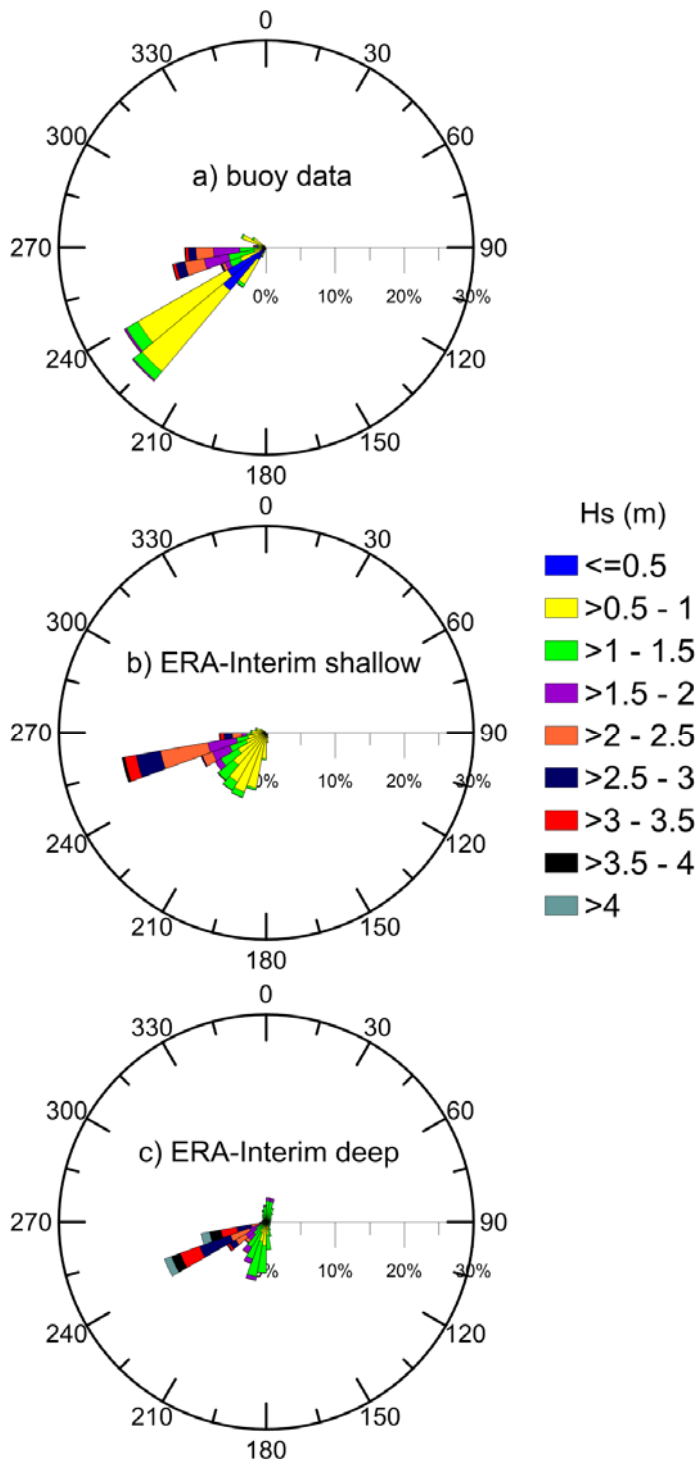


Figure 12: Wave rose plots during March 2008 to February 2016 based on the measured buoy data and the ERA-Interim reanalysis data at shallow and deep water locations

Table 1: The comparison of 50 and 100 year significant wave height return levels based on buoy, ERA-Interim shallow and ERA-Interim deep at 6-h interval along with data statistical parameters

