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Trajectories of three drifters deployed simultaneously in the northeastern Arabian Sea

Shrikant Dora[1,2], Rahul Khedekar[1] and S G Aparna[1,2,*]

[1]*CSIR–National Institute of Oceanography (CSIR–NIO), Dona Paula, Goa 403 004, India.*
[2]*Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201 002, India.*
**Corresponding author. e-mail: aparna@nio.org*

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Three drifters were deployed in the northeastern Arabian Sea at (69.18°E, 19.77°N). They were released almost at the same time on 29 November 2016. The three drifters, initially moved poleward along the direction of the west India coastal current. The distance between any two drifters is less than 5 km for initial 8 days. The drifters veered apart when they moved along the edge of an anti-cyclonic or cyclonic circulating loop, thereby increasing the distance between them. Within a period of six months, the three drifters were in different directions and the distance between them was more than 600 km.

Keywords. Drifter; dispersion; northeastern Arabian Sea; Lagrangian tracking.

1. Introduction

The circulation in the oceans varies at different time scales from very short duration diurnal periods to the long-term variations like seasonal, interannual and decadal time-scales. The study of the circulation patterns at very high resolutions is important to observe the short-term events like oil-spills. The oil-spill studies require high resolution surface current data. The trajectories of the drifters replicate the motion of consolidated surface slicks and hence the satellite tracked drifters are used to study the source of oil-spills in the oceans and also to track the movement of the oil spill in the ocean basins (Liu *et al.* 2011). During the short-term events like cyclones, the *in-situ* measurements of surface currents are not easy, because of their destructiveness. Satellite tracked drifters have been used to demonstrate the strong ocean currents and their characteristics under various storm intensities (Chang *et al.* 2016).

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Drifters are not only used to study these short term events in the oceans, but also to study the circulation at seasonal scales and interannual time-scales. For example, the seasonal cycle of the surface currents in the north Indian Ocean was studied by using near-surface current climatology estimated using trajectories of the drifters (Shenoi *et al.* 1999). A more recent and high (spatial and temporal) resolution climatology of surface currents are developed by Laurindo *et al.* (2017) for the global oceans. Rayaroth *et al.* (2016) have used surface currents estimated from the drifters trajectories and satellite altimetry to describe the surface circulation in Bay of Bengal and they describe the significant changes that occur in the surface circulation during the Indian Ocean Dipole mode events.

Sansón *et al.* (2017) used the drifters deployed over a period of 7 yrs at selected five spots (each spot is defined by a 20 km radius circle) in Gulf of Mexico, to construct dispersion ellipses. The dispersion ellipses are a simple statistical tool that reflect the spread of drifters from a point that are used to make preliminary estimates of the dispersion of marine pollutants. The drifters spread in different directions as they were deployed over a period of 7 yrs (not simultaneously) and over region (not exactly at the same location) and hence their dispersion ellipses have description both in space and time.

But do the drifters deployed at same location and at nearly same time, drift along in the same direction and speed? A study by Lumpkin and Elipot (2010) showed that the drifters deployed at nearly same location and time dispersed in two different directions. They deployed an array of 60 drifters (in Gulf Stream region) in pairs or trios, each launched over the span of a few seconds with an initial separation of a few meters maximum. They estimated the spreading rate, by estimating the distance between the drifters from the day of deployment. Initially for around 4 days, the distance between the drifters pairs were less then 10 km. For the next few days, the distance between the drifters started increasing. After around 9 days, the motion of the two drifters became completely independent and uncorrelated to each other and the distance between the drifters became more than 50 km (figure 5 of Lumpkin and Elipot 2010).

In a similar study, Gerin *et al.* (2014) deployed 12 drifters in two clusters in Northern Aegean Sea during 2008 and 2009. The trajectories deviated after moving coherently for the initial few days. Koszalka *et al.* (2009) deployed 27 pairs and 21 triplets of drifters simultaneously. They noted that during the first 4 days, the drifters moved together, separating slowly. But on the fifth day, they veered apart, moving independently thereafter and by 10 days most pairs are decorrelated. Schroeder *et al.* (2011) deployed drifters in a cluster of 3–5 at a single location in Mediterranean Sea, with an initial separation distance less than 1 km. The drifters in most of the clusters moved coherently for the first few days after the launch and then slowly separating after 3–8 days.

