A study of ocean parameters in Bay of Bengal (BoB) using indigenised drifting buoys

R SRINIVASAN^{1,2,*} , V RAJENDRAN², SHIJO ZACHARIA¹ and TATA SUDHAKAR¹

¹National Institute of Ocean Technology, (Ministry of Earth Sciences, Govt. of India), NIOT Campus, Pallikaranai, Narayanapuram, Chennai 600 100, India.

²School of Engineering, Department of Electronics & Communication, Vels Institute of Science, Technology & Advanced Studies (VISTAS), Vels University, Pallavaram, Chennai 600 117, India.

*Corresponding author. e-mail: rsrini@niot.res.in

MS received 21 December 2018; revised 28 May 2019; accepted 3 June 2019; published online 12 July 2019

Drifting buoys (DBs) are widely deployed to observe near-surface ocean currents and sea surface temperature. The National Institute of Ocean Technology (NIOT), Chennai, India, had indigenised the DB with the Indian satellite (INSAT) in 2012. This paper describes the results of various studies conducted by NIOT using the indigenised DBs and also describes unique features attempted in indigenised DBs to measure the near-surface ocean current with 24 position acquisitions per day to capture small-scale surface eddies and the use of real-time geostationary satellite communication every hour. Additionally, the surface currents observed with indigenous DB are compared with DBs available in the market, Marlin-Yug (coefficient of determination $R^2 > 0.88$) and forecast using the ocean surface current analyses real-time (coefficient of determination $R^2 > 0.90$). Our results show that the DBs in the Bay of Bengal are carried with the East India Coastal Current in the March–May periods and the in-situ observations by the DB provide accurate surface current observations than satellite-based data. Furthermore, the new observations near the world's largest tidal mangrove and delta system, the Sundarbans and Bengal Delta, will help in further enhancing our understanding of the spatiotemporal variability in the region in terms of coastal currents and its influence on marine environments.

Keywords. Drifting buoy; surface current; EICC; INSAT; GPS; eddies.

1. Introduction

Meso-scale eddies are energetic, swirling and time-dependent circulations with horizontal scales at about 100 km and a time scale on the order of a month. The surface currents are measured indirectly from satellite systems (Koffler 1975; Dohan and Maximenko 2010). Another method to measure surface current involves deriving a drifting speed from the drifting buoy (DB) positions. The Lagrangian drifting floats are widely deployed to measure near-surface ocean currents (Lanza 1984; Smith *et al.* 1984). Drifting buoys majorly used for the world ocean

circulation experiment (WOCE) (Scripps Institution of Oceanography Reference Series 1993; Sybrandt 2009). The challenges for measuring surface current include measuring small and fast processes, capturing the vertical variations and overcoming sensor limitations near coasts. This research describes a unique attempt to measure the near-surface ocean current using 24 position acquisitions from the global positioning system (GPS) per day to capture small-scale surface eddies and using geostationary satellite communication to obtain almost real-time data every hour using the DB. The paper further explains the indigenisation efforts of the National Institute of

Ocean Technology (NIOT), Chennai, in developing the DBs (Atmanand 2013). A patent has been filed with the Indian Intellectual Property Office for the indigenously developed DB with Indian national satellite system (INSAT communication and the initial stage examinations have been completed (Srinivasan *et al.* 2013). The field test results of indigenous DBs P2 and P5 in the Bay of Bengal (BoB) experiments are also reported. The near-surface current observed with DBs P2 and P5 is compared with the DB available in the market (Marlin-Yug) and remotely sensed ocean current, respectively.

