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A Study On The Seasonal Variability Of Nearshore Waves Off Visakhapatnam, East Coast Of India

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Abstract:
Wave rider buoy data during the period June 2009 to May 2010 was analyzed to examine the seasonal trends in the nearshore waves off Visakhapatnam, east coast of India. During fair weather conditions, wave heights were observed to be higher in the southwest monsoon season with maximum significant wave height (Hs) of about 2.76m in the month of July and average Hs of about 1.6m. The higher values of spectral band width emphasize that the wave heights covered a wide range for major period of the year. A large standard deviation of swell period represents the occurrence of distant swell in a wide range to the study region. The seasonal cycle of wave heights off Visakhapatnam, East Coast of India is dominated by SW monsoon winds. The waves at study area are resultant of sea and large swells from south of Bay of Bengal

1.Introduction

The knowledge on sea state in the nearshore region is extremely important for navigation, nearshore and coastal applications. Waves over Indian Ocean show a seasonal variability in accordance with reversing monsoonal winds. Along East Coast of India (ECI) the occurrence of extreme weather events are more frequent. A study conducted by Bhasar Rao et al., (2001) reveals that cyclonic systems are more frequent over Bay of Bengal compared to the Arabian Sea. The depressions and storm frequencies are more during monsoon and post-monsoon seasons respectively with low variability. Deep depressions and Depressions occur frequently during SW monsoon with a maximum during August. Wave climate off the East Coast of India is dominated by three different seasons namely, the southwest (SW) monsoon from June to September (JJAS), the northeast (NE) monsoon from October to January (ONDJ) and the fair weather (FW) season from February to May (FMAM). Among the three seasons during JJAS the wave climate is generally rough (Chandramohan et al. 1991, Nayak et al. 1992, Neetu et al. 2006). The significant wave height (H_s) varies from 1 to 3m during SW monsoon (except during the cyclone periods). The average wave period varies from 9 to 12 sec for most of the year. During storm conditions, wave periods of 10 and 14 s (Sarma, 1986; Sanil Kumar, et al., 2004) were reported. Sathe (Sathe, et al., 1979) reported that maximum H_s of about 2.25 m over western Bay of Bengal during summer monsoon 1978. The waves predominantly approach the coast from the SE during March to September and from the east during December to February. Maximum H_s of 3.29 m was reported at Tikkavanipalem, east coast of India 15km SW of present study area during a cyclone in November 1998 (Sanil Kumar, et al., 2004). In the present study area it has been reported that during SW monsoon the contribution of swell to the measured wave heights is 63.2 % and good positive correlation of 0.84 obtained between H_s (resultant significant wave height) and H_{ss} (significant wave height of swell) indicates that the dominance of distant swells (Suresh, et al., 2010).

In the present paper, the seasonal distribution of nearshore wave parameters from June 2009 to May 2010 off Visakhapatnam, East Coast of India is studied. The location of the study area is shown in figure (1). At the location of measurement, the coastline is aligned west-south-west (WSW) to east-north-east (ENE) direction with almost parallel bathymetry contours offshore. The shoreline is characterized by different types of sediment characteristics like sand with different grain size, scattered rocky out crops, rocky protrusions and sand dunes etc. The tides in this region are semi-diurnal, mean spring tidal range is around 1.43 m and neap tidal range is 0.54 m.

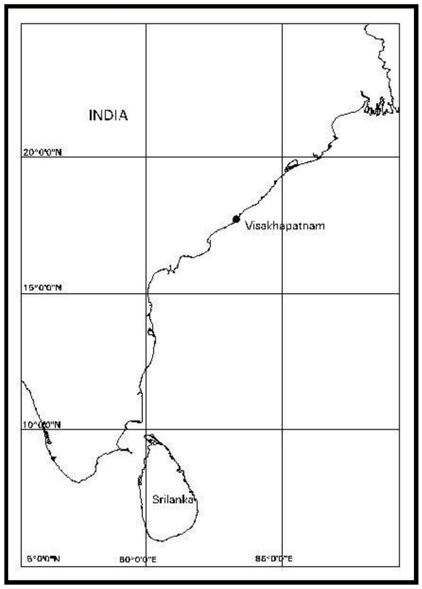


Figure 1: Study Area

2.Data And Methodology

Waves were measured using directional wave rider buoy (Datawell) from June 2009 to May 2010 with 30 min interval. Buoy anchored at 20 meters depth off Gangavaram coast (17° 38.011′ N, 83° 15.946′ E) south of Visakhapatnam harbor. The wave data were recorded continuously at 1.28 Hz. From the recorded heave data covering 20 min duration, the wave spectrum was obtained through Fast Fourier transform (FFT). Heave was measured in the range of -20 to 20 m with a resolution of 1 cm and an accuracy of 3%. When the moored buoy follows the waves, the force of the mooring line may change resulting in a maximum error of 1.5% in the measurement of surface elevation. Also, if the wavelength is less than 5 m, the buoy will not follow the wave amplitude and hence will not measure the wave.

