

Seasonal and Inter-Annual Variations in Wave Characteristics of Vizhinjam, South-West Coast of India



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Abstract Understanding of nearshore wave characteristics is vital for beach processes, sediment transport, the design of coastal structures and shoreline management. Identification and separation of wind sea and swell wave characteristics provide more realistic depiction of sea state and are of great importance in sea safety, offshore structure design and ship operations. Seasonal and inter-annual wave characteristics based on observed wave data collected for the period March 2015–February 2017 from 2 km off Vizhinjam coast at 25 m water depth are studied. The separation of wind sea and swell components from the wave spectrum was done by wave steepness method that separates by a separating frequency (f_s) into sea and swell parts and their components, viz. significant wave heights (H_s , H_{sw} and H_{ss}), zero crossing periods (T_z , T_{sw} and T_{ss}) and mean wave periods (θ_{sw} , θ_{ss}). The predominant wave direction is SSW (202.5°) followed by South (180°) and SW (225°), recorded annually. The maximum and significant wave height of 4.7 and 2.85 m, respectively, was recorded during June 2015; however, there was no major cyclone impact in the study duration. The result of long-term (two years) wave characteristics of Vizhinjam shows the monthly and seasonal variations of wave parameters are within a range and repetitive.

Keywords Sea and swell · Wave rider buoy · Wave spectrum

1 Introduction

The study on short- and long-term wave characteristics primarily helps coastal engineers and oceanographers for proper planning and design of coastal structures, navigation, forecasting and shore protection measures [1]. Long-term measured wave data collection along Indian coast is not adequate till date to derive wave climate of

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Indian coast as a whole; however, there are few site-specific observation since last decade [2–5].

Sea waves are generated by wind and as they propagate away from the generating area, are called swell waves. Swell waves are known to travel long distances across the world. Wind waves are generated locally and are strongly coupled to the local wind field, surpassing the contribution of tides, tsunamis, coastal surges. Separation of wave from wave spectrum into wind sea and swell provides a more realistic depiction of the sea state and is of great importance to oceanography and engineering applications [6]. The wave characteristics along west coast (Karwar to Ratnagiri) dominated by long swells during SW monsoon period and found the seasonal average wave height and period did not vary significantly [7]. However, there is an increase in wave height from June to August from south to north direction along eastern Arabian Sea [8]. The seasonal average wave height and period did not vary significantly. The Indian coast is governed by southwest monsoon (June–September) to the northeast monsoon (October and January) and fair weather (February–May) period [9].

Vizhinjam is situated along the south-west coast of India with a shore line orientation of approximately 310° with respect to north (Fig. 1). The Government of Kerala is developing the existing Vizhinjam harbour into International Deepwater Multipurpose Seaport. It has named a separate company, viz. Vizhinjam International Seaport Limited (VISL), as a special purpose Government company (fully owned by Government of Kerala) that would act as implementing agency for development of the Greenfield port at Vizhinjam under Public Private Partnership component on a design, build, finance, operate and transfer (DBFOT) basis with Adani port as private partner. Therefore, the present study on wave characteristics is useful to understand seasonal and inter-annual variation of the sea, swell and other wave characteristics for port development, design of coastal structures (groyne, breaker water, pier, etc.), shoreline management planning and monitoring of future geo-morphological changes along Vizhinjam coast.

2 Data and Methodology

As a part of long-term coastal observational studies, National Institute of Ocean Technology (NIOT), Chennai under Ministry of Earth Sciences, Government of India, has been collecting various coastal oceanography and hydrodynamics data along Indian coasts (Fig. 1). Under this programme, NIOT in collaboration with Vizhinjam International Seaport Limited (VISL) has deployed a Datawell which makes Global Positioning System (GPS)-based directional wave rider buoy in 25 m water depth [10], 1.5 km offshore off Vizhinjam (Lat/Long— $8^\circ 21.089'N/76^\circ 59.571'E$) since March 2015, to cater the need of future upgradation of NIOT Technical Criteria Atlas (TCA) for wave and coastal sedimentation budget planning under Sustainable Shoreline Management (SSM) project.

