Inter comparison of wave height observations from buoy and altimeter with numerical prediction

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An inter-comparison exercise has been carried out between altimeter derived significant wave height with buoy measurements and numerical prediction. Measurements during the year 2004 have been taken from the buoys located in the Arabian Sea and Bay of Bengal. The statistics of variation between these observations has been studied at each buoy locations with the special emphasis to explore the applicability of altimeter measurements and numerical model prediction.

Keywords: Significant wave height, WAM

Introduction

The recent developments in the satellite technologies, the remote sensing wave measurements from altimeter and SAR form a vast database for many applications. The in-situ wave measurements from the data buoys continue to provide temporally intense data sets at specified spatial location. The numerical modelling can however supplement for the extraction of spectral details at every grid location. The combination of remote and in-situ measurements would be beneficial to extract long term historical measurements at any given spatial location. In order to get the most reliable wave forecast, the measurements from these sources must be incorporated into the assimilation schemes of the wave model, where the role of geo-spatial variation is crucial. Hence, integrating different data sources is highly essential not only for filling gaps, but also for the performance of the system itself.

Previous studies show that the comparison between buoy and altimeter was found to be good1. Another such study using triple collocation method was performed by2, to find the root mean square error in buoy, altimeter and analyzed wave heights. The present study addresses the differences between Altimeter, Buoy and WAM (herein after ABW) derived significant wave heights with a special focus on directional distribution. The relative importance of altimeter and Buoy derived wave characteristics in terms of buoy measurements is highlighted.

Materials and Methods

The significant wave height (Hs) measurements from JASON-1A (J1A), ENVISAT-1B (EN1B) and GFO-1A (GF1A) have been obtained from Radar Altimeter Database System (RADS) for the year 2004. All the three altimeter measurements are from Ku-band mode. RADS default correction settings has been applied. The repeat period with respect to ground station of J1A, EN1B and GF1A are 10, 35 and 17 days, respectively. The buoy measurements were obtained from data buoy programme of National Institute of Ocean Technology, Chennai. The locations of buoys along with the satellite tracks are given in Fig. 1. The buoy measurements are of three hour interval. Both deep and shallow water buoys located in Arabian Sea and Bay of Bengal are used for the study. For the purpose of comparison, the altimeter data has been derived within the band of three hour time interval time stamp and within a spatial distance of 50 km of buoy location.

For the numerical modeling of wave characteristics in Indian Ocean, the third-generation wave model, WAM3 has been used. WAM estimates the evolution of the energy spectrum for ocean waves by solving the wave transport equation explicitly without any presumption on the shape of the wave spectrum.

\[
\frac{\partial F(f, \theta, x, t)}{\partial t} + u \nabla_x F(f, \theta, x, t) = S_{in} + S_{nl} + S_{ds} + S_{bot} \quad \ldots (1)
\]
Where \( F(f, \theta; x, t) \) is the wave energy spectrum in terms of frequency \( f \) and propagation direction \( \theta \) at the position vector \( x \) and at time \( t \); \( v \) is the group velocity. The net source function, \( S \), takes into account all physical processes such as wind input, nonlinear wave–wave interaction \( (S_{nn}) \), dissipation due to wave breaking \( (S_{bw}) \), and bottom friction \( (S_{bot}) \). The NOAA-NCEP wind data sets \((1.0^\circ \times 1.25^\circ; \text{three hourly})\) have been used in the model domain extending from \(30^\circ\text{E} \) to \(120^\circ\text{E} \) and from \(50^\circ\text{S} \) to \(30^\circ\text{N} \) with \(0.5^\circ\) model grid resolution in both latitude and longitudinal directions. Bathymetry has been derived from Earth Topography 2(ETOPO-2) data sets.

