The performances of Accelerometer and GPS buoy were tested off Cuddalore at 30 m water depth during 15 to 30 November 2010 by mooring the buoys 225 m apart from each other. Compared to other wave parameters, results of regression analysis on significant wave heights ($H_s$) shows a better correlation (correlation coefficient $R = 0.94$) between accelerometer and GPS buoy. A lesser coefficient of $R = 0.85$ and 0.77 were resulted for wave direction and peak wave period ($T_p$) respectively. Waves were basically approaching from two directions, i.e. two wave forms or wave fields. One wave field was from around 80° and other was 140°. However, the wave directions averaged within each field over the observation period individually are in good agreement with both buoys. It was noticed that the predominant directions reported by these buoys were not identical always. Even though the buoys were placed at identical water depths ($\sim 30$ m) and in close proximity ($\sim 225$ m), they were reporting different predominant directions. The correlation seems low because it was determined to a large extent, with waves from different directions. Comparatively, zero up-crossing wave period ($T_z$) shows a better agreement with $T_p$, which may not be a robust parameter due to its dependence on estimation of spectral peak.

[Keywords: Accelerometer and GPS buoy, significant wave height, wave period and wave direction.]

Introduction

In the collection of ocean wave data, based on the measurements of the buoy motions accelerometer and GPS sensors have been extensively used in the past. Most successful commercial wave buoys have been Datawell wave rider (used widely since the late 1960s). Datawell original directional buoy, the Wavec, replaced later by the Directional Waverider since the early 1990s, together with the two multi-sensor buoys Wavescan since the mid-1980s and Seawatch 1990s mainly for deep water deployments and for multi-parameter environmental and
metocean data collection. In 1996, the smart-800 buoy was launched, representing a novel approach to operational open–sea wave measurement technology. The Smart-800 measures ocean wave using the differential GPS (Global Positioning System) and the raw data are transferred to the shore station via UHF radio link making it ideal for coastal wave monitoring. With the introduction of GPS satellite positioning system and continual improvement of the receiver’s measurement of wave motion, these buoys became popular in the twenty first century.

Various field experiments and sea trials have been reportedly carried out to facilitate the choice between two wave buoys in the past few years. Waves are measured by measuring the motion of a moored buoy that follows the motion at the sea surface. The dynamics of the mooring (at the low frequency side and the dynamics of the buoy (at the high frequency side) determine the water surface following quality of the system. In this respect the accelerometer and GPS buoy, having the same mooring configuration and the same dimensions perform well in following waves. In practice, the accelerometer wave buoy reportedly demonstrated 1 cm precision up to 30 sec wave period upper limit, whereas GPS buoy demonstrate same 1 cm accuracy up to 100 sec periods.

Most of the Oceanographic institutes in India viz. National Institute of Oceanography (NIO), Indian National Centre for Ocean Information Services (INCOIS), National Institute of Ocean Technology (NIOT), Integrated Coastal and Marine Area Management (ICMAM), Centre for Earth Science Studies (CESS) etc. being extensively using the directional wave rider buoys in the Indian coastal waters since, the last three decades. In order to identify the distinct advantage of individual system, NIOT tested both buoys off Cuddalore for the period of 15 to 30 November, 2010. In the present study the comparisons of wave measurements by accelerometer and GPS measurement are assessed.
Materials and Methods

Wave measurements were carried out using two Datawell directional wave rider buoy (GPS and accelerometer) in 30 m of water depth, 225 m apart, 12 km off Cuddalore. The data used here is from the period 15 to 30 November, 2010. Table 1 presents the deployment schedule, sampling and analysis parameters for accelerometer and GPS buoy.

GPS wave buoy measurement principle bears a strong anomaly with the Doppler-shift phenomenon of a nearly passing car blowing its horn. The GPS system calculates the velocity of the buoy from changes in the frequency of GPS signals. The velocities are integrated with time to determine buoy displacement. In practice the GPS system uses signals from multiple satellites to determine three-dimensional buoy motion. Accelerometer buoy measures wave height by means of vertical acceleration of the accelerometer mounted on the gravity sensitive platform of the buoy.

The separation of Wind Sea and swell components from the wave spectra was done by wave steepness method of National Data Buoy Center. Estimation of wind sea and swell are made by selecting a separation frequency \( f_s \), that partitions the wave spectrum into its wind 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 \( \theta_{sw} \) and \( \theta_{ss} \). For this study, a separation frequency of 0.125 Hz is used.

Results and Discussion

To analyse the huge amount of current data set, correlation plots of various wave parameters are most preferable. A correlation plot allows comparison of results from both the accelerometer and GPS wave buoys over a whole range of marine conditions and over the full period of measurement. For buoy displacement measurement various wave parameters are significant such as significant wave height \( H_s \), wave directions, peak wave period \( T_p \), zero-crossing wave period \( T_z \), etc. These parameters are computed over records of circa 30 min duration to reduce statistical variance.
The comparative analysis between accelerometer and GPS buoy is presented in the Figure. 1a, which shows that the correlation coefficient of significant wave height $R = 0.96$. Earlier studies on accelerometer and GPS sensors contained in a buoy reported $R$ greater than $0.99^{4,5}$. These correlations with buoy displacement may not be resulting from a single wave field for the entire data set. When more than one wave field is present, for example in case of sea and swell, the correlation plot of individual sea and swell wave height (Figure. 1b and 1c) is in good agreement. Wave heights reported by both buoys look similar in case of local sea waves ($R = 0.97$) compared to swell waves ($R = 0.89$). In swell condition it was observed that a bias was present between the buoys when significant wave height exceeds 0.8 m. In fact, time series plot between accelerometer and GPS buoy (Figure. 1d) looks very similar without any deviation.