Data were recorded for 30 min duration at every one hour interval and sampled at a frequency of 1.28 Hz using fast Fourier transform of 6 series, each consisting

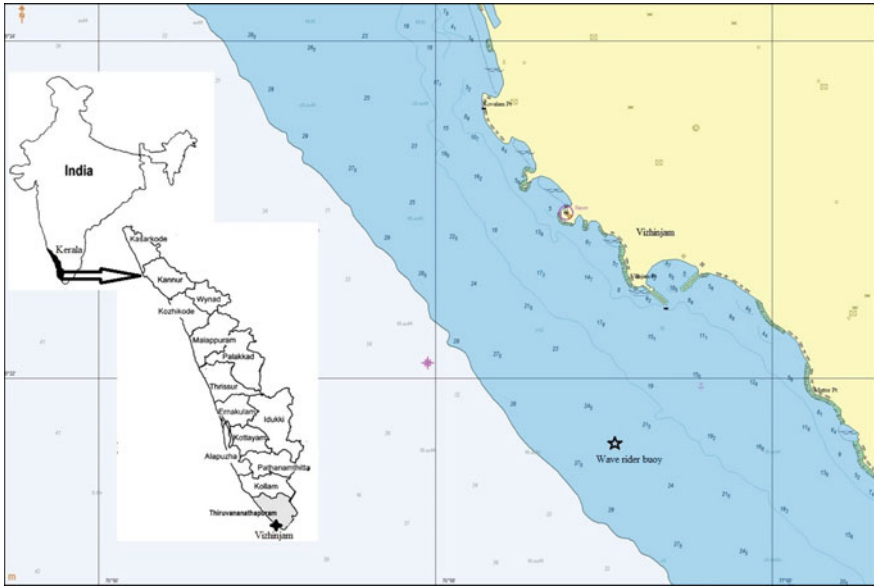


Fig. 1 Study map showing wave rider buoy location at 25 m water depth off Vizhinjam

of 256 data points. The high-frequency cut-off was set at 0.6 Hz, and the frequency resolution was 0.005 Hz. The measurement principle of the GPS wave buoy is based on the Doppler shift phenomenon. The system calculates the velocity of the buoy from changes in the frequency received in the observed GPS signals 14. The velocities are integrated with time to determine buoy displacement. In practice, the system uses signals from multiple satellites to determine three-dimensional buoy motions. In GPS buoy, data were sampled at a frequency of 2 Hz and measured velocities are digitally filtered using integrated high-pass filter with a cut-off frequency of 0.01 Hz. These velocities are converted into north–south, east–west and vertical motions at 1.28 Hz sample interval. The wave parameters, viz. significant wave height (H_s), average wave period (T_{02}), wave period corresponding to maximum spectral energy (T_p), were obtained from spectral analysis. The sharpness or flatness in the shape of the wave spectrum is judged through the spectral peakedness parameter (Q_p). Spectra with sharper peaks will have larger value of peakedness parameter. The width of the spectra is determined using spectral width parameter (ϵ) and spectral narrowness parameter (ν).

The separation of sea and swell components from the wave spectra was done by wave steepness method adopted by US National Data Buoy Centre, based on the frequency of the wave [11]. Estimations are made by selecting a separation frequency f_s that partitions the wave spectrum into its sea and swell parts and their components, viz. significant wave height (H_{sw} and H_{ss}), zero crossing period (T_{sw} and T_{ss}), mean wave direction (θ_{sw} and θ_{ss}). The steepness function $\xi(f)$ and separation frequency f_s are given by Eqs. (1) and (2).

$$\xi(f) = \frac{8\pi m_2(f)}{g\sqrt{m_0(f)}} \quad (1)$$

$$f_s = Cf_m \quad (2)$$

where f_m is the frequency of maximum of $\xi(f)$, g is acceleration due to gravity, m_0 and m_2 are the zeroth and second-order spectral moments, and $C = 0.75$ is an empirically determined constant.