2. Means and methods

2.1 System description

The DB is made of a flanged two-part spherical float 0.4 m in diameter made of acrylonitrile butadiene styrene. The bottom half of the float houses the battery, embedded system, power control switch, power controller and satellite modem and is coated with an antifouling paint. The upper half portion of the float is given an ultraviolet-protective coating. A 12 m stainless steel tether wire is connected to an eye bolt at the bottom centre of the float, which is strengthened internally. The bottom end of the tether is attached to a disc-type frame on a windowed cylindrical holy sock drogue. The battery (11–15 V, 56 Ah) consists of 32 alkaline cells. It is connected to the circuits through an external switch and a power controller. The power controller is controlled by an embedded controller and enables power to the subsystems and sensors. The DB is instrumented with a sea surface temperature (SST) sensor at a depth of 0.16 m, an atmospheric pressure sensor and a GPS system. A strain gauge-based load cell monitors the presence of drogue and it acts as the drogue presence sensor. A total of six temperature and pressure sensor modules are attached at a depth of 1–15 m on an underwater cable. The sensors are installed on the DB according to the application. A photograph of the DB with a thermistor string is shown in figure 1. A unique attempt with 96 temperature measurements and 24 GPS position acquisitions per day enables the DB to measure fluctuations in SST and smaller surface eddies. The geostationary satellite communication (Indian Satellite Telemetry) provides near real-time data every hour. Coastal DBs are built with general packet radio service (GPRS) modems (www.motorola.com) for high-data rate telemetry for high-resolution coastal current measurements.

Figure 1. Drifting buoy with thermistor string.

2.2 Indigenisation of DBs

The NIOT, under the Ministry of Earth Sciences (MoES) in the Government of India, deployed the DBs with Argos transmitters as part of the Indian DB program for observing SST and surface current. These DBs acquire positions only four to six times per day from the Argos satellite signals. Their data latency time is about 4–6 hr, which is insufficient for real-time measurements. Their positional accuracy is limited to about 350–1000 m under clear sky conditions and is subject to variations under weather conditions. In 2012, NIOT developed a DB with improved positional accuracy to capture small-scale surface eddies (Srinivasan *et al.* 2013; Tata *et al.* 2013). The DB consists of an SST sensor, battery, hull, data acquisition system and satellite telemetry systems. The DB is made of a flanged two-part spherical float 0.4 m in diameter made of epoxy resins. A 12 m stainless steel tether wire is connected to an eye bolt at the bottom centre of the float. The bottom end of the tether is attached to a disc-type frame on a windowed cylindrical holy sock drogue (Shijo *et al.* 2014). The surface float is tested for 0.5 bar pressure rating.

NIOT deployed the indigenously developed DBs for 2–9 months in deep sea (Tata *et al.* 2013; Shijo *et al.* 2014). The DB with the GPRS modem is deployed for a short duration (1–2 days) in the coastal regions (Srinivasan *et al.* 2016; Motorola.com). The details of the deployment are given in table 1. The trajectories of the indigenous DBs, deployed from 2012 onwards, are shown in figure 2. The field test results of P2 DB is validated with the data from a commercially available DB (Marlin-Yug) deployed along with it.

3. Sea surface current mapping with DBs

A spherically symmetrical surface float with a submergence ratio of 42% is designed to reduce the effects of wind stress, surface gravity wave effects and vertical shear of currents on the DB. The holy sock drogue acts as a sea anchor. The DB follows the near surface current due to drag force on the holy sock drogue. A GPS receiver module on the DB captures its position hourly with an accuracy of ± 10 m. The data from the DB are transmitted to land station through INSAT telemetry (www.isro.org). The near-surface current is computed from

the position and time data (Shijo *et al.* 2014) sampled at 1-hr interval.

3.1 Ocean surface current analyses real-time (OSCAR)

The OSCAR is a National Aeronautics and Space Administration (NASA) funded research project and contributes to the global surface current database 16. The ocean circulation features of the region during the period are studied from the OSCAR forecast. The OSCAR global ocean surface mixed layer velocities are calculated from satellite-sensed sea surface height gradients, ocean vector winds and SST fields using geostrophic, Ekman and thermal wind dynamics. The forecast for surface current gives five days of temporal resolution and 1° of spatial resolution.

3.2 Sea trials

The Pradyu II (DB P2) and Marlin-Yug DBs were deployed from the ocean research vessel (ORV) *Sindhu Sankalp* on 8 March 2013 at 16:39:00 hr at lat. 11.0867°N and long. 82.033°E in the BoB. Both Pradyu II and Marlin-Yug DBs have the same drift characteristics. Pradyu II transmits the GPS

Table 1. Details of deployment.

