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Monsoonal impact on circulation pathways in the Indian Ocean

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Abstract

Monsoon driven water mass exchange between the Bay of Bengal (BoB) and Arabian Sea (AS) is the common experience. However, it is not yet firmly confirmed that the exchange pathway is either passing through southern tip of Sri Lanka or Palk Strait. Local circulation patterns impact the pathways followed by the East Indian Coastal Currents (EICC) that drive exchange, thereby modulating mixing and water mass transformation in the Bay of Bengal around Sri Lanka. In this study, observations from surface drifters were incorporated with the satellite derived data to understand the monsoonal impact on circulation patterns in the Indian Ocean. This was the first multi-national scientific effort which was conducted in the BoB and AS during 2013 to 2015 to understand the monsoonal impact on circulation patterns in the complex region. The results indicated that seasonally reversing monsoonal currents of southern Sri Lanka, traced by the wintertime freshwater export pathways of the EICC. The deflection of monsoon currents running along the east coast of Sri Lanka by forming cyclonic and anti-cyclonic eddies, which influence the mixing and stirring associated with these flows. Results further indicate the low salinity cold water flows from the BoB to AS along the western boundary of the BoB during northeast monsoon. In the same way, reverses the phenomena during southwest monsoon, transporting high salinity warm water from AS to the BoB. This maintain the bay status which occurred due to freshwater influx from large rivers and high saline water from AS. However, no evidences were observed for the exchange through Palk Strait during the study. Also, there are some mis-matches in *in-situ* and remotely sensed measurements which imply the necessity of systematic observation system for the complex region as an alternative approach.

Key words: Bay of Bengal, northeast monsoon, southwest monsoon, circulation, surface drifters

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1 Introduction

Drifter deployment program was carried during 2013 to 2015 out as the framework of Air-Sea Interaction in the Indian Ocean (ASIRI) project off the east coast of Sri Lanka. The program consists of different objectives such as coastal boundary currents and water mass exchange between Bay of Bengal (BoB) and the Arabian Sea (AS) (Wijesekera et al., 2015; Lee et al., 2016). The perspectives of ASIRI were to improve the present knowledge of coupled air sea interactions in the Indian Ocean region (Lucas et al., 2014).

Indian Ocean is the least explored and the most complex ocean among the world's three major oceans. Indian Ocean is divided into two subdivisions namely the Arabian Sea (AS) and Bay of Bengal (BoB) which located in the same latitude and comprise with unique characteristics. Both basins are influenced by Indian and Asian monsoons. The surface circulation characterizes with the seasonally reversing currents (Fig. 1) as a response to the seasonal winds (Schott and McCreary, 2001).

The BoB receives substantial freshwater flux from both precipitation and river discharges during southwest monsoon where precipitation well exceeds evaporation (Sengupta et al., 2006; Seo et al., 2009). Seasonal freshwater influx (precipitation and river runoff) and evaporation force to changes the salinity levels. The observed salinity levels suggest that AS is consisted of high (low) salinity water. Thus, higher evaporation over AS and higher freshwater influx to the BoB creates a hydrological imbalance between the AS and BoB (Kumar et al., 2004).

The seasonally reversing circulation plays a key role in controlling the imbalance between AS and the BoB which maintains long-term average salinities (Jensen, 2001). The observations based on earlier studies (Shetye et al., 1991; Schott et al., 1994; Vinayachandran and Yamagata, 1998; Gopalakrishna et al., 2005) and model simulations (Jensen, 2001; Zhang and Du, 2012; de Vos et al., 2014) pointed out that eastward flowing. Southwest Monsoon Current (SMC) brings high saline AS waters into the BoB during summer monsoon which increases the salinity in the BoB. Also, it was noticed that the westward propagation of Northeast Monsoon Current (NMC) carries low saline BoB waters into the AS during winter monsoon. Thus, the circulation within the BoB is affected by the seasonal variability of general current patterns in the Indian Ocean. East Indian Coastal Currents (EICC), which runs along the western boundary of the BoB reverses its direction twice a year (Vinayachandran et al., 2005; de Vos et al., 2014). EICC flows towards northeast from February to Septem-