3 Results and Discussion

3.1 Observed Wave Characteristics of Vizhinjam

The percentage occurrence of significant wave height (H_s), periods (T_z and T_p) and direction (θ) is analysed for March 2015–February 2016 and depicted in Fig. 2. However, the data for the period March 2016–February 2017 are analysed for comparison purpose only with previous year to understand seasonal and inter-annual change, due to gaps in data set. During the study periods, the maximum (H_{\max}) and significant (H_s) wave height of 4.7 and 2.85 m were recorded on 22 June 2015, respectively. Moreover, H_{\max} also exceeded 4 m during May and September 2015 and 2016 by south west monsoon impact although there was not major cyclone recorded during these days.

The significant wave height (H_s) for one-year period (2015–2016) ranged from 0.38 to 2.85 m with an average of 1.11 m and the distribution is shown in Fig. 2a. The percentage distribution of significant wave height shows that 47.1% of waves are within the range of 0.5–1 m, 30.3% of waves are in the range of 1–1.5 m, and only 2.8% of waves are less than 0.5 m. During SW monsoon, 49.4% of waves are between 1 and 1.5 m, 50% of waves are more than 1.5 m, and only 0.6% are less than 1 m. During the SW monsoon season, the sea was rougher with due to high wave intensity by 99% of wave recorded more than 1 m in height. The period during December–February was recorded calm with 96.4% of wave less than 1 m and only 3.6% are more than 1 m in height.

The distribution of zero crossing periods (T_z) is shown in Fig. 2b. One year of T_z analysis shows within the range of 3.67–10 s, with average of 6.35 s. The wave periods are ranged between 4 and 6 s with 37.7% and 6–8 s with 58.4%, respectively. During SW monsoon period, nearly 80.8% occurs in the range of 6–8 s and 19% are in the range 4–6 s. However, during December to February, T_z in the range of 4–6 s contributes nearly 55.5% of the distribution; 32.7% are in the range of 6–8 s; and 9.2% are ranged 8–10 s. This above distribution indicates that long swells dominate during SW monsoon over sea waves and the presence of very long swells during fair weather period (December–February).

The peak period ranged from 4 to 20 s with an average of 12.8 s and the distribution of peak period is presented in Fig. 2c. During one-year observation, the T_p ranged