The significant wave height (H_s) and the Zero upcross wave period (T_z) are obtained for every 30 minutes duration using spectral moments calculated from the wave spectrum (Tucker, 1963). The high frequency cut off was set at 0.58 Hz and low frequency cut off was set at 0.03 Hz with resolution 0.005 Hz. Height of the highest wave (H_{max}) is estimated from zero-crossing analysis. Other parameters obtained from spectral analysis were spectral width parameter (ε) (Cartwright

& Longuet-Higgins, 1956), spectral narrowness parameter (ν) and spectral peakedness parameter (Q_p) (Goda, 1970). Sea and swell components were separated by using the wave steepness method suggested by NDBC (National Data Buoy Center) (Gilhousen & Hervey, 2001). Estimated significant wave height (H_{sw} and H_{ss}), zero crossing period (T_{sw} and T_{ss}) and mean direction (θ_{sw} and θ_{ss}) of wind sea and swell portions respectively. Wind speed (U_{10} m/s) averaged over Bay of Bengal (2N-27N and 75E-100E) at 10m above mean sea level calculated by using zonal (u) and meridional (v) components from NCEP reanalysis data with 6 hr interval. The u and v components downloaded from (http://www.gdfc.nasa.gov/). The 30 day moving averages for Hs, Tz, Ss, ε, U_{10} and wind direction to study the seasonal variations. The minimum, maximum, average, standard deviation and anomaly from annual mean are calculated for all parameters and are given table 1. The data analysed for the three seasons separately and compared, i.e., southwest (SW) monsoon, northeast (NE) monsoon and fair weather (FW) seasons. In order to eliminate the cyclone event 'Lila' the data from May 16^{th} to 31^{st} is not included in the analysis. Percentage distribution of $U_{10,}$ Hs, Tz, ε and Ss were calculated for each season separately. Correlation coefficients among different parameters are calculated and presented in table 2.

3.Results And Discussion

3.1 Wind

The wind speed and direction averaged over Bay of Bengal is shown in figure 2. The 30 day moving average showed a large seasonal variability during the study period. Wind speed shows higher values in SW monsoon season compared to other seasons. The trend is found to be decreasing during southwest monsoon with its maximum (7.55m/s) during July. During SW monsoon period wind speed shows positive anomaly of 1.72 m/s, whereas for other seasons it is negative. The mean wind direction is SW during entire season. The transition of winds from southwesterly to northeasterly is clearly observed during October. The wind speed rapidly decreased during the transition period. During NE monsoon the wind speed shows increasing trend with maximum (5.38m/s) in January and predominant direction is northeast. During FW season the wind speed shows increasing trend. The wind direction shifted gradually from northeast during February to southwest during May. The percentage distribution of U10 for the three seasons is shown in figure 3. It is observed that higher wind speeds covering wide range (SD = 1.21m/s) during southwest monsoon, lower wind speeds during non-monsoon and moderate wind speeds covering narrow (SD = 1.12m/s) range during northeast monsoon prevailed over Bay of Bengal.

