Bathymetry prediction over a part of the Bombay High in the western offshore using very high resolution satellite gravity data

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Bathymetry, when convolved with a response function, yields geoid or gravity. The predictive model as computed using high-resolution satellite gravity, and its downward continuation, is a generalized approach and seems to be satisfactory for bathymetry prediction in a complex region. The predictive model has been modified and applied over the study area in the western Indian offshore using very high resolution satellite gravity data (data gap ~4 km) as obtained from Geosat, Seasat, ERS-1/2 and Topex altimeter data. The area consists of variable bathymetric features, e.g. ridges and trenches, and it has been found to be successful to detect more number of features in comparison to those obtained from the presently available bathymetry data. Results from the predicted model have been compared with ETOPO2, NHO ship-borne and GEBCO bathymetry data and have been found satisfactory for geophysical and oceanographic applications.

Keywords: Bathymetry prediction model, ETOPO2, Gujarat–Maharashtra offshore, GEBCO, high-resolution satellite gravity.

THE floor of an ocean is characterized by the presence of numerous seamounts, atolls, ridges, trenches, etc. The variation in relief constitutes the morphology of the ocean floor. Charting of the ocean is very important for many reasons: it affects circulation, potential site for living and non-living resources, submarine navigation, geophysical exploration, etc. Most areas of the oceans are uncharted because ships could map only a small fraction of the seafloor. Detailed bathymetry data of the seafloor in the Indian offshore is sparse as bathymetry data collection is expensive and time-consuming and complete coverage of the whole area by ship is a daunting task to be achieved in the years to come. Hence, bathymetry prediction using high-resolution satellite geoid/gravity may be a viable option in the unexplored regions. The most commonly used model to relate geoid/gravity with bathymetry is a convolution model. Bathymetry, when convolved with a

response function, yields geoid or gravity. The response function for the model is generally obtained either through theoretical simulation or direct observation. Two-dimensional bathymetry model has become feasible with the availability of high-resolution satellite altimeter data, e.g. ERS-1 (168-day repeat) and a number of workers have generated various models for bathymetry prediction. Talwani et al.[1,2] and McKenzie and Bowin[3] have shown that the free-air anomalies with wavelengths not exceeding about 300 km correlate well with bathymetry. Relationship between free-air anomaly and bathymetry had been investigated by Cochran and Talwani[4] for nearly all oceans; showing a tentative correlation between amplitudes and wavelengths of a large number of free-air gravity anomaly profiles, with the corresponding bathymetry.

The surface of the ocean is a good approximation to the marine geoid. A major contribution to the marine geoid is made by topographic anomalies in the very shallow rock–water interface at the base of the ocean, because this surface represents the large density contrast. The largest contrasts occur at the earth's surface and at the ocean bottom (or at the base of the sediments in the ocean) and are affected by seafloor undulations. Consequently, there is a strong correlation between the shape of the geoid and ocean bottom topography.

Necessity for bathymetry prediction

By definition, bathymetry is the ocean depth. It is the most localized topographic information hidden just at the end of the water column in the ocean. Bathymetric study is necessary to locate major and minor structural features, which are normally ignored because of difficulty to map. The undersea volcanoes and seamounts also create major problem for undersea survey, especially for submarines and dredgers. So, detailed knowledge of the seafloor is necessary. Most of the bathymetric information is available in the form of Bathymetric Charts[5,6]. However, these maps do not have sufficient accuracy and resolution, for assessing the navigational hazards.

At the National Oceanic and Atmospheric Administration (NOAA), the renowned geophysicist Walter Smith[7] said that, 'about 90% of the seafloor is still unknown'. Only a small part of the deep ocean floor has been mapped, as the density of ship tracks leaves areas as large as 10^5 sq. km untraversed and all bathymetry grids are not even created equally[8]. Global bathymetric grids have thus largely involved patching together various types of data collected at different scales, local ship tracks and multibeam surveys, global satellite bathymetry solutions and charts contoured from sparse ship data from both old and more recent surveys, using data collected with ancient to modern navigation techniques. Different bathymetric information available globally, mainly in three different formats, is discussed below.

Gridded bathymetric information

Different digital bathymetry grids are presently available for global/western Indian offshore region. These are as follows:

(i)   DBDB2 (Digital Bathymetric Data Base; an ongoing project of the US Naval Research Laboratory (NRL))[9].
(ii) ETOPO5 (Earth Topography with 5 min gridded data, available with US National Geophysical Data Center (NGDC), US Department of Commerce, Boulder, Colorado, USA)[10].
(iii) ETOPO2 (Earth Topography with 2 min gridded data, available with US NOAA)[11].
(iv) GEBCO (General Bathymetric Charts of the Oceans, available at British Oceanographic Data Centre)[5].
(v)   Smith and Sandwell (S&S)[12].
(vi) ETOPO2v2 (Earth Topography with 2 min gridded data, version 2, available with US NGDC)[13].
(vii) An *improved bathymetric dataset* for the shallow water regions in the Indian Ocean (after Sindhu et al.[14]).

