# Development of a GPS-GPRS tracked surface drifter for monitoring of surface currents in tidally dominated estuaries

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***Abstract***

*The Vembanad estuary is one of the largest estuarine systems in India, heavily influenced by monsoonal variations and coastal dynamics. As industrial development and navigation activities increase in the region, understanding the estuary's circulation patterns, predominantly driven by tidal currents, has become crucial. This is essential for assessing the dispersal of industrial waste, sediment transport and ensuring safe and efficient navigation for meeting any disaster preparedness. However, collecting precise circulation data near shorelines remains difficult with traditional field deploying current meters and satellite altimeters due to different logistic challenges and land-sea interactions respectively.*

*Additionally, advanced instruments such as Acoustic Doppler Current Profilers (ADCPs) are not well-suited for shallow water environments. To address this challenge, an indigenously developed surface drifter, based on the Lagrangian technique, has been designed and tested for real-time monitoring of circulation and tidal currents in the estuary. The drifter is equipped with a GPS (Global Positioning System) module and a GPRS (General Packet Radio Service) module, allowing for real-time tracking. By analyzing GPS data collected at regular intervals, current patterns in the estuarine region can be effectively studied. A comparison between current flow patterns measured by the surface drifter and an in situ current meter demonstrated a strong correlation, validating the drifter's accuracy in capturing estuarine circulation data which signifies the utility of such devices for remotely monitoring.*

**Keywords:** Circulation, Lagrangian Drifter, GPS, GIS.

## Introduction

Surface drifting buoys, also known as surface drifters are now widely used by oceanographers for a variety of applications such as monitoring of water currents and eddies, cyclonic or anticyclonic circulations in lakes, oil spill dispersion and marine debris, iceberg tracking, search and rescue operations and for the validation of high frequency radar and satellite-derived ocean surface currents[1,13]. Surface drifters are also preferred as an alternative for satellite altimetry to study surface currents near the coastal regions since the latter causes data gaps due to land interferences[12,33,34]. Surface drifters monitoring is mainly based on Lagrangian techniques by which their position can be tracked to determine the movement of water parcel in the ocean[11] and the drifter trajectories can help to study the current flow[21].

With the advancement of telecommunication system, GPS technology is used to track the drifter remotely while GSM (Global System for Mobile Communication) or GPRS (General Packet Radio Service) enables the real time monitoring of drifter which transmits surface current data to the server system[27]. Alternatively, online data transfer is also possible using satellite communication modules in the drifter system [25,35].

Surface drifters enabled with satellite trackers like GPS are now widely used both in the open ocean and coastal and estuarine regions for monitoring and mapping large scale ocean currents as well as tidal currents to study the variability and characteristics of the mean currents and also to understand the mesoscale variability as well as eddy kinetic energy from drifter trajectories[17,18,21]. Also, it is possible to observe the speed and direction of surface, sub surface as well as mixed layer surface currents in the ocean using drifter trajectories[9,28,29]. Small, compact and low cost GPS drifters were developed for studying surface circulation in the near shore zones, lakes and estuaries to measure sub surface currents with different drogues under various environmental conditions[9].

Similarly, surface drifters based on GPS/GSM technology for measuring surface currents under a wide variety of wind conditions in shallow water basins were earlier tested[15]. Studies on low cost surface drifters also observed their utility in coastal waters which can reduce the direct wind drag effect without altering the performance of drifters[19,30].

GPS enabled drifters are also capable of measuring rip currents in the surf zone[20]. Quantitative study on the surface geostrophic circulation of the Mediterranean Sea was done using drifter observations and satellite altimetry and it found that mean currents and kinetic energy levels derived from drifter data appeared to be more accurate than satellite-based data for nearshore waters and helped us to understand better the spatiotemporal variability of coastal currents[16].

Drifting buoys are also capable of measuring fluctuations in sea surface temperature and smaller surface eddies[26]. The dispersion of simultaneously deployed drifters was studied based on their trajectories in the northeastern Arabian Sea[4]. Satellite tracked surface drifters can also be used along with remote sensing data to estimate the oil spill dispersion and the oil slick resident time[1,5]. Another study on the formation and floating of marine debris or ocean garbage patches was done based on the observational data from Global Drifter Program[32]. Few modern drifter designs are also available for monitoring surface currents which include Surface Velocity Program Drifter, Global Drifter Program (GDP), Coastal Ocean Dynamics Experiment Drifter (CODE or Davis Drifter), Lagrangian Submesoscale Experiment Drifter (LASER) and Argo floats[13] etc.

