Moored array oscillation under strong currents during fair weather

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Sensors attached to a vertically moored array showed large variability in the depth values (~ 13 m) as recorded by CTDs. During the observational period, though fair weather conditions prevailed, very strong subsurface currents (> 90 cm/s) with abrupt change in the direction (within 1 h) were noticed. The tidal amplitude in this region was less than 1.5 m, as indicated by the depth sensor attached to the bottom moored acoustic buoy and the ADCP. Hence, the large variability recorded in the depth sensors was attributed to the tilting of the array in the direction of strong subsurface currents.

SENSORS were moored in the ocean to obtain long-term measurements of various parameters. Prior to the design of mooring configuration, various factors, viz. external forces (wind, wave action and oceanic currents) and the environmental factors (corrosion, fish bite, etc.) have to be taken into account. The subsurface sensors will be subjected to underwater currents and hydrostatic pressure. Therefore, a priori knowledge of the environmental conditions is essential for any successful array deployment. Recently, an array of underwater sensors was moored in the shallow waters off Little Andaman during a fair weather season. The mooring was designed by considering the available environmental factors. Despite all these precautionary measures, the vertical array was found to oscillate during the experiment. In this communication, we discuss the array oscillation based on simultaneous current measurements from a nearby platform.

An experiment was conducted in the Andaman Sea during April 2001 by mooring an array of hydrophones to receive acoustic signals transmitted from a ship anchored at a nearby location. The three hydrophones in the array were placed in such a way that they occupied surface, thermocline and bottom layers. In the array, three mini CTD systems were attached at the same depths of hydrophones to know their exact depth and to record the temperature and salinity fields. In addition, one CTD was attached to the moored acoustic buoy, which was kept near the bottom. One of the notable results was that the depth values of the CTDs at the free end of the array showed large variations and the one attached to the acoustic buoy at the fixed end of the array showed minimum variation. In this communication, an attempt is made to explain the observed variability in the depth records utilizing the prevailing flow pattern obtained from the Acoustic Doppler Current Profiler (ADCP) operated from the transmitting ship.

Previous studies[1–3] have indicated that relatively calm conditions (weak winds, currents < 15 cm/s) prevailed in the Andaman Sea during April. Considering these factors, a subsurface mooring was designed (Figure 1) with a marker float at the surface and the major buoyancy package just below (~ 1 m) the sea surface. A surface marker float (125 kg buoyancy) was attached to three sets of trawl float sets (each set is of 12 kg buoyancy) through 8 mm polypropylene ropes of 10 m length each. This resulted in an overall slack of 40 m (24 kg buoyancy) and overall upward buoyancy of 185 kg at the surface. The last end of the polypropylene wire rope was attached to the major buoyancy package (two vinyl floats each of 20 kg buoyancy, i.e. 40 kg). To this buoyancy package, one end of a polypropylene rope of 50 m (12 mm diameter, 45 kg buoyancy) was connected, while the other end was connected to an acoustic buoy (30 kg buoyancy) at 52 m. Finally, the anchor weight (240 kg) was attached to this acoustic buoy through an acoustic release (34 kg). To the 50 m polypropylene rope, three CTD systems (each of 1.3 kg) were attached at 8, 18 and 32 m depths. The fourth CTD was attached to the leg of a moored acoustic buoy (at 52 m). The total wet weights of these CTD systems were 5.2 kg. Hydrophone array (cable of 90 m length, 10.5 kg weight), consisting of three B&K hydrophones (4.2 kg) was attached to the 12 mm polypropylene rope. The hydrophones were attached to the cable using metallic brackets to avoid tapping of hydrophones with the cable. These brackets, shackles and other connecting material weigh 5 kg. In this array, the total

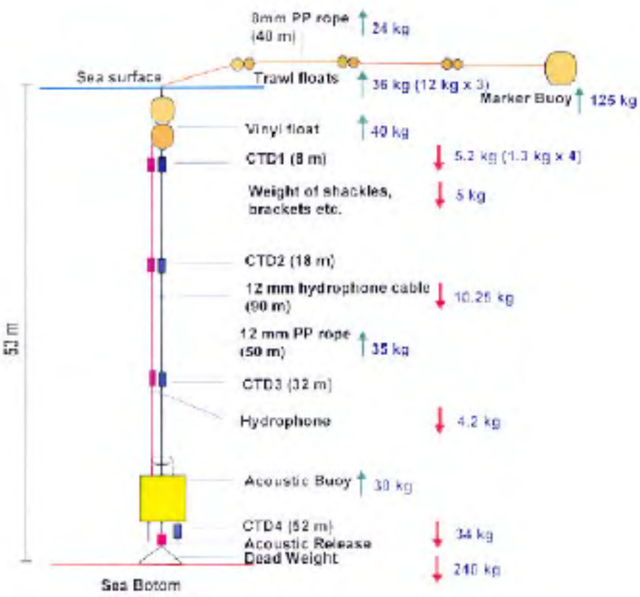

Figure 1. Array configuration.