These grids are diverse in their sources of data – ranging from ship soundings to satellite altimetry – and some are augmented with regional or local surveys as well. The grid spacing and registration of each grid are different, and one may be more suitable than another for any given purpose. Table 1 shows the attributes of different gridded available bathymetric datasets. The gridded dataset becomes useful for bathymetry measurements for filling the unmapped areas of the ocean[10–13]. Because several interpolation techniques are involved, the gridding becomes a rough estimate of the unmapped areas and needs to be corrected and validated with ship-borne bathymetry data at every step while applying the gridded dataset.

The details of various bathymetric datasets, their positive and negative aspects have been discussed below mainly for those used in this study.

ETOPO5:   ETOPO5 data was generated from a digital database of land and seafloor elevations on a 5 min lat./long. grid.

Advantage: The database has been generated from digitization of depth contours greater than 200 m from 1 : 4,000,000 scale navigational or bathymetric charts.

Disadvantage: Because it has been digitized with greater than 200 m contours, the ETOPO5 dataset is not reliable in regions where the depth is less than 200 m. Moreover, the resolution varies for different regions. For USA, Europe, Japan and Australia, it is of 5 min, while of one degree in data-deficient parts of Asia, South America, northern Canada and Africa[8].

ETOPO2:   ETOPO2 is a 2 min bathymetry grid and a product of NGDC. It was assembled from the S&S[12] grid between 64°N and 72°S, from the US Naval Oceanographic Office's (NAVOCEANO) Digital Bathymetric Data Base Variable Resolution (DBDBV) data south of 72°S, and from the International Bathymetric Chart of the Arctic Ocean (IBCAO) data north of 64°N. Land topography is from the GLOBE database[15].

Table 1.   Attributes of different gridded bathymetric datasets (after Marks and Smith[8]; Sindhu et al.[14])

Grid	Spacing	Node	Projection	Coverage	Based on
DBDB2[a]	2′	Grid	Geographic	Global	S&S[b] below 1000 m depth and between 72°N and 66°S
ETOPO5[c]	5′	Grid	Geographic	Global	Digitization of depth contours greater than 200 m
ETOPO2[d]	2′	Grid	Geographic	Global	S&S[b] between 64°N and 72°S
GEBCO[e]	1′	Grid	Geographic	Global	Digitization of depth contours at 500 m interval along with ship-borne data
S&S[b]	2′ longitude	Pixel	Mercator	±72° lat.	Satellite gravity
ETOPO2v2[f]	2′	Grid	Geographic	Global	Modified ETOPO2
Sindhu et al.[g]	1′	Grid	Geographic	20°E to 112°E and 38°S to 32°N	Digitized depth contours and sounding depths <200 m from Hydrographic Charts of NHO, India, along with ETOPO5[c] and ETOPO2[d]

[a]NRL[9]; [b]S&S[12]; [c]NGDC[10]; [d]NOAA[11]; [e]GEBCO[5]; [f]ETOPO2v2[13]; [g]Sindhu et al.[14].

Advantage: Though ETOPO2 is a satellite-derived bathymetry and also assembled product of S&S[12] database, it shows a smoother appearance. This smoothing results from NGDC's interpolation of the pixel-registered S&S grid onto a grid-registered ETOPO2 grid.

Disadvantage: The main problem with ETOPO2 is the misregistration of latitude and longitude. This occurred while the global grid was being assembled from its major components at NGDC, as observed by Marks and Smith[8].

GEBCO data: The GEneral Bathymetric Charts of the Oceans grid is a one-minute grid written from bathymetric controls of the world ocean that was originally available as a series of paper maps at 1 : 10,000,000 scale and later as digital controls in the GEBCO Digital Atlas[5].

Advantage: These maps were contoured by hand, from both digital and analogue ship soundings. The 1 : 10,000,000 scale paper maps used in the digitization were only contoured at 500 m intervals. At this scale, contours can only be drawn about 3 mm apart. Thus, the map scale alone limits the horizontal resolution to about 30 km, and the slope of the ocean floor to about one degree. In the areas of widely spaced contours, such as abyssal plains and wide continental shelves, a number of echo-sounding isolated areas have been taken into account for gridding.

Disadvantage: The ship track coverage is sparse, irregular and of uneven quality and navigational control. The most common grid artefacts were over-shoots in areas of relatively steep topography.

ETOPO2v2: ETOPO2v2 dataset is a newly constructed global elevation database gridded at 2-arc min resolution. The different data sources used to derive the updated ETOPO2v2 are S&S database[12], the 'Global Land One-kilometer Base Elevation' (GLOBE) database[15], the International Bathymetric Chart of the Arctic Ocean (IBCAO), NGDC Coastal Relief Model[16], NGDC Great Lakes Bathymetric Data[11] and Caspian Sea bathymetry.

Advantage: The updated version of ETOPO2 was released in 2006, which has many improvements over the earlier version released in 2001.

Disadvantage: The main gridding is not uniformly done incorporating different coastal data[8].

Ungridded bathymetric information/bathymetric charts

Ungridded bathymetric information is mainly available nationally and internationally in the form of different bathymetric charts with contours or isobath lines and is given below:

(i) The Geological and Geophysical Atlas of the Indian Ocean[17].
(ii) Naval (Currently, National) Hydrographic Office (NHO)[6] Bathymetric Chart for the Indian offshore region.
(iii) GEneral Bathymetric Charts of the Oceans (GEBCO)[5].