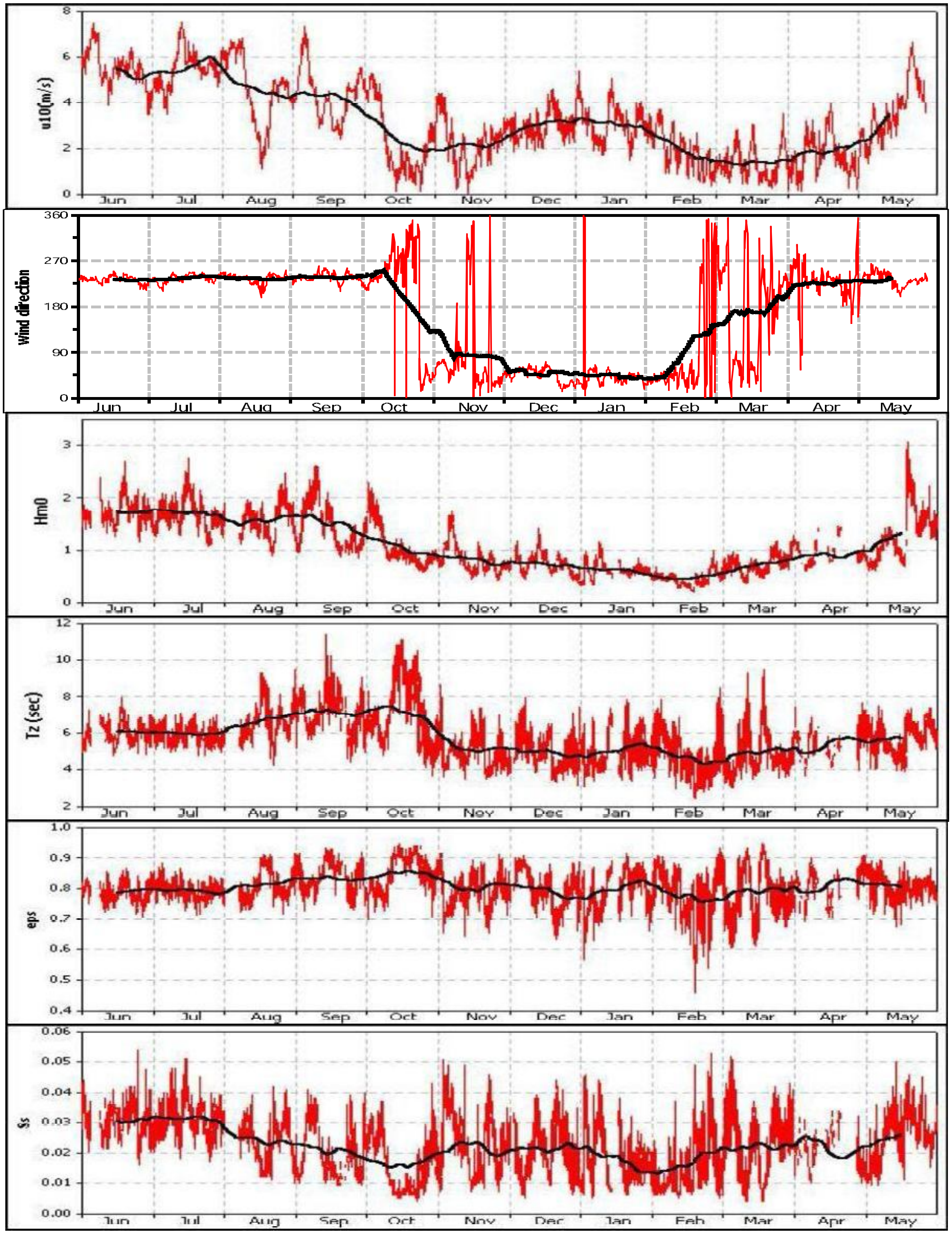


*Figure 2: Seasonal variation of wind speed (U10), wind direction (angle of wind vector in degrees w.r.t north), significant w*ave height (Hs), zero upcross period (Tz), spectral band width parameter (ε) and significant steepness (Ss). Thin line shows the measured data with 30min interval and thick line shows 30 days moving average.*

a. b. c.

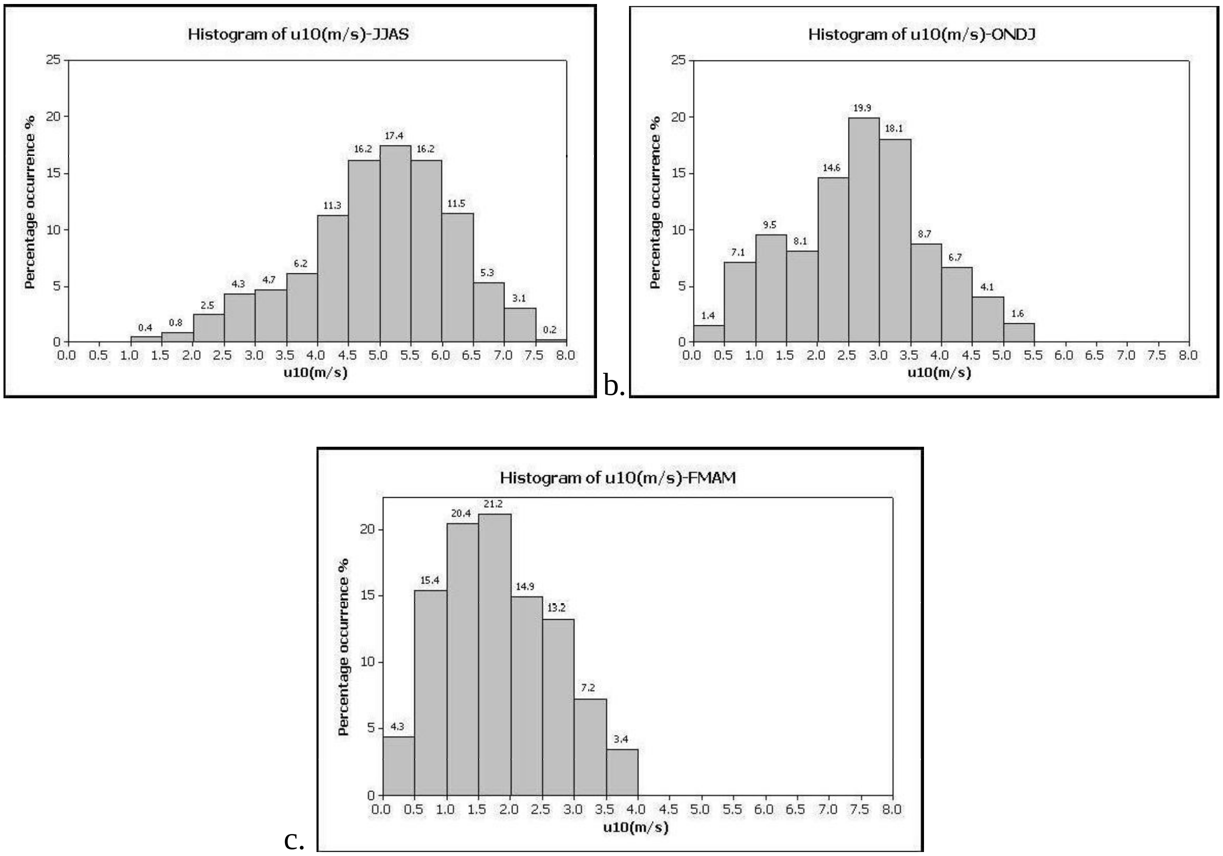


Figure 3: Percentage occurrence of U10 (m/s) for (a) southwest, (b) northeast and (c) non-monsoon period.

3.2.Significant wave height

The seasonal distribution of wave heights in this region are dominated by SW monsoon winds which results larger heights during this period. From figure 2 it can be noted that Hs shows one complete cycle with higher value during SW and lower values during NE monsoon season. Wave height shows decreasing trend during southwest monsoon season. Even though the winds over Bay of Bengal shows slow increasing trend during NE monsoon, the decreasing trend of wave height continued and reached minimum values during February. During FW season the wave heights shows increasing trend in May. A maximum Hs of 2.76m observed during SW monsoon. The percentage distribution of Hs shows significant contrast among the three seasons (fig 4). The maximum percentage occurrence (55.7%) of Hs during southwest monsoon season is from 1.5m to 2.0m. During NE monsoon most of the waves (76.9%) having height between 0.5

to 1.0m, whereas during FW the same range with 59.4% as maximum. The wave heights are wide spread (SD=0.33m) during SW and narrow spread (SD=0.27m) during FW season.