Tidal currents serve as the primary source of energy that generates horizontal and vertical mixing in estuaries which in turn triggers movements of water upstream and downstream depending on the different phases of the tide. Similarly, tidal currents govern the movement of marine debris and non point source pollutants and floating vegetation in the estuarine environments[2]. The tidal amplitude in estuaries mainly depends on the phase of the tide as well as estuarine bathymetry and its amplitude is generally greater than those in the open sea[2]. Estuarine currents vary due to funnelling effect and frictional dissipation due to its interaction with the estuarine bottom[6]. The Cochin estuarine system which is at the downstream reaches of the Vembanad estuary is strongly influenced by tidal variations, with semi-diurnal tides with high amplitude prevailing during the spring phase and low amplitude tides during the neap phase[10,23].

This study, which uses an indigenously developed drifter to investigate the surface currents and its monitoring at different phases of the tide in Vembanad estuary, on the southwest coast of India, lies in its ability to provide direct and high-resolution data on water movement within the estuary. By deploying drifters, researchers can track real-time horizontal movements of water influenced by tidal currents, which are crucial for understanding estuarine dynamics. This information is crucial for validating models of tidal amplification and dissipation effects in the Cochin estuarine system. It plays a key role in enhancing the understanding of water circulation, oil spill and marine debris movements, mixing processes, larval transport and sediment transport in this ecologically and economically important region.

## Material and Methods

**Drifter Design and Development:** The drifter set up is very simple and cost- effective. It is made of PVC (PolyVinyl Chloride) cylindrical pipe equipped with electronic parts consisting of microcontroller (ATmega 2560), GPS module (MIKROE-1032), GPRS module (SIM 800L), lithiumbattery (7.4V, 5Ah) and dead weights for proper buoyancy. The electronic components are assembled on a metal board as depicted in fig. 1a which is securely positioned within a cylindrical pipe. In fig. 1b, two sides of the metal board are shown where one side contains the microcontroller system, while the opposite side accommodates the GPS and GPRS modules, alongside the SD card recorder, battery and buck down converter (to step down the voltage from 7.4V to 3.3V for GPS module).

Fig. 1c provides a top view of the metal board and fig. 1d presents the ultimate configuration of the drifter, illustrating the completed assembly and its final appearance. GPS antenna is attached to the drifter’s topside, keeping it above the water's surface for optimal signal reception. Upper casing along with GPS antenna is exposed to air whereas rest of the casing is below water for making drifter neutrally buoyant in order to reduce the wind drag. The GPS module captures latitude and longitude coordinates from satellites by means of the GPS antenna, obtaining location data. This information is then processed by the microcontroller that transmits the data to a remote server via the GPRS module and also writes this data onto an SD card for local storage at regular 10-minute intervals.

Subsequently, the recorded data can be exported for subsequent analysis and evaluation. The initial drifter cost is approximately Rs.32000/-, encompassing electronic components, PVC hardware, server charges and labour expenses. Scalability can lead to cost reductions when deploying multiple devices.

**Study area and Drifter Deployment:** The Vembanad estuary, a designated Ramsar site is the largest tropical wetland ecosystem in the southwest coast of India spanning between latitudes 9˚28' N and 10˚10' N and longitudes 76˚13'E and 76˚31' E. It is a tidally dominated estuary with seasonal circulation patterns: stratified from June to September, partially mixed from October to January and well mixed from February to May[8,22]. Studying circulation patterns in estuaries, lakes and coastal deltas are crucial for coastal designs and pollution monitoring in the context of natural and anthropogenic disasters in the coastal environments and aquaculture habitats management in the context of climate change scenarios. In order to study the surface circulation during varying tidal conditions, the drifter was deployed at two sites within the Vembanad estuary (Fig. 2), site 1 and site 2 respectively during high tide and low tide phases. The tidal characteristic at these estuarine regions are semidiurnal during spring tide conditions and diurnal during neap tide conditions[23], with maximum range varying between 90cm-110cm.

