

Tidal propagation off the central west coast of India

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Present study reviews the characteristics of tidal propagation on the continental shelf off the central west coast of India. Available observations from tide gauges are used to describe the variations of tidal ranges along the west coast. Amplitudes and phases from a global tidal model in the open ocean and those at the coast are used to construct co-amplitude and co-phase lines of M_2 and K_1 , which are the largest among the semi-diurnal and diurnal constituents respectively. One of the characteristic features off the central west coast of India, particularly north of Mumbai, is the amplification of semi-diurnal constituents caused primarily by large width of the continental shelf in the region.

[Keywords: Tidal propagation, Mumbai high, Global tidal model, Shelf model, Central west coast of India]

Introduction

In coastal regions, tides play an important role in determining circulation and hydrography. Barotropic tides coming from the open ocean get amplified on the shelf because of shallow depths. Besides, continental slope and shelf regions are often characterized by the presence of internal tides, which are generated on the slopes due to abrupt variations in topography and the presence of stratification. Internal tides propagate in onshore as well as offshore directions. A brief description of the tide-related processes in coastal regions may be found in a recent review article¹.

In nearshore regions, currents are largely influenced by tides. This is particularly true for regions characterized by large tidal ranges. When tidal ranges are large, vertical homogeneity in the water column becomes dominant and in regions of small tidal ranges, stratification, caused by winds, river run off, solar heating in the upper layers etc., prevails.

Along the west coast of India, the Gulf of Kutch and Gulf of Khambhat are characterized by the presence of large tidal ranges. Numerical and analytical modelling studies have shown that quarter wave length resonance is primarily responsible for the amplification of semi-diurnal tides in the Gulf of Kutch^{2,3}. However, for the Gulf of Khambhat, Nayak and Shetye⁴ showed that geometric amplification and quarter wavelength resonance are responsible for the amplification of semi-diurnal tides. Though tidal propagation and circulation is relatively well

understood in these Gulfs, current knowledge on tidal propagation on the shelf off the west coast is inadequate for describing various tide-related physical processes on the shelf.

Fig. 1 shows the observed tides at four locations along the coast. The tidal ranges are low in the southern side of the coast. At Kochi, the ranges are of the order of 1 m. The tidal range increases northward and reaches to more than 2 m at Marmagao. At Mumbai, maximum ranges in tidal elevations are of about 5 m. At Veraval, tides are of much lower amplitudes than those at Mumbai. The continental shelf off the west coast of India is very narrow in the southern side; the width is about 50 km at about 8° N. The shelf broadens northward and the width becomes more than 250 km north of Mumbai. North of the Gulf of Khambhat, the shelf becomes narrow. The tidal range at the coast is found to increase with increase in the width of the shelf.

Materials and Methods

Global tidal models

Schwiderski⁵ used a hydrodynamic interpolation technique to determine the amplitude and phase of tidal constituents of global ocean. Since the availability of satellite altimetric data since 1992, global tidal models, which assimilate these data, have been providing more accurate simulation of tides, particularly, in the open ocean. For instance, a global tidal model using finite element technique was developed⁶, whose results have been widely used for prescribing open boundary conditions for regional

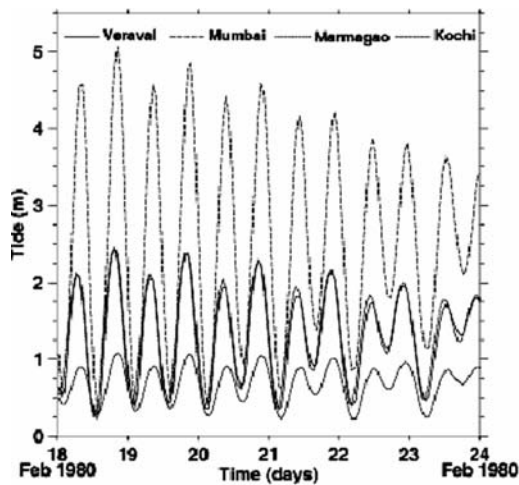


Fig. 1—Observed tide at Kochi, Marmagao, Mumbai and Veraval. Observations are from the tide gauges maintained by the Survey of India.

models. Simulations from an updated version⁷ of the above model, FES2004, were used in an ongoing study. In near shore regions, however, global tidal models are not found to be accurate. This problem can be overcome in two ways. One way is to assimilate coastal tide gauge data into global tidal models⁸ or alternately, by developing regional tidal models. The present-day tidal models for coastal regions make use of the results from global tidal models for prescribing open boundary conditions.

Offshore measurement of tides

In the north Indian Ocean, sea-level measurements on the continental shelf or slope hardly exist. One such measurement⁹ was made at Mumbai High on the mid-shelf region of the Arabian Sea. Continuous observations using self-recording tide gauges were made from an oil-drilling platform of the Oil and Natural Gas Corporation Ltd. The observations lasting about 40 days were analysed to determine the major tidal constituents.