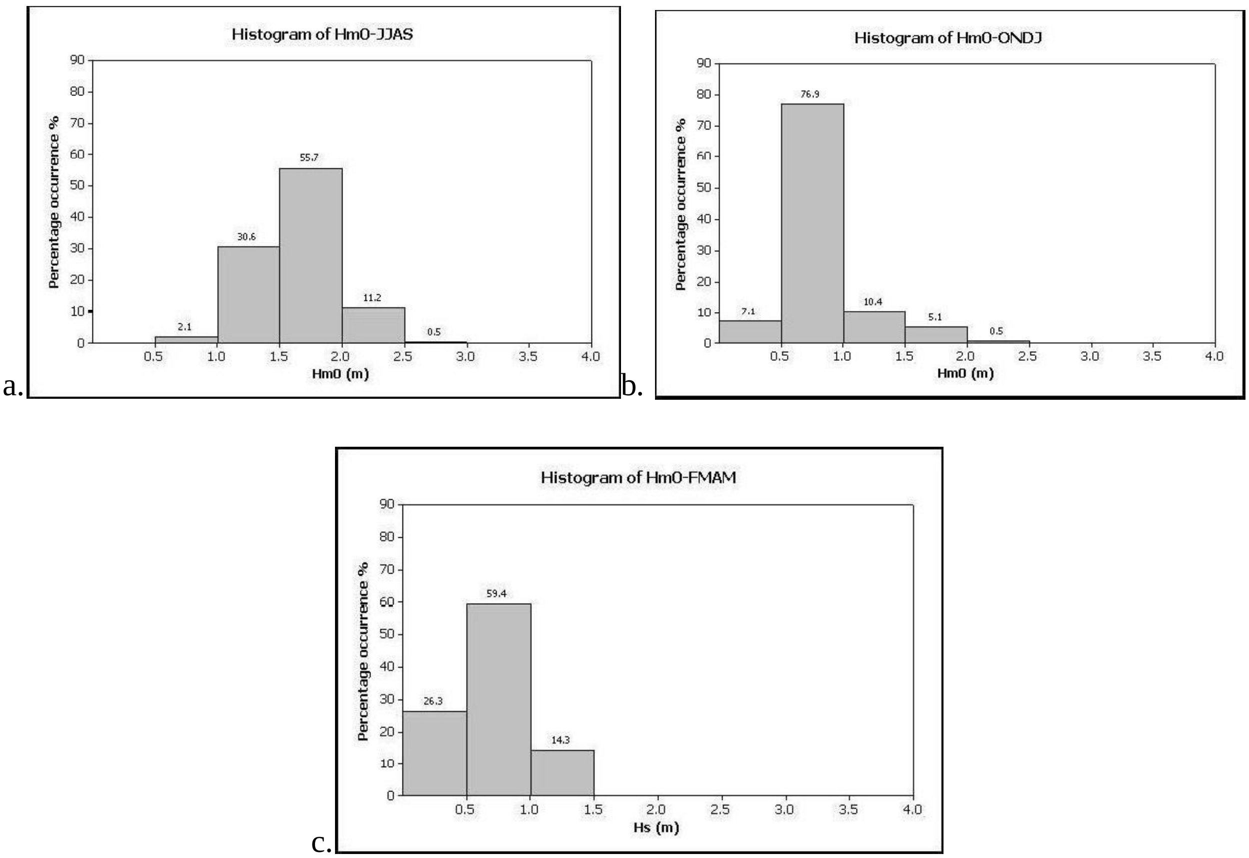


Figure 4: Percentage occurrence of Hs (m) for (a) southwest, (b) northeast and (c) non-monsoon period.

3.3.Zero Upcross Period

Zero Upcross Period Is Found To be higher during SW monsoon compared to other seasons. The 30 day moving average of Tz shows significant increasing trend with decreasing wind speed during SW monsoon and attains its high values during September and October (fig 2). This shows that the increase in Tz is due decrease in local wind forcing. And later it show slow decreasing trend during NE and increasing trend during FW season with less deviation. This shows that the availability of fetch for longer duration is responsible for the higher waves with longer time periods during SW monsoon. These are the resultant waves of sea and dominant swell from south generated by strong monsoon winds. The percentage distribution of Tz for three seasons is shown in fig 5. During NE monsoon Tz is spread over a wide range with large SD (1.52). During FW season the wind direction gradually changed from NE direction to SW direction with increasing wind speed resulted the increasing trend of wave heights. The wave heights are found to be low (Average Hs= 0.7m) with short time periods (Average Tz= 05.01s) for FW season. This shows that the dominance of sea during this season.

