and type of words introduced in subsequent levels show the gradation. The number of keywords in secondary level is 670 and in higher secondary level it is 840. It does not mean that 170 words were newly introduced in the next level. Actually, 537 words were introduced in the higher secondary level because only 303 words were found to be common between the secondary and higher secondary keywords lists. Whereas for students who study in vernacular medium schools till class 10, all the 840 words are new. There is another dimension to the problem faced by the vernacular-medium students. There are words other than keywords, like names of the elements, chemical processes, etc. which are not familiar to them in English translation. For example, 'sulphuric acid' is கந்தக அமிலம் (kandaga amilam) in Tamil and copper is তামা (tama) in Bengali. While names such as ozone, aluminium, platinum are not translated in vernacular languages, names like oxygen, carbon dioxide, copper, mercury, etc. are translated. Thus, students are forced to find the meaning of many more words in the textbooks and master the registry within two years and write the exams that would determine their choice of profession. Lack of gradation in the vocabulary introduced in subsequent levels of education compounds the problem. Consequently, rote learning replaces cognitive learning, and science education loses its meaning and purpose.

The possibility of English language learnt in English classes helping the students in reading of core textbooks is also ruled out, as the 111,927 word English corpus and 620,852 word science corpus of higher secondary level share only 4949 words with each other. It is thus evident that communicative English has a limited role in developing proficiency in academic English. It is also a fact that learning is compartmentalized in schools, and teachers of science and English do not want to step into each other's area of instruction. It is probable that the English teachers do not know the concepts in science, and science teachers do not have training in language teaching. Ultimately, it becomes a huge burden for the students of science. Those who study in vernacular medium schools till class 12 face a similar problem in their first year in colleges[6]. While the situation of college students draws the concern of educationists, that of higher secondary students has been overlooked. The present study not only highlights their difficulties in science learning, but also attempts to ease their difficulties by providing them with the keywords harvested from the corpus of their textbooks in the form of word lists for each level.

The word lists thus created can be powerful pedagogic tools as they comprise target words necessary for understanding the textbooks. The corpus is static and the word lists once made based on recent developments in linguistics and sound parameters, can be used in all the Central Board of Secondary Education schools across India by either the English teachers or science teachers. It can be used in content language integrated learning, task-based learning and classroom activities. It would be more fruitful if it is made part of the curriculum or used in material designing to promote integrated learning. Since language proficiency is paramount in promoting scientific temperament, awareness and interest in science subjects, we intend to share our resources with anyone in the academic community upon request.

1. *Ethnologue: Languages of the World*, 2017, 20th edn; https://www.ethnologue.com/language/eng/[Google Scholar] (accessed on 15 May 2018).
2. Hsueh-Chao, M. H. and Nation, P., Unknown vocabulary density and reading comprehension. *Read. Foreign Lang.*, 2000, **13**(1), 403–430.
3. Laufer, B. and Ravenhorst-Kalovski, G. C., Lexical threshold revisited: Lexical text coverage, learners' vocabulary size and reading comprehension. *Read. Foreign Lang.*, 2010, **22**(1), 15–30.
4. MHRD, Statistics of School Education, Ministry of Human Resource Development, Government of India, 2017; http://mhrd.gov.in/statist?field_statistics_category_tid=33 (accessed on 6 June 2018).
5. Scott, M., PC analysis of keywords – and key keywords. *System*, 1997, **25**(1), 1–13.
6. Viswanathan, U. M. and Sultana, A. S., An Indian ESWL: a pedagogic tool to improve the lexical competency of students in context of horizontal diversity. *Asian EFL J.*, 2018, **20**(4), 23–38.

Received 11 December 2018; accepted 12 October 2019

doi: 10.18520/cs/v118/i2/271-273

Design and development of a low-cost GNSS drifter for rip currents

Surisetty V. V. Arun Kumar[1,*], Rakesh Kumar Luhar[2], Rashmi Sharma[1] and Raj Kumar[1]

[1]Earth, Ocean, Atmosphere, Planetary Sciences and Applications Area, and
[2]Mechanical Engineering Systems Area,
Space Applications Centre (ISRO), Ahmedabad 380 015, India

Lagrangian drifters are analogues of particles that are relevant to flow-field characterization and therefore they represent realistic surface currents compared to Eulerian techniques. The use of global navigation satellite system (GNSS) in such drifters with Differential Global Positioning System mode at high frequency (5–10 Hz) sampling and post-processing kinematic results in position estimates with centimeter-level accuracy. In the complex nearshore zone, deploying