The dispersion can also be strongly affected by the mesoscale features in the oceans. These dispersed trajectories gave an insight into the cyclonic pattern of the basin scale circulation. Brink *et al.* (2000) have deployed a coherent array of 13 (23) drifters in a cyclonic (anticyclonic) eddy to study the eddy currents in California Current System. These trajectories would be an added advantage to the oil-spill studies which depend entirely on the trajectory of a single drifter.

However, such studies have not been reported previously in the Indian Ocean. Hence in the present study, we show the three different trajectories of the drifters deployed nearly at the same time and same location. Initially for around 8 days, the drifters move coherently with each other along the direction of west India coastal current (WICC) after which one drifter deviated from the path and the two drifters continued in the same direction for a few more days. From the 9th day of the deployment all the three drifters are at different locations.

The paper is organised as follows. The data and methods are described in section 2. The trajectories of the drifters are described in section 3. Section 4 concludes the paper.

2. Data and methods

The data from the three satellite tracked drifters with WMO numbers (2301703, 2301704, and 2301705) are used in this study. WMO numbers are the identification numbers allocated by World Meteorological Organization (WMO) to ocean platforms reporting on the Global Telecommunication System (GTS). The buoys used in this study have a similar design, a spherical surface flotation unit, a tether, and a holey sock drogue as sea anchor centered at 15 m below the surface. The drifters have strain sensors attached to them. This sensor value indicates the status of the drogue, whether attached or detached. These drifters are manufactured by M/s Metocean Data systems. This implies that all the buoys have a similar water-following capabilities and have no design difference. These drifters were deployed during a cruise (on board *RV—Sindhu Sadhana*, SSD-029) conducted in the Arabian Sea from 18 November 2016 to 2 December 2016 to study the frontal systems in the Arabian Sea (figure 1a). The buoy data consisted of an unevenly spaced time series of locations of the drifters (around 18–20 observations per day per buoy) determined by the CLS Argos system with an accuracy of approximately 150–1000 m (Lumpkin and Pazos 2007) and were downloaded from http://odis.incois.gov.in/index.php/in-situ-data/drifting-buoy/data-access. The trajectories of the three drifting buoys are shown in figure 1(a). The strain sensor data show that drogues remained attached to the drifters during the entire study period (figure not shown). The