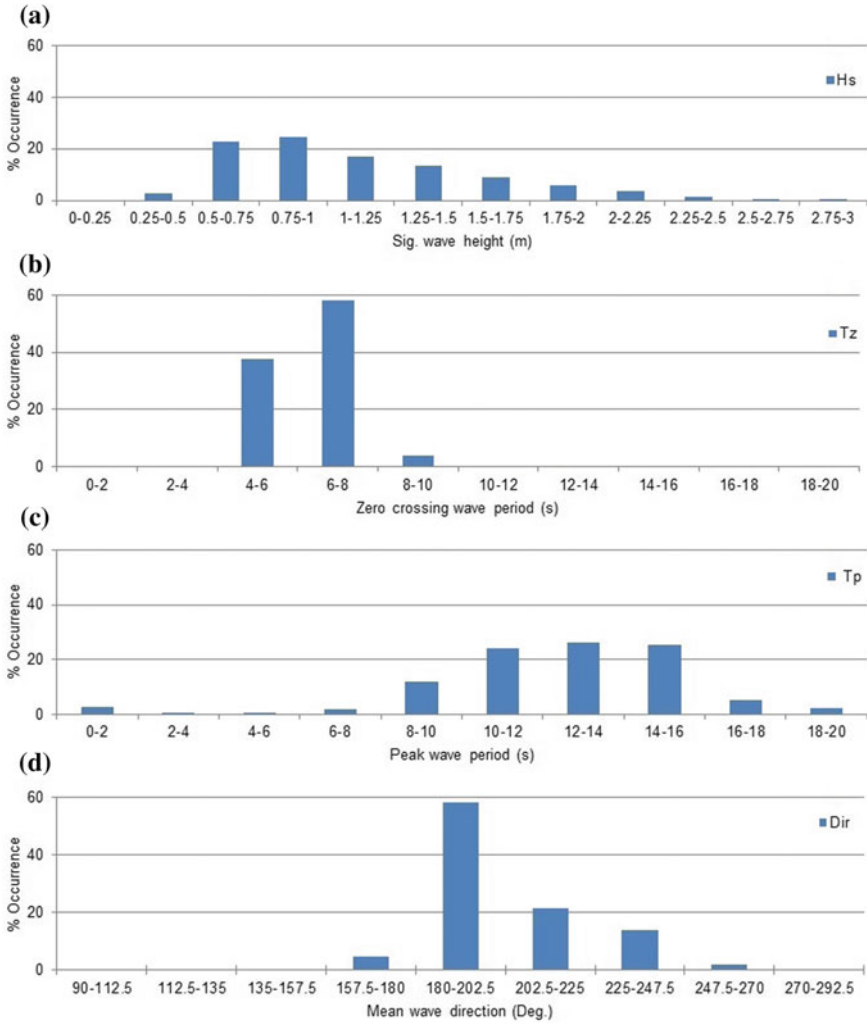


Fig. 2 Percentage occurrence of significant wave height (H_s), zero crossing wave period (T_z), peak wave period (T_p) and mean wave direction (θ)

between 8 and 12 s by 36%, 12–16 s by 51.5%, and more than 16 s by 7.5% of waves. During SW monsoon, T_p range is maximum between 8 and 12 s by 53.2%, followed by 12–16 s with 34.6 and 8.8% with greater than 16 s waves. During fair weather period, the T_p distribution for 8–12, 12–16 and >16 s are 31.8, 51.5 and 5.6%, respectively. The distribution of T_p did not specify the dominance of any types of wave (sea or swell), due to its dependence on spectral peak where power density is maximum, and small stochastic effects easily modify the peak of the spectra and yield a different peak period [12].

The wave direction distribution clearly indicates that 58% of waves are South–SSW, 21.5% are SSW–SW, and 13.8% are SW–WSW directions (Fig. 2d). The dominant wave direction for SW monsoon is SW and SSW, and the rest of year is South and SSW. The seasonal reversal of wave direction is not fairly understood from the mean wave direction distribution. Hence, the necessary splitting of the total wave spectrum into sea and swell components is estimated separately and explained in sea and swell section.

3.2 Spectral Wave Characteristics

The directional wave energy spectra provide a complete description of the wave energy distribution over spectral frequencies (f) and direction (θ). As sea state consists of local wind-generated waves and swells of distant storms, the wave energy spectra often show two or more spectral peaks corresponding to different generation sources (Fig. 3). The measure of spectral energy density (S_{\max}) depicts the sea state condition, which largely depends upon spectral peakedness parameter (Q_p) known as Goda's peakedness parameter suggested by [13] is a measure of the irregularity of the sea state. Theoretically, Q_p becomes very large for narrowband spectra and low value for broad band spectra, and under natural conditions, it remains within the interval 1.5–5.

The observed maximum spectral energy density (S_{\max}) varies between 0.23 and 13.23 m^2/Hz with average value of 2.21 m^2/Hz . The % occurrences of S_{\max} between 0–2, 2–4 and 4–6 m^2/Hz are 57.2, 28.1 and 10.9%, respectively. The high value of S_{\max} observed during SW monsoon, due to prevalent rough condition over the sea monsoonal wave and prevailing wind. During the study period, Q_p varied between 1 and 7.81 with an average of 1.83. Majority of the wave spectra are broader in