Results and Discussions

Fig. 2a shows observed tides at Mumbai High⁹, while Fig. 2b shows predicted tides for the same period at the nearest coastal tide-gauge station, i.e., at Apollo Bandar (Mumbai Harbour). The prediction was made using the tidal constituents, obtained from the analysis of the past tidal observations at Apollo Bandar. The measurements (Fig. 2a) show that tidal ranges are large in Mumbai High reaching to more than 3 m during spring tide. The tidal ranges at Mumbai (Apollo Bandar) reach maximum values of

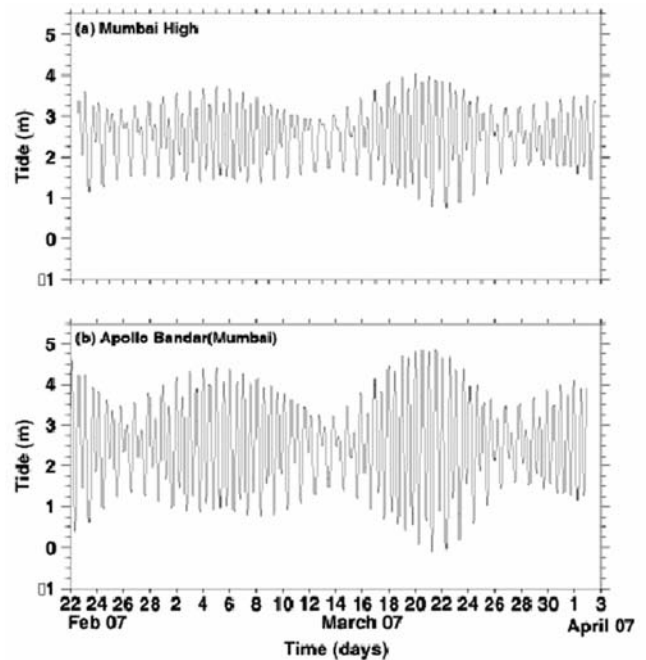


Fig. 2(a)—Observed tide at Mumbai High (b) Predicted tide at Apollo Bandar (Mumbai).

about 5 m during spring tide. The characteristics of tides vary considerably from Mumbai High to those at the coast (Apollo Bandar). The tides are mixed semi-diurnal type on the mid-shelf, which become nearly semi-diurnal type at the harbour (Fig. 2).

Shelf model off the west coast of India

In a previous study¹⁰, a 2 D model was developed for the shelf region off the central west coast to simulate the tides off the coast as well as the tidal circulation in the region. The model uses vertically integrated equations of momentum and continuity. The equations are solved on an Arakawa-C grid with a leap-frog scheme in time. The model was forced by tides from a global tidal model⁶. In an ongoing study¹¹, the model domain was extended to cover the entire shelf region off the west coast. The present model made use of a modified bathymetry¹¹ and has a grid resolution of about 5.4 km. The model was forced by tides from the global tidal model, FES2004. The simulations are used to study the tidal propagation on the shelf.

The amplitude and phase distribution of M_2 and K_1 constituents are shown in Figs. 3a, b and 4a, b respectively. The values at the coast are taken from Admiralty Tide Tables¹² and those in the open ocean from the results of the global tidal model. The amplitudes of semi-diurnal constituent M_2 undergo high amplification on the wide shelf, while the diurnal