Correlation analysis of wave periods ($T_z$ and $T_p$) is shown in Figure. 2a and 2b. The correlation coefficient for $T_p$ and $T_z$ were found to be 0.77 and 0.93 respectively between accelerometer and GPS buoy. This number indicates that most of the observations were in good agreement for $T_z$, whereas for $T_p$ there was a large difference. Difference was due to the presence of multiple peaks in the spectra, associated with sea and swell components. $T_p$ can only represent the single largest peak in the spectra. On occasions when two peaks were of equal magnitude with very small difference in spectra peak, it leads to very different value of $T_p$ (Figure. 3a:3b). Value of $R$ for $T_{sw}$ and $T_{ss}$ were 0.93 and 0.72 respectively (Figure. 2c and Figure. 2d). Swell Zero crossing wave period found a bias when it was more than 12 s.

Peak wave period is not a very robust parameter. It is the reciprocal of frequency where the power spectral density is maximum. A small stochastic effect may easily modify the peak of the spectra and yield a different peak period. Figure. 3 shows the comparison of spectral energy density between accelerometer and GPS buoy, during 21 and 29 November 2010 respectively. On 21 November single peaked swell dominated wave spectra was observed (Figure. 3a). Frequency spectrum during 29 November, 2010 was double peaked, where the wave energies were concentrated at 0.1 and 0.15 Hz respectively. From the peaks of the spectra it was noticed that
there was a significant shift in the frequency of peak in the sea wave region (right peak of the spectra) compared to swell wave (left peak of spectra) region (Figure. 3b).

In the present study, the waves were observed basically from two directions, i.e. two wave fields (Figure. 4). Analysis for total wave direction shows correlation coefficient of 0.85 between accelerometer and GPS buoy (Figure. 5a). The correlation seems low because it was determined to a large extend, where there is not a single wave direction. One wave field was centred at 80° (sea wave direction) and other was at 140° (swell wave direction). Separated plots of sea and swell in Figure. 5b and 5c indicate better correlations individually (0.93 and 0.89) than in combined plot (5a). However, the wave directions averaged within each field over the observation period individually are in good agreement with both buoys. It was noticed that the predominant directions reported by these buoys were not identical always. Even though the buoys were placed at identical water depths (∼ 30 m) and in close proximity (∼ 225 m), they were reporting different predominant directions.

**Conclusion**

The accelerometer and GPS buoy performed well for the duration of deployment in the shallow water off Cuddalore producing fairly identical results. Results of Comparison between two wave buoys are as follows. Significant wave height between accelerometer and GPS buoy compared well with local sea waves than swell conditions (R = 0.97 and 0.89 for sea and swell $H_s$). Waves were basically approaching from two directions, i.e. two wave forms or wave fields. The correlation seems low (R = 0.85), because it was determined to a large extent, with waves from different directions. Both buoys are in close agreement with zero up-crossing wave period ($T_z$);
on the other hand the value of peak period ($T_p$) vary largely due to the presence of multiple peaks in the spectra, associate with separate sea and swell components ($R = 0.93$ and $0.77$ for $T_z$ and $T_p$).

Acknowledgement

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References


### Table Caption

Table 1- The deployment schedule, sampling and analysis parameters for accelerometer and GPS buoy

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<thead>
<tr>
<th>Device/Parameter</th>
<th>Accelerometer Buoy</th>
<th>GPS Buoy</th>
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<tr>
<td>Deployment location (Lat/Long)</td>
<td>11° 40.5870’/ 79° 52.7862’</td>
<td>11° 40.6572’/ 79° 52.992’</td>
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<td>Water depth (mean)</td>
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<td>30 m</td>
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<tr>
<td>Burst interval for waves</td>
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<td>Sampling frequency</td>
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<td>0.01 Hz (using high-pass filter)</td>
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<td>Phase-linear, combined band-pass and single-integrating FIR type</td>
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<td>Heave range</td>
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<td>-20 to +20 m</td>
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<tr>
<td>Wave period time (frequency range)</td>
<td>1.6 to 30 s (0.033 to 0.064 Hz)</td>
<td>1.6 to 100 s (0.01 to 0.064 Hz)</td>
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</table>
Figure Caption

Figure 1a:1c- Comparison of total, sea and swell significant wave height between accelerometer and GPS buoy

Figure 1d- Time series plot of $H_s$ between accelerometer and GPS buoy

Figure 2a:2d- Comparison of time periods [$T_p$ and $T_z$ (total, sea and swell)] between accelerometer and GPS buoy

Figure 3- Comparison of the accelerometer and GPS measured frequency spectrum. a) Sea dominated spectrum observed on 21 November, 2010 at 1:34 hours, b) Swell dominated spectrum observed on 29 November, 2010 at 1648 hours and 1649 hours respectively

Figure 4- Time series plot of accelerometer and GPS measured wave directions

Figure 5a:5c- Comparison of total, sea and swell wave directions between accelerometer and GPS buoy