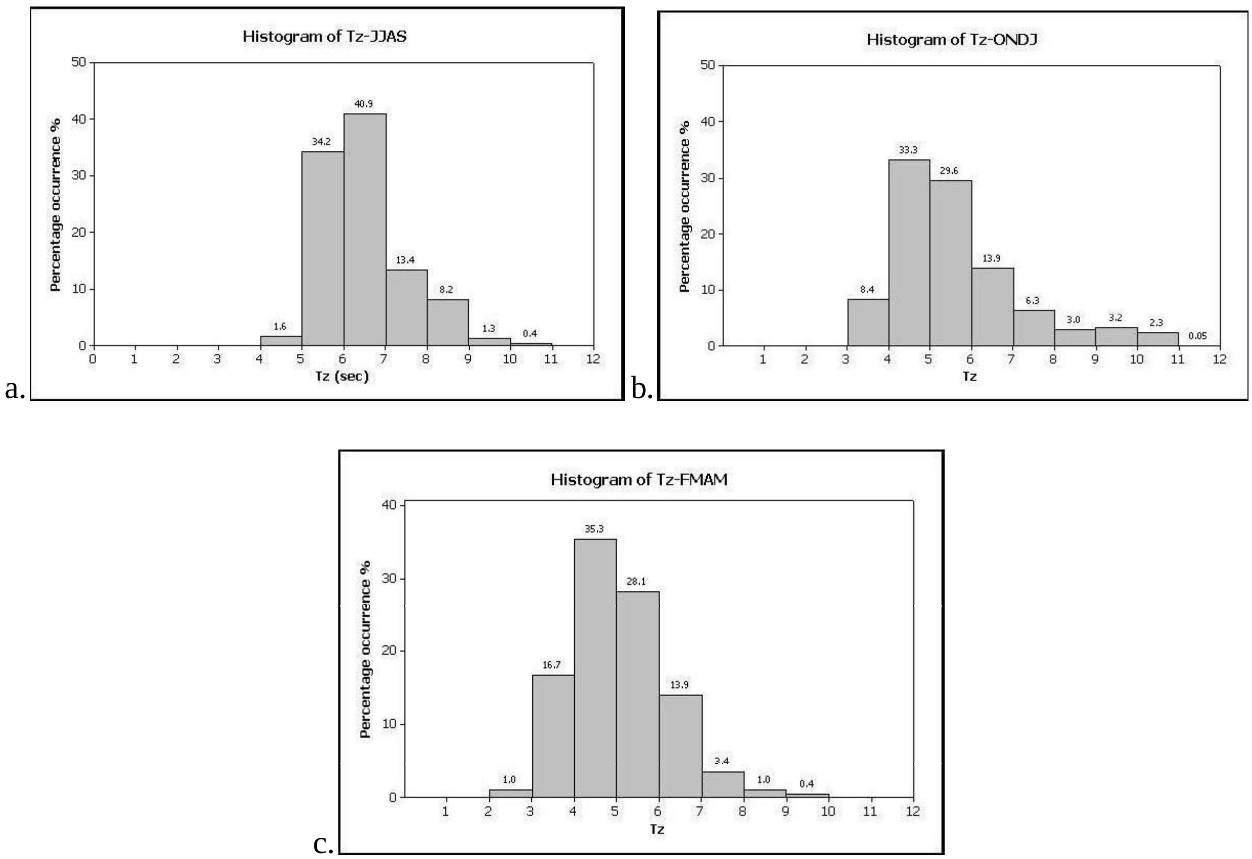
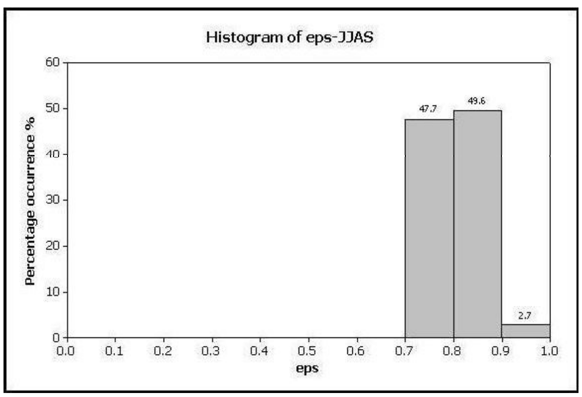
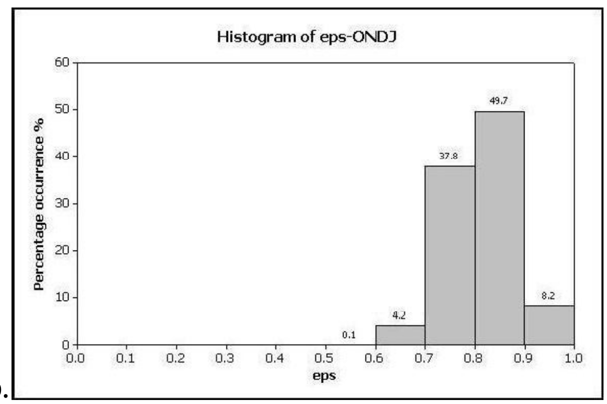


Figure 5: Percentage occurrence of Tz (sec) for (a) southwest, (b) northeast and (c) non-monsoon period.

3.4.Spectral band width parameter

The distribution of wave heights can reasonably be represented by a spectral width parameter (ε). The value of ε (which varies between 0 and 1) is determined by the relative magnitudes of crest period (Tc) and zero upcross period (Tz). For example if in a given situation a wide range of wave heights is present, Tz becomes far greater than Tc. Since many wave components may not be crossing zero-line, the resulting ε in this case is nearing unity. However, if wave heights are confined to a small range, the result is a usual swell and most of the waves cross the zero-line. In this case Tz does not differ much from Tc and ε is close to zero. The spectral band width parameter (ε) shows increasing trend during SW monsoon and FW season and slow decreasing trend during NE monsoon (fig 2). Higher values of ε observed during the transition period (October) from SW to NE monsoon. This may be due to decrease of swell component and increase in sea results a wide range of wave heights. It is observed from figure. 6, that about 99% of the values are >0.6 for all seasons and the highest value is 0.95. This shows that the spectral width parameter is nearing one over the year. As all the values of ε were close to unity, it can be concluded that the wave components covered wide range of frequencies, i.e. long waves carry short waves on top of them (Draper, 1966). In other words the local sea conditions were super-imposed on light swells. Thus, the wave heights in the study region are spread over a wide range.

a.


b.


