Inter-annual variations in wave characteristics off Ratnagiri, Northeast Arabian Sea

Johnson Glejin, Sanil Kumar V*, Jai Singh
CSIR-National Institute of Oceanography (Council of Scientific & Industrial Research), Dona Paula, Goa - 403 004 India

*Corresponding author: Tel: 0091 832 2450 327 Fax: 0091 832 2450 602 Email: sanil@nio.org

Abstract
The wave data measured using the Datawell directional wave rider buoy at 13 m water depth off Ratnagiri during 2010 to 2013 is used to study the inter-annual variations in the wave characteristics. The percentage occurrence of waves with significant wave height (H_s) less than 1 m is the same in all 3 years, but the occurrence of high waves (H_s > 1 m) is not same in all the years. The extreme wave events occur during the monsoon period and if these wave events persists for longer periods cause coastal erosion and hence we have examined the events lasting more than 5 h with different threshold limits of wave height (2.5, 3 and 3.5 m). Average H_s during the monsoon is around 3 times that in non-monsoon period. Average of the maximum wave spectral energy density is 12 times higher in monsoon than in non-monsoon. Inter-annual variations in monthly average H_s is maximum (0.5 m) in June and September due to the change in the monsoon intensity. The inter-annual variation in annual average H_s is around 0.1 m and the annual average peak period is 0.1 to 0.5 s. The monsoon average peak period is slightly higher than the values during the non-monsoon period. The joint distribution of the peak wave period and the mean wave direction indicate three peaks; one corresponding to the southwest swells during the post-monsoon season, the second for the southwest-westerly monsoon waves and the third for the northwest waves during the pre-monsoon season.

Keywords: Ocean science; diurnal variability; annual variability; significant wave height
1. **Introduction**

Coastal areas of the west coast of India is highly populated and a slight change in the wave height, wave period and direction trigger coastal erosion and cause impact on the socio-economics of the area. Hence, it is important to know the inter-annual variations in wave characteristics at a location. The change in wave characteristics at a location can be either due to the change in the local winds or remote swells. The different wave systems present at a location can be identified by analyzing the wave spectrum (Hanson and Phillips 1999). The studies in the eastern Arabian Sea indicate that wave spectrum is bimodal due to the presence of wind-seas and swells (Baba et al. 1989; Kumar et al. 2003). Sajiv et al. (2012) has shown that the inter-annual variations in the bulk wave parameters at a location off the central west coast of India during 2008 to 2010 is negligible. The studies based on satellite derived data and ERA-Interim data have indicated that the significant wave height is marginally increasing in the south Indian Ocean and Arabian Sea (Young et al. 2011; Shanas and Kumar 2014). Wave data collected off Ratnagiri for the years 2010 and 2011 are used to analyze the effect of wind systems on the near shore waves observed off the central west coast of India (Glejin et al. 2013).

The inter-annual variations in the bulk wave parameters and the wave spectrum off Ratnagiri are not known at present. Hence, a study on the inter-annual variations in wave characteristics at a location in central west coast of India is carried out.

2. **Data used in the study**

The wave data measured using the Datawell directional wave rider buoy at 13 m water depth off Ratnagiri during March 2010 to December 2013 is used in the study (Fig. 1). The significant wave height (Hs), mean wave period and peak wave period is estimated from the wave spectrum. The details of the data analysis are presented in Glejin et al. (2013a) and Kumar et al. (2014).

3. **Results and discussions**

3.1 Bulk wave parameters

Around 50% of the waves in a year are with Hs between 0.5 and 1 m (Fig. 2). The percentage occurrence of waves with Hs less than 1 m is the same in all 3 years, but the occurrence of high waves (Hs > 1 m) is not the same. The distribution of wave height is similar during 2011 and 2012, but during 2013, high waves (Hs with 2.5 to 4 m) are higher than that during other years.

Fig. 3 represents different oscillations observed in Hs during the summer monsoons in different years with periods 30 min, 1, 5, 10, 15, 20 days. Oscillations with lower periods are dominant during the
first part of the wave data. Whereas, when the measurement period is advancing forward the oscillations with higher period are more dominant because of SW monsoon winds peaks up during the period. The Hs during the monsoon shows oscillations of 5 to 60 days mainly due to the change in the monsoon intensity during the monsoon period (Fig. 3).