<u>Distribution</u>	<u>Particulars</u>	<u>Buoy</u>	<u>ERA-Interim shallow</u>	<u>ERA-Interim deep</u>		
	<u>Location</u>	<u>74.391° E</u> <u>14.304° N</u>	<u>74.380° E</u> <u>14.250° N</u>	<u>69.250° E</u> <u>14.250° N</u>		
	<u>Total number of data points</u>	<u>11479</u>	<u>55520</u>	<u>55520</u>		
	<u>Data period</u>	<u>2008-2016</u>	<u>1979-2016</u>	<u>1979-2016</u>		
<u>GEV</u>	<u>No. data points between different range</u>	1) <u>$\geq 5m$</u> 2) <u>$\geq 4.5m$ & $< 5m$</u> 3) <u>$\geq 3.5m$ & $< 4.5m$</u> 4) <u>$\geq 3m$ & $< 3.5m$</u>	<u>0</u> <u>0</u> <u>32</u> <u>137</u>	<u>5</u> <u>11</u> <u>275</u> <u>1224</u>	<u>70</u> <u>229</u> <u>2846</u> <u>3263</u>	
	<u>DATA max (m)</u>	<u>4.11</u>	<u>5.45</u>	<u>7.13</u>		
	<u>Second highest value (m)</u>	<u>4.03</u>	<u>5.37</u>	<u>6.09</u>		
	<u>DATA mean (m)</u>	<u>1.12</u>	<u>1.24</u>	<u>1.67</u>		
	<u>DATA std (m)</u>	<u>0.73</u>	<u>0.70</u>	<u>0.88</u>		
	<u>Return levels (m)</u>	<u>50-y return period</u> <u>100-y return period</u>	<u>3.88</u> <u>4.18</u>	<u>3.52</u> <u>4.39</u>	<u>4.58</u> <u>5.67</u>	
	<u>GPD</u>	<u>No. data points between different range after decluster</u>	1) <u>$\geq 5m$</u> 2) <u>$\geq 4.5m$ & $< 5m$</u> 3) <u>$\geq 3.5m$ & $< 4.5m$</u> 4) <u>$\geq 3m$ & $< 3.5m$</u>	<u>0</u> <u>0</u> <u>9</u> <u>23</u>	<u>2</u> <u>4</u> <u>46</u> <u>133</u>	<u>15</u> <u>42</u> <u>253</u> <u>235</u>
		<u>Threshold (m)</u>	<u>3.19</u>	<u>3.50</u>	<u>4.41</u>	
		<u>Return levels (m)</u>	<u>50-y return period</u> <u>100-y return period</u>	<u>4.36</u> <u>4.46</u>	<u>5.55</u> <u>6.18</u>	<u>6.69</u> <u>7.28</u>

Table 2: Different goodness of fits used for selecting threshold values of POT analysis. H =0 indicates the test does not reject hypothesis at 5 % significance level (i.e., p-value > 0.05 or test statistics is less than critical value) and H=1 indicates hypothesis is rejected

Return period (m)	H _{smax} (m)	Threshold (m)	KS test				CM test			
			p-value	Test statistics	Critical value	H	p-value	Test statistics	Critical value	H
4.70	3.31	3.31	0.332	0.167	0.242	0	0.320	0.178	0	0
4.28	3.31	3.31	0.920	0.114	0.287	0	0.808	0.062	0	0
4.11	3.19	3.19	0.402	0.183	0.281	0	0.490	0.122	0	0
4.11	2.72	2.72	0.745	0.092	0.187	0	0.595	0.098	0	0
4.00	2.74	2.74	0.525	0.126	0.213	0	0.739	0.072	0	0
1.94	1.32	1.32	0.952	0.081	0.218	0	0.985	0.027	0	0
1.88	1.19	1.19	0.258	0.126	0.170	0	0.222	0.226	0	0
1.83	1.19	1.19	0.203	0.151	0.192	0	0.210	0.234	0	0
1.83	1.19	1.19	0.447	0.143	0.227	0	0.446	0.134	0	0
1.83	1.19	1.19	0.296	0.210	0.294	0	0.423	0.142	0.458	0
4.70	3.49	3.49	0.562	0.158	0.275	0	0.665	0.085	0	0
4.28	3.36	3.36	0.722	0.141	0.281	0	0.657	0.087	0	0
4.11	2.94	2.94	0.766	0.084	0.174	0	0.758	0.069	0	0
4.11	3.20	3.20	0.890	0.117	0.281	0	0.906	0.046	0	0
4.00	2.78	2.78	0.961	0.070	0.194	0	0.990	0.024	0	0
2.81	1.06	1.06	0.131	0.123	0.144	0	0.193	0.247	0	0
2.61	1.00	1.00	0.247	0.106	0.142	0	0.307	0.183	0	0
2.59	0.98	0.98	0.488	0.092	0.151	0	0.451	0.133	0	0
2.18	0.84	0.84	0.197	0.102	0.129	0	0.350	0.166	0	0
2.18	0.87	0.87	0.195	0.155	0.196	0	0.207	0.237	0.460	0

Table 23: Table showing different parameters and corresponding RMSE of data and estimated CDF used during each data series analysis