**Wind slip:** The windage effects are comparatively less for drogued drifters than undrogued ones[31]. The leeway drift velocity ($U$) or wind slip represents the drift velocity experienced by floating objects on the sea surface due to the

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drag force exerted by the wind. It can be calculated using equation 1 as follows[32]:

$$U = \sqrt{\frac{\rho_a}{\rho_w} * \frac{C_a}{C_w} * \frac{A_a}{A_w}}\, W \quad (1)$$

where $C_a$ and $C_w$ indicate the drag coefficient of the elements of the drifter above and below the water surface, $A_a$ and $A_w$ are the values for the cross-sectional area above and below the water surface, $\rho_a$ and $\rho_w$ represent density of air and water at sea level respectively and $W$ is the wind speed at 10m above mean sea level.

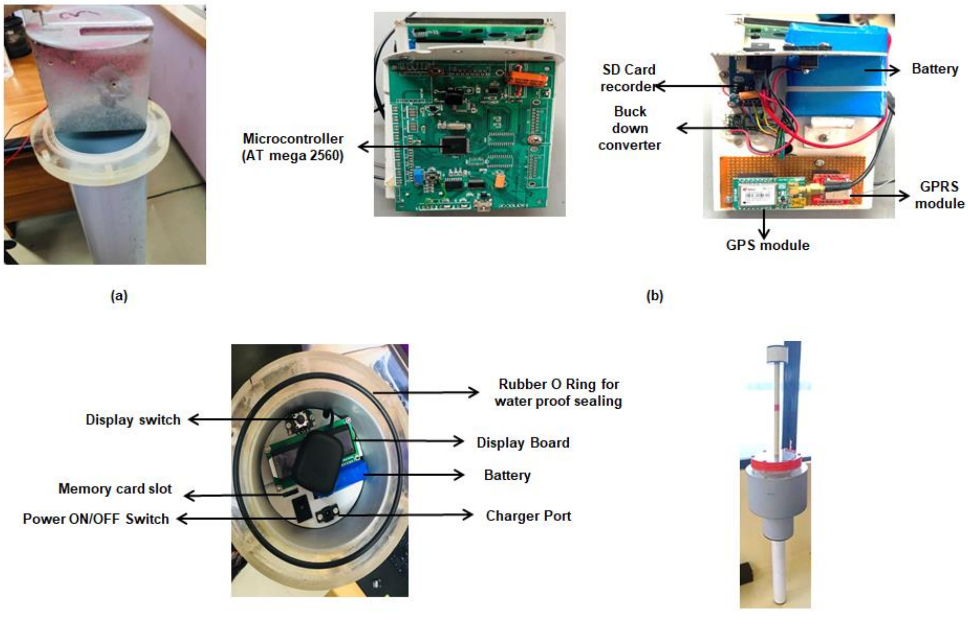


**Figure 1: Assembling of drifter system components**

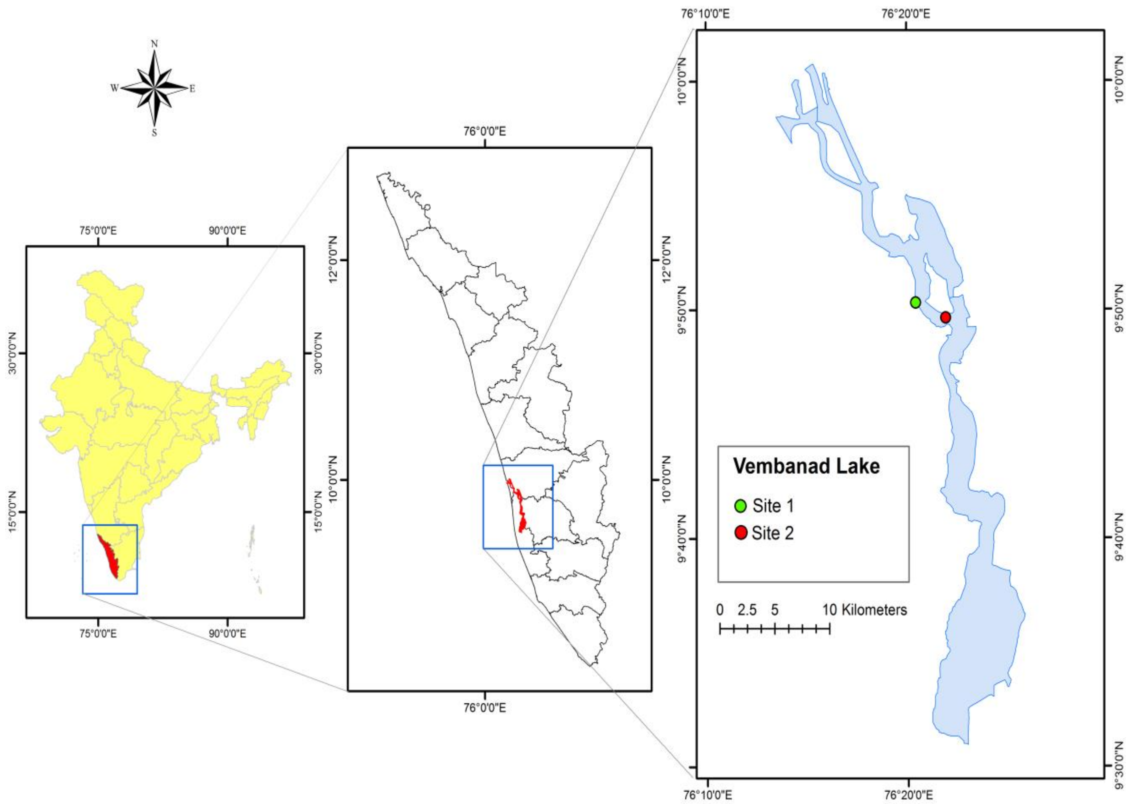


**Figure 2: Location map of the device testing site**

For our undrogued drifter, the leeway drift velocity is obtained as $U = 0.013\,W$ or 1.3% of wind speed with $\rho_a, \rho_w, C_a, C_w, A_a, A_w$ respectively as 1.225 kg/m$^3$, 1024 kg/m$^3$, 0.82, 0.82, 0.054 m$^2$, 0.561 m$^2$. Therefore, a wind speed of 5 m/s gives only a leeway drift velocity of 0.054 m/s.

**Positioning and Telemetry:** The GPRS module transmits signal at every 10 minute intervals. This sampling interval can be set up by the user. But, for the present experiment, the sampling interval was fixed to 10 minutes to get prolonged life time for the batteries. The drifter is designed to be recovered and reused for further field experiments. The deployed drifter is shown in fig. 3 and its location at every 10 minute interval is transmitted through GPRS network that can be plotted using QGIS software (Figs 4a and c). The recorded GPS locations are utilized to plot the trajectory of the drifter for both tidal phases (Figs 4b and d).

**Drifter data analysis and surface current velocity estimation:** To determine the eastward and northward movements of the surface current, a forward differencing scheme was used as outlined in equation 2[14].