*For correspondence. (e-mail: tsonpol@vsnl.com) upward buoyancy in the water column was 105 kg, while the total downward weight was 298.65 kg, to ensure that the array was in the same location.

Analysis of the depth records of the CTD at 8, 18 and 32 m revealed large variations in the depth values with a periodicity of 6 h (Figure 2). For example, the depth recorded at the first CTD varied from 8 to 21 m, resulting in a variation of 13 m over a period of 6 h. The corresponding variations in the second and third CTDs are 14 m (18 to 32 m) and 12 m (32 to 44 m), respectively. However, in the last CTD, the depth variation was less than 1.5 m, as it was attached to the acoustic buoy. Here, it is interesting to note that the periodicity of the depth variation was ~ 12 h, not 6 h as observed in the other three cases. Analysis of the ADCP data collected during this period, confirmed the dominance of semi-diurnal tides (~ 12 h) with amplitudes of ~ 1.5 m. This suggested that the observed depth variation in this CTD was caused by the semi-diurnal tides.

As the tidal amplitude in this region was less than 1.5 m, we believe that the large depth variations (~ 13 m) in the first three sensors were not due to tides alone. The other possibility is the oscillations of the array due to the prevailing flow pattern. Current data collected from a nearby ship (3 km away from the mooring) were utilized for the interpretation of this aspect.

During the observational period, fair weather conditions, as indicated by weak winds (< 1 m/s), clear skies

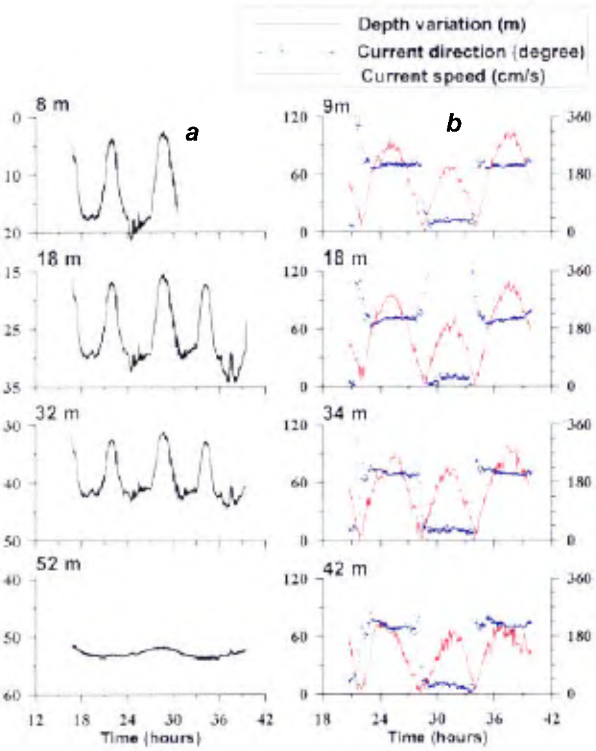

Figure 2. Time series of (*a*) depth recorded by four CTD sensors and (*b*) current speed and direction from ADCP at the respective depths.

and no visual surface waves, prevailed in the observational region. However, the subsurface currents were very strong (> 90 cm/s) in the entire water column, with maximum values of ~ 110 cm/s observed at 9 m (Figure 2). Such strong currents were not reported in earlier studies[1–3], especially during fair weather. The current direction changed every 6 h at all depth levels, which occur when semi-diurnal tides dominate, but with a slight reduction in magnitude (~ 110 cm/s at 9 m to 80 cm/s at 42 m). It is also observed that the reversal of currents (from northeasterly to southwesterly) was very abrupt (within one hour), which is not common. Moreover, maximum current speed (> 90 cm/s) was noticed when the flow was consistently in one direction and minimum (< 10 cm/s) during the transition period. As these strong currents were observed during fair weather, it can be concluded that these currents are not wind-driven. Further, as the study region is located in the ten-degree channel, the topographic features along with tides of semi-diurnal periodicity can induce a strong tidal current.

The depth sensors of the first three CTDs recorded minimum values when currents were weak (< 10 cm/s) and maximum values when currents were strong (> 90 cm/s). The correlation coefficient computed between the depth variation and current speed for the first three CTDs was 0.93, 0.9 and 0.86, respectively, suggesting a good relationship between the two. The poor correlation (0.3) between the depth values from the CTD attached to the buoy and the currents, suggests that the influence of varying currents on the depth variation was negligible.

NIOT made simulation studies on array movement under varying current speeds (0.5 to 2 m/s) using a theoretical model[4]. It was found that at low current speed (< 50 cm/s), the sensors were stable at the prescribed depths, and when the speed increased to 100 cm/s, the sensor at 50 m moved to 65 m, indicating a depth variation of 15 m. The shallow water mooring off Andaman also revealed that the sensor originally kept at 8 m remained in its position (8 m) at low current speed (< 10 cm/s), and occupied at 21 m when current speed increased to more than 100 cm/s, resulting in a depth variation of 13 m (Figure 2). Similar variations were also observed in the other two sensors.