Charts used: Table 2 lists the available bathymetric charts for the Indian Ocean region from all three above

Table 2. Bathymetric charts used as references for the study in different regions in the western Indian Ocean

Publication	Charts name	Chart/sheet no.	(a) Projection	(b) Scale	Year
Academy of Sciences, Pergamon Press, USSR, Moscow*	Bottom topography of the Indian Ocean	Sheet no. 1 Map no. 10–11	–	1 : 500,000 at lat. 45°N	1975
Academy of Sciences, Pergamon Press, USSR, Moscow*	Bottom topography of the Indian Ocean, Mid-Indian Ocean	Sheet no. 1 Map no. 1	–	1 : 5,000,000 at lat. 45°N	1975
NHO[†]	Indian Ocean: western portion	Chart no. 7072, INT72	Mercator	1 : 10,000,000 at equator	1978
NHO[†]	Dwarka to Bombay	Chart no. 292, INT7021	Mercator	1 : 750,000	1980
NHO[†]	Bombay to Cape Comorine	Chart no. 22, INT752	Mercator	1 : 500,000	1980
NHO[†]	Muscat to Bombay	Chart no. 21	Mercator	1 : 1,500,000 at lat. 17°N	1981
NHO[†]	Indian Ocean: eastern part	INT 73/7073	Mercator	1 : 10,000,000 at equator	1993
NHO[†]	Arabian sea	INT 705/7705	Mercator	1 : 3,500,000 at (22°30′)	1996
NHO[†]	Bay of Bengal	INT 706/7706	Mercator	1 : 3,500,000	1996
NOAA/NGDC**	GEBCO	–	Mercator	Variable scale	2003

–, Not available; *Udintsev *et al.*[17]; **GEBCO[5]; [†]NHO[6].

described sources for different parts of the western Indian Ocean including the western Indian offshore. Two map sheets of Udintsev *et al.*[17] Atlas, seven bathymetric charts of NHO and one GEBCO sheet have been consulted for reference in bathymetry study. Their scale, year of publication, projection, map/sheet/chart numbers have been listed. A brief review for those informative charts along with their positive and negative aspects is discussed below.

The Geological and Geophysical Atlas of the Indian Ocean[17], published by the Academy of Sciences of USSR, Moscow in 1975 is another source of bathymetric information available for the Indian Ocean. Two different charts are available from the Atlas for the study area in the western Indian Ocean. The bottom topography of the Indian Ocean along with the mid-Indian Ocean is shown as sheet 1 in this Atlas.

Advantage: The Atlas of the Indian Ocean has been generated by assimilation of various International Indian Ocean Expedition ship-cruises of Russia (former USSR) during 1959–1965 (Udintsev *et al.*[17]). The ship track collected data by depth sounding method and track lines then compiled and the contour lines have been generated. These contour lines strictly follow the international norms and format of navigation.

Disadvantage: Like NHO charts, this Atlas also fails to convey more bathymetric information between contours in abyssal planes.

NHO charts: The Naval Hydrographic Office (NHO)[6] chart is prepared by ship-cruise surveys on execution of eight fully equipped oceangoing surveying ships according to international norms of the International Hydrographic Organization (IHO). The Indian Naval Hydrographic Department (INHD) of NHO, Dehradun keeps information on safety of navigation, offshore development work (ports and harbours), maritime routes, fishing, offshore exploration and coastal recreation.

Advantage: In the present study, seven different bathymetric charts of international chart series of NHO of the western Indian offshore have been used. Though all these charts are of variable areal extent as evident from scale, the contour values at times show variable features in different charts. So, after consulting available charts over the study area, a good amount of information could be extracted.

Disadvantage: Though the accuracies are maintained and widely distributed contour information or isobath exists (e.g. 200, 1000, 2000, 3000, 4000 m along with some spot depths), it fails to give detail bathymetric information between contours in abyssal planes.

GEBCO charts: The GEneral Bathymetric Charts of the Oceans are available as a series of paper maps/charts at 1 : 10,000,000 scale and later as digital controls in the GEBCO Digital Atlas[5].

Advantage: It is available both in digital form as well as charts. GEBCO has been prepared under the supervision of International Hydrographic Organization (IHO) and the Intergovernmental Oceanographic Commission (IOC), United Nations Educational, Scientific and Cultural Organization (UNESCO). It has been prepared by hand drawn contours of isobaths at 500 m intervals for the world oceans, viz. 500, 1000, 1500, 2000 m, and so on (GEBCO)[5]. However, it is helpful for navigation purposes in present days.

Disadvantage: Like other bathymetric charts, this also could not help to describe information about the unmapped regions.

Ship-tracks

It is available in the form of profile data or ship tracks. A number of research organizations like National Institute of Oceanography (NIO), National Centre for Antarctic and Oceanographic Research (NCAOR), Oil and Natural Gas Corporation (ONGC), Indian Naval Hydrographic Department (INHD), Directorate General of Hydrocarbon (DGH), Geological Survey of India (GSI) and many other oil companies are having their own ship-track data collection, including bathymetry and other geophysical data like gravity, magnetic and seismic for various research and offshore exploration purposes. However, these data are very scanty and restricted to the concerned organizations and are also classified.