**Figure 3: Drifter in test site**

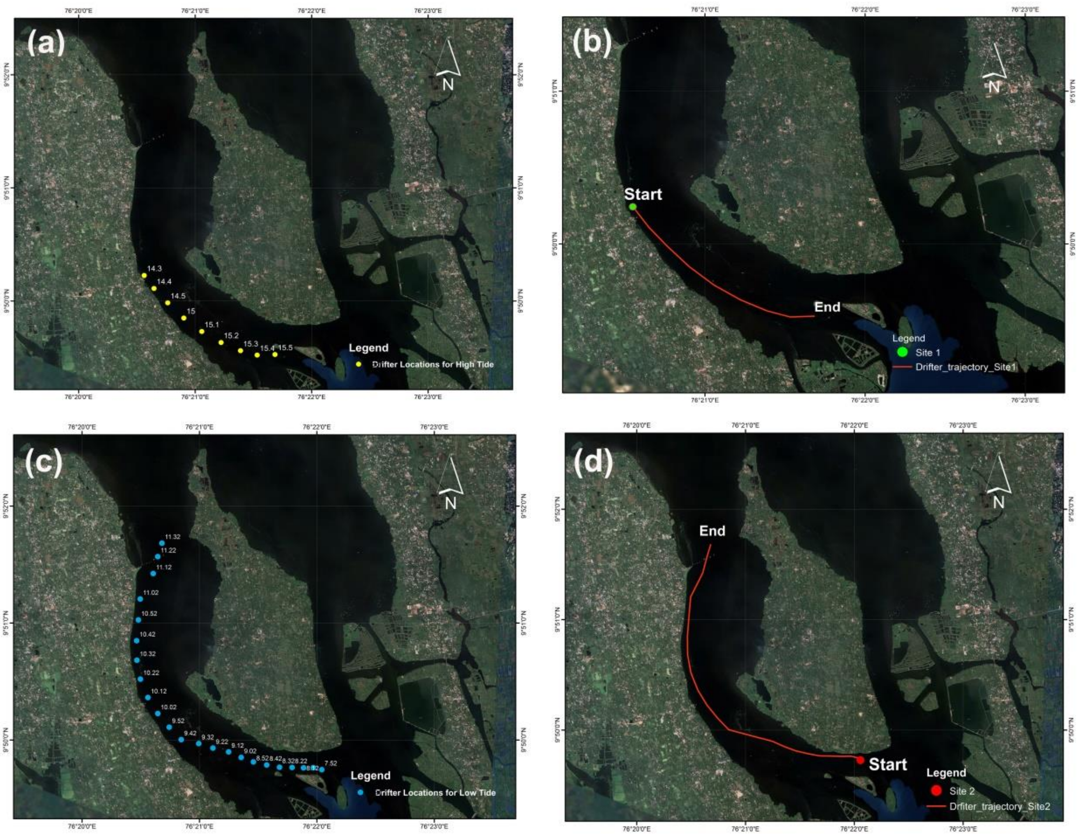


**Figure 4: (a) Drifter locations during flood (high) tide phase (b) Drifter Trajectory during flood tide phase (c) Drifter locations during ebb (low) tide phase (d) Drifter Trajectory during ebb tide phase**

The latitude and longitude data acquired from the drifter were converted from Decimal Degrees to the Universal Transverse Mercator (UTM) coordinate system coordinates. This conversion provided the drifter's position in terms of its zonal and meridional coordinates, denoted as $\left(X_d(t), Y_d(t)\right)$ respectively and the drifter velocity in zonal and meridional direction was computed using equation 2.

$$U_d = \frac{X_d(t+\delta t) - X_d\,(t)}{\delta t}$$
and (2)
$$V_d = \frac{Y_d(t+\delta t) - Y_d\,(t)}{\delta t}$$

where $\delta t$ is the time interval between two consecutive location data points obtained from the drifter (here, 10 minutes), $U_d$ is the drifter velocity in the zonal direction and $V_d$ represents the meridional drifter velocity component. Utilizing the values of $U_d$ and $V_d$, total surface current and also the eastward and northward displacement of drifter can be calculated with the elapsed time.

**Field Validation:** For the validation of drifter, an *in situ* rotor current meter (Fig.5) was used to observe current speed approximately at 0.5m from water surface and direction at certain time interval at locations in the vicinity of drifter. The current meter was deployed at a location and the corresponding current speed and direction displayed on the meter were noted and this was continued for all the locations. Also, the obtained currents at each location were resolved into zonal and meridional components.

