

## Observed tides at Mumbai High offshore region near the continental shelf break in the eastern Arabian Sea

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**The observed large tidal range (up to 3 m during spring tide) at the Mumbai High offshore region located near the continental shelf break, off the central west coast of India, is described based on simultaneous tidal measurements (30 s average) at 15 min sampling interval using four tide gauges deployed from an oil drilling platform of the Oil and Natural Gas Corporation of India. All the four gauges provided identical measurements. The measured tides were harmonically analysed and the amplitudes and phases of the five major constituents, i.e.  $M_2$ ,  $S_2$ ,  $K_1$ ,  $O_1$  and  $N_2$  were compared with those observed at the closest coastal station (Apollo Bandar, Mumbai). It was found that the observed tidal range at this offshore location was unusually larger than those found in the open-ocean regions. This large tidal range was found to be associated with the large width of the continental shelf off the central west coast of India.**

**Keywords:** Continental shelf break, current measurements, tides, tide gauges.

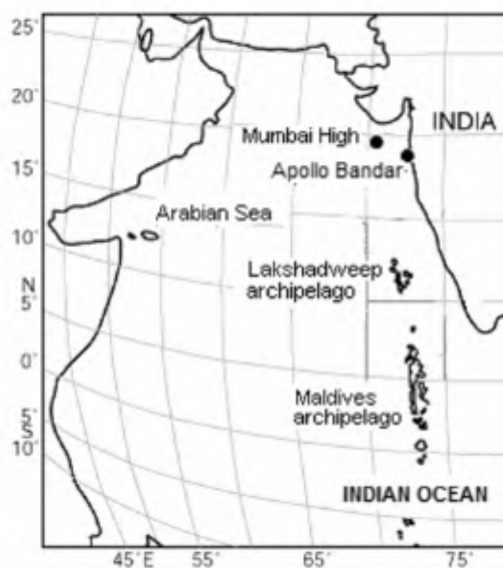
TIDES have considerable importance in the field of ocean dynamics. For example, they play a significant role in the efficient use of nautical charts in shallow waterbodies. To the mariner, the importance of tidal information increases quickly as the land approaches; reaching critical level for deep-draft ships in shallow ports, straits and channels. In fact, some maritime nations are traditionally at the mercy of the tides.

So far, no tidal observations are available either in the mid-shelf or outer shelf regions of the continental shelf off the west coast of India. Fernandes *et al.*<sup>1</sup> reported current measurements in this region. These measurements, during December 1981 for a period of about 10 days, were carried out at four different depths. The measured currents showed little variations in the vertical, thereby implying that the water column is vertically homogenous. Unnikrishnan *et al.*<sup>2</sup> simulated the observed currents using a numerical model driven by tides. The good match found between the modelled and observed currents indicated that the currents in this region are primarily driven by tides. During the present work, we carried out simultaneous tidal measurements using four tide gauges

deployed from the oil drilling platform of the Oil and Natural Gas Corporation of India (ONGC) at Mumbai High region, which is located on the continental shelf and close to the continental shelf break of the eastern Arabian Sea (Figure 1). Whereas tidal variations in the open ocean are usually less than a metre in range, the present measurements revealed a much larger tidal range. In this communication, we report these measurements that were carried out for a period of about 40 days.

Field measurements were carried out at the offshore platform called 'ICP' of the ONGC at the Mumbai High offshore region. The latitude and longitude of the location are 19°21'N and 71°18'11"E (Figure 1). The ICP platform is located approximately 160 km from the shore. The water depth at this location is about 65 m. Measurements consisted of deployment of four tide gauges and installation of an autonomous weather station (AWS). Observations were carried out during the period between 22 February and 2 April 2007. Three of the four tide gauges were based on absolute metal resistance strain gauges developed in-house<sup>3</sup> and the fourth one was based on absolute piezo-resistive strain gauge developed in-house<sup>4</sup>, whose performance was found to be adequate for oceanographic and limnological studies<sup>5,6</sup>. Technical details may be found elsewhere<sup>7,8</sup>. All the gauges used in the present study measured absolute pressure (i.e. atmospheric pressure plus the pressure exerted by the water column above the transducer).