So far, various bathymetric information, as available throughout the Indian/Global Ocean including the western Indian offshore, has been discussed. However, detailed bathymetry is still a mystery. Presently available worldwide bathymetry dataset, as discussed from the above surveys, shows that they are not enough to explore the oceans and there is a need of a uniform gridded dataset for bathymetry of mighty oceans at a denser grid. It could be concluded that satellite gravity has opened up a new tool for bathymetric prediction[18] which will be helpful to provide uniformly gridded information. An attempt has been made here for bathymetric prediction with the available dense satellite gravity data over a part of the western Indian offshore.

Study area

The area selected for the present study is a part of the Arabian Sea encircling Gujarat–Maharashtra offshore region between lat. 12–22°N and long. 67–77°E (Figure 1).

The area is surrounded by Gujarat mainland in the north; offshore Mangalore in the south; mainland of Maharashtra–Karnataka in the east and Laxmi Ridge (at the ocean bottom) in the west.

Bathymetry prediction model

Bathymetry prediction is still a difficult task to achieve for the entire ocean. Since the Seasat mission of 1978, satellite altimetry is being applied by many researchers for bathymetry modelling[19–22]. The data for bathymetric modelling can be purely from satellite altimetry or from a combination of altimetry and ship-borne bathymetric depths. Hwang[23] has used a more sophisticated bathymetric model for the South China Sea from altimeter-derived gravity anomalies, ship-borne depths and ETOPO5 bathymetry data.

In this study, the bathymetry model depending upon the altimeter-derived gravity information as developed by Hwang[23] has been adapted. The model has been tested using the ERS-1 coarser resolution satellite altimeter-derived gravity data of grid spacing ~16 km, ship track data as acquired from NIO and ETOPO5 digital gridded bathymetry data downloaded from website. Later, the model has been modified before applying over a part of the western Indian offshore with very high resolution satellite gravity data.

The relationship between gravity field and seafloor topography is analysed using a linear transfer function called admittance. This linear relationship, coupled with isostatic modelling, has been successfully used for predicting ocean bathymetry[18,19,24–28]. Calmant and Baudry[20]

pointed out that the prediction of bathymetry from gravity anomalies is a complicated process. The linear response function can be considered only as a linearization of a complicated relationship and has to be determined empirically area by area[29]. Basically, admittance is a ratio between the Fourier transforms of gravity and bathymetry[3,19,25,28]. The admittance function has been used in predicting bathymetry from Geosat altimeter and gravity data. Basu and Saxena[30] have used ship-borne free-air gravity for prediction of bathymetry near Hawaii islands. Geoid variation over the area of interest can be used for prediction of bathymetric anomaly along the satellite ascending/descending tracks using a model given by McKenzie and Bowin[3] and later by Dixon et al.[19]. According to them, bathymetry and geoid/gravity can be expressed as different time series. The frequency domain response curve of convolution model is shown in Figure 2.

A filter f can then be designed which, when convolved with bathymetry b, produces a time series resembling gravity or geoid data g.

Thus, in the wavenumber domain[19]:

$$G(k) = Q(k) \cdot B(k) + n, \tag{1}$$

where G, Q, B are discrete Fourier transforms of g, f and b. n is the noise function. Q is termed as one-dimensional response function and predicted from the following equation:

$$Q(k) = \frac{G\rho_1}{gk} \left\{ \exp(-2\pi k Z_1) - \left[1 + \frac{16\pi^4 k^4 D}{g(\rho_1 - \rho_2)} \right]^{-1} \\ \times \exp(-2\pi k Z_2) \right\}, \tag{2}$$

where Z_1, Z_2 are respective depths from ocean surface to the mean ocean bottom and plane of major density contrast (Mohorovicic discontinuity). ρ_1, ρ_2 are the densities of bottom topography and the upper mantle. D the Flexural rigidity $= 2$–3×10^{23} Nm (Newton-meter), $|k|$ is one-dimensional wavenumber.

Once the response function is defined, the bathymetry below a satellite footprint with a typical geoidal variation can be predicted. Collation of ship-borne geophysical data with altimeter-derived parameters has been described by Lundgren and Nordin[31]. In the two-dimensional case, it is observed that using an uncompensated plate mode[23,32]:

$$K(u, v) = (1/(2\pi\Delta\rho G))\exp(2\pi d(u^2 + v^2)^{1/2}), \tag{3}$$

where K is the two-dimensional transfer function, and u, v are two spatial frequencies, $\Delta\rho$ is the difference between the densities of seafloor material and of seawater, and d