**Figure 5: Ocean current meter for *in situ* measurements**

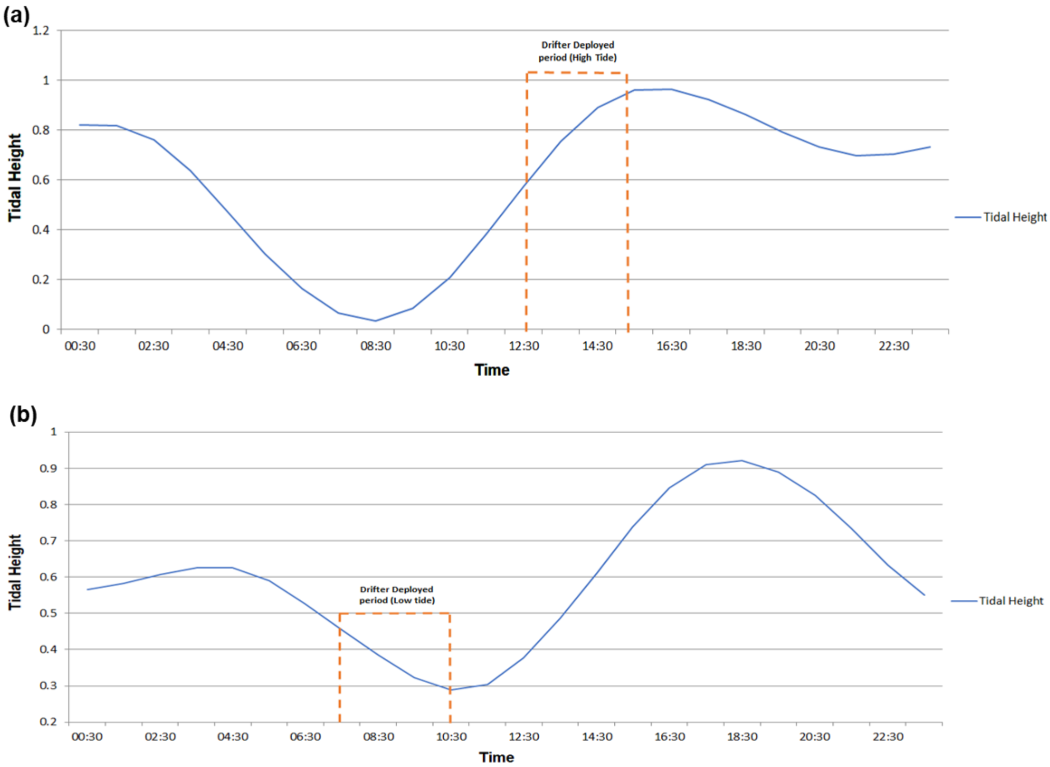


**Figure 6: Tidal amplitude during (a) High Tide (b) Low Tide**

## Results and Discussion

**Tidal current monitoring with drifter and current meter:** Vembanad estuary has mixed, semidiurnal tides with a maximum range of 1 m and two high and low water levels[24]. Tidal hydrodynamics study for Vembanad estuary revealed that there exists a good agreement with tides and currents[2]. Here, figures 6a and b depict the tidal amplitude of Vembanad estuary for high tide and low tide obtained from global predicted tide data during the day of field observation.

Surface tidal current measurements were computed using both drifter and current meter and they were also compared. As the current meter and surface drifter operate on different principles (Eulerian and Lagrangian respectively), direct validation of their readings can be problematic[19]. We use drifter data within a defined radius of 25-50 meters around the current meter to ensure both measurements representing the same location. Velocities are compared only when the drifter is near the current meter, with a minimal time difference between their measurements. Statistics are calculated for all the data together and very good agreement was found during low tide conditions ($R^2$=0.58) and high tide conditions ($R^2$=0.53).

During low tide (ebb tide), an average current velocity of 0.32 m/s for drifter and 0.29 m/s for current meter was observed whereas during high tide (flood tide), average current velocity was 0.55m/s for drifter and 0.47m/s for current meter. The average velocity measurement indicates that the drifter covered a greater distance and also achieved higher velocity during high tide compared to low tide. Here, drifter velocities appear to be higher than those recorded by current meters which could be attributed to variations in measurement locations. Progressive vector diagram (PVD) was employed to compare the current flow obtained by both instruments[3]. PVDs integrate the recorded displacements over a pre-determined period of time and they are useful for estimating and comparing water current's flow from different instruments. The PVDs plotted in this study provide valuable insight into the trajectory of the particles and can facilitate the comparison of both instruments' results. PVD is a Lagrangian representation of Eulerian measurements[24].

The progressive vector diagrams (PVD) of both the drifter and current meter at site 1 and 2 were plotted using the cumulative eastward and northward displacements [computed using the zonal (eastward) and meridional (northward) velocity components and time] and were compared, as depicted in figure 7. Figures 7a and b illustrate the PVD of the drifter and current meter respectively during low tide conditions. On the other hand, figures 7c and d represent the PVD of the drifter and current meter respectively during high tide conditions. Here, the positive X-axis represents eastward movement and negative X-axis denotes the direction of westward movement. Similarly, the positive Y-axis indicates the direction of northward movement and the negative Y-axis represents southward movement. The start and end of the observation period are shown on the graph. Also, the slope of the displacement vectors provides insights into the movement patterns of current during different tide conditions.

During low tide (Figs 7a and b), the initial measurements showed a slight difference in the flow pattern between the drifter and current meter, with the drifter moving entirely westward (Fig. 4b) while the flow direction observed from current meter indicated a southwesterly flow. However, we noticed that both the drifter and current meter vectors follow the same trajectory, initially heading west before changing to a northerly direction during the final phase.