There is large variation (~ 0.5 m) in monthly average Hs in different years during the monsoon, but the average Hs for the monsoon period is the same (~ 2 m) in different years. Similarly the variation in annual average Hs during 2010 to 2013 is negligible (< 0.1 m). The average Hs during the monsoon is around 3 times that in the non-monsoon period and ~ 2 times of the annual average Hs (Fig. 4). Inter-annual variations in monthly average Hs is maximum (0.5 m) in June and September due to the change in the monsoon intensity (Fig. 4). Same trend is also observed in the mean period (Tm02) and maximum spectral energy density (Emax). The average Tm02 during the monsoon is 1.5 times higher than that in the non-monsoon period. The difference in Tm02 between the monsoon and non-monsoon period is not only due to the monsoon factor but also the diminution of locally generated wind-sea by the weaker sea breeze land breeze wind system. This influence is also evident in the variation of Tp, however maximum values of Tp are observed mainly during the non-monsoon period. Variation in monthly average of mean wave direction show a decrease in wave angle from 300° to 220° as the season advancing from pre-monsoon to post-monsoon through the SW monsoon season (230-260°). Average of the maximum wave spectral energy density is 8 times higher in monsoon than in non-monsoon (Fig. 4d).

Even though the monthly average Hs is similar in different years except the monsoon period, large inter-annual variations in monthly average peak period are observed during April, May and October due to the variations in the predominance of wind-sea and swell. During 2010, predominance of swell is observed in April, whereas in other 3 years wind-sea dominance is observed (Fig. 4c and 4e). Similarly during 2011 and 2012, predominance of swell is observed in October, but predominance of wind-sea is found in 2010 and 2013. During December, wind-sea predominance is observed in 2010, whereas during the other years swell is dominant. The joint distribution of the peak wave period and the mean wave direction indicate three peaks; one corresponding to the southwest swells during the post-monsoon season, the second for the southwest-westerly monsoon waves and the third for the northwest waves during the pre-monsoon season. 15 to 18% of the waves in a year are with Hs of 0.5 to 1 m and from 225 to 240° and similarly 11 to 14% of the waves are with Hs 0.5 to 1 m and from 300-315°.
3.2 Diurnal variation in wave parameters

The range of Hs (difference between the maximum and the minimum) in a day varied up to 1.5 m with the high values (>1 m) during the SW monsoon period (Fig. 5), whereas during the pre and post monsoon season the observed range in wave height is less than one meter except two events (one during 2012 Feb and second during 2013 Jan) in the entire study period. During the pre and post monsoon, eastern Arabian Sea is influenced by the weak seasonal NE winds and light and gentle sea-land breeze (1.6-5.4 m/s) developed by the ocean-land interaction (Glejin et al., 2013a). Higher range in wave height (Hs) observed during the pre-monsoon season is due to the propagation of wave height in the range of 1-2 m from the NW due to the Shamal swells (Aboobacker et al. 2011, Glejin et al., 2013b). Lower limit of this range during the SW monsoon is slightly higher (~0.5 m) than that during the pre and post monsoon season (~0.2 m). Higher lower limit and higher range are due to the persistent strong wind over the Arabians Sea which causes the high energy waves to interact with the coastal area and result in erosion of the beaches. Observation in variation in mean wave period (Tm02) shows the range of Tm02 in a day varied up to 5 s with the high values (> 2 s) during the post and pre-monsoon period due to the influence of land/sea breeze and long period swells from the southernmost Indian ocean and less than 2 s in the SW monsoon season by the SW swells dominance.

The extreme wave events occur during the monsoon period and if these wave events persists for longer periods it cause coastal erosion. We have examined the events lasting more than 5 h with different threshold limits of wave height (2.5, 3 and 3.5 m). Hs more than 2.5 m occurred up to 12 times during 2012 and 2013 and persisted up to 260 h in 2010 (Fig. 6). Up to 9 events of Hs more than 3 m are observed and the maximum duration of a single event is up to 40 h. One event of Hs more than 3.5 m is observed in June and July, but did not last for more than 9 h. The average peak wave period during the monsoon in different years is 10.4 to 10.7 s. The monsoon average peak period is slightly higher than the values during the non-monsoon period and the annual average peak period is 10.1 to 10.5 s.