Figure 1. Study area.
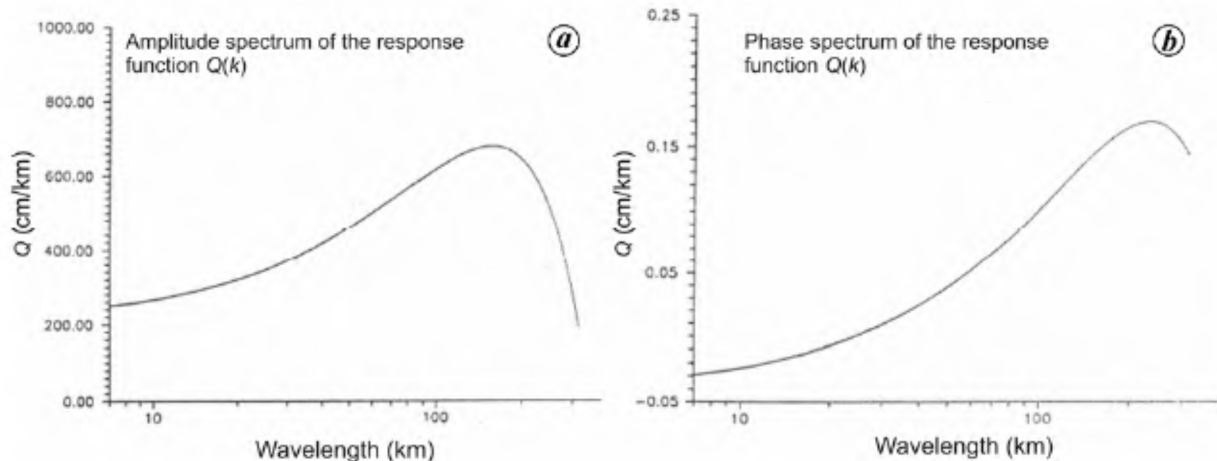
Figure 2. Amplitude and phase spectrum of the response function $Q(k)$ (after Dixon et al.[19]).

is the mean depth. The resulting bathymetry is highly oscillatory in nature and requires a low-pass filter. The best way to obtain K is to decompose the gravity/bathymetry field into a long-wavelength component and a short-wavelength component.

With eqs (1) and (3) a predictive bathymetric model is computed using the following steps[23]:

1. Low-pass filter the initial model by Gaussian filter with a wavelength of 110 km to obtain the reference field for bathymetry. The residual bathymetric field is obtained by subtracting the reference field from the initial model. The same process is applied to gravity anomalies as obtained from satellite altimetry data.

2. Downward continuation of the residual gravity anomalies to depth levels of multiples of 400 m to obtain multi-layered gravity anomalies, with a maximum depth level of 8000 m.

3. At an arbitrary grid node, the mean depth is interpolated from reference bathymetry created in step 1. With the mean depth, the downward continued gravity anomaly at this node is interpolated from the multi-layered gravity anomalies.

4. At all grid nodes, the ratios between the residual depths in step 1 and the downward continued gravity anomalies in step 3 are computed and used to estimate the density contrasts, which are then filtered by the same Gaussian filter used in step 1.

5. Compute refined residual depths using estimated density contrasts, and eqs (1) and (3).

6. Add the reference depths in step 1 and the residual depths in step 5 to obtain the predicted depths.

Results and discussion

The gravity data are downward continued to the level of mean ocean depth, and then the response function is estimated (calibrated) statistically. Because of the complexity of the isostatic compensation of oceanic crust, the relationship between the gravity anomalies and bathymetry is very complicated[3,4,12,24]. The model has been further modified and generalized using linear regression technique with a stochastic approach[23].

The different model parameters used in the study are as given below:

Flexural rigidity (D): 2×10^{23} Nm; $Z_1 = 4000$ m; $Z_2 = 10,000$ m; $\rho_1 = 2600$ kg m^{-3}; $\rho_2 = 3300$ kg m^{-3}; $G = 6.67 \times 10^{-11}$ kg^{-1} m^3 s^{-2}; $g = 9.80$ ms^{-2}.

The predictive model as computed using high-resolution satellite gravity, and its downward continuation, is a generalized approach and seems to be satisfactory for bathymetry prediction in a complex region, such as the eastern Indian offshore near the Ninetyeast Ridge and Andaman subduction zone[33,34]. The area is too complex as could be observed in the Atlas prepared from ship-borne data and predicted bathymetry patterns have satisfactory resemblance[17,33].

A similar predictive bathymetric model has been applied with the available denser satellite gravity data (~3.5 km off-track resolution) and the GEBCO Digital Atlas data over the area of interest (12–22°N lat. and 67–77°E long.). Figure 3 shows the predicted bathymetry over the study area with contour interval of 100 m. All different contour lines have been given different colours. The ridges are marked with blue colour and the three latitudinal profiles studied for comparison are also marked (19.5°N, 17°N and 14.1°N).