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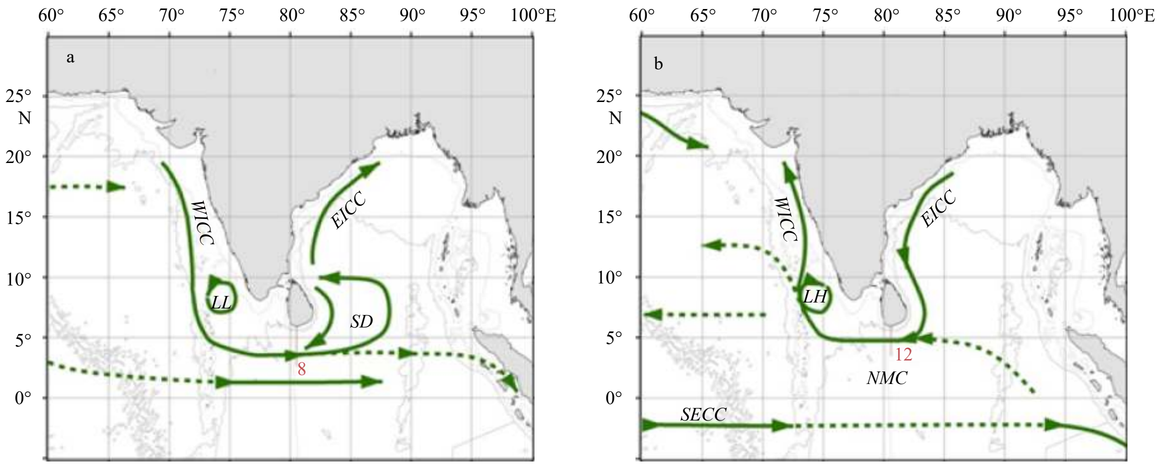

Fig. 1. A schematic representation of identified current branches during the Southwest Monsoon, including some choke point transport numbers ($Sv=10^6$ m^3/s). Current branches indicated are the South Equatorial Current (SEC), South Equatorial Countercurrent (SECC), West Indian Coast Current (WICC), Laccadive High and Low (LH and LL), East Indian Coast Current (EICC), Southwest and Northeast Monsoon Current (SMC and NMC), Sri Lanka Dome (SD). a. Summer monsoon (January/Februay); b. winter monsoon (January/Februay) (Schott and McCreary, 2001).

ber with a strong peak in March to April and southwestward from October to January with the strongest flow in November (Schott and McCreary, 2001).Within this seasonal cycle, EICC plays a crucial role in the freshwater balance of the northern Indian Ocean during northeast monsoon since it is an efficient conduit for the export of low salinity water from the BoB to the Arabian Sea (Hacker et al., 1998; Han and McCreary, 2001; Jensen, 2001).

McPhaden et al. (2009) pointed out that ocean-atmospheric interaction in the region is highly dynamic, involving seasonal current reversals associated with monsoon wind forcing and significant exchange of heat across the air-sea interface. Lin et al. (2013) suggested that the current pattern reversals in the Indian Ocean are specially related to the heat and moisture transport effect on climate changes within the region. There are two possible pathways available for the transport of low salinity water from the BoB to the southeastern AS (Vinayachandran et al., 2005). One low salinity pathway is located along the coastline around Sri Lanka and the southern tip of India during October–November. Other one is running through the Palk Strait during northeast monsoon from December–March which is fed by the EICC (Shankar et al., 2002). The low salinity water mass is observed in the southeastern AS during November–December (Boyer et al., 2005). The numerical models show that the EICC flows around India and Sri Lanka in to the Arabian Sea (Vinayachandran et al., 1996; Han and McCreary, 2001) suggest that the EICC is a definite conduit (Jensen, 2001).

However, it is not yet firmly confirmed that the exchange of water mass between AS and BoB is either around the southern tip of Sri Lanka or passing through the Palk Strait due to lack of systematic *in-situ* measurements.

The monsoon activation is a natural phenomenon and timely variability have been investigated in the literature. The wind data from Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA) clearly shows the change in monsoon onsets between 2013 and 2014 (Table 1).

After analyzing the time series data from RAMA moorings during 2013–2014, it is noted that the shifting of monsoon onset over the region (Fig. 2). The observations indicated that northeast monsoon seems to be activated in the mid December while southwest monsoon in mid-May in 2013. The seasonal shifts observed in 2014 indicated the northeast monsoon activated in mid-November and southwest monsoon in early June. Thus, it is important to know that how the variability of monsoon onset period and strength of monsoon is affected on the wind driven circulation in the region. However, the drifter data utilized in this investigation does not cover the entire northern Indian Ocean both spatially and temporally, and it makes difficulties to address the changes in the wind driven circulation in the region.