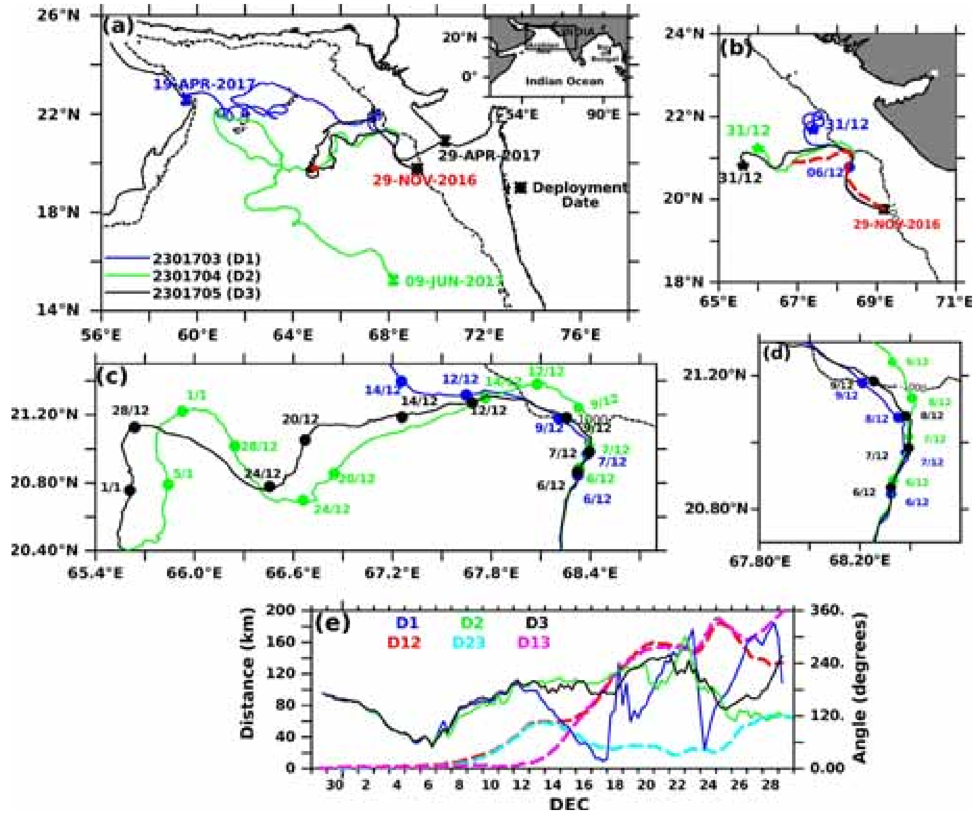

Figure 1. (**a**) Trajectories of the three drifters D1, D2 and D3 are shown in blue, green and black lines respectively. The location of deployment and last transmission is given in asterisk and cross, respectively. Red dot denotes 28 January 2017. The inset shows the larger region around that shown in figure, (**b**) drifter trajectories from 29 November 2016 to 31 December 2016; 6/12 and 31/12 represents 6 and 31 December 2016 given by dot and star, respectively; red dash contour shows Lagrangian track of a particle from 29 November 2016 to 31 December 2016, (**c**) drifter trajectories with dates given by dots; 6/12 and 1/1 represents position of drifters on 6 December 2016 and 1 January 2017 and so on, (**d**) enlarged view of drifter trajectories showing initial separation with dates from 6–9 December 2016 in dots, (**e**) separation distance between drifter pairs D12, D23, D13 is shown in dashed curve (on left y-axis) by red, cyan and magenta respectively; here D12 refers to distance between drifters D1 and D2, and so on. Daily angles (direction) by drifters D1, D2 and D3 are shown in blue, green and black on right y-axis. In panels (**a–d**), the dashed black line represents 1000 m contour.

presence of drogue is crucial for determining the trajectories of the drifters. Separation distance and angles were calculated using 6-hourly interpolated positions of drogued drifters downloaded from https://www.aoml.noaa.gov/phod/gdp/interpolated/data/one_id.php.

The other datasets which are used in this study are altimeter sea-level anomalies (SLAs). These data are based on the gridded sea-level product from AVISO (Archiving, Validation, and Interpretation of Satellite Oceanographic data). The AVISO product merges data from several altimeters to produce a daily SLA field on a 0.33° × 0.33° Mercator projection grid (Ducet *et al.* 2000). The merged SLAs have low mapping errors and better spatial coverage than the TOPEX/Poseidon data alone. SLAs and geostrophic current data products were downloaded from marine.copernicus.eu. To estimate the Ekman current, we used Advanced Scatterometer (ASCAT) wind-stress data from apdrc.soest.hawaii.edu. SLAs, geostrophic currents and wind-stress data has a spatial (temporal) resolution of 0.25° grid (1 day). The Ekman current and the geostrophic current is added to get the net-current. Net-current is used for estimating Lagrangian trajectory.