As the bottom end of the array was fixed to the acoustic buoy and anchor weight, the movement of the sensor from 8 to 21 m is possible only when the array is tilted. Estimation of the displacement of the sensors on the array (Figure 3 *a*) revealed that the sensor at 8 m displaced horizontally by 32 m to occupy its new position, i.e. at 21 m. Similarly, the movement of the sensors from 18 to 32 m depth and 32 to 44 m depth was due to the horizontal displacements of 30 m and 20 m, respectively. Decrease in the amplitude of depth variation towards the bottom and hence the horizontal displacement is mainly due to proximity to the fixed end. The simulation of array-tilting is schematically presented in Figure 3 *b*.

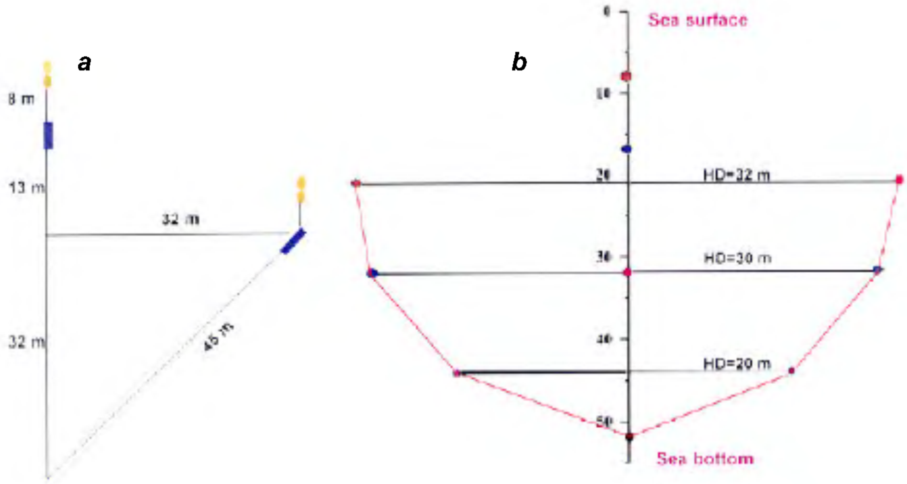

Figure 3. ***a***, Horizontal displacement (HD) of first sensor in the array, and ***b***, simulated array movement.

The analysis revealed that the strong currents (> 1 m/s) in the shallow waters off Andaman during fair weather season significantly altered the position of sensors (~ 13 m in the vertical) in the moored array. As strong currents were observed during fair weather, they are not driven by local forcing, but are remotely forced. The study stresses the importance of a priori knowledge of the environment (mainly the sub-surface currents) for design of the array configuration and deployment of moorings. Moreover, logging of sensor positions at fine sampling interval is also recommended for any meaningful post-processing and analysis of data from moored sensors.

1. Cutler, A. N. and Swallow, J. C., Institute of Oceanographic Sciences, Report No. 187, 1984, p. 8 and 36 Charts.
2. Murty, C. S., Das, P. K. and Gouveia, A. D., *Indian J. Mar. Sci.*, 1981, **10**, 221–227.
3. Sanilkumar, K. V., Ph D thesis, CUSAT, 1995, p. 121.
4. NIOT design of deep-sea current meter mooring for NPOL, National Institute of Ocean Technology, Chennai, 2002, p. 87.

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Hydrocarbon reserve estimation using evolutionary programming technique

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The oil industry is riddled with risk and uncertainty. Both loom large at almost every stage – exploration, production and downstream. The industry is regarded as a classic illustration of the need for sophisticated approaches to risk assessment. In the present communication an attempt is made to use Evolutionary Programming technique for estimation of hydrocarbon reserves. The algorithm is applied to a prospect identified in Rajasthan basin, India.

WITH the advent of high speed computers having higher disk space and parallel processing environment, several global optimization techniques (simulated evolution, simulated annealing, very fast simulated annealing, etc.) are adapted to solve various inherent problems in inversion of geological and geophysical data. Several risk-analysis techniques are already in use for hydrocarbon reserve estimation[1–3]. In this communication, an optimization technique called Evolutionary Programming (EP) is used to reduce the risk and uncertainty in hydrocarbon reserve estimation.

EP brings risk and uncertainty centre stage as integral parts of the calculations rather than afterthoughts. Most importantly, it brings probability into the picture. Once the initial inputs for hydrocarbon distribution are estimated, the simulation procedure starts. In EP simulation, each of these inputs is randomly sampled and then the individual values are multiplied together (a procedure known as the trial). The result of a single trial provides one possible answer for recoverable reserves. The random sampling of each of the input distributions is repeated many times – typically between 1000 and 100,000 depending on the type of calculation required. With so many

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