The current study is an attempt to explain the monsoonal impact on circulation pathways in the Indian Ocean utilizing drifter data with other *in-situ* (RAMA) and satellite observations during 2013–2015. The paper is organized as introduction, methodology, results, discussion and conclusion as in different sections.

2 Methodology

The data collected from satellite tracked SVP (surface velocity program) drifters were used to study the surface circulation patterns between the BoB and the AS. The investigations were conducted as part of the ASIRI program by National Aquatic Resources Research and Development Agency (NARA) of Sri Lanka

Table 1. Variation of monsoon onsets in northern Indian Ocean (AS and BoB)

Source	SWM activation	NEM activation
Dickey et al. (1998)	June–September	November–February
Shankar et al. (2002)	May–September	November–February
Tomczak and Godfrey, (2003)	June–October	December–April
Shenoi (2010)	June–September	November–February
Rao et al. (2012)	June–September	November–January
Glejin et al. (2013)	June–September	October–January

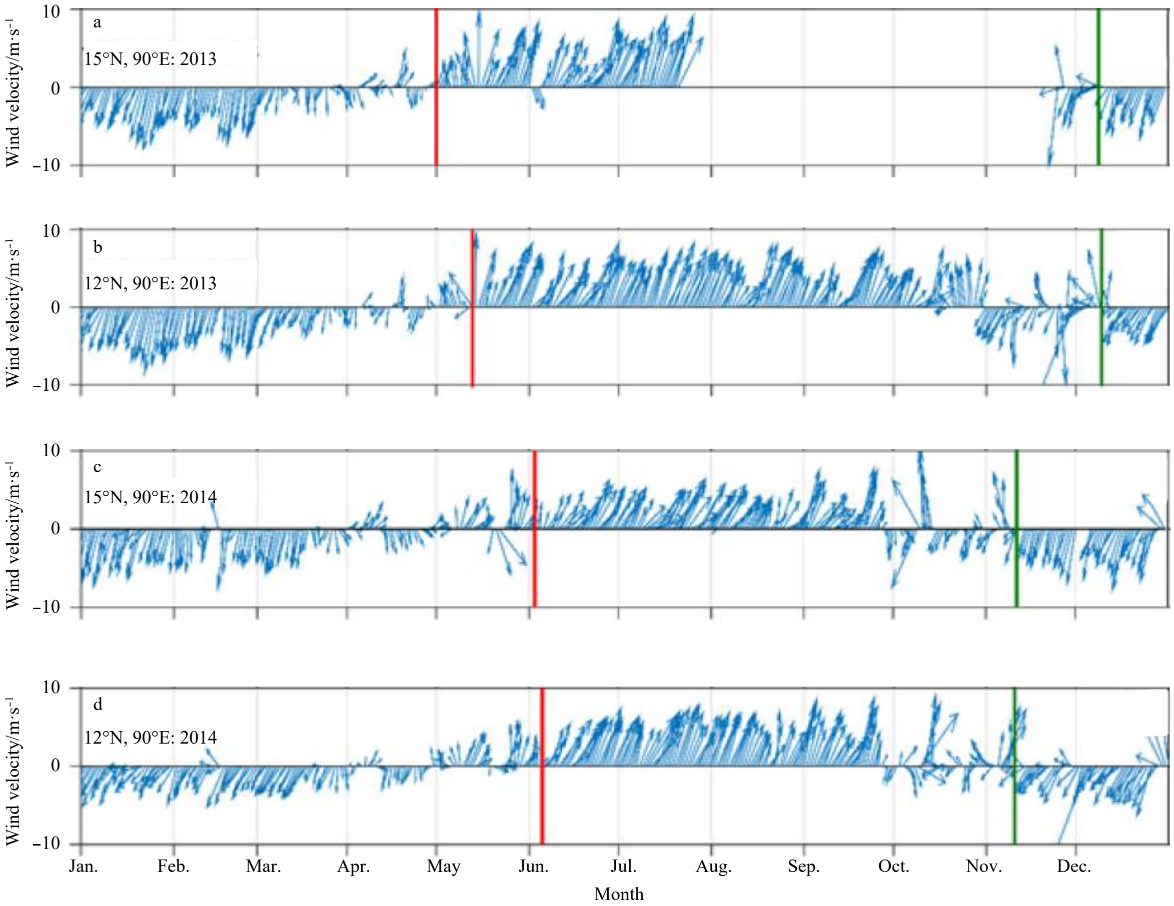

Fig. 2. Variation of wind speed at 15°N, 90°E (a), 12°N, 90°E (b) during 2013 and 15°N, 90° E (c), 12°N, 90°E (d) during 2014. Red lines indicate the activation of SWM and green lines indicate the activation of NEM (data source: RAMA moorings, NOAA/PMEL).