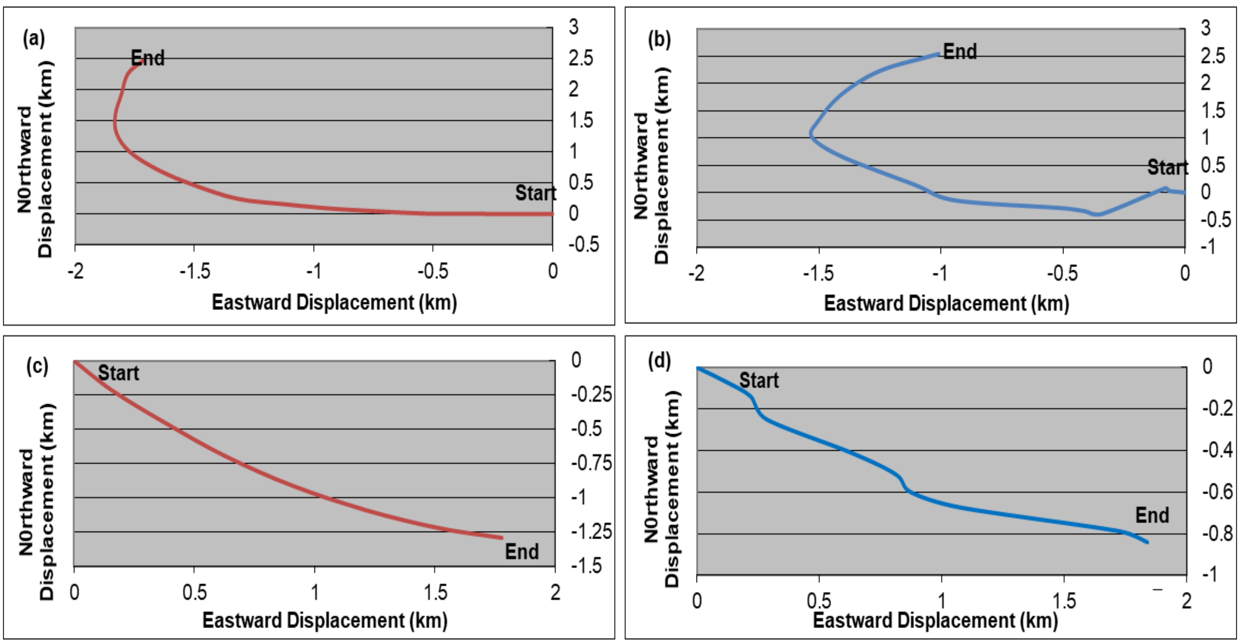


**Figure 7: Progressive vector diagrams during low tide conditions (a) for drifter (b) for current meter and progressive vector diagrams during high tide conditions (c) for drifter and (d) for current meter**

The slope of the drifter and current meter displacements in figures 7a and b indicates that the current experiences a strong movement towards the north during low tide (ebb tide) i.e. towards offshore. During high tide (flood tide), as depicted in figures 7c and d, both the drifter and current meter exhibited a similar current flow pattern with minor deviations at specific time intervals. Notably, the observed displacement shows an increase in movement from northward to southward direction during high tide and the flow is towards inshore.

Hence, these observations highlight the significant role of the drifter in yielding valuable insights into the dynamics and the flow pattern of water currents. Moreover, the drifter's movement serves as a crucial tool for characterizing the direction and the magnitude of water currents under varying tidal conditions.

## Conclusion

Monitoring water currents is crucial for navigation, search and rescue, marine resource management and understanding the fate of pollutants. Due to satellite coverage limitations near the coasts, an indigenous GPS-GPRS tracked surface drifter was developed and deployed in Vembanad lake, India, to monitor tidal currents and also to test the efficacy of such devices in remotely monitoring the movement of surface waters. Real-time data from the drifter, transmitted every 10 minutes, allowed calculation of surface current velocities and trajectory plotting. Comparison with current meters showed similar flow patterns. This study illustrates the importance of GPS-GPRS-tracked surface drifters in monitoring pollutant and floating vegetation movements which depends on the distribution and dispersion of pollutants in the surface waters that can be monitored by physical methods. Here, the physical method is real-time tracking of the drifter by utilising GPS-GPRS technology. Similarly, this study also signifies the State-of-the Art tool of GPS-GPRS technology with locally available components to study inland, tidal and coastal waters where the dispersion, distribution and spreading of point and non-point pollutants can be monitored for surface waters.

The use of this technology can help in industrial establishments where their effluent discharge points are located near the river banks for industrial wastewater treatment, disposal and reuse of water by monitoring water movement for informed decision-making and conservation. This drifter study enhances understanding of tidal influences on water movement and supports particle tracking models, aiding in oil spill simulations, biological monitoring and algal bloom management for informed decision-making and conservation.

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