The pressure inlets of the subsurface pressure gauge remained at the centre of, and flush with, a flat surface, thereby minimizing the Bernoulli dynamic pressure effects arising from flows, waves and a combination of both<sup>9,10</sup>. Absolute subsurface pressure values were sampled at a frequency of 2 Hz and averaged over an interval of 30 s to filter out the wind-waves and swell from the



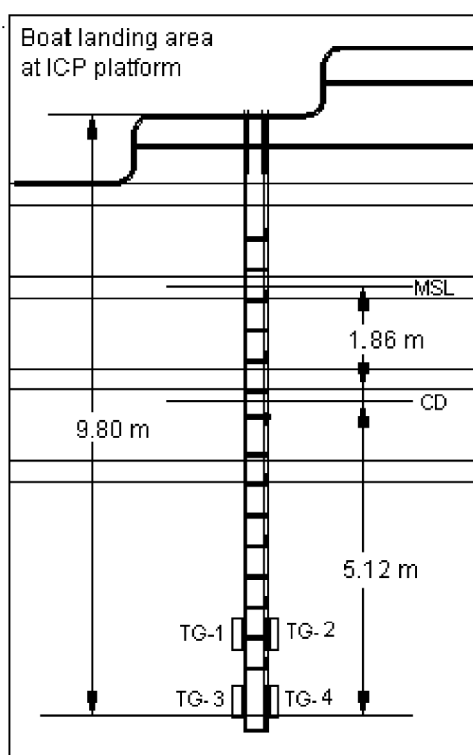
**Figure 1.** Location map of tidal measurements at Mumbai High.

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tide signal. Barometric pressure at sea level obtained from an AWS established on top of the ICP platform and the measured water density from the vicinity of the installation site have been used for the estimation of the tide from the subsurface pressure measurements (absolute pressure). Deployment of the instruments was made using a frame which was rigidly mounted on the platform rails at multiple points (Figure 2). Details about the fabrication of the frame, deployment and retrieval are elaborated elsewhere<sup>11</sup>. All the gauges provided identical measurements and therefore, tidal measurements from one of them are presented in this communication.

Tidal measurements reported here have been acquired at fast sampling interval as indicated earlier, and are free from gaps. Because of fast sampling, the tidal curves (represented by a finite number of harmonic constituents) are well represented. The duration of measurements was

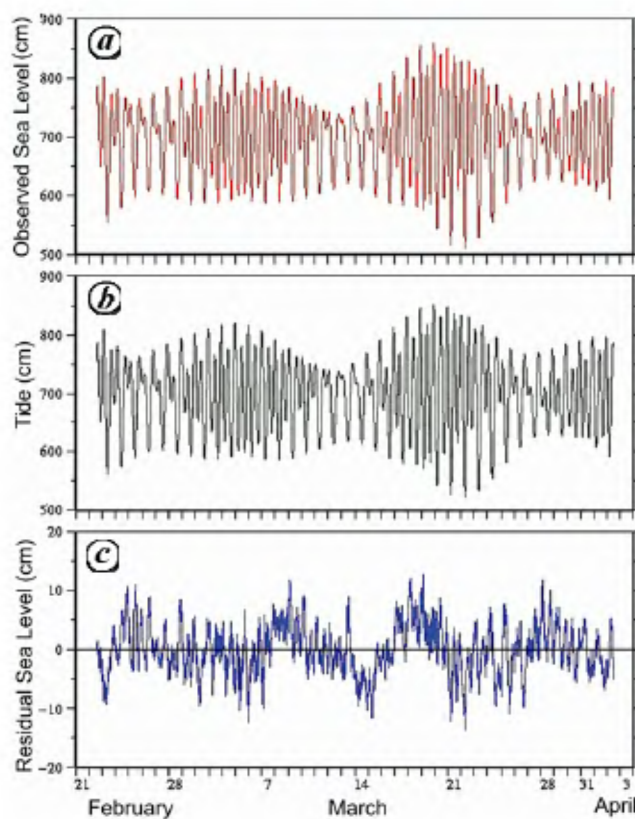
kept a little over a month because continuous observations for a period of one month are required to resolve the major constituents. We determined the tidal constituents (amplitude and phase) by harmonic analysis, which was performed using a Tidal Analysis Software Kit, developed at the Proudman Oceanographic Laboratory, UK<sup>12</sup>. This method resolved 35 tidal constituents which described the salient features of the astronomical tides at this location (Table 1). Figure 3 shows the observed sea level, tides and residuals (difference between measured sea level and astronomical tide) during the observation period. In this region, the tidal ranges are high, reaching about 3 m during spring tide. Residuals found during this period were less than 20 cm, much smaller than the tidal ranges. Residuals are often caused by wind effects or due to the occurrence of extreme events, etc.