3.3 Joint distribution of wave period and direction

The joint distribution of the peak wave period and the mean wave direction indicate three peaks; one corresponding to the southwest swells during the post-monsoon season, the second for the southwest-westerly monsoon waves and the third for the northwest waves during the pre-monsoon season (Fig. 7). 15 to 18% of the waves in a year are with Hs 0.5 to 1 m and from 225 to 240° and similarly 11 to 14% of the waves are with 0.5 to 1 m and from 300-315° (Fig. 7).
4. Conclusions

Inter-annual variations in the wave characteristics are studied based on the wave data measured using the Datawell directional wave rider buoy at 13 m water depth off Ratnagiri during 2010 to 2013. The study shows that around 50% of the waves over an annual cycle are with significant wave height (Hs) between 0.5 and 1 m. Oscillations with lower periods are dominant during the first part of the wave data. Whereas, when the measurement period is advancing forward the oscillations with higher period are more dominant because of SW monsoon winds peaks up during the period. Inter-annual variations in monthly average Hs is maximum (0.5 m) in June and September due to the change in the monsoon intensity. The range of Hs (difference between the maximum and the minimum) in a day varied up to 1.5 m with the high values (>1 m) during the SW monsoon period. The swell heights are the highest in 2013 compared to other months.

Acknowledgments

The authors gratefully acknowledge the financial support given by the Earth System Science Organization, Ministry of Earth Sciences, Government of India to conduct part of this research. The directors of CSIR-NIO, Goa and INCOIS, Hyderabad provided encouragement to carry out the study. We thank Dr. T. M. Balakrishnan Nair, Head of the Ocean Science & Information Services Group and Mr. Arun Nherakkol, scientist, INCOIS, Hyderabad for the help during data collection. This work forms a portion of the Ph.D. thesis by the first author. This is NIO contribution No. xxx.

References


Glejin, J., Kumar, V.S., Nair, T.N.B., Singh, J., 2013a. Influence of winds on temporally varying short and long period gravity waves in the nearshore regions of the eastern Arabian Sea, Ocean Sciences 9, 343–353


Oceanogr 29, 1633-1648


Table 1. Average of wave parameters over 2010-2013

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Year</th>
<th>Hs (m)</th>
<th>Tp (s)</th>
<th>Tz (s)</th>
<th>Emax (m²/Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monsoon average</td>
<td>2010</td>
<td>1.9</td>
<td>10.6</td>
<td>6.4</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>2011</td>
<td>2</td>
<td>10.7</td>
<td>6.4</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>2</td>
<td>10.5</td>
<td>6.3</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td>2013</td>
<td>2</td>
<td>10.6</td>
<td>6.2</td>
<td>6.0</td>
</tr>
<tr>
<td>Non-monsoon average</td>
<td>2010</td>
<td>0.7</td>
<td>10.4</td>
<td>4.6</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>2011</td>
<td>0.7</td>
<td>9.8</td>
<td>4.6</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>0.7</td>
<td>10.3</td>
<td>4.4</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>2013</td>
<td>0.7</td>
<td>10.2</td>
<td>4.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Annual average</td>
<td>2010</td>
<td>1.2</td>
<td>10.5</td>
<td>5.4</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>2011</td>
<td>1.1</td>
<td>10.1</td>
<td>5.1</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>1.1</td>
<td>10.4</td>
<td>5.0</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>2013</td>
<td>1.2</td>
<td>10.3</td>
<td>5.1</td>
<td>2.6</td>
</tr>
</tbody>
</table>
Figure 1. Map showing the study location

Figure 2. Percentage occurrence of a) significant wave height and b) mean wave direction during 2011 to 2013
Figure 3. Time series plot of significant wave height with 1, 5, 10, 15 and 20 day moving average in SW monsoon period during 2010 to 2013
Figure 4. Monthly average wave parameters a) significant wave height, b) mean wave period, c) peak wave period, d) maximum spectral energy density and e) mean wave direction.
Figure 5. Daily range of significant wave height and mean wave period during different years
Figure 6. Number of time the Hs exceed 2.5, 3 and 3.5 m during the monsoon period along with the longest duration of an event and the total time of all events
Figure 7. Joint distribution of mean wave direction with peak wave period (top panel) and mean wave direction with significant wave height (bottom panel)