*For correspondence. (e-mail: arunkumar@sac.isro.gov.in)

expensive instruments is a risk due to greater chances of loss. To avoid this, two drifters have been designed and developed using a low-cost Emlid Reach® GNSS receivers, antennae and 'off-the-shelf' PVC components to measure the surface currents. The dimensions of the drifters were optimally chosen to minimize the wind and wave impacts and to increase the subsurface current drag. An analysis of relative position and velocity errors from stationary observations indicates that the drifter can resolve motion accurately with minimal errors of ±1 cm and ±2 cm/s respectively. These drifters were used to measure surf zone currents at the RK Beach, Visakhapatnam during May 2018 and to successfully identify dangerous rip current zones. This study presents the design, development aspects, error analysis and testing of GNSS drifters. Although these drifters are primarily developed to measure the rip current velocities and trajectories in the nearshore zone, they can also be operated in any marine environment like rivers, lakes, estuaries, etc. without change in the design. An extensive study using a fleet of such drifters is required to understand the complex physical processes in the marine environment.

Keywords: Drifter, error estimation, rip currents, relative position and velocity.

COASTAL zone processes have extreme temporal and spatial scale variability at small scales, which is difficult to study using conventional methods like moored instruments, vessel-based surveying, etc. The traditional techniques are localized, expensive and risky during operations. A large number of fixed, single-point current measurements would be required to resolve spatially complex circulation. Lagrangian drifters/floats have been widely used as an alternative to such measurements to study the oceans[1], lakes[2], and nearshore and coastal regions[3].

Handheld GPS-based drifters described by MacMahan *et al.*[4] could be used to resolve flow features in the order of 3 m. Schmidt *et al.*[5] developed a PVC GPS-tracked surf zone drifter to measure surf zone circulations. Spydell *et al.*[6] studied dispersion in the surf zone using drifters. Run-off pollution on the beaches was studied by Boehm *et al.*[7]. A small drifter prototype for measuring current immediately below the free surface in a water basin was proposed by Nasello and Armenio[8] and used for shallow-water applications. Earle[9] designed a riverine drifter that measures currents, bathymetry and water temperature. Some of the drifters have provision for real-time transmission of position data through GPRS or telemetry system, which increases the cost several folds. Some global navigation satellite system (GNSS) receivers facilitate the storage of raw carrier phase and pseudo-range internally or externally via data-loggers, like the one developed by Schmidt *et al.*[5]. Also, they are expensive and therefore cannot be manufactured in large numbers. A low-cost GNSS tracked drifter was developed by Suara *et al.*[10], where the raw data were post-processed using open-source RTKLib software to get accurate positions. However, the design aspects limit its usage in complex, high-energetic surf zone environments. In this study, we describe the design and development of a low-cost GNSS drifter, which is practically suitable for all marine environments.

The drifter design has been adapted from the previous works of MacMahan *et al.*[4] and Schmidt *et al.*[5]. However, slight changes have been made like a PVC cylinder with circular aluminium disc affixed to the bottom to prevent vertical motion due to waves (Figure 1). A stainless-steel ballast weight was fixed below the disc to lower the centre of gravity and thereby increase the stability. To reduce the multipath effects, a Tallysman® GNSS antenna was placed on a circular aluminium disc of 10 cm diameter and attached to a 1.5 in (3.8 cm) diameter UPVC cylindrical pipe (0.5 m above the waterline), through which the GNSS antenna cable was passed into a big PVC cylinder. The cylinder contains Emlid Reach® L1 GNSS receiver (Reach M module), which has a data storage capacity of 4 GB, WiFi, on-board Intel® Edison processor (Table 1).

The Reach module has the capability to record L1 carrier phase and pseudo-range raw data from GPS, GLONASS, GALILEO, Beiduo, SBAS, etc. for post-processing a differential solution. The power is supplied from a 15,000 MAh 5 V power-bank battery via USB cable. The cylinder is made air- and watertight with a closing circular cap and an O-ring. Therefore, it offers good buoyancy and always floats on the sea surface. In