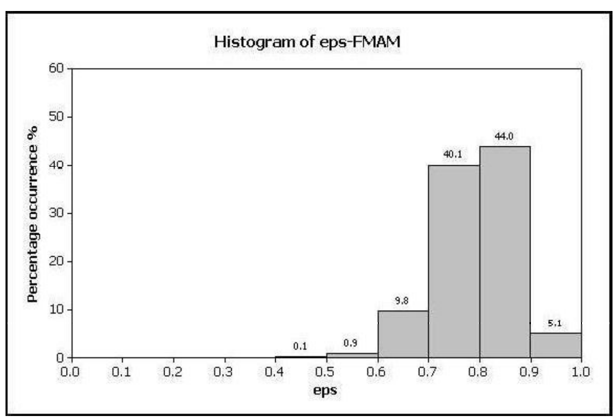
c.


Figure 6: Percentage occurrence of Tz (sec) for (a) southwest, (b) northeast and (c) non-monsoon period.

3.5.Significant Steepness

The significant steepness (Ss) which is the ratio of significant wave height (Hs) and wave length (L) gives shape of the wave. Higher value of Ss indicates steep waves with sharp crest and lower values of Ss indicates flat waves with smooth crest. From figure.2 in can be noted that seasonal cycle of Ss follows the pattern similar to wind. Higher the winds steeper the waves. The occurrence of more steep waves (Average Ss=0.03) is frequent during SW monsoon, whereas less steep waves (Average Ss= 0.02) during other seasons. The percentage occurrence of Ss for three seasons is shown in figure 8. The anomaly from the annual mean is positive during SW monsoon, whereas negative for other seasons.

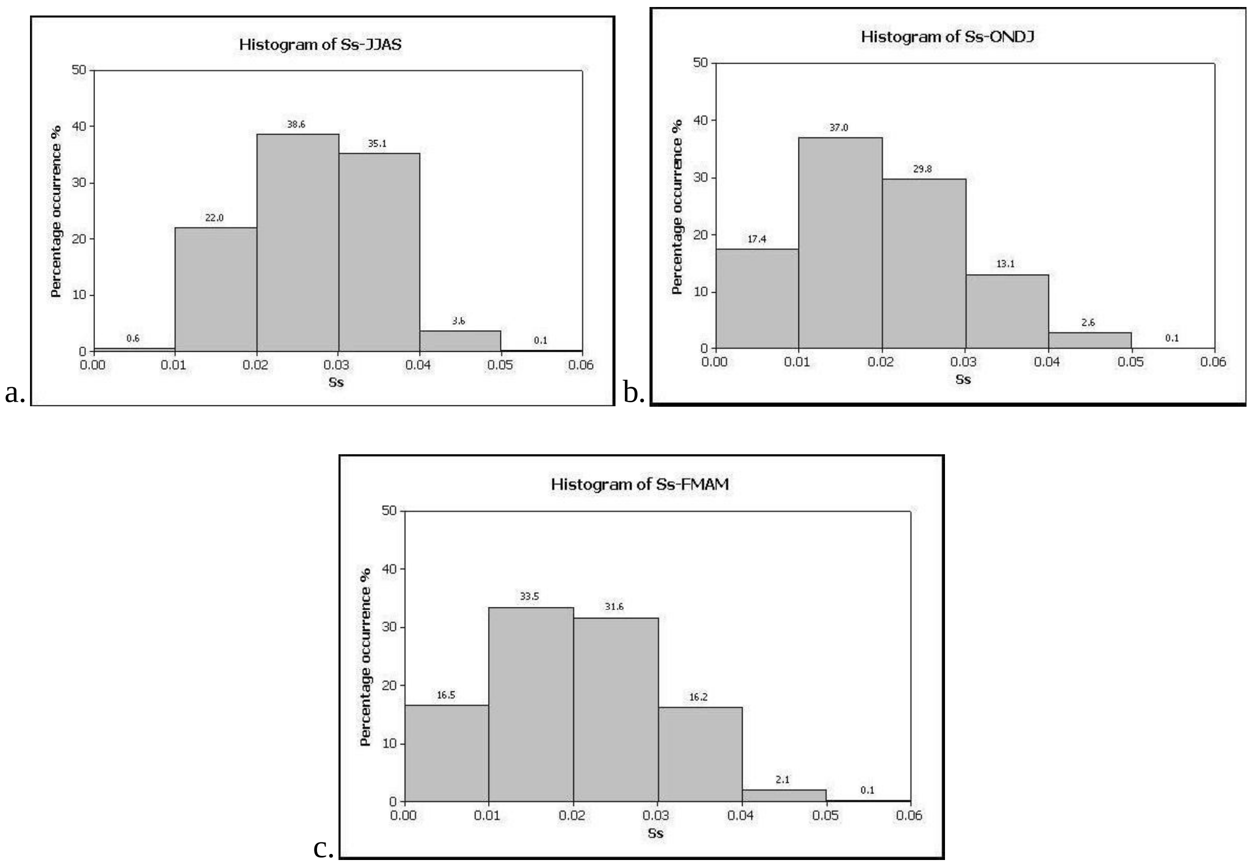


Figure 7: Percentage occurrence of significant steepness (Ss) for (a) southwest, (b) northeast and (c) non-monsoon period.