Seasons	Data	GPD			GEV			RMSE (m)
		k (m)	α (m)	RMSE (m)	k (m)	α (m)	β (m)	
Full Year	½ h	-0.233	0.208	0.222	-0.004	0.416	2.462	0.023
	3 h	-0.091	0.232	0.028	-0.006	0.381	2.439	0.008
	6 h	0.161	0.346	0.110	-0.008	0.418	2.223	0.004
	12 h	0.094	0.420	0.102	0.005	0.416	2.206	0.020
	24 h	-0.082	0.314	0.071	0.037	0.458	2.015	0.060
FMAM	½ h	-0.105	0.130	0.037	-0.126	0.115	1.134	0.090
	3 h	-0.132	0.125	0.078	-0.139	0.104	1.143	0.098
	6 h	-0.139	0.123	0.077	-0.155	0.099	1.147	0.100
	12 h	-0.271	0.095	0.167	-0.162	0.108	0.998	0.125
JJAS	24 h	-0.247	0.099	0.082	-0.157	0.114	0.872	0.142
	½ h	-0.184	0.216	0.124	-0.069	0.298	2.782	0.088
	3 h	-0.046	0.280	0.068	-0.069	0.274	2.786	0.074
	6 h	0.041	0.328	0.051	-0.081	0.288	2.583	0.118
ONDJ	12 h	-0.002	0.265	0.042	-0.060	0.281	2.598	0.065
	24 h	-0.090	0.267	0.083	-0.009	0.312	2.423	0.007
	½ h	-0.225	0.189	0.393	-0.335	0.117	1.023	0.631
	3 h	-0.215	0.178	0.333	-0.332	0.116	1.025	0.533
ONDJ	6 h	-0.208	0.177	0.284	-0.309	0.114	0.912	0.525
	12 h	-0.192	0.167	0.267	-0.345	0.104	0.911	0.523
	24 h	-0.251	0.183	0.315	-0.334	0.111	0.780	0.498

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Table 34: Estimated return values corresponding to different seasons using total wave height (Hs) following GEV and GPD methods. Here GEV method follows initial distribution approach

Seasons	DATA	GPD			GEV		
		10	50	100	10	50	100
		Years	Years	Years	Years	Years	Years
		(m)	(m)	(m)	(m)	(m)	(m)
Full Year	½ h	4.24	4.73	4.96	3.37	4.00	4.26
	3 h	4.01	4.36	4.50	3.28	3.88	4.13
	6 h	4.08	4.37	4.47	3.17	3.88	4.18
	12 h	4.17	4.59	4.76	3.14	3.81	4.10
	24 h	4.18	4.92	5.27	3.00	3.68	3.95
FMAM	½ h	1.94	2.29	2.45	1.43	1.71	1.85
	3 h	1.93	2.33	2.52	1.42	1.68	1.81
	6 h	1.87	2.26	2.46	1.41	1.68	1.81
	12 h	1.82	2.35	2.66	1.29	1.59	1.74
	24 h	1.68	2.12	2.36	1.18	1.48	1.64
JJAS	½ h	4.24	4.62	4.80	3.48	4.04	4.29
	3 h	4.02	4.21	4.27	3.42	3.91	4.12
	6 h	4.24	4.66	4.84	3.29	3.90	4.19
	12 h	4.08	4.51	4.69	3.27	3.83	4.09
	24 h	4.11	4.78	5.10	3.13	3.66	3.89
ONDJ	½ h	2.64	3.69	4.28	1.41	1.96	2.30
	3 h	2.46	3.41	3.93	1.41	1.95	2.28
	6 h	2.35	3.23	3.71	1.28	1.77	2.07
	12 h	2.22	3.03	3.47	1.27	1.77	2.09
	24 h	2.16	3.16	3.74	1.15	1.67	2.00

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Table 45: Return levels estimated by GEV model using total, wind-sea and swell data for different block maxima series.

DATA	Total Hs (m)			wind-sea Hs (m)			swell Hs (m)		
	10 years	50 Years	100 Years	10 years	50 Years	100 Years	10 years	50 Years	100 Years
Monthly Maxima	3.21	5.28	6.02	2.45	3.43	3.88	2.92	4.77	5.72
<u>Seasonal Maxima 1</u> <u>Two</u> <u>maximum values</u> <u>from each season</u>	3.66	5.58	6.56	2.68	3.78	4.29	3.31	5.07	5.95
<u>Seasonal Maxima 2</u> <u>One</u> <u>maximum value from</u> <u>each season</u>	3.85	6.04	7.20	2.91	4.32	5.06	3.51	5.40	6.35
Annual Maxima	4.50	5.28	5.66	3.27	4.86	6.16	3.97	4.83	5.35

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Table 56: Table showing the results of the case study. Standard deviation (STD) of each data series considered are provided, and percentage difference among the STD of each series with parent series (S0) are given in the brackets. Percentage difference in the corresponding return level estimation also shown in the brackets of respective return periods.