3. Results

3.1 *Description of the trajectories*

Figure 1(a) shows the trajectories of the three drifting buoys with WMO numbers 2301703, 2301704 and 2301705, hereafter referred to as D1, D2 and D3, respectively. The trajectories for the drifters D1, D2 and D3 are shown in blue, green and black lines, respectively. All the three drifters were deployed at (69.18°E, 19.77°N) on 29

November 2016 at 1320 hrs (IST). Because of the consecutive deployment there would be a slight change in the exact time and location of the deployment. That would only be around a few meters in distance and a few minutes in time. Initially for around 8 days (till 6 December 2016), all the three drifters moved coherently (figure 1b–d). The distance between any two drifters is less than 5 km till 6 December (figure 1e). On 7 December 2016, drifter D2 moved slightly ahead towards north increasing the separation distance before moving northeast (~ 71°) (figure 1d and e). Please note that the notation of angle runs anticlockwise, i.e., East = 0°, North = 90°, West = 180°, South = 270°. From 8 December 2016, the drifter D2 moved northwestwards (~ 121°), whereas drifters D1 and D3 moved along ~ 140° and ~ 135°, respectively (figure 1e). On 9 December 2016, the drifter D2 veered towards west (~ 139°) and the drifters D1 and D3 continued to move northwestwards (~ 147° and ~ 153°, respectively) (figure 1e). Drifters D1 and D3 moved coherently till 12 December (figure 1c) and the distance between them is less than 10 km (figure 1e). After 12 December 2016, the drifter D1 moved towards northwest (~ 177°). Drifters D2 and D3 moved towards southwest (~ 201° and ~ 195°, respectively) (figure 1e). After 24 December 2016, the drifter D2 moved westward and the drifter D3 moved northwest for around 4 days and drifted towards south (figure 1c). The location of the last transmission of drifters D1, D2 and D3 are (59.53°E, 22.58°N), (68.19°E, 15.25°N) and (70.37°E, 20.9°N) respectively. The drifter D2 stopped transmitting on 9 June 2017, to this drifter the drogue was attached till the last transmission. Whereas for the drifters D1 and D3, drogues were disconnected on 19 April 2017 and 29 April 2017 respectively. The drifters D1 and D3 transmitted even after their drogues were disconnected but at the same location. Hence these dates were taken as the last date of transmission for drifter D1 and D3, respectively. Within a period of around 6 months all the three drifters are apart by distance of more than a 600 km.

3.2 *Possible reasons for the diverse trajectories*

What could be the possible reason for such diverse trajectories of the three drifters? The drifter trajectories are driven by the near surface current. During the winter monsoon, the west India coastal current (WICC) is poleward, the core of this eastern boundary current lies along the slope. Hence, initially drifters are seen to move poleward along the current. The geostrophic component of the current and the sea-level anomalies (SLAs) in central and eastern Arabian Sea on 1 December 2016 are shown in figure 2(a). High positive SLAs and strong poleward geostrophic currents are observed in the eastern Arabian Sea. These downwelling signals are remotely forced from the southeastern Arabian Sea. The currents are strong in the south due to strengthening of Lakshadeep high (LH) and further north, the magnitude of the currents tend to rapidly reduce to 10–20 $\mathrm{cm\,s^{-1}}$ at 20°N. There are no meso-scale features observed from 29 November 2016 till 7 December 2016 along the trajectories of the drifters. The strong poleward flow which is observed on 1 December 2016 slightly weakened by 9 December and many small recirculating loops are formed in the eastern Arabian Sea (figure 2b). The strong positive SLAs observed on 1 December also weakened by 9 December 2016. And on 9 December 2016, the current flow meanders around a high sea-level patch observed along the path of the drifters (figure 2b). At this juncture on 9 December 2016, the drifter D2 which moved slightly ahead north on 7 December 2016 (figure 1d) can be seen flowing along the northern branch of the current and the drifters D1 and D3 flowing along the northwestward branch of the current (figure 2c). The drifter D2 also starts drifting westwards after 9 December 2016 (figure 1c). After a few days, the drifters D1 and D3 are along the edge of an anticyclonic circulating loop on 12 December 2016 (figure 2d, shown for 14 December 2016). Figure is shown for 14 December 2016 with trajectories from 12–14th December 2016 overlaid. This was done to depict the splitting/branching of the drifters/currents with more clarity. The geostrophic current branches into two parts, one flowing northward along the edge of the anticyclonic meso-scale feature and the second part flowing offshore. The drifter D1 flows along the northern branch and the drifter D3 flows along the western branch of the current. The value of angle of drifter D1 decreases sharply from ~ 177° to ~ 16° within a few days from 12 December (figure 1e). The drifter D2, which moved along the northern branch on 9 December, started drifting westward along with the strong offshore current. Now, the drifters D2 and D3 drift southwestward with angle ranging from 190°–240° from 12 December till 20 December 2016. The drifter D1 flows along with the northward current with an angle less than 140°.