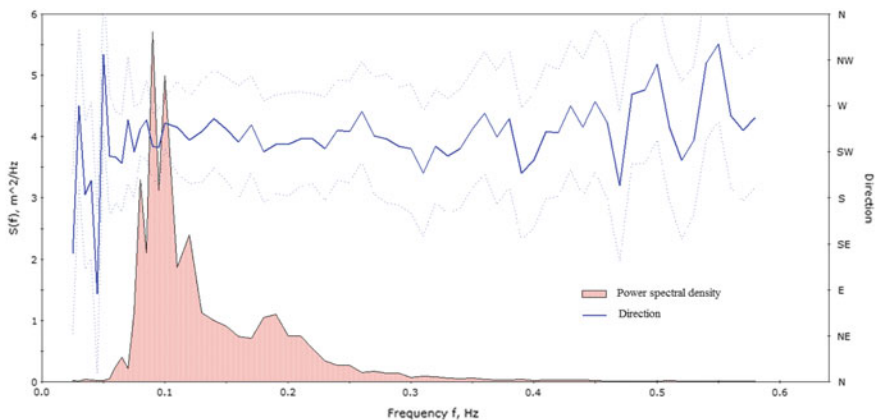


Fig. 3 Measured wave spectra observed during 25 June 2015 at 3:30 pm

shape and Q_p value fall within the range of 1–2 (72.3%). The spectral width (ϵ) and narrowness (ν) parameters vary from 0 to 1 and have smaller values for narrower spectra and larger for broader spectra. The spectral width parameter for one-year period ranged from 0.66 to 0.94 with a mean value of 0.83, out of which major portion in the range of 0.8–1 (75.6%). The high spectral width parameter indicates the dominance of the swell waves over sea waves. The spectral narrowness parameter ranged from 0.37–0.96 with a mean average value of 0.62. About 95.3% of waves fall within the range of 0.4–0.8.

3.3 Sea and Swell Characteristics

The significant wave height of H_s , H_{sw} and H_{ss} is plotted in Fig. 4a. The range of H_{sw} and H_{ss} varies from 0.19–2 m to 0.22–2.46 m, respectively. The annual average of H_{sw} and H_{ss} is recorded as 0.67 and 0.86 m, respectively. The swell wave height (H_{ss}) exceeded more than 1 m during May–September. The dominance (above 50% in wave heights) of sea and swell waves over total H_s is analysed and depicted in Table 1.

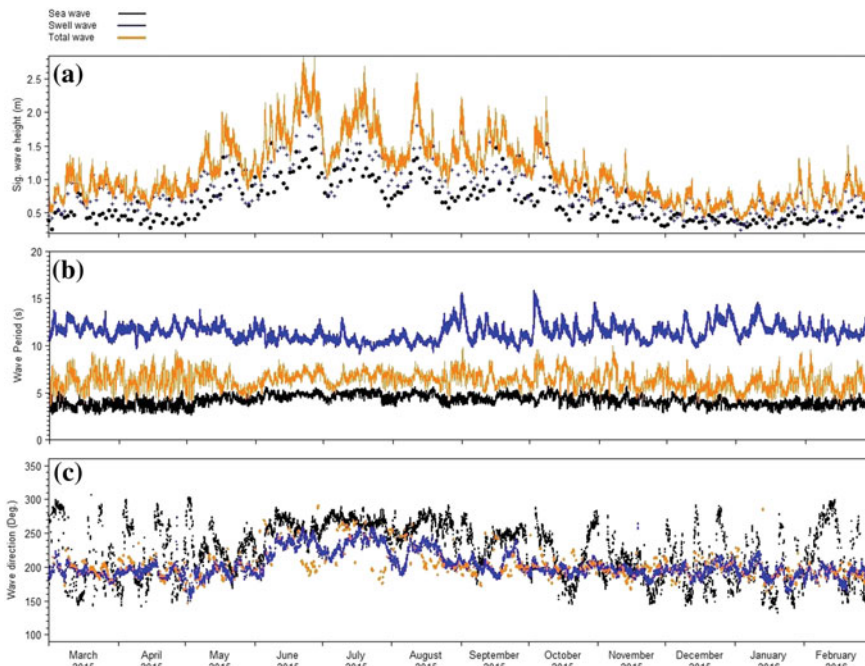


Fig. 4 Time series plot for sea, swell and total wave height, period and direction for March 2015–February 2016