To improve the prediction of bathymetry, presently available satellite gravity and ship data from National Institute of Oceanography, Goa and GEBCO digital data of 1′ grid have been used[5,35,36]. These data are found to be most reliable consisting detailed gridded bathymetric information over the study area. As the gravity anomaly dataset is the base data with spatial resolution of 2′, the same spatial resolution is required to fit with gravity data in the software. Accordingly, the bathymetry data has been
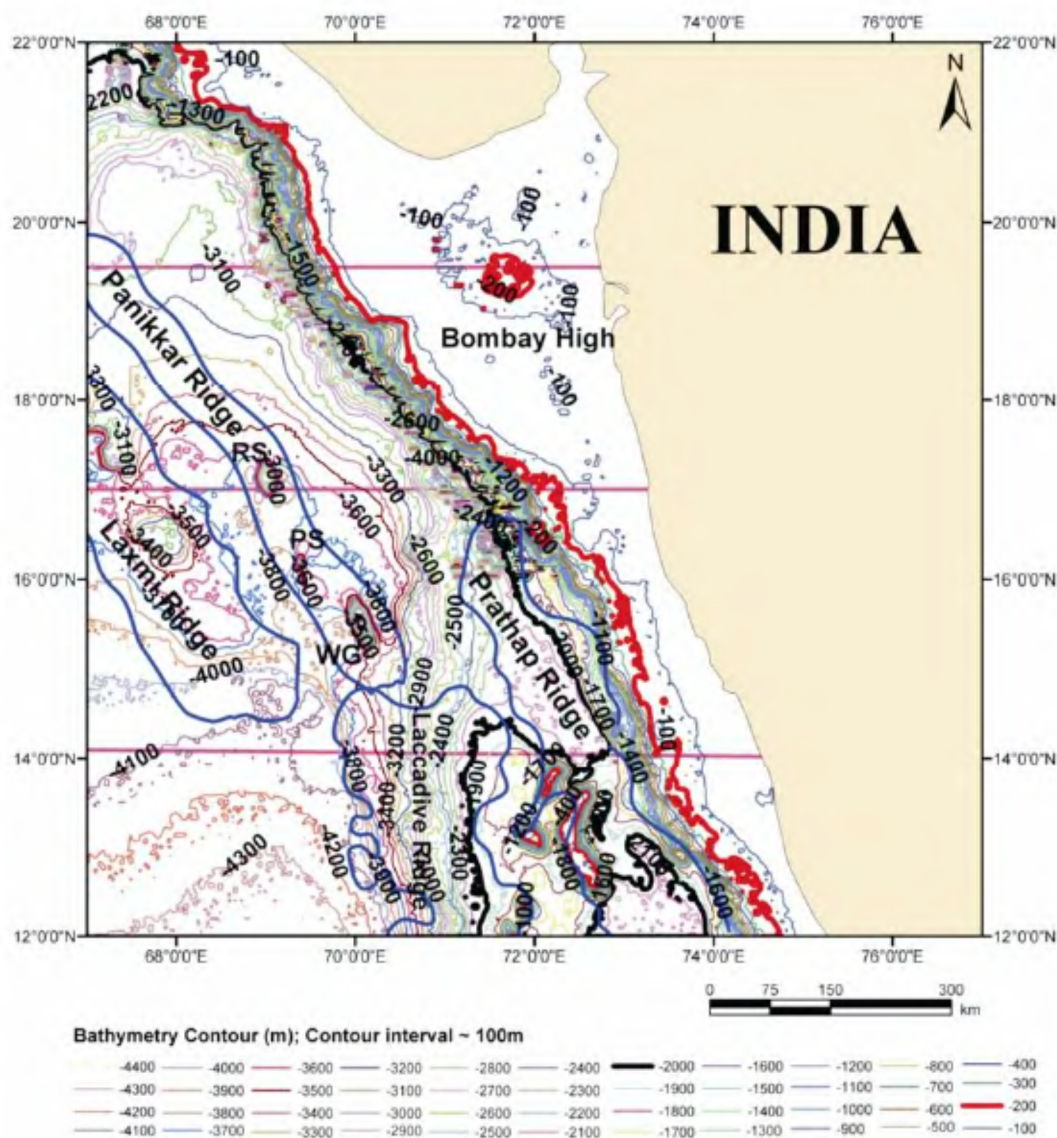
Figure 3. Predicted bathymetry over the study area in the western Indian offshore.

resampled/interpolated from ship data and the GEBCO dataset with moving average gridding at the same resolution of 2′.

However, the contour values –200 and –2000 m have been highlighted with red and black colours to show the continental shelf and continental slope boundaries respectively. Over the Bombay High region, another –200 m contour line has also become prominent. A comparative study has also been carried out between the predicted, ship-borne and GEBCO and other available bathymetry data.

Comparative study of the bathymetry model results with other bathymetry maps

Figure 4 shows a comparison between the ship-borne, GEBCO, and the final predicted bathymetry (Figure 3)

over the study area. This predicted bathymetry shows more number of features in the study area, including Bombay High, Laxmi ridge and Continental margin apart from a number of seamounts[37]. However, a close resemblance between the GEBCO and the predicted bathymetry could be observed which reveals various seamounts in and around the Laxmi ridge and basin complex and the Bombay High region.