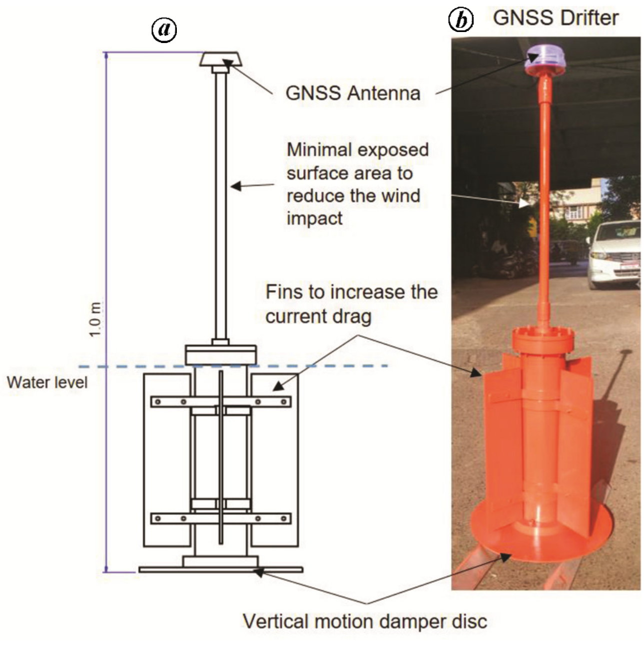

Figure 1. Design (***a***) and photograph (***b***) of the low-cost GNSS drifter developed at SAC, Ahmedabad.

Table 1. Technical specifications of the EMLID reach M module

Parameters	Specifications
Mechanical	
Size	56.4 × 45.3 × 14.6 mm (L × B × H)
Weight	20 g
Operating temperature	–20–65°C
Data	
Internal storage	4 GB
Correction input	RTCM2, RTCM3
Solution output	ERB, plain text, NMEA
Logs	RINEX2.X, RINEX3.X
Connectivity	WiFi (802.11a/b/g/n), Bluetooth (4.0/2.1 EDR)
Interfaces	USB, UART, Event
Electrical	
Input voltage on USB	4.75–5.5 V
Antenna DC bias	3.3 V
Average current consumption @5 V	200 mA
Global navigation satellite system	
Signals	GPS/QZSS L1, GLONASS G1, BeiDou B1, Galileo E1, SBAS
Tracking channels	72
IMU	9 DOF
Update rate	14 Hz/5 Hz
Positioning	
Static	H: 5 mm + 1 ppm, V: 10 mm + 2 ppm
Kinematic	H: 7 mm + 1 ppm, V: 14 mm + 2 ppm

the case of rivers and lakes (freshwater), if buoyancy is not sufficient, a styrofoam may be wrapped as a collar at the top of the drifter to provide positive buoyancy. MacMahan *et al.*[4] found from the tests involving dye and different drifter designs that drifters with vertical fins mounted-off the subaqueous cylinder tracked the leading edge of the dye cloud better than those without. Therefore, the main body has been fitted with four PVC fins (0.37 m × 0.1 m) to improve the stability and increase the current drag. The design of Schmidt *et al.*[5] does not have fins, whereas that of MacMahan *et al.*[4] has electronics outside the PVC cylinder in a small waterproof box.

Schmidt *et al.*[5] and Murray[11] studied the importance of wind slippage and found ~0.01 ms^{-1} per 1 ms^{-1} of the near-surface (0.5 m elevation) wind speed. There is no facility to evaluate the wind slippage of the present drifters. The flagpole used by Murray[11] was 0.03 m in diameter and 1.5 m in length (cross-sectional area 0.045 sq. m). The antenna pole used on the drifter herein has a diameter of 0.013 m and length of 0.5 m, resulting in a much smaller cross-sectional area (0.0065 m^2). We assumed the wind slippage to be negligible compared to that of Murray[11]. As reported by Schmidt *et al.*[5], the windage effects within an energetic surf zone are unknown. The minimum operating depth of this design is around 0.5 m. However, it is advised to operate this drifter beyond 1 m depth in the surf zone in order to avoid washout due to backwash/surge.

The drifters were configured to record the raw L1 GNSS data at 5 Hz sampling frequency. Similarly, a base station was set up using EMLID Reach RS within a few metres close to the experiment location on an ordinary survey-grade tripod stand. The raw data were recorded in all the instruments at the same time to have similar satellite coverage. Although EMLID Reach has a provision of real-time kinematic (RTK) mode, it requires two reach RS systems with long range (LoRa) antenna for communication, which could increase the cost of the equipment. Hence, in order to minimise the cost of the experiment, one Reach RS and two Reach M modules were utilized in this experiment. Schmidt *et al.*[5] observed that the real-time differential positioning is limited by the telemetry range between the drifter and the base station within 5 km and both of them should be in line-of-sight. On the other hand, post-processing kinematic (PPK) is advantageous as it requires only raw RINEX (receiver independent exchange) data from both base and rover (drifter) simultaneously. The GNSS post-processing in DGPS PPK mode ideally requires a baseline distance (distance between the base station and rover) within 30 km. Accuracy of GNSS solution of the rover depends on the accuracy of the base position and the basline distance. Greater the baseline distance, poorer will be the accuracy. In general, we get an accuracy of around 2.5 m in the base position when an 'average of single position' option is used in the post-processing. This would be increased to around 30 cm if any precise point positioning (PPP) service is used. An accurate base position up to 7 mm can be obtained if PPK is conducted on the base receiver data with a reference station (e.g. continuously operating reference station, CORS) within 30 km from the station. As CORS stations are unavailable in India, we have used NRCan (natural