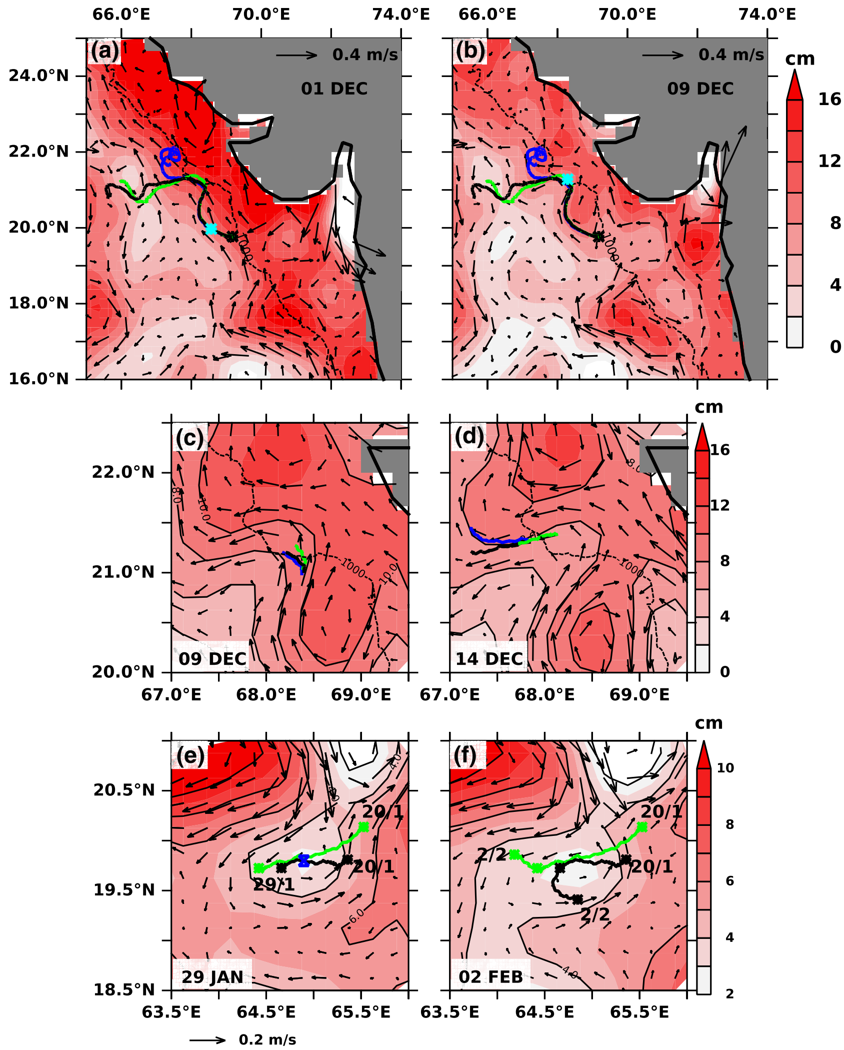

Figure 2. SLA with drifter trajectories. The overlaid vectors show the geostrophic currents. (**a**) SLA on 1 December 2016 with trajectories of drifters D1, D2 and D3 from 29 November 2016 to 31 December 2016; cyan coloured star represents position of drifters on 1 December 2016. (**b**) Same as (**a**), but for 9 December 2016, (**c**) SLA on 9 December 2016 with drifters trajectories from 8–9 December 2016, (**d**) SLA on 14 December 2016 with drifters trajectories from 12–14 December 2016, (**e**) SLA on 29 January 2017 with drifters trajectories from 20–29 January 2017; 20 January 2017 and 29 January 2017 are denoted by black stars, blue cross represents 28 January 2017, (**f**) SLA on 2 February 2017 with drifters trajectories from 20 January 2017 to 2 February 2017. In panels (**a–d**), the dashed black line represents 1000 m contour.