Three profiles have been chosen across the 19.5°, 17° and 14.1°N comprising maximum number of features in the study area and a detailed comparative study has been done using ship-borne, GEBCO, NHO, ETOPO5, ETOPO2 and ETOPO2v2 data. However, due to the variable width of the continent (wide at the north and tapering at the south), the longitudinal extent becomes variable for all the three profiles (Figure 5). The predicted bathymetry differs with the available dataset mainly
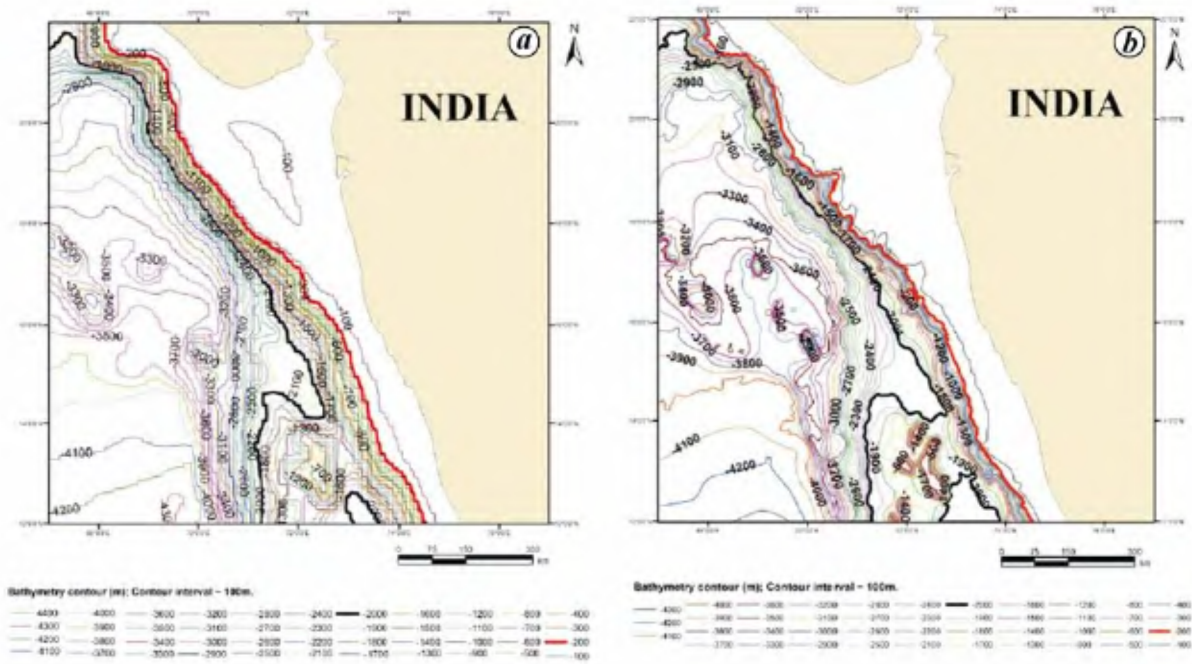
Figure 4. Ship-borne (*a*) and GEBCO (*b*) bathymetry over the study area.
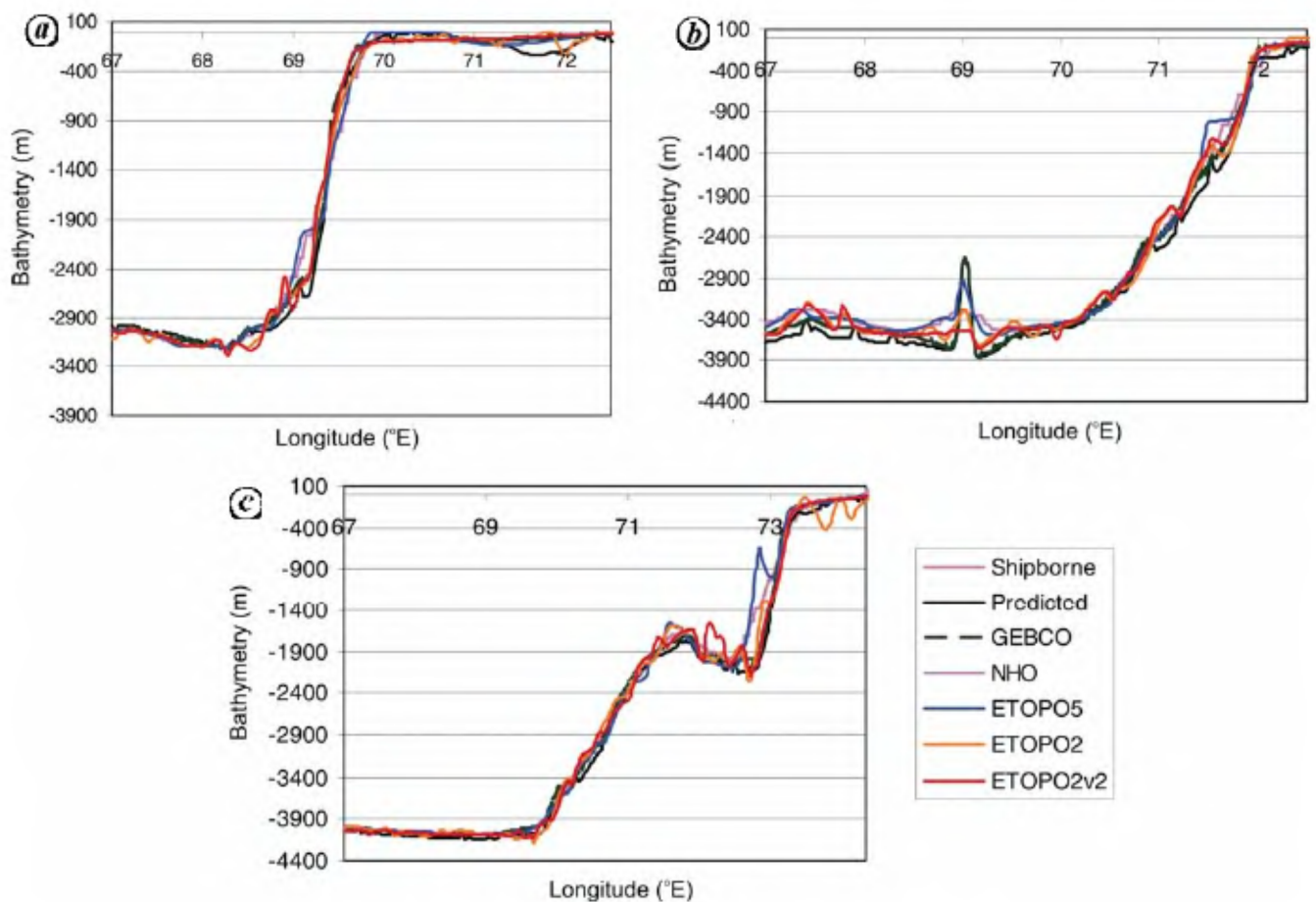
Figure 5. Comparison of various bathymetry datasets for profiles (*a*) 19.5°N, (*b*) 17°N and (*c*) 14.1°N.