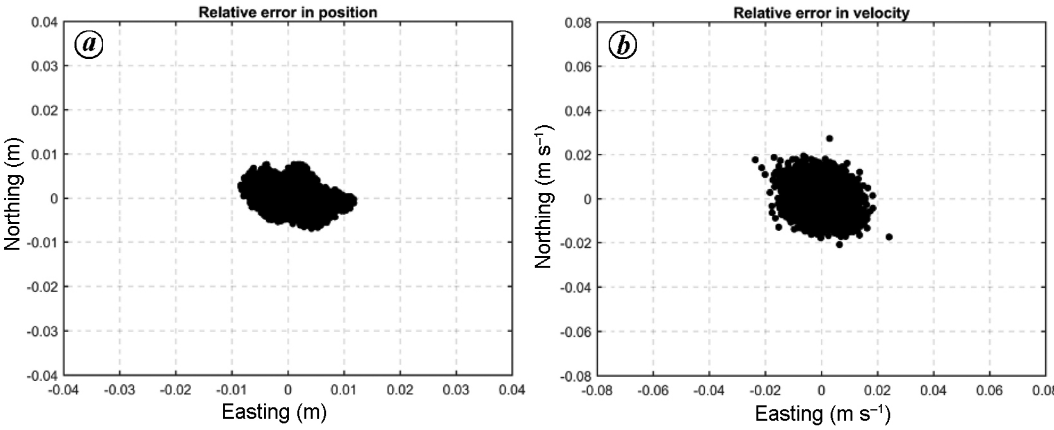

Figure 2. Relative error in (***a***) position and (***b***) velocity obtained from stationary measurements of the GNSS receiver.

resources Canada) PPP free service to obtain the base position (17°42′51.30069″N, 83°19′24.25475″E, ellipsoid height: –64.659 m).

The relative error in position and velocity of the drifter was estimated by setting up the system with the same configuration and data were logged for about 2–3 h with stationary drifters. First, all the raw data were converted into RINEX 3.03 format using RTKCONV in RTKLib software licensed under version 2.4.3 GNU License, and thereafter processed using RTKPOST. The RINEX OBS data obtained from the rover and base station were presented along with the navigation (*.nav) and SBAS (*.sbs) files. The 'kinematic' positioning mode was selected and frequency was set to 'L1 forward filter type'. An elevation mask of 15° was set to exclude satellites with poor coverage. The integer ambiguities were estimated and resolved with 'fix and hold' mode. The software outputs the data in *.pos file in ASCII format with time, latitude, longitude, height, quality (1: fix, 2: float, 3: sbas, 4: dgps, 5: single, 6: ppp), number of satellites, etc. For accurate positions, quality 1: fix is generally preferred.

All positions recorded in an open location leaving the drifters stationary were converted to Universal Transverse Mercator (UTM) and de-meaned to determine relative errors (Figure 2 *a*). Velocity estimates were determined using a forward-differencing scheme on the de-meaned position data (Figure 2 *b*). The maximum northing and easting position errors were ±0.01 m (1 cm), with a standard deviation of 0.003 m and 0.002 m respectively. The relative errors of velocity in the easting and northing were ±0.02 m s^{-1} (2 cm s^{-1}) with a standard deviation of 0.004 ms^{-1}. The low relative errors of position and velocity indicate that the drifters are capable of measuring currents of an order greater than 0.02 m s^{-1}.

As the drifter does not have any movable mechanical parts to record the motion, velocity measurements are dependent on the flow of water in which it is operated and coverage of the GNSS satellites. However, we have observed that the drifter can record the motion of a car moving at a speed 100 km h^{-1} while carrying it to the field site (not shown). The lowest possible measurable velocity is 2 cm s^{-1} based on our experiments.

The stationary evaluation suggests that the present configuration works well for measuring surf zone currents. A field experiment was conducted as described and the data were used to calculate the spectra of positions and velocities. Fast Fourier Transform (FFT) was applied to both stationary and field observations. The position and velocity spectra were computed as an average of eight overlapping sections of 4096 points Hanning windowed at 95% confidence level.