Dataset	Series (Years)	Maximum observed (m)	Standard deviation (% difference)	Return levels		
				10 Years (m)	50 Years (m)	100 Years (m)
Total	S1 (2008-2012)	4.32	0.36 (21.8)	4.24 (6.1)	4.89 (8.6)	5.20 (10.42)
	S2 (2008-2013)	4.32	0.32 (32.7)	4.17 (8.0)	4.67 (13.1)	4.90 (15.5)
	S3 (2008-2014)	4.32	0.32 (34.5)	4.23 (6.4)	4.65 (13.5)	4.83 (17.2)
	S0	4.70	0.45	4.50	5.28	5.66
	S1 (2008-2012)	2.80	0.13 (128.90)	2.82 (14.81)	2.88 (51.29)	2.89 (72.30)
	S2 (2008-2013)	2.80	0.14 (125.06)	2.81 (15.00)	2.95 (48.96)	3.00 (69.16)
Wind- sea	S3 (2008-2014)	2.89	0.16 (114.08)	2.89 (12.35)	3.05 (45.80)	3.11 (66.00)
	S0	4.29	0.60	3.27	4.86	6.16
	S1 (2008-2012)	3.47	0.23 (48.17)	3.65 (8.23)	4.16 (14.93)	4.45 (18.36)
Swell	S2 (2008-2013)	3.47	0.20 (58.53)	3.62 (9.18)	4.01 (18.53)	4.22 (23.56)
	S3 (2008-2014)	3.47	0.22 (50.80)	3.71 (6.62)	4.05 (17.53)	4.21 (23.97)
	S0	4.28	0.37	3.97	4.83	5.35

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Table 7: The percentage of time the waves in shallow, intermediate and deep water regime in different years along with the mean wave period and mean peak wave period

<u>Year</u>	<u>Mean wave period (s)</u>	<u>Criteria based on ratio of water depth and wave length corresponding to mean wave period</u>			<u>Mean peak wave period (s)</u>	<u>Criteria based on ratio of water depth and wave length corresponding to peak wave period</u>		
		<u>Shallow water</u>	<u>Intermediate water</u>	<u>Deep water</u>		<u>Shallow water</u>	<u>Intermediate water</u>	<u>Deep water</u>
<u>2008-2009</u>	<u>5.5</u>	<u>0</u>	<u>98.7</u>	<u>1.3</u>	<u>12.1</u>	<u>1.0</u>	<u>98.9</u>	<u>0.1</u>
<u>2009-2010</u>	<u>5.6</u>	<u>0</u>	<u>98.3</u>	<u>1.6</u>	<u>12.0</u>	<u>0.5</u>	<u>99.3</u>	<u>0.2</u>
<u>2010-2011</u>	<u>5.4</u>	<u>0</u>	<u>97.5</u>	<u>2.5</u>	<u>11.7</u>	<u>0.6</u>	<u>99.2</u>	<u>0.2</u>
<u>2011-2012</u>	<u>5.7</u>	<u>0</u>	<u>99.5</u>	<u>0.5</u>	<u>11.9</u>	<u>0.9</u>	<u>98.5</u>	<u>0.6</u>
<u>2012-2013</u>	<u>5.5</u>	<u>0</u>	<u>99.4</u>	<u>0.6</u>	<u>12.0</u>	<u>0.3</u>	<u>99.6</u>	<u>0.1</u>
<u>2013-2014</u>	<u>5.0</u>	<u>0</u>	<u>95.0</u>	<u>5.0</u>	<u>11.8</u>	<u>1.4</u>	<u>97.8</u>	<u>0.8</u>
<u>2014-2015</u>	<u>5.7</u>	<u>0</u>	<u>98.7</u>	<u>1.3</u>	<u>12.6</u>	<u>1.8</u>	<u>98.1</u>	<u>0.1</u>
<u>2015-2016</u>	<u>5.5</u>	<u>0</u>	<u>98.0</u>	<u>2.0</u>	<u>12.3</u>	<u>0.8</u>	<u>99.0</u>	<u>0.2</u>

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