![Fig. 1](Image)

**Fig. 1**—Buoy Locations (top-left), satellite crossings along with buoy locations for JASON-1A (top-right), ENVISAT-1B (bottom-left) and GEOSAT follow-on (bottom-right)

**Results and Discussion**

Table 1 summarizes the relative mean difference and percentage of greater values paired among the ABW \((H_s)\) measurements. In general, except at DS7, WAM underestimates in all the deep water buoy stations with the mean difference up to 21 cm. Variation shown at DS7 station is quite different from other deep water buoy stations. At DS7, altimeter measurements are higher with mean increment up to 0.6 m by J1A and 0.4 m by GF1A. The mean difference was around 0.5 m with nearly 92% of data, where WAM predicts higher compared to buoy measurements. Further, altimeter measurements are also high compared to buoy. It should be noted that DS7 is located in the middle of the Lakshadweep islands. Buoy measurements from Bay of Bengal are always higher compared to altimeter.

Fig. 2 and Fig. 3 represent the ABW- \( H_s \) time series of three hour interval for the year 2004. It is clear that except DS7 and OB8, all the other buoy stations match well with the numerical model. In shallow water regions, J1A and EN1B are found to be good compared to GF1A when compared to buoy and WAM, between buoy and WAM in shallow water regions, WAM overestimates with a maximum of 75% at SW3. This might be due to absence of shallow water effects such as depth induced breaking in WAM application.

It is known that rain disturbs the altimeter measurements; hence, during monsoon season (June to September) one can expect the higher variations. However, altimeter compares well with WAM. But, both of the above do not match with buoy measurements during monsoon season.

<table>
<thead>
<tr>
<th>Altimeter /Buoy</th>
<th>Depth (m)</th>
<th>J1A</th>
<th>EN1B</th>
<th>GF1A</th>
<th>WAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS1</td>
<td>4200</td>
<td>-0.0947</td>
<td>0.1438 {30</td>
<td>60}</td>
<td>-0.2268</td>
</tr>
<tr>
<td>DS2</td>
<td>1850</td>
<td>0.0688</td>
<td>0.0232 {52</td>
<td>42}</td>
<td>-0.1900</td>
</tr>
<tr>
<td>DS3</td>
<td>3156</td>
<td>-0.1276</td>
<td>0.1855 {27</td>
<td>63}</td>
<td>-0.2213</td>
</tr>
<tr>
<td>DS4</td>
<td>2350</td>
<td>NaN</td>
<td>NaN</td>
<td>-0.1954</td>
<td>-0.0113 {13</td>
</tr>
<tr>
<td>DS5</td>
<td>3267</td>
<td>NaN</td>
<td>NaN</td>
<td>-0.2530</td>
<td>-0.1225 {14</td>
</tr>
<tr>
<td>DS7</td>
<td>2076</td>
<td>0.5848</td>
<td>-0.0022 {90</td>
<td>42}</td>
<td>0.4938</td>
</tr>
<tr>
<td>MB11</td>
<td>2807</td>
<td>0.0108</td>
<td>0.1243 {33</td>
<td>63}</td>
<td>-0.2733</td>
</tr>
<tr>
<td>OB3</td>
<td>1665</td>
<td>NaN</td>
<td>NaN</td>
<td>-0.1065</td>
<td>-0.1106 {33</td>
</tr>
<tr>
<td>OB8</td>
<td>3510</td>
<td>-0.0228</td>
<td>0.0745 {54</td>
<td>59}</td>
<td>-0.1404</td>
</tr>
<tr>
<td>SW3</td>
<td>-</td>
<td>0.2282</td>
<td>0.2449 {78</td>
<td>75}</td>
<td>0.0600</td>
</tr>
<tr>
<td>SW5</td>
<td>12</td>
<td>0.1195</td>
<td>-0.1243 {100</td>
<td>32}</td>
<td>0.4800</td>
</tr>
</tbody>
</table>

Note: Columns 3, 4 and 5, represents mean difference of A-B \( |A-W| \) and absolute percentage of positive values \{A-B | A-W\}, where A, B, and W denotes altimeter, buoy and WAM measurements respectively. Similarly, the last column represents mean of B-W \{absolute percentage of positive values in B-W\}. 