The position spectra of the stationary measurement were similar in shape and trend with those obtained by Johnson *et al.*[12], Johnson and Pattiaratchi[13], and MacMahan *et al.*[4] with magnitudes of 10^{-4} to 10^{-2} m^2s (Figure 3 *a* and *c*), while the velocity spectra had magnitudes of 10^{-9} to 10^{-8} m^2s. The lower magnitudes indicate a lower relative error when compared with the previously designed GPS drifters. Similarly, spectra were computed for field observations (Figure 3 *b* and *d*). It is known that stationary observations are uncorrelated with field observations[4,10]. The error spectrum in position (velocity), $S_{rr}(f)(V_{rr}(f))$, was produced from the position (velocity) time series generated by a stationary GNSS receiver unit, and assumed to be constant for all measurements recorded. This stationary spectrum was compared to the $S_{xx}(f)(V_{xx}(f))$ spectrum generated from a position (velocity) time series acquired by field-deployed units. The ratio of these spectra is defined as the signal-to-noise ratio (SNR), which is defined as

$$\mathrm{SNR}_{xx}(f) = \frac{S_{xx}(f) - S_{rr}(f)}{S_{rr}(f)}. \quad (1)$$

For estimates to be considered acceptable in a certain frequency range, SNR must be greater than 10, which

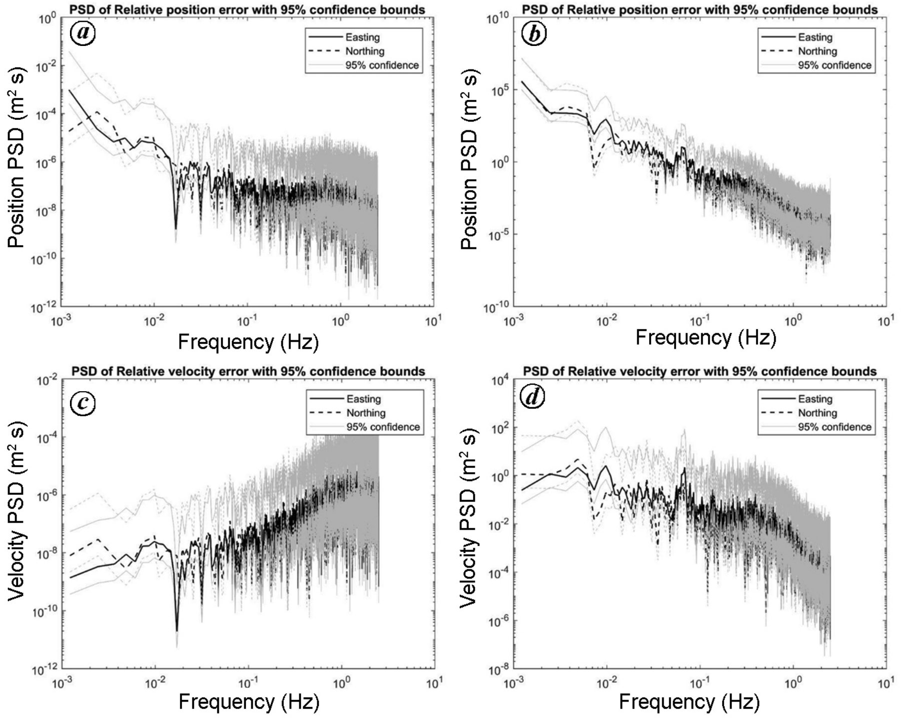

Figure 3. Spectral analysis of a 30 min signal. ***a***, ***b***, Relative position error from (***a***) stationary observations and (***b***) field observations. (***c***) Relative velocity error from (***c***) stationary observations and (***d***) field observations.