3.6.Separation of Sea and Swell

Sea and swell components are separated from the measured wave data by using the steepness method suggested by NDBC (fig 8). It is observed that during the three seasons a significant linear trend followed by sea components, whereas swells are scatterly distributed. From tables 1, 2 and 3, the SD of Tzs is larger than that of Tzw, where as SD of Hsw and Hss are more or less same. This show that the wide spreading of swell components are due to the occurrence of swells with wide range. The average Hss is maximum (1.32m) during SW monsoon than other seasons.

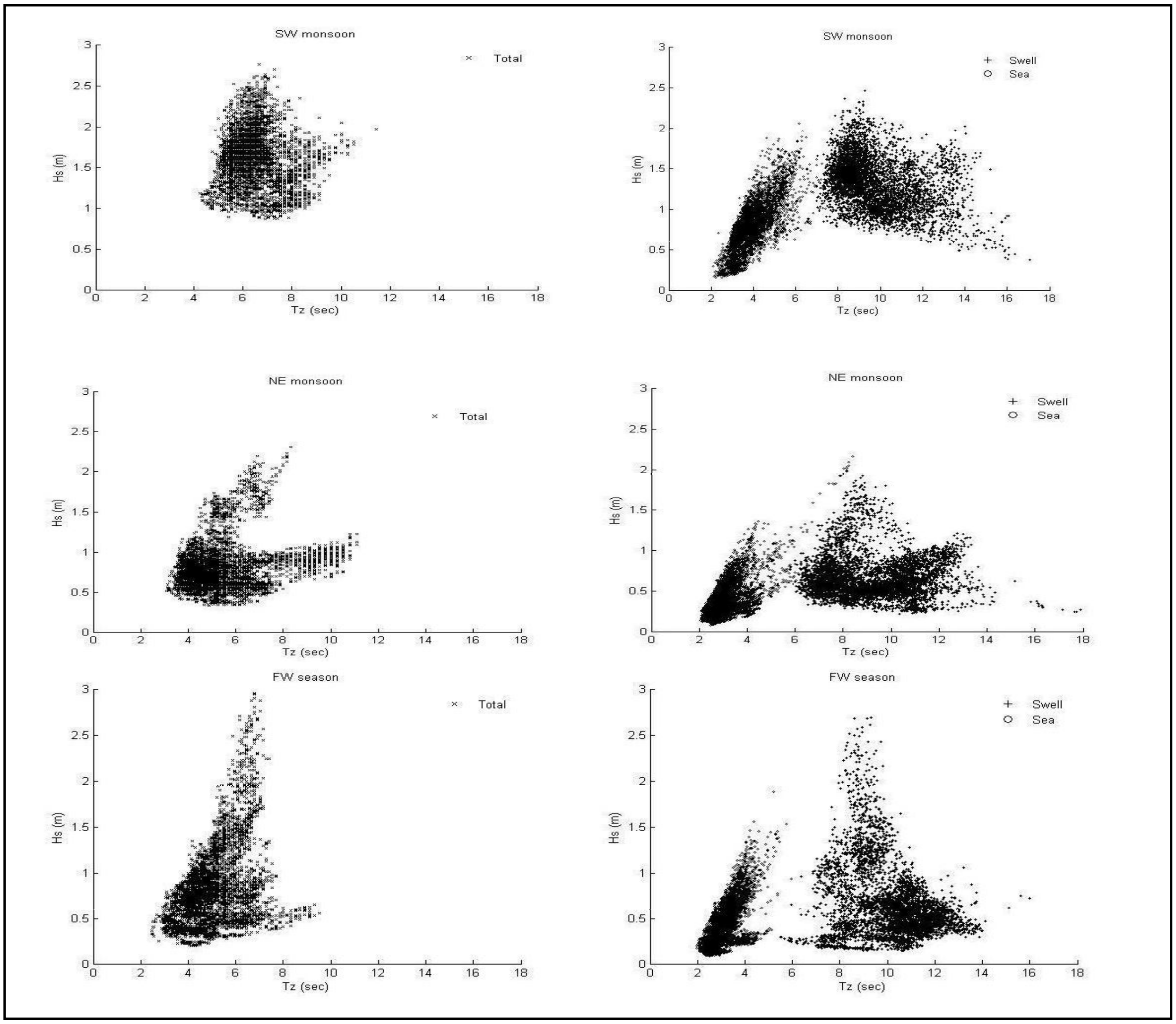


Figure 8: Scatter diagrams of wave groups (Hs vs Tz) for total (left panels) and separated (right panels) components.

4.Conclusion

The knowledge of wave conditions along the East Coast of India has great importance because of their large seasonal variability and frequent occurrence of storms. High winds from SW direction sustained for a long time during SW monsoon and comparatively low winds during NE and FW season. Comparatively high wave conditions observed in SW monsoon with average wave height of 1.62m. During FW season it is observed that the small waves with less SD, whereas during NE monsoon Hs spread over a wide range. The maximum occurrence of Hs is between 1.5 – 2.0m for SW monsoon and 0.5 – 1.0m for NE and FW seasons. During total study period a maximum Hs of 2.76m observed during July. Zero upcross period is found to be higher (Average Tz = 6.46 sec) during SW monsoon compared to other seasons. The highest values of Tz shows the effect of swells due to monsoon winds. Due to large area available for generation of waves with sustained high winds high wave conditions observed during SW monsoon period and comparatively calm during other seasons.

