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Short communication

Prediction of bathymetry from satellite altimeter based gravity in the Arabian Sea: Mapping of two unnamed deep seamounts

B. Jena[a], P.J. Kurian[a,*], D. Swain[b], A. Tyagi[a], R. Ravindra[a]

[a] National Centre for Antarctic and Ocean Research, Goa 403804, India
[b] National Remote Sensing Centre (NRSC), ISRO, Hyderabad 500037, India

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ABSTRACT

This work attempts to predict bathymetry from satellite altimeter based gravity in the Arabian Sea. A collocated match-up database ($n = 17,016$) was created on Multibeam Echosounder (MBES) bathymetry and satellite gravity values (~1 min spatial resolution) derived from remote sensing satellites. A Radial Basis Function (RBF) based Artificial Neural Network (ANN) model was developed to predict bathymetry from satellite gravity values. The ANN model was trained with variable undersea features such as seamount, knoll, abyssal plain, hill, etc. to familiarize the network with all possible geomorphic features as inputs through learning and the corresponding target outputs. The performance of the predictive model was evaluated by comparing bathymetric values with MBES datasets that were not used during the training and verification steps of the ANN model formulation. The model was then compared with MBES surveyed seamount observations (those were not used during ANN analysis) and global model bathymetry products. Results demonstrate better performance of ANN model compared to global model products for mapping of two unnamed seamounts in the Arabian Sea. These two unnamed seamounts have been predicted, mapped and their morphology is reported for the first time through this work.

1. Introduction

Echosounding techniques have been classically used for accurate bathymetric mapping of the sea floor. The conventional singlebeam echosounder (SBES) is outdated by the modern multibeam echosounder (MBES) techniques, which has 100% coverage of the seafloor. However MBES bathymetry data collection of vast offshore domains for these purposes is a difficult task to achieve. In such circumstances, the synoptic characteristics of satellite radar altimetry could be utilized as an effective method for predicting bathymetry, which can be complementary to SBES and MBES bathymetry to create a reasonably accurate and complete coverage of sea floor bathymetry map of vast areas.

Satellite radar altimeters are used to map mean sea surface heights from which geoid undulations and subsequently gravity anomalies are estimated (Kim et al., 2010; Sandwell and Smith, 1997, 2009). The satellite altimetry gravity anomalies can be used to predict bathymetry over a wavelength band of 15–200 km (Smith and Sandwell, 1994, 1997). However, the bathymetry/gravity ratio varies spatially because of changes in sediment thickness and other geological factors, which makes the estimation of bathymetry from gravity a complicated approach (McKenzie and Bowen, 1976; Smith and Sandwell, 1997). The main problem associated with algorithm development or model formulation for parameter estimation is the complexity of physical processes involved and the uncertainties associated with them. In such cases, advanced computer-based approaches like fuzzy logic, genetic algorithms, artificial neural networks (ANNs) and fractals can serve to derive the required parameter from known influencing parameters. In this work, we have developed an ANN model to predict bathymetry from satellite altimeter based gravity in the Arabian Sea. This model has been validated with MBES bathymetry data. The performance of ANN model is then evaluated by comparison with MBES surveyed seamount observations and global scale bathymetry products such as SS V13.1 (Smith and Sandwell, 1997), ETOPO1 (Earth Topography One Arc-Minute Global Relief Model, 2009), and GEBCO V2.0 (General Bathymetric Charts of the Oceans, 2008) in mapping two seamounts. These two unnamed seamounts (Fig. 1) are located in the Lacadive basin on the eastern part of the well known Chagos-Lacadive Ridge (CLR).

2. Data analysis and methodology

The MBES data used in the present study was acquired using SeaBeam 3012 Echosounder Onboard Oceanographic Research Vessel (ORV) Sagar Kanya (SK). The raw MBES datasets were processed after following the guideline of special publication No. 44

* Corresponding author. Tel.: +91 832 2525570; fax: +91 832 2520877.
E-mail addresses: kurian.ncaor@gmail.com, john@ncaor.org (P.J. Kurian).

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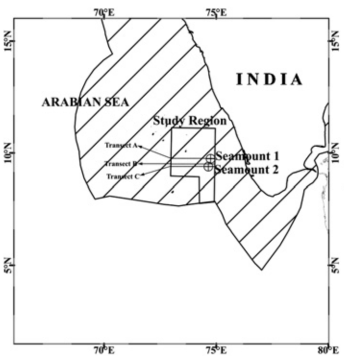

Fig. 1. Study area showing Multibeam Echosounder (MBES) surveyed region with three transects (A–C) over two unnamed deep seamounts (depicted as circles) in the exclusive economic zone (EEZ) of India.

(S-44), International Hydrographic Organization (IHO) Standards for Hydrographic Surveys, 5th Edition [2008]. The processed MBES datasets were imported, mapped and analyzed using ArcGIS v 9.2. The spatial resolution of MBES datasets were downgraded to 1″ to match up with the resolution of satellite gravity anomaly and global scale bathymetry products.