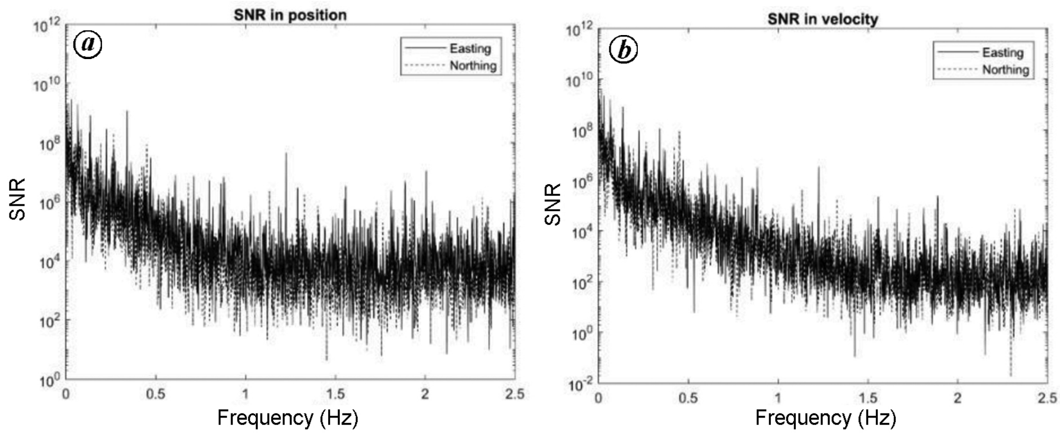

Figure 4. Signal-to-noise ratio (SNR) for (***a***) position and (***b***) velocity measurements using the present drifter configuration.

means $S_{xx}(f)(V_{xx}(f))$ must be an order of magnitude larger than $S_{rr}(f)(V_{rr}(f))$. This ensures that the contribution of noise to the recorded signal is small enough to be statistically irrelevant. The same was applied for the *y*-component (northing). It has been observed from the data that SNR was above 100 (Figure 4), quite high compared to the receivers used by MacMahan *et al.*[4], and Suara *et al.*[10]. Also, the receivers can measure the positions and velocities of lower frequency motion in the surf zone. Hence, no filters were applied to the data recorded by the drifters.

A rip current experiment was conducted during May 2018 at RK Beach and Rushikonda Beach, Visakhapatnam, India. Two drifters were released in approximately 1 m of water in the surf zone and allowed to drift until they either exited the surf zone or grounded on the seabed. Drifters were deployed over a variety of wave and tidal conditions on 15 and 18 May 2018. All deployments took place in the morning to avoid adverse windage effects from diurnal afternoon sea breezes. Typical wind speeds were ~1 ms^{-1}, with a maximum of 5 ms^{-1}. The raw data were logged internally in the drifters and in

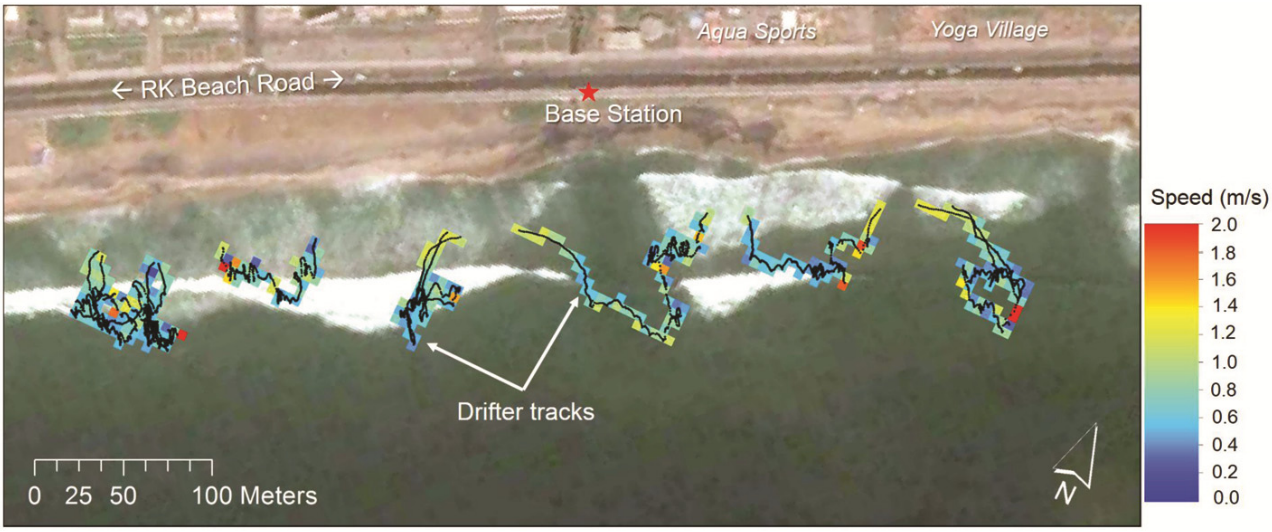

Figure 5. The 5 × 5 m bin averaged measured speeds in the surf zone using two GNSS drifters on 14 May 2018 at RK Beach, Visakhapatnam. Red star denotes position of the base station.

a base station, where a similar EMLID Reach RS receiver was installed temporarily as discussed earlier.

The drifter positions were transformed into UTM coordinates (easting and northing components). Cross and alongshore velocities were estimated by a forward-difference scheme on the position time series. The experimental area was divided into 5 m × 5 m bins. Based on the position information, velocity data were sorted into the appropriate bin and averaged over the deployment duration (Figure 5). Only bins with five or more velocity measurements were included, resulting in statistically confident results[6].