Drifting buoy ID	Position latitude ($^\circ\text{N}$), longitude ($^\circ\text{E}$)	Deployment duration
P1 ¹⁰	6.94, 82.97	21 April–19 June 2012
P2 ¹¹	11.0, 82.51	09 March–17 April 2013
CDB ¹²	17.01, 73.24	21–23 February 2014
P4	13.14, 83.5	01 May–04 November 2015
P5	14.03, 84.1	08 March–12 May 2015
P6	8.699, 83.6	02 October–03 November 2015
P25 ¹³	11.96, 72.1	21 March–01 May 2016
P30	11.92, 74.0	25 June–01 July 2016

Figure 2. Trajectories of the indigenous DBs deployed from 2012 onwards, P1, P2, P4–P6, P25 and P30: indigenous DB, CDB: deployed for coastal observation.

Figure 3. Trajectories of drifter buoys and position of BD11.

Figure 4. Drift speed of Pradyu II and Marlin-yug.

position every hour. DB P5 was deployed at location lat. $14^{\circ}03.0'N$ and long. $84^{\circ}14.20'E$ on 8 March 2015 from ORV *Sagar Manjusha*.

Figure 5. Scatter plot of current derived from drifter positions.

4. Results and discussion

4.1 Surface current observation with P2 and Marlin-Yug DBs

The East India Coastal Current (EICC) makes a steady progress and becomes stronger during the period March–May when winds in the region are weakest in the year (Shetye 1993; www.earth.nullschool.net 2018). The trajectories of the DBs from 9 March 2013 to 12 April 2013 are shown in figure 3. It is obvious that the EICC carried the DBs. Due to the time lag of 10 min in deployment and local surface turbulence, the DBs initially followed dissimilar trajectories in the same direction. The Marlin-Yug DB followed a clockwise north-south elliptical eddy on 16–17 March 2013 with a major and minor axis of 4.2 and 2.7 km, respectively. The Marlin-Yug drifter mapped in a second similar eddy on 17–19 March 2013 with a major and minor axis of 2.6 and 1 km, respectively. The Pradyu II DB drifted to a position of $11.8716^{\circ}N$ and $81.106^{\circ}E$ on 20 March 2013 at 18:37:00 hr, but the Marlin-Yug drifter arrived there only on 24 March 2013 at 15:03:42 hr. The two-clockwise elliptical eddies of the Marlin-Yug drifter made its position towards the south compared to Pradyu II in the initial trajectory. The drifters followed a similar trajectory from the above position, except a north–south clockwise elliptical eddy (Thamos 2010) with a major axis of 2.6 km and a minor axis

Figure 6. (a) Trajectory of P5, sea-surface current on 12 March 2015 from OSCAR (red circles, positions of P5; pink circle, position of P5 on 12 March 2015). (b) Trajectory of P5, sea-surface current on 18 March 2015 from OSCAR (red circles, positions of P5; pink circle, position of P5 on 18 March 2015). (c) Trajectory of P5, sea-surface current on 23 March 2015 from OSCAR (red circles, positions of P5; pink circle, position of P5 on 23 March 2015). (d) Trajectory of P5, sea-surface current on 28 March 2015 from OSCAR (red circles, positions of P5; pink circle, position of P5 on 28 March 2015). (e) Trajectory of P5, sea-surface current on 2 April 2015 from OSCAR (red circles, positions of P5; pink circle, position of P5 on 2 April 2015). (f) Trajectory of P5, sea-surface current on 7 April 2015 from OSCAR (red circles, positions of P5; pink circle, position of P5 on 7 April 2015). (g) Trajectory of P5, sea-surface current on 12 April 2015 from OSCAR (red circles, positions of P5; pink circle, position of P5 on 12 April 2015). (h) Trajectory of P5, sea-surface current on 17 April 2015 from OSCAR (red circles, positions of P5; pink circle, position of P5 on 17 April 2015). (i) Trajectory of P5, sea-surface current on 22 April 2015 from OSCAR (red circles, positions of P5; pink circle, position of P5 on 22 April 2015). (j) Trajectory of P5, sea-surface current on 27 April 2015 from OSCAR (red circles, positions of P5; pink circle, position of P5 on 27 April 2015).

of 2.3 km made by the Pradyu II drifter on 23 March 2013. In this section, the Marlin-Yug DB followed the trajectory of Pradyu II within 1–4 hr. The maximum observed distance between the trajectories is 73.7 km and the minimum is 0.4 km. Even though the both buoys drifted to distinct neighbouring trajectories with 1–4 hr delay, they intersected again at the location 14.16°N and 83.78°E on 4 April 2013 and at the location

13.51°N and 83.91°E on 6 April 2013. The DBs underwent a clockwise eastern-south semi-circular trajectory of 146 km diameter from 29 March 2013 to 12 April 2013.