collaboratively with Scripps Institution of Oceanography (SIO), University of California, USA. Time series measurements of SST, SSS, and air-temperature data were obtained from the RAMA moorings located at 15°N, 90°E and 12°N, 90°E (www.pmel.noaa.gov). High resolution daily SST from Optimum Interpolation Sea Surface Temperature (OISST) (www.esrl.noaa.gov) and sea surface height anomalies data (SSHA) were obtained Avsio satellites (www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global) for this study.

3 Results

3.1 *Seasonal variation of surface current patterns in the BoB and around Sri Lanka*

Indian and Asian monsoons play a major role, controlling the seasonal conditions in the northern Indian Ocean. Onset, tenor and strength of the monsoons are not consistent with the time. The *in-situ* wind measurements from RAMA moorings were utilized to understand the onsets and breakdowns of SWM and NEM from January 2013 to December 2014. The directional changes in the wind patterns indicate a year to year variability of monsoon onset and breakdown (Fig. 2). The results pointed out that the onset of SWM is around early May while the onset of NEM is around mid-December (Figs 2a and b) in 2013. However, results further indicated that the onset of SWM is shifted to early June and the NEM starts in early November (Figs 2c and d). Further, Fig. 2 clearly exemplifies the year to year variability of the span (SWM/NEM) and the intensity of monsoon. The observed variability of monsoon onset can influence on the surface currents in the region which mainly forced by the winds drifter data collected under this research provides us encouraging results to study the seasonal variability of surface currents in the northern Indian Ocean. Figure 3 illustrates the variability of surface currents between the AS and BoB during 2013–2014.

It is noted that the surface currents flows from BoB towards the AS along the east coasts of India and Sri Lanka (blue color in Fig. 3) during NEM. Thus, it suggests that the drifters have been trapped by the northeast monsoon driven surface currents (Fig. 1) in east of Sri Lanka and India. In consistent with earlier studies, it is evident that EICC flows towards equator and then enters to the AS during NEM along the Sri Lanka coast. Drifter trajectories further indicated that the surface current (EICC) flows closely to the east coast of India and Sri Lanka during NEM. With the onset of the SWM, the surface currents change their direction and start to flow towards eastward during NEM. The observed drifter trajectories during SWM in the BoB and AS (circled in Fig. 3) clearly provide the evidence for the observed change in surface currents. Vinayachandran et al. (1999) pointed out that the existence of a strong flow into the BoB during summer, which is identified as the intrusion of the Summer Monsoon Current (SMC) into the BoB. Also, their studies clearly highlighted the existence of strong surface currents in south of Sri Lanka which flows from AS to the BoB during SWM. The surface currents flow equator ward during 1st inter monsoon and SWM along the west-