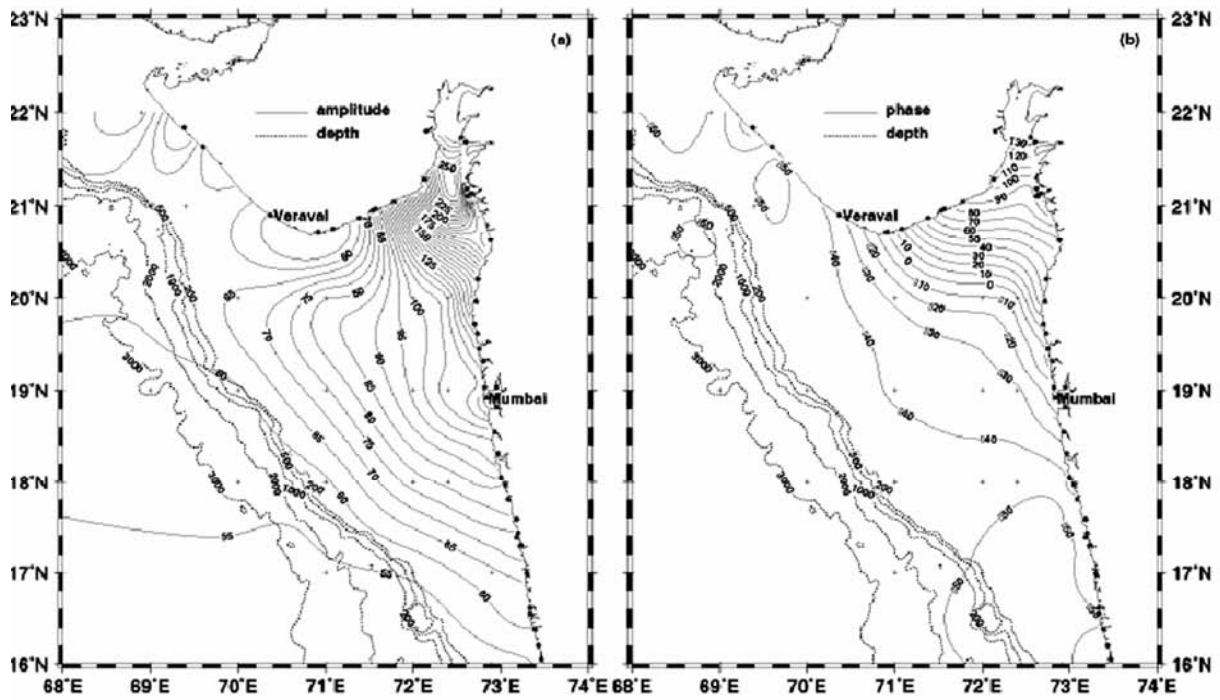


Fig. 3—Distribution of amplitude (cm) and phase (g) (degree) of M_2 tide (continuous line) in the domain (Reproduced from Unnikrishnan *et al.*, 1999). Dotted lines indicate bathymetric contours, plotted using the modified bathymetric data set¹².

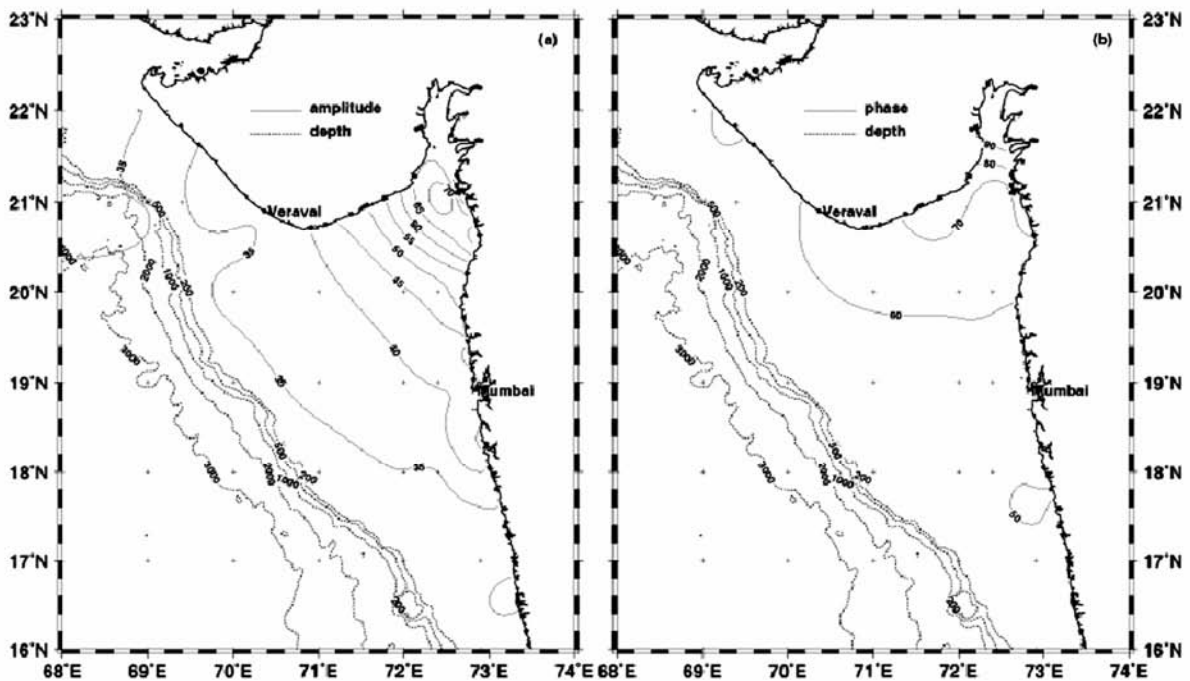


Fig. 4—Distribution of amplitude and phase (g) (degree) of K_1 tide (continuous line) in the domain (Reproduced from Unnikrishnan *et al.*, 1999). Dotted lines indicate bathymetric contours, plotted using the modified bathymetric data set¹².

constituent K_1 undergoes only marginal amplification. This is consistent with the theory of Clarke and Battisti¹³, which explained semi-diurnal amplification over wide shelves in non-polar latitudes.

Tidal circulation on the shelf

Based on current measurements of about 24 hours duration during March, 1976 at four different locations off Mumbai, Varkey *et al.*¹⁴ reported that observed currents are dominated by tidal flow. In the earlier study¹⁰, we compared the currents simulated by the numerical model with those observed¹⁵ in the Mumbai High region. The measurements, made at four different depths for a period of about 10 days, showed vertical homogeneity. Simulations performed for this period showed the model reproduces the observed currents well, indicating the currents in the region could be primarily driven by tides. However, observations of currents that were used for comparison with model simulations are confined to only one season. More observations of currents covering all the seasons and model simulations are required to determine the role of tides in the circulation of the region. This is NIO contribution No.4880.

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