During the experiment, two well-developed rip currents were observed near Yoga village to Aqua Sports location, where many cases of drowning were reported earlier[14]. Local lifeguards are presented at the location nowadays to reduce drowning in this stretch. The drifters upon deployment started drifting along with the current and were observed to be rotating in the form of surf zone eddies at the same location for some time and returned to the beach after a few minutes[4]. Rips were found strong with velocities ranging between 1 and 1.4 m s^{-1} along the rip neck and thereafter reduced gradually to 0.5 m s^{-1} at the rip head (Figure 5). The rip currents are generally strong along the rip neck and lose energy in the rip head[4]. However, we observed very strong current speeds in the range 1.8–2 m s^{-1} at a few locations during the experiment. This could be due to sudden high waves hitting the drifter and displacing its position by a few metres within a few seconds (far right side of the rip current in Figure 5). Although the drifter has good balancing and buoyancy since the top part is extended 50 cm above the sea surface (Figure 1), it is prone to hitting by sudden splashing waves. During the experiment, we observed only a few such instances of sudden increase in the drifter velocity. During post-processing, such erroneous data can be removed. No drifters had exited the surf zone during the experiment and most of the times, they came back to the shore within a few metres from the point of deployment. In case the drifters exit the surf zone, they can be retrieved using a jet ski or a small boat.

During the experiment, rhodamine-B dye was used to track water motion in the surf zone. A small amount of rhodamine-B dye was taken in a tissue pouch and released simultaneously along with the drifter. After few seconds, the dye dissolved in the water and moved in the form of a pink patch. An observer at the shore followed the path along with the patch for 3 min and measured the longshore velocity (V = total path/time elapsed in seconds). As a traditional method, researchers use dye or LEO plate to track the longshore velocities in the surf zone. It was observed that both the drifter and dye patch followed the same path (Figure 6). However, once the drifter was caught in the rip current, the patch started moving offshore and therefore could not be measured using the dye experiment. There were no Eulerian instruments during the experiment to compare the offshore velocity (rip) observations derived from the drifters. However, it has been observed that the longshore velocity measured using dye and that obtained from the drifter are close to the order of surf zone currents. Therefore, the drifters demonstrate the ability to obtain Lagrangian velocity observations in a rip-current system. The flow field of rip currents has a large spatial variability that is difficult to measure with *in situ* instruments owing to high cost and deployment complexities. The cost of a Reach receiver and GNSS antenna is around the US $260 (Rs 19,500 @ Rs 75 = 1 US$) plus the PVC hardware parts including labour charges (Rs 25,000); thus the total cost of each drifter would be around Rs 44,500.