The drifters D2 and D3 moved nearly in the same direction for about 62 days. On 28 January 2017, the drifter D3 starts orbiting around a point near (64.87°E, 19.79°N) (red dot in figure 1a), while the drifter D2 moves westward (figure 2e). The distance between D2 and D3 remained less than 60 km till 29 January 2017 (figure not shown). On 29 January 2017, the drifters D2 and D3 are along the edge of a cyclonic loop, where the current branches into two parts, one branch is towards southeast and the other towards west/northwest (figure 2e). The drifter D3 followed the path of south-eastern branch of the current and the drifter D2 drifted north (figure 2f). The two drifters diverge in two different directions on 2 February at (64.75°E, 19.78°N). Within a period of six months, the three drifters are positioned at three different locations in the Arabian Sea (figure 1a). The distance between drifters D12, D23 and D13 are 1221, 670 and 1136 km, respectively.

3.3 *Relative dispersion*

From the diverse trajectories it is understood that the drifter pairs spread over a period of time. A measure of this spread is given by relative dispersion. A commonly used relative dispersion is the mean square pair separation defined as

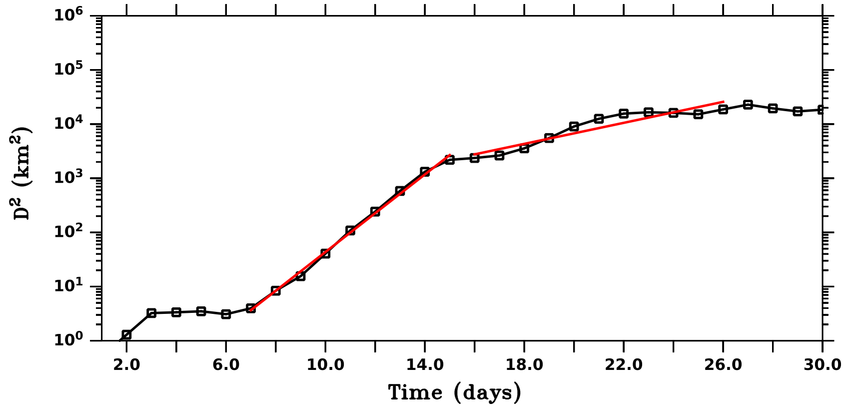

Figure 3. Relative dispersion on a semi-logarithmic graph. Red lines shows exponential fit for 7–15 and 16–26 days, respectively.

$$D^2(t) = \frac{1}{n_p}\sum (x_i(t) - x_j(t))^2 + (y_i(t) - y_j(t))^2,$$

which indicates how the particles separate as a function of time (Koszalka *et al.* 2009), where (x, y) is the location of the drifter and n_p is the total number of drifters pairs. In the present case, since we have only three drifters, we averaged $D^2(t)$ for the three drifters for each day. Figure 3 shows the relative dispersion, plotted on a semi-logarithmic graph. The figure suggests that there are three distinct growth phases. The first phase occurs during the initial 6 days at spatial scales less than 10 km. During first phase, the drifters are nearly following the same path. This phase suggests the drifter motion is correlated during the initial 6 days. Then the dispersion increases approximately exponentially in the second phase following the equation $D^2 = 0.01e^{0.82t}$. During the second phase that extended from 7th till 15th day, distance between the drifters drastically increased. The last and the third phase is also exponential function following the equation $D^2 = 77.45e^{0.223t}$. This phase extended from 16th till 26th day. Though the third phase is also an exponential function, the increase in D^2 during this phase is relatively smaller than that during the second phase.

