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Comparison of gridded multi-mission and along-track mono-mission satellite altimetry wave heights with in situ near-shore buoy data

P.R. Shanas, V. Sanil Kumar *, N.K. Hithin

Ocean Engineering, CSIR-National Institute of Oceanography (Council of Scientific & Industrial Research), Dona Paula, Goa 403 004, India

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ABSTRACT

The applicability of altimeter data for the coastal region is examined by comparing the gridded multi-mission and along-track mono-mission significant wave height (SWH) data with the in situ buoy measurements at four stations off the east and west coasts of India. Among all of the satellites, a greater number of collocated points and better correlation were found for Jason-2. A comparison of the SWH data from multi-mission products (Jason-1, Jason-2, Envisat, and ERS-2) obtained from AVISO with the measured buoy data shows that all of the satellites overestimated the SWH. Applying a correction factor of 0.75, 0.70 and 0.69 to the altimeter data for stations 1, 2 and 4, respectively, resulted in close agreement with the buoy data (correlation coefficient ~0.9–0.96). Monthly averaged buoy and altimeter SWH values show convincing correlation ranging from 0.97 to 0.98 for three stations. The smallest correlation coefficient (0.6) was found at station 3, where the selected grid points are located close to the coast and are influenced by land contamination and wave decay effects. For waves with a SWH < 0.5 m, the correlation coefficient is sparingly low for all stations, which underlines the fact that the altimeter observations for SWH < 0.5 m are unreliable.

1. Introduction

Wave data over periods of many years are necessary for estimating the wave climate at a location. Because the measured data are scarce and measurements are expensive, the wave data are generally derived either from numerical hind-cast models or from satellite-derived observations. During the 1970s, global monitoring of significant wave height (SWH), defined as the average of the highest one third of the waves over time, became a reality and resulted in the first global atlas of SWH data derived from satellite observation (McMillan, 1981), and satellite altimetry brought a global perspective to ocean wave climate assessment (Chelton et al., 1981). Since then, the SWH data from several different satellites have become available, including SEASAT (1978), GEOSAT (1985–1990), TOPEX/POSEIDON (1992–2006), ERS-1 (1991–2000), ERS-2 (1995–2011), ENVISAT (2002–2012), Jason-1 (2002–2013), Jason-2 (2008-present) and Cryosat-2 (2010-present), SARAL/AltiKa (2013-present).

Satellite altimetry has proven its ability to measure a wide variety of oceanographic phenomena, particularly over the data-sparse Indian Ocean region. In the Indian Ocean region, studies have been designed to: (i) examine the applicability of altimeter data in the circulation and large-scale model (Eigenheer and Quadfasel, 2000; Basu et al., 2003; Shenoi, 2010), (ii) explore the coastal dynamics (Birol et al., 2006), (iii) compare the model results (Sarkar et al., 1996) and (iv) investigate the variation in sea surface height (PrasannaKumar et al., 1993). Sarkar et al. (1990) synthesised the SWH data off the Indian coastline, derived charts showing the monthly mean values over $2.5^\circ \times 2.5^\circ$ grids and studied the validity of these observations against ship-reported and buoy data. Many studies have been undertaken on how best to use the data available from satellite observation systems in wave models (Mastenbroek et al., 1994; Young and Glowacki, 1996; Voorrips et al., 1997; Greenslade, 2001; Raj Kumar et al., 2009). Kshatriya et al. (2001) compared the TOPEX/POSEIDON altimeter-derived wind speed and wave parameters with buoy data in the north Indian Ocean. Validation and calibration of satellite altimetry wave heights have been carried out in many studies (Queffeulou, 2004; Durrant et al., 2009; Abdalla et al., 2010; Ablain et al., 2010; Quartly, 2010; Ray and Beckley, 2003, 2012). The overall accuracy of altimeter measurements of the SWH is compared with buoy observations (Young, 1994; Janssen et al., 2007; Li and Holt, 2007; Zieger et al., 2009), including the systematic calibration and cross-validation of the SWH data from different sensors. Buoy data are generally assumed to be of high quality and have been used in numerous studies for validation of model data (Janssen et al., 1997; Caires and Sterl, 2003; Caires et al., 2004) and altimeter data (Tolman et al., 2002; Queffeulou, 2004; Faugere et al., 2006). Similar efforts have been carried out with Jason-1 data by Desai and Vincent (2003) and

* Corresponding author. Tel.: +91 832 2450 327; fax: +91 832 2450 602.
E-mail address: sanil@nio.org (V. Sanil Kumar).

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Durrant et al. (2009). Calibrations and validation of the TOPEX/POSEIDON, Jason-1 mission have been performed by Ray and Beckley (2003) and Queffeulou and Bentamy (2007).

Most of the above studies were performed for locations away from the coast, and the altimeter observations collected over the coastal region remain largely unexploited in the data archives (Cipollini et al., 2008). The coastal domain represents a challenging target for exploiting satellite information in which the accuracy is degraded due to a number of factors, including issues of land contamination in the altimeter and radiometer footprints, and these corrections require special attention (Andersen and Scharroo, 2011; Bouffard et al., 2011; Cipollini et al., 2010). Recent developments and processing techniques have increased the level of accuracy of the altimetry data. Even though the altimeter data is contaminated near the coast (<10 km), the long-term measurements in the coastal region are a challenge and the measured data are scarce especially for the North Indian Ocean, we have done a study to know what will be the error in the altimeter data for the coastal locations in North Indian Ocean. Because the waves off the Indian coastlines are influenced by the monsoons, understanding the quality of altimeter data over different seasons or different ranges of wave height is important. Recently, the near-shore wave data collection program off the Indian coastline was launched; therefore, the work described in this paper is designed to compare these data with the nearest available altimeter data. The main objectives of the study are to examine the performance of satellite altimetry SWH data along the coastal region via comparison with the measured buoy data during the years 2010–2012 and to understand the variation in the altimeter data for different wave height ranges at four locations off the east and west coasts of India.