The daily drift speeds of drifters are derived from the positions observed with GPS in the DB (Shijo *et al.* 2014). The drift speeds of Pradyu II and Marlin-Yug DBs, their difference and distance between them are shown in figure 4. It is observed

Figure 6. continued

that typical spatial variations of currents measured by the drifters are less than 0.15 m/s within a 40 km range. A maximum spatial variation of current measured by the drifters is 0.4 m/s in a 70 km range. The near-surface current observed with DB P2 is compared with the Marlin-Yug DB. A scatter plot of current derived from the DBs' position from 25 March 2013 to 12 April 2013 is shown in figure 5. A strong agreement of current measurements with a correlation coefficient of 0.88 is observed over the region where the buoys are separated less than 40 km.

4.2 Surface current observation with P5 DB

The P5 DB was deployed at the west central BoB 8 March 2015. This deployment was also about 50 km away from the coast. The EICC carried the P5 DB towards northern bay along the coast. The trajectory of P5 is shown in figure 6(a–j). The surface current at P5 positions from the OSCAR forecast is accessed. The drifting speed of P5 and the surface current from OSCAR are compared (figure 7). In the middle of April 2015, P5 drifted to the shallow basin near the world's largest tidal mangrove and delta system, Sundarbans and Bengal Delta (Shenoi 2010; Rogers and Goodbred 2014). P5 drifted with its highest speed of 1 m/s on 2–7 April 2015. The OSCAR forecast was in agreement with P5 observation. It is seen that the P5 observations and the OSCAR forecast are strongly correlated (coefficient of determination, $R^2 > 0.90$). A scatter plot of current derived from P5 and data from the OSCAR forecast are shown in figure 8. The marginal disagreements in the observations are due to differences in the data averaging method between the observations. P5 drifted only about 0.01 m/s speed on 2–5 May 2015. Its drogue might ground in very shallow water depths. Further, the status of P5 is unknown afterwards.

5. Conclusions

In this article, we have described the performance of indigenous DBs and data from experiments conducted from 2012 onwards. Additionally, we reported a unique attempt to measure near-surface ocean current with 24 position acquisitions per day to capture small-scale surface eddies and the use of real-time geostationary satellite communication every hour in indigenously developed DBs. Furthermore, the surface current observed with P2 is compared with the DB

Figure 7. Comparison of P5 drifting speed with OSCAR forecast.

Figure 8. Scatter plot of drifting speed from P5 and surface current from OSCAR forecast.

available in the market, Marlin-Yug, and the P5 data with the OSCAR forecast. A strong agreement of surface current observations is seen with a coefficient of determination (R^2) of 0.88 over the region when P2 and Marlin-Yug buoys were separated by less than 40 km. Similarly, P5 observations and the OSCAR forecast are strongly correlated (coefficient of determination $R^2 > 0.90$). Notably, both sets of deployments were in the March–May period and influence of EICC on the DB trajectories is studied. The new observations near the world's largest tidal mangrove

and delta system, Sundarbans and Bengal Delta (Austin and Atkinson 2004), will help in further enhancing our understanding of the spatiotemporal variability in the region. More numbers of DBs with a higher rate of position sampling may be deployed in the Indian Ocean to map the ocean surface water circulation and climate change.

Acknowledgements

The authors gratefully thank all the staff members of National Institute of Ocean Technology and heartfelt thanks to director, NIOT for his vital and continuous encouragement and support extended during this developmental work. The development and deployment are fully funded by MoES (Ministry of Earth Sciences, Govt. of India). The authors are also thankful to vessel management cell, NIOT for allocated vessel time for DB deployment operations.

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