Table 1 Percentage occurrence of sea and swell waves during January–December

Month	% Sea waves	% Swell waves
January	24.0	76.0
February	23.7	76.3
March	12.6	87.4
April	10.0	90.0
May	37.7	62.3
June	13.4	86.6
July	22.0	78.0
August	10.3	89.7
September	22.4	77.6
October	23.3	76.7
November	20.8	79.2
December	28.0	72.0
Total	20.7	79.3

Annually, 79.3% of waves are dominated by swell and 20.7% by sea. The swell waves are dominant throughout the year. However, the highest percentage of sea waves found during onset of summer monsoon in May. Similar study conducted along the Gulf of Mannar shows 55.5% of the waves dominated by seas and 45.5% by swell waves annually [14] and 30% of the waves by seas and 70% by swell waves annually along west coast [15]. This result confirms that the magnitude of the significant wave height of the study area is dominated by long swell waves by south Indian Ocean.

The range of T_z for sea and swell waves is from 2.6 to 5.8 s and 9.1 to 15.8 s, with mean value of 4.2 and 11.4 s, respectively. The measured T_{sw} is closely distributed over the periods 3–6 s (95%) and T_{ss} between 10 and 14 s (90%). The distribution of H_s with T_{sw} and T_{ss} is fairly uniform and is range bound due to its dominance by long swells throughout the year and the absence of any extreme events (cyclones).

The time series plot of sea, swell and total wave direction is depicted in Fig. 4c. The sea wave direction varies diurnally with daily reversal of sea and land breeze. There is no distinct shift in sea wave direction SW monsoon to NE monsoon, with respect to prevailing wind condition of the subcontinent [3]. The dominant swell wave direction during SW monsoon is SW, followed by SSE and WSW and South; it is SSW and South during rest of the year (Fig. 5). The mean (total) wave direction follows the pattern of swell direction due to its complete dominance (79.3%) over sea wave throughout the year.

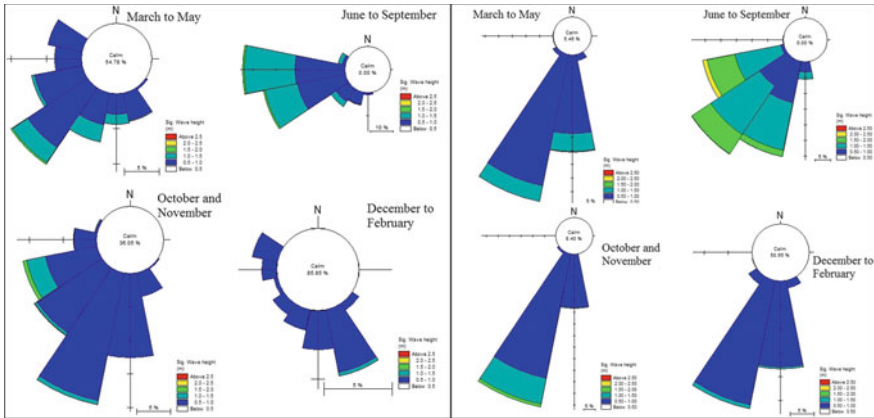


Fig. 5 Rose plot for sea (left side) and swell waves (right side) for four different seasons

3.4 Seasonal and Inter-Annual Wave Characteristics

In the present study, wave data of two complete years (2015–2016 and 2016–2017) are compiled and are presented (Fig. 6). The standard deviations for all the wave parameters for two years are less than 10% and quite comparable. Monthly mean H_s are higher (>1.5 m) during SW monsoon and lower (<0.8 m) during fair weather (DJF) period. The wave period T_z is higher (>6.5 s) during SW monsoon and lower (<5.5 s) during rest of the periods. There is no explicit seasonal trend of the wave period T_p (10–14 s) due to its dependence on spectral peak [16]. The mean wave direction (mode of monthly mean) is SW and SSW direction during June to September, and it is South and SSW for the rest of the year.