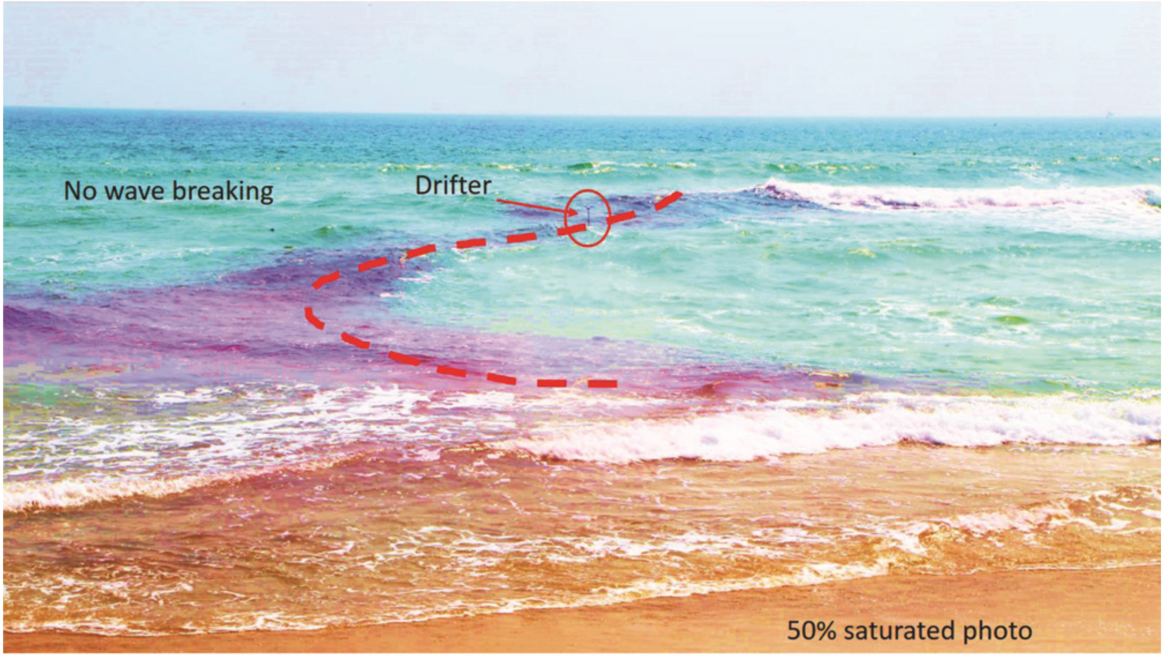

Figure 6. GNSS drifter following the rhodamine-B dye during the experiment.

There is no commercial drifter available in the market at present with such a low cost. If more number of such drifters are made, the cost of each drifter would reduce to a great extent. The proposed inexpensive system has the ability to fill in the gaps between *in situ* instruments, advancing our understanding of the hydrodynamics of a rip-current system.

1. Poje, A. C. *et al.*, Submesoscale dispersion in the vicinity of the Deepwater Horizon spill. *Proc. Natl. Acad. Sci. USA*, 2014, **111**, 12693–12698.
2. Stocker, R. and Imberger, J., Horizontal transport and dispersion in the surface layer of a medium-sized lake. *Limnol. Oceanogr.*, 2003, **48**, 971–982.
3. Schroeder, K. *et al.*, Targeted Lagrangian sampling of submesoscale dispersion at a coastal frontal zone. *Geophys. Res. Lett.*, 2012, **39**.
4. MacMahan, J., Brown, J. and Thornton, E., Low-cost handheld global positioning system for measuring surf-zone currents. *J. Coast. Res.*, 2009, 744–754.
5. Schmidt, W. E., Woodward, B. T., Millikan, K. S., Guza, R. T., Raubenheimer, B. and Elgar, S., A GPS-tracked surf zone drifter. *J. Atmos. Ocean. Techolnol.*, 2003, **20**, 1069–1075.
6. Spydell, M., Feddersen, F., Guza, R. T. and Schmidt, W. E., Observing surf-zone dispersion with drifters. *J. Phys. Oceanogr.*, 2007, **37**, 2920–2939.
7. Boehm, A. B. *et al.*, Decadal and shorter period variability of surf zone water quality at Huntington Beach, California. *Environ. Sci. Technol.*, 2002, **36**, 3885–3892.
8. Nasello, C. and Armenio, V., A new small drifter for shallow water basins: application to the study of surface currents in the Muggia Bay (Italy). *J. Sensors*, 2016; http://dx.doi.org/10.1155/2016/65896362016.
9. Earle, M. D., Riverine drifter. Technical Report, Planning Systems Inc Slidell LA, 2007.
10. Suara, K., Wang, C., Feng, Y., Brown, R. J., Chanson, H. and Borgas, M., High-resolution GNSS-tracked drifter for tudying surface dispersion in shallow water. *J. Atmos. Ocean. Technol.*, 2015, **32**, 579–590.
11. Murray, S. P., Trajectories and speeds of wind-driven currents wear the coast. *J. Phys. Oceanogr.*, 1975, **5**, 347–360.
12. Johnson, D., Stocker, R., Head, R., Imberger, J. and Pattiaratchi, C., A compact, low-cost GPS drifter for use in the oceanic nearshore zone, lakes, and estuaries. *J. Atmos. Oceanogr. Technol.*, 2003, **20**, 1880–1884.
13. Johnson, D. and Pattiaratchi, C., Transient rip currents and nearshore circulation on a swell-dominated beach. *J. Geophys. Res.: Oceans*, 2004, **109**.
14. Arun Kumar, S. V. V. and Prasad, K. V. S. R., Rip current-related fatalities in India: a new predictive risk scale for forecasting rip currents. *Nat. Hazards*, 2014, **70**, 313–335.

ACKNOWLEDGEMENTS. We thank the Director, Space Applications Centre (SAC, ISRO), Ahmedabad for support and encouragement. The first author thanks Dr A. S. Rajawat (SAC) and Prof. K. V. S. R. Prasad (Andhra University) for their suggestions and encouragement in taking up this task. We also thank the DD-MESA and SSAA, SAC and the teams from SAC and Andhra University for assistance during the field campaign. This work is a part of SAMUDRA project at SAC.

Received 7 February 2019; revised accepted 30 August 2019

doi: 10.18520/cs/v118/i2/273-279