4. Discussion and summary

In the present study, we deployed three drifters at the nearly same location (69.18°E, 19.77°N) and at the same time. The three drifters drifted along the same path for initial 8 days, when strong poleward current is observed. During winter monsoon, the poleward downwelling favourable current WICC flows along the west coast of India (Amol *et al.* 2014) and references therein. The core of this current lies along the continental slope ($\sim$1000 m) contour. Though this current is more jet-like flow along the slope of the west coast of India, it is decorrelated along the coast (Amol *et al.* 2014). Patches of strong currents are observed along the coast in the region where drifters are located (figure 2a). By 9th December, the strength of the WICC weakened in the small region where the drifters are drifting (figure 2b). The jet-like flow, which existed in the first week of December (near the region, where drifters are afloat), turned into a discontinuous flow, taking the form of a few recirculating loops along the path of WICC (figure 2a and b). The vorticity in the region near to the drifters' locations are low during 29th November–1st December and high during 7–9th December (figure not shown). When the drifters are along the edge of a recirculating loop, they diverged and took different paths. Such diverged drifter trajectories were earlier observed by Lumpkin and Elipot (2010) in Gulf stream; when one of the two drifters orbiting a cyclonic cold-core ring had gone completely out of the ring.

Not only in the circulating loops or eddies, the drifters diverge when branching of currents occurs. For example, on 12th December when the geostrophic current branches into two parts, drifter D1 flows along the northern branch and drifter D3 along the western branch (figure 2d). A similar behaviour by the drifters is shown by Gerin *et al.* (2014) when the branching of surface currents was observed around Lemnos Island (in North Aegean Sea).

The distance between the drifters deployed simultaneously is a function of time from release and in general increases with time. The relative dispersion of the drifters (mean square separation of drifter pairs) is characterized by a Power law (Lumpkin and Elipot 2010) or an exponential law (Schroeder *et al.* 2011). Koszalka *et al.* (2009) observed that the dispersion curve is characterized by Power law and linear equation. They attributed the dispersion in the trajectories of the drifters deployed in pairs to random motion and to greater shear. We observed the dispersion curve in three phases. Correlated motion of drifters is observed during the first phase, occurs with spatial scales less than 10 km. The second and third phases are characterized by exponential functions (figure 3). During the last phase, the increase in the distance is relatively smaller compared to the second phase. The reasons for the differences between the dispersion curves are not evident. However, the reasons for the drifters to follow different paths can be listed as:

- Circulating loops or eddies,
- High shear zones,
- Branching of currents,
- Random motion which includes non-linearity in the system and the turbulent diffusion.

If the random component in the total current, i.e., the instantaneous current velocity at that location is negligible compared to the net current (sum of geostrophic current and wind driven ekman current), the trajectories of the drifters are more predictable. This random motion/walk is one of the components of the total current that drive the trajectories of the drifters. It defines the uncertainty in the trajectories of the drifters (Yu *et al.* 2017). Also the method of Lagrangian tracking could trace the trajectories where the net current (sum of geostrophic current and wind driven ekman current) are dominant, with random motion being negligible. In the present case, the Lagrangian tracking could retrace the path of all the drifters for the initial 8 days of the trajectories and thereafter Lagrangian trajectory nearly retraces the trajectories of drifters D2 and D3 (figure 1b).

It has to be noted here that this study is based on a single experiment with only three drifters. With no other similar experiments conducted earlier in this region, generalizing the dispersion relation to this region would be little overstated. However, study is first of its kind to examine the dispersion relation in this region.