4 Conclusion

The study on wave characteristics of Vizhinjam in south west coast of India is dominated by long swell waves originated from south Indian Ocean. The swell wave is dominant by 79.3% annually, compared to sea waves. The long-term wave data (2015–2017) reveal that the monthly and seasonal wave parameters vary within a range, repetitive and cyclic. The analysis of the spectral width (ϵ) and narrowness (ν) parameters shows that majority of the wave spectra are broader in shape (72.3%) and are of high spectral energy (42%). During the SW monsoon season, the sea condition was rough with due to high wave intensity (99% of wave recorded more than 1 m in H_s) and during December–February was recorded calm with 96.4% of wave less than 1 m. The predominant mean wave direction is SSW, followed by South and SW.

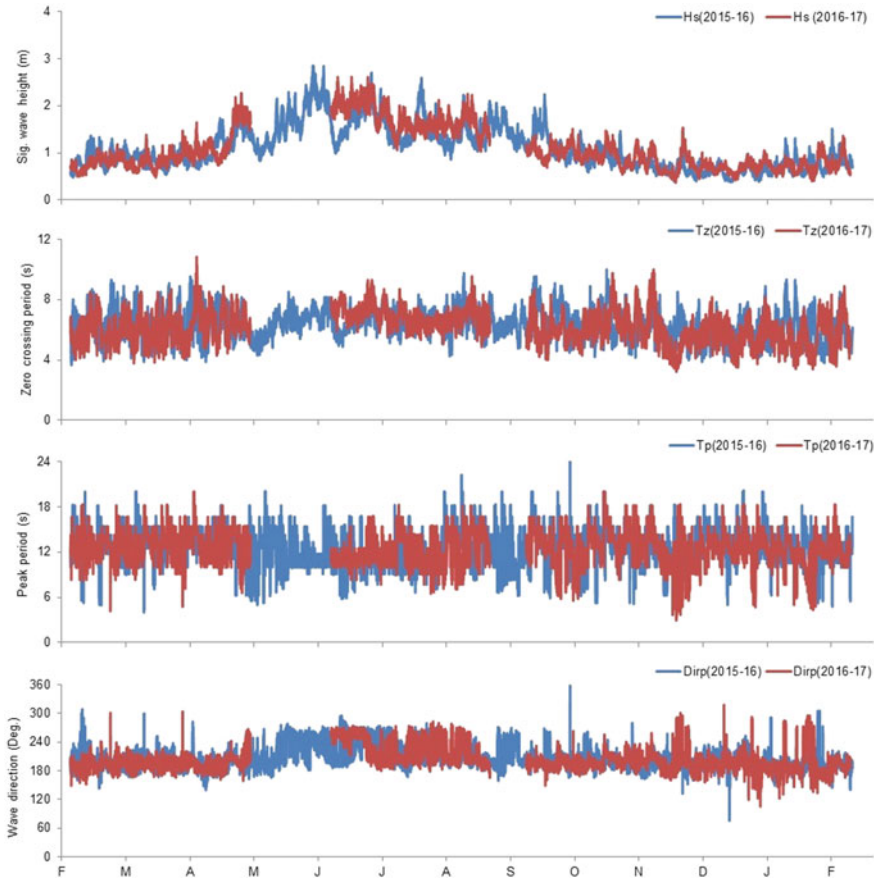


Fig. 6 Inter-annual variability (2015–2016 and 2016–2017) for wave height, period and direction

The result of the study is helpful for the ongoing port construction near Vizhinjam and shoreline management prospective in future.

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