The global marine gravity anomaly V18.1 (Sandwell and Smith, 2009) derived from Geosat and European Remote-Sensing Satellite (ERS-1) altimetry has been subset and utilized in the present study to predict bathymetry. Detailed methodology for estimation of gravity anomaly from satellite altimetry is given in Sandwell and Smith (1997, 2009) and later summarized by Kim et al. (2010). Finally, a collocated database (n = 17,016) between MBES surveyed datasets and satellite derived gravity anomaly was constructed for the ANN analysis.

The performance of ANN predictive model was tested with MBES surveyed seamount observations and recent version of global scale datasets (∼1 min spatial resolution) such as SS V13.1 (1997), ETOPO1 and General Bathymetric Charts of the Oceans V2.0, 2008 (GEBCO).

2.1. The ANN model approach

ANN is a massive parallel-distributed computer model consisting of simple processing units called artificial neurons, which are interconnected through activation links modulated by weights, with a natural propensity to store experimental knowledge through learning or training. ANNs are applicable both for stochastic as well as deterministic forecast processes and have the capability to handle complex and nonlinear problems better than the conventional statistical techniques (Rumelhart et al., 1986). Mathematically, the ANN model can be represented in its most general form as:

$$Y_q = A_{q0} + \sum_{j=1}^{k} A_{qj}\Phi\left(B_{j0} + \sum_{i=1}^{n} B_{ji}X_i\right), \quad q = 1, 2, \ldots, m$$

where X_i and Y_q are the components of the input and output vectors, respectively, and A and B are the fitting parameters. Φ is the activation function, n and m are the number of inputs and outputs, respectively, and k is the number of neurons in the layer.

In the present work, an ANN model based on Radial-Basis-Function was developed by systematic variation of the architecture of input and hidden-layer nodes after evaluating the performance of multiple ANNs based on statistical summary and network performance. This particular model consists of one input and one output layer comprising of a single neuron each, and one hidden layer with 21 neurons (Fig. 2a).

For the ANN model, the input (independent) parameter is satellite radar altimeter derived gravity anomaly values and the output (dependent) parameter is the MBES bathymetric values. Out of the 17,016 collocated observations considered for this work, we have randomly selected about 50% of the data sets (8508 observations) for training the model, about 25% (4254 sets) for verification and the rest 25% (4254 sets) for prediction and validation of the predicted results, thus ensuring to train the model with variable undersea features such as seamount, knoll, abyssal plain, hill etc. to familiarize the network with all possible geomorphic features as inputs through learning and the corresponding target outputs.

3. Results and discussion

The performance of the predictive model was evaluated by comparing bathymetric values with MBES datasets that were not used during the training and verification steps of the ANN model formulation. We compared 25% (n = 4254) of collocated ANN-based bathymetry and MBES observations which revealed the correlation (r) of 0.90 (Fig. 2b) and root mean square (RMS) error of 123 m. Histograms on absolute error of the ANN predicted bathymetric values (figure not shown) calculated by subtracting MBES bathymetry from ANN based bathymetry revealed that, on an average 60% of ANN predicted bathymetric errors are with in ±50 m (2% of depth) and 94% with in ±150 m (7% of depth) when compared with MBES observations. However the gravity anomalies and bathymetry is strongly correlated only over a wavelength band of 15–200 km (Smith and Sandwell, 1994, 1997).

The performance of ANN model was then tested with MBES surveyed seamount observations (those were not used during ANN analysis) and global model bathymetry products such as SS V13.1, ETOPO1 and GEBCO V2.0. Analysis of spatial variation of

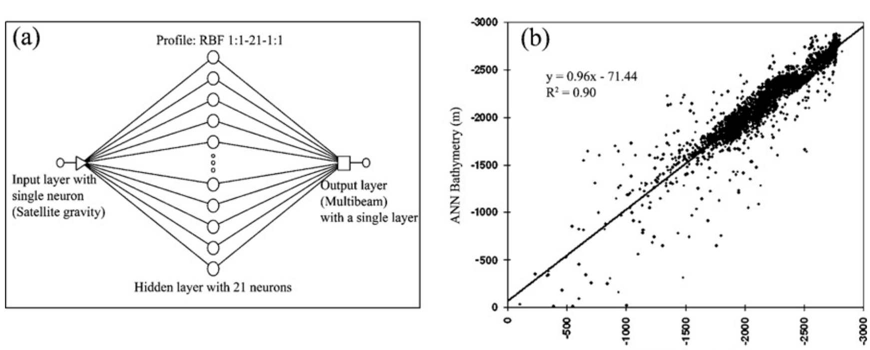

Fig. 2. (a) The radial basis functions (RBF) based artificial neural network (ANN) model architecture used in the present study and (b) validation of 25% (n = 4254) of collocated ANN-based bathymetry and Multibeam Echosounder (MBES) observations showing the correlation (r) of 0.90 and root mean square (RMS) error of 123 m.