In summary, in this study we show that the trajectories of the drifters deployed consecutively in northeastern Arabian Sea drifted together initially for a week and then drifted apart. Within a span of about 6 months, the drifters were more than 600 km apart. The diverse trajectories show that the trajectory of a drifter is dependent mainly on the instantaneous current vector at that particular location and not the average current pattern in an area or grid (figure not shown). Hence, this study suggests that if the trajectories of the drifters are being used for the oil-spill research or the studies of boat drifts for activities such as search and rescue operations, more emphasis should be given to the instantaneous current velocities along with studying the circulation features such as eddies, branching of currents, etc.

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References

Amol P, Shankar D, Fernando V, Mukherjee A, Aparna S G, Fernandes R, Michael G S, Khalap S T, Satelkar N P, Agarvadekar Y, Gaonkar M G, Tari A P, Kankonkar A and Vernekar S P 2014 Observed intraseasonal and seasonal variability of the West India Coastal Current on the continental slope; *J. Earth Syst. Sci.* **123** 1045–1074.

Brink K H, Beardsley R C, Paduan J, Limeburner R, Caruso M and Sires J G 2000 A view of the 1993–1994 California Current based on surface drifters, floats, and remotely sensed data. *J. Geophys. Res.-Oceans* **105** 8575–8604.

Chang Y C, Tseng R S, Chu P C, Chen J M and Centurioni L R 2016 Observed strong currents under global tropical cyclones; *J. Mar. Syst.* **159** 33–40.

Ducet N, Le Traon P Y and Reverdin G 2000 Global high-resolution mapping of ocean circulation from TOPEX/Poseidon and ERS-1 and-2; *J. Geophys. Res.-Oceans* **105** 19,477–19,498.

Gerin R, Kourafalou V, Poulain P M and Besiktepe Ş 2014 Influence of Dardanelles outflow induced thermal fronts and winds on drifter trajectories in the Aegean Sea; *Mediterr. Mar. Sci.* **15** 239–249.

Koszalka I, LaCasce J H and Orvik K A 2009 Relative dispersion in the Nordic Seas; *J. Mar. Res.* **67** 411–433.

Laurindo L C, Mariano A J and Lumpkin R 2017 An improved near-surface velocity climatology for the global ocean from drifter observations; *Deep-Sea Res. Pt. I* **124** 73–92.

Liu Y, Weisberg R H, Hu C, Kovach C and Riethmüller R 2011 Evolution of the Loop Current system during the Deepwater Horizon oil spill event as observed with drifters and satellites; *Monitoring and Modeling the Deepwater Horizon Oil Spill: A Record-Breaking Enterprise, Geophys. Monogr. Ser.* **195** 91–101.

Lumpkin R and Elipot S 2010 Surface drifter pair spreading in the North Atlantic; *J. Geophys. Res.-Oceans* **115 (C12017)** 1–20, https://doi.org/10.1029/2010JC006338.

Lumpkin R and Pazos M 2007 Measuring surface currents with Surface Velocity Program drifters: The instrument, its data, and some recent results; *Lagrangian analysis and prediction of coastal and ocean dynamics*, pp. 39–67.

Rayaroth M K, Peter B N and Mahmud M R 2016 High-Resolution Surface Circulation of the Bay of Bengal Derived from Satellite Observation Data; *J. Mar. Sci. Technol.* **24** 656–668.

Sansón L Z, Perez-Brunius P and Sheinbaum J 2017 Point source dispersion of surface drifters in the southern Gulf of Mexico; *Environ. Res. Lett.* **12** 024,006.

Schroeder K, Haza A C, Griffa A, Özgökmen T M, Poulain P M, Gerin R, Peggion G and Rixen M 2011 Relative dispersion in the Liguro–Provencal basin: From sub-mesoscale to mesoscale; *Deep-Sea Res. Pt. I* **58** 209–228.

Shenoi S S C, Saji P K and Almeida A M 1999 Near-surface circulation and kinetic energy in the tropical Indian Ocean derived from Lagrangian drifters; *J. Mar. Res.* **57** 885–907.

Yu F, Li J, Zhao Y, Li Q and Chen G 2017 Calibration of backward-in-time model using drifting buoys in the East China Sea; *Oceanologia* **59** 238–247.

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