between 71.25°E and 72.5°E, showing a regional depression around the Bombay High region, which is partly evident from ETOPO2v2 dataset (Figure 5 *a*). In the 17°N profile, from 67°E to 69°E, the abyssal plane shows about 50 m depression with minute undulating seafloor topography; however, in the continental slope and shelf region (from 69°E to 72.5°E), the bathymetry matches with the existing datasets, with little undulations (Figure 5 *b*). The profile along 14.1°N is the area of wide continental slope. Here the predicted bathymetry matches nicely with the available dataset. However, it shows a steep slope around 73°E, whereas ETOPO5 and ETOPO2 datasets show little variation (Figure 5 *c*).

Thus, the comparison of predicted bathymetry with the other available bathymetry datasets for three different profiles has been found satisfactory. The RMSE errors as computed for predicted bathymetry are: with ship-borne (30–63 m), GEBCO (8–25 m), NHO (60 m), ETOPO5 (28–34 m), ETOPO2 (23–40 m), ETOPO2v2 (16–39 m). The RMSE shows close resemblance of results from the predicted bathymetry with the GEBCO bathymetry.

Conclusions

In this study, a review of all the globally available bathymetry data and information over the western Indian offshore has been made and their advantages/disadvantages have been discussed. It has been found that most of the available datasets are generated from digitized contour lines of bathymetric charts and then interpolated and a high resolution, uniformly gridded bathymetry data is still not available. An attempt has thus been made to predict the bathymetry over the study area consisting of variable bathymetric features, and the predicted bathymetry could successfully detect more number of features in comparison to those obtained from the presently available bathymetry data. Finally, comparison of the model predicted bathymetry with existing ship-borne and other available gridded data along three different profiles, containing maximum structural features in the western Indian offshore, was found satisfactory. This bathymetry model is mainly useful for geophysical and oceanographic applications in the deeper oceans only, because of problem in signal processing, as altimeter data is not reliable in the coastal region[34]. In general, the model could be further improved with the availability of more high-resolution satellite gravity anomalies along with more sophisticated transfer function. However, as several interpolation techniques are involved for generating grid, gridding needs to be corrected and validated with ship-borne bathymetry data. Also, the expected accuracy will depend on the types of applications to be carried out using bathymetry data; higher resolution bathymetry may still be expected for sea navigation and exploration.

However, for generalized modelling for ocean processes studies, current bathymetry information may be quite satisfactory.

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MEETINGS/SYMPOSIA/SEMINARS

Communication and Presentation Skills for Women Scientists

Date: 16–21 November 2009
Place: Bhubaneswar

Contents: Self-understanding in terms of gender roles and limitations; Managing self for managing communication; Neurolinguistic programming for effective communication; Communication basics and dynamics, focusing on all aspects; Communication in the context of science; Interpersonal issues and team dynamics; Presentation skills: theory and over 16 hours practice.

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Conference on Current Trends in Free Radical Research and Herbal Antioxidants

Date: 8–9 January 2010
Place: Thrissur

Topics for discussion: Oxidative stress in cancer, Cardiovascular diseases, Neurological disorders, Diabetes mellitus, Inflammation, Gastrointestinal diseases, Hepatic disorders, Nephritis and aging. Methods of evaluation of oxidative stress, Natural antioxidants, herbal antioxidants, synthetic antioxidants, and antioxidants in traditional herbal medicines. Radiation biology, Radioprotectors and radiosensitizers. Cancer chemotherapy and chemoprevention.

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