**Figure 2.** Tide gauge installation scheme used at the ICP offshore platform of ONGC in Mumbai High.

**Table 1.** Amplitudes and phases of tidal constituents at Mumbai High. The phases (g) are with respect to Greenwich

Constituent	Amplitude (cm)	Phase (g) in degrees
M <sub>2</sub>	73.8	342.5
S <sub>2</sub>	28.7	18.9
N <sub>2</sub>	17.2	319.2
K <sub>1</sub>	45.0	61.5
O <sub>1</sub>	18.9	53.7



**Figure 3.** (a) Observed sea level, (b) tides and (c) residual sea level at ICP platform, Mumbai High during 2007.

**Table 2.** Amplitudes and phases of major tidal constituents at Apollo Bandar (Mumbai). The phases (g) are with respect to Greenwich

Constituent	Amplitude (cm)	Phase (g) in degrees
M <sub>2</sub>	123.0	345.0
S <sub>2</sub>	48.0	25.0
N <sub>2</sub>	29.0	326.0
K <sub>1</sub>	42.0	55.0
O <sub>1</sub>	20.0	52.0

An important result from the tidal measurements at Mumbai High offshore region was that the observed tidal range of about 3 m at spring tide phase was considerably larger than the open-ocean tide. Amplitudes of the major tidal constituents  $M_2$ ,  $S_2$ , and  $N_2$  at Mumbai High were nearly half of those at Apollo Bandar, which is the closest shore station (Table 2). Selective amplification of certain tidal constituents is often observed in some estuaries and gulfs. Amplification of semi-diurnal tides in the Gulf of Kutch and Gulf of Khambhat on the northwest coast of India, arising partly from quarter-wavelength resonance<sup>13–15</sup>, is an instance of selective amplification of tidal constituents.

On the shelves, tidal currents that are driven by tides, are large compared to the currents generated by winds or driven by buoyancy. Shelves have depths typically less than 200 m, and since tidal wavelengths are much larger (of the order of 1000 km), these waves propagate as shallow-water waves. A description of the basic processes of tidal propagation on continental shelves may be found in Dyke<sup>16</sup>.

Amplification of semi-diurnal tides on wide continental shelves caused by resonance was explained theoretically by Clarke and Battisti<sup>17</sup>. The observed amplification of tidal range in the Mumbai High offshore region off the central west coast of India appears to be a consequence of such a resonant phenomenon. However, more detailed studies using numerical modelling are needed to confirm this. A useful effect of the large tidal ranges in this offshore location is that the tidal currents could be large. This would prevent accumulation and stagnation of surfactants, such as residual crude oil and other waste generated during oil drilling and processing, around the offshore platform.

Measurements and modelling of tides in this region are important for operational purposes. Observed large tidal ranges imply that currents in this region could be largely driven by tides, as reported in our earlier study. This is useful for the maintenance of a relatively clean environment in the vicinity of the oil drilling and processing offshore platforms at the Mumbai High region.

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