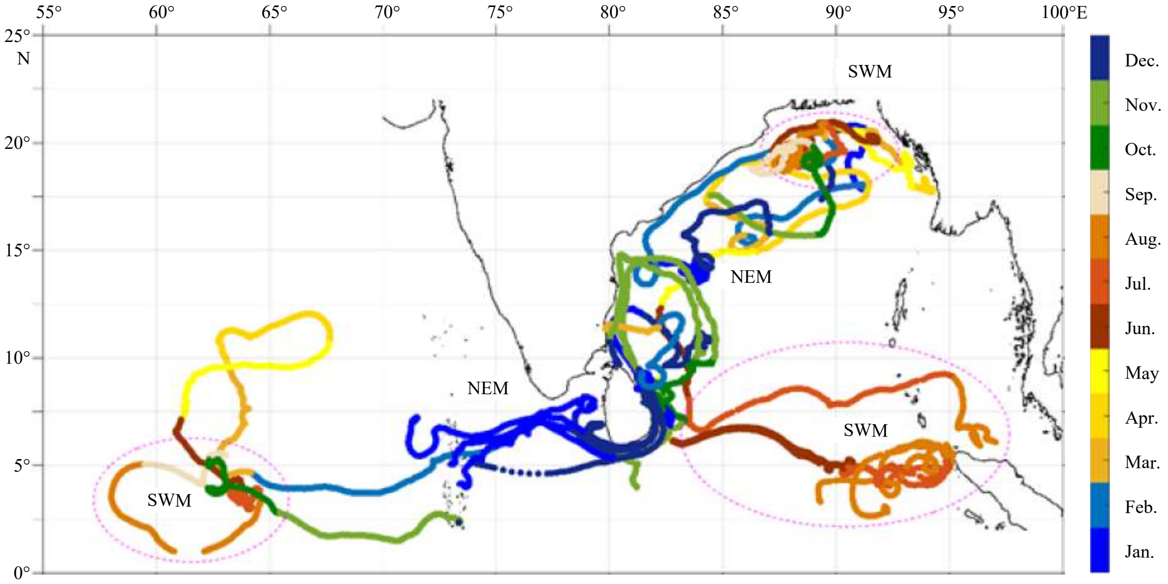

Fig. 3. The trajectories of SVP drifters deployed during 2013–2014. Color bar represents the observation months. The drifter trajectories observed during south west monsoon are marked by circles (SWM: south west monsoon and NEM: north east monsoon).

ern boundary of the BoB. However, it changes the direction towards the east instead of flowing towards AS which is similar to the NEM. The change in the flow direction of currents in southeast of Sri Lanka indicates the presence of strong SMC at south of Sri Lanka during SWM. The drifters which were trapped by SMC near the southeast of Sri Lanka during June and July 2014, pointed out the presence of strong SMC and its variability with the progression of the SWM. Also, it was observed that more eddy like features are formed in the AS and the BoB along the drifter trajectories during SWM. Thus, it suggests the surface currents are influenced by strong winds which are leading to the mixing in the region during SWM (Fig. 3).

Variability of the circulation in the region during monsoon transition periods is important due to the presence of more air-sea disturbances compared to the SWM and NEM. The data from the drifters which were deployed close to the east coast of Sri Lanka during 1st inter monsoon (March–May) and 2nd inter monsoon(October–November) were used to study the surface currents during monsoon transition periods. It was noted that the surface currents flow towards the equator closely to the east coast of Sri Lanka during 1st inter-monsoon and then turns to east during SWM. The currents flow towards north-northeast at first during 2nd inter monsoon and turns westward. However, this flow further continues to the equator along the east coast of India and Sri Lanka with the EICC. Thus, the drifter data clearly illustrates the seasonal variability of surface circulation between the AS and the BoB. The seasonally reversing monsoonal currents around Sri Lanka is well presented in drifter trajectories and provide the evidences for water mass exchange between the AS and BoB. Furthermore, the *in-situ* observations provide detail description of the surface currents around Sri Lanka compared to that from either model simulations or remote sensing data.

3.2 *Seasonal variation of SST along the drifter trajectories in the AS and BoB*

Sea Surface Temperature in the AS and BoB follows a strong seasonal cycle with peaks during monsoon transition periods. Minimum SSTs could be observed both in the AS and BoB during NEM. The maximum SST is observed during 1st inter monsoon (Figs 4 and 5). The difference of SST is obvious with surface cooling in the AS compared to that of BoB during SWM. The observed SST cooling in the AS is mainly due to the upwelling of subsurface waters under the forcing of strong winds over the region during SWM. Relatively weaker winds and lack of upwelling minimize the mixing of the surface waters and favors the existence of warmer SSTs in the BoB during SWM compared to the AS. The SST peaks during the monsoon transition periods, are mainly associated with the solar heating. Apart from the seasonal cycle, OISST data indicates a year to year shifting of the SST in the northern Indian Ocean (Figs 4 and 5).

The colder and warmer SSTs were observed during northeast monsoon and 1st inter monsoon respectively in the AS in 2014 (Fig. 5) compared to the 2013 (Fig. 4).However, average SST is quit warmer in the BoB during 2014 compared to 2013.The presence of cold water band in the east coast of India and around Sri Lanka during NEM indicated in Figs 4 and 5. Further, they indicated warm water conduit south of Sri Lanka during SWM. Thus, it emphasizes the importance of examining the temperature changes along the drifter trajectories.

The drifter trajectories were separated into two sub divisions for examining the seasonal variation of SST along their path ways (Figs 6 and 7). Figures 6 and 