It is observed that about 99% of the values of ε are >0.6 for all seasons. The highest values (0.95) during October and March and lowest values (0.46) during February are observed. This shows that the wave heights coved a wide range for major period of the year and narrow spread during February. The seasonal cycle of Ss follows the pattern similar to wind. The occurrence of steep waves is more frequent during SW monsoon, whereas less frequent during transition periods. Hence, it is concluded that the seasonal cycle of wave heights off East Coast of India is dominated by SW monsoon winds. The wave heights are resultant of sea's over Bay of Bengal and large swells from south.

SW	**Minimum**	**Maximum**	**Average**	**STDEV**	**Anomaly**
Tp	5.56	20.00	11.88	3.32	0.02
Dirp	112.50	202.50	160.03	11.50	4.48
Sprp	7.30	48.30	18.94	5.01	-3.22
Tz	4.26	11.43	6.46	0.95	0.74
Hs	0.86	2.76	1.62	0.33	0.56
Tc	2.45	5.42	3.72	0.42	0.47
eps	0.71	0.93	0.81	0.04	0.004

SW	Minimum	Maximum	Average	STDEV	Anomaly
QP	1.08	4.15	1.70	0.33	-0.02
Ss	0.01	0.05	0.03	0.01	0.004
Hsw	0.15	2.06	0.81	0.31	0.26
Tzw	2.08	8.33	3.99	0.84	0.55
ss	0.38	2.46	1.32	0.31	0.46
Tzs	6.98	17.07	9.82	1.63	0.08
dm	88.30	235.50	173.95	16.30	18.61
dmw	46.90	292.50	185.07	25.85	27.52
dms	114.60	193.10	151.98	9.37	2.79
u10	1.13	7.55	4.97	1.21	1.76
udir	18.04	80.79	56.52	8.64	-72.18

Table 1: The minimum, maximum, average and standard deviation of wave parameters

NE	Minimum	Maximum	Average	STDEV	Anomaly
Tp	3.03	25.00	11.54	2.97	-0.32
Dirp	73.10	246.10	153.65	19.07	-1.91
Sprp	8.60	70.60	23.16	6.50	1.00
Tz	3.08	11.11	5.57	1.52	-0.15
Hs	0.33	2.30	0.81	0.30	-0.25

NE	Minimum	Maximum	Average	STDEV	Anomaly
eps	0.57	0.95	0.81	0.06	0.006
QP	0.92	5.70	1.73	0.52	0.01
Ss	0.00	0.05	0.02	0.01	-0.003
Hsw	0.08	2.16	0.40	0.22	-0.15
Tzw	2.06	8.42	3.12	0.70	-0.31
Hss	0.21	1.92	0.67	0.25	-0.20
Tzs	5.92	17.88	9.23	1.73	-0.51
dm	81.00	264.60	131.33	31.06	-24.01
dmw	43.70	339.80	120.14	50.05	-37.40
dms	100.60	200.50	146.53	12.38	-2.66
u10	0.03	5.38	2.67	1.12	-0.55
udir	7.47	292.04	193.81	62.41	65.11

Table 2: The minimum, maximum, average and standard deviation of wave parameters

FW	Minimum	Maximum	Average	STDEV	Anomaly
Tp	2.33	25.00	12.28	2.85	0.42
Dirp	7.00	357.20	152.65	14.65	-2.91
Sprp	7.80	78.20	24.75	8.69	2.59
Tz	2.47	9.52	5.01	1.12	-0.71

FW	Minimum	Maximum	Average	STDEV	Anomaly
Hs	0.20	1.55	0.70	0.27	-0.35
Tc	1.99	4.70	2.89	0.34	-0.36
eps	0.46	0.95	0.79	0.07	-0.013
QP	0.91	7.29	1.74	0.61	0.01
Ss	0.00	0.05	0.02	0.01	-0.002
Hsw	0.09	1.14	0.41	0.20	-0.13
Tzw	1.97	5.14	3.13	0.51	-0.30
Hss	0.15	1.35	0.53	0.22	-0.33
Tzs	5.49	15.98	10.34	1.53	0.60
dm	94.10	237.80	164.09	17.38	8.75
dmw	75.50	266.40	173.08	26.33	15.54
dms	113.40	210.80	149.21	11.44	0.02
u10	0.14	3.97	1.80	0.87	-1.42
udir	2.12	359.88	136.38	92.22	7.68

Table 3: The minimum, maximum, average and standard deviation of wave parameters

	Tp	Tz	Hs	Tc	eps	QP	Ss	Hmax	Hsw	Tzw	Hss	Tzs
Tp	1.00											
Tz	0.28	1.00										
Hm0	-0.17	0.38	1.00									
Tc	-0.04	0.75	0.66	1.00								
eps	0.48	0.66	-0.04	0.09	1.00							
QP	0.03	0.56	0.06	0.26	0.43	1.00						
Ss	-0.43	-0.46	0.58	-0.04	-0.63	-0.34	1.00					
Hmax	-0.17	0.35	0.92	0.59	-0.03	0.05	0.53	1.00				
Hsw	-0.31	0.01	0.81	0.51	-0.44	-0.16	0.72	0.74	1.00			
Tzw	-0.16	0.29	0.55	0.77	-0.30	-0.03	0.19	0.50	0.77	1.00		
Hss	-0.08	0.47	0.95	0.60	0.16	0.12	0.45	0.88	0.60	0.35	1.00	
Tzs	0.41	0.46	-0.06	0.30	0.29	0.41	-0.43	-0.06	0.02	0.35	-0.13	1.00

Table 4: Correlations among different parameters

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