2. Data sources

2.1. Satellite altimeter data

A satellite altimeter measures the wave height using the shape of the radar return pulse. Each altimeter mission (GEOSAT, ERS-1, ERS-2, TOPEX, Jason-1, Jason-2, ENVISAT, GFO, and Cryosat-2) has collected global SWH data at various spatial and temporal resolutions. The repeat period (the time required for the satellite to return to the same location) for each altimeter mission varies, and the minimum period is 10 days (Table 1). The altimeter SWH data were obtained from two sources: (i) the along-track mono-mission products of Jason-1, Jason-2, Envisat, ERS-2 and Cryosat-2 from the TUDelft RADS database (Schrama et al., 2000) (http://rads.tudelft.nl/rads/rads.shtml) enabling records to be retrieved with the most up-to-date corrections already applied and (ii) the near-real-time merged gridded data with a resolution of $1^\circ \times 1^\circ$ from the multi-mission product of AVISO (http://www.aviso.oceanobs.com/); these data are used in the study.

2.1.1. Mono-mission processing

The mono-mission product arrays are averaged using $1^\circ \times 1^\circ$ boxes, which are subsequently smoothed and extrapolated using a low-order equivalent system filter algorithm of $16^\circ \times 8^\circ$. Gaps or missing data are filled accordingly. The extrapolation is limited to $8^\circ \times 4^\circ$ to avoid artificial filling of areas without data. Next, a reduced bathymetry mask is applied in which points greater than 2° from the sea are forced to a default value. If more than 30% of the points have default values, no map will be generated (http://www.aviso.oceanobs.com/).

2.1.2. Multi-mission processing

High precision altimetry data can be retrieved by multi-mission processing. It allows more along-track data for model assimilation, higher resolution of multi-mission mesoscale maps and better resilience of the multi-mission observation system if an old altimeter becomes unavailable. Topex/Poseidon-ERS and Jason-Envisat are fine examples of how altimetry satellites can operate together. Topex/Poseidon and Jason-1 follow a repeat cycle of 10 days designed to monitor ocean variations, so they pass over the same points fairly frequently but their ground tracks are some 315 km apart at the equator-more than the average span of an ocean eddy. On the other hand, ERS-2 and Envisat only revisit the same point on the globe every 35 days but the maximum distance between two tracks at the equator is just 80 km. If one location is the focus of the study, a balance must be ensured between the spatial and temporal resolution. In fact, a satellite that revisits the same location frequently covers fewer points than a satellite with a longer orbital cycle. A better solution for the problem is to combine several operating satellites. At least two altimetry satellites are required to map the ocean and monitor its movements precisely, particularly at scales of 100 to 300 km. With four altimetry satellites available, the resolution of the sea surface height measurements is greatly enhanced in the mesoscale variability (Pascual et al., 2006). A merged map is generated if a minimum of two missions are available and the data are cross calibrated using OSTM/Jason-2 as reference mission. The mapping method is similar to that of the mono-mission products (http://www.aviso.oceanobs.com/).

2.1.3. Data quality check

All flagged data are rejected, and if a data point is identically zero or exceeds 25 m, then that point is excluded. Data records are also rejected if the orientation of the satellite altimeter drifts significantly from the nadir. Finally, if the along-track samples are highly variable, then the data are also rejected. The Ku-band SWH data are used for all altimeters because this band is available from all missions. The data rejection has been carried out with default editing criteria on the 20 Hz standard deviation has been applied. The SWH data are generated at a rate of 1 Hz from more rapidly sampled (10 or 20 Hz) data. The details of the RADS altimetry data used in the present study are given in Table 1.

2.2. Buoy data

As we are comparing spatially varying data of satellite with temporally varying significant wave height data from buoys, it is important that the buoy data are measured in areas where the gradients in significant wave height are rather small. The wave

Table 1
Description of the RADS altimetry data used in the study.

Altimeter	Phase	Period	Cycle numbers	Satellite Inclination (deg)	Cycle (days)	Spacing at Equator (km)	Launch date and end date
ERS-2	A	01 Jan 2010–04 Jul 2011	153–169	98.54	35	80	21 Apr 95–6 Jul 2011
Jason-1	B	01 Jan 2010–03 Mar 2012	294–368	66	10	315	07 Dec 2001–01 Jul 2013
	C	07 May 2012–31 Dec 2012	382–407				
Jason-2	A	01 Jan 2010–31 Dec 2012	055–165	66	10	315	20 Jun 2008–present
ENVISAT	B	01 Jan 2010–22 Oct 2010	006–094	98.55	35	80	01 Mar 2002–01 May 2012
	C	26 Oct 2010–08 Apr 2012	095–113				
Cryosat-2	A	28 Jan 2011–31 Dec 2012	011–036	92	30	250	08 Apr 2010-Present