Table 1—Mean difference between \( H_s \) values from ABW and the absolute percentage values
Fig. 4 and Fig. 5 present the comparison of monthly average $H_s$ for ABW. The monthly average statistics at DS1 location shows that WAM either coincides (non-monsoon) or under-predicts (during monsoon, peak activity) than buoy throughout the year at DS1. Altimeter slightly under-predicts during dry season and is close to buoy measurements when compared to WAM during SW monsoon. At DS1, the monthly maximum is high for buoy when compared to both altimeter and WAM. There is about 1 m difference between WAM and buoy data, whereas almost 2 m difference between buoy and altimeter during June. Altimeter shows over-prediction throughout the year at DS2, whereas buoy and model prediction compare well, wherever data is available during low wave activity season. The deviation between the ABW average values is marginal. At DS7, both monthly average and maximum statistics depict that altimeter and WAM are close to each other while buoy measurements show (less) a marked difference of around 1 m. This needs further investigation on all ABW data sets starting from investigating the water depth, closeness to islands, relative altimeter track position with reference to buoy location and sensitivity of satellite measurements.

The shallow water buoy, SW3, the trend in the variation of $H_s$ from ABW is similar. Altimeter slightly over-predicts the peak during June and WAM slightly under-predicts $H_s$ (buoy location is in between WAM grid and altimeter track). At this location, buoy measurements are available only during the dry season. As noted earlier, the low wave activity ($< 1$ m) is highly over-predicted by altimeter at this shallow water location. The applicability of altimeter in shallow water locations needs further investigation. The monthly average values at OB3 location in Arabian Sea show reasonably good performance with buoy, whereas, the monthly maximum is high for buoy measurements during the SW monsoon season. Altimeter maximum is comparatively lower than WAM and buoy.

At DS3, both altimeter and WAM prediction (monthly maximum) are far less than the buoy measurements. The altimeter under-predicts the peaks than WAM (1.5 m less) during June. The average values compare well during non-monsoon season with respect to buoy measurements and the deviation between altimeter and WAM during June is not present for average values. The monthly average $H_s$ at DS4 shows that WAM compares well with buoy for the wave heights less than 1.5 m (with a maximum of 30 cm deviation) during July and August. The monthly maximum with altimeter measurements is low from February to November when compared to WAM/buoy, and peak activity is under-predicted. WAM performs better in this case than altimeter at DS5. Monthly maximum altimeter $H_s$ shows marked deviation (less than WAM) for the entire year whereas; WAM is further slightly less than buoy measurements. Monthly average at DS5 during monsoon season (Jun, Jul and Aug.) shows that altimeter prediction is close to buoy while WAM is under-predicting. During north-east monsoon (Nov-Dec) season, WAM compares well with buoy.
and altimeter under-predicts the low wave activity (<1.5 m). At MB11, altimeter measurements in general closely follows WAM and both compare well with buoy during Sep.-Dec. During SW monsoon (July-Aug), the discrepancy is high for peaks and low for average values for altimeter. It is observed that, this trend is reversed for WAM. Altimeter performs better at this location. At OB8 location in Bay of Bengal, both maximum and average statistics show that WAM and altimeter under-predict at OB8. Altimeter measurements (average) are comparatively better though, the maximum values are 30-50 cm less at this location with wave activity always less than 3.0 m throughout the year.

Conclusions
An inter comparison exercise between altimeter, buoy measurements with WAM prediction shows the applicability of various regions in which altimeter and numerical prediction perform better. Altimeter measurements show marked differences between a deep water and shallow water locations. Even though, the performance of numerical model has been promising, it still needs the validation. In a spatial location surrounded by islands, like in DS7 location, the predictability is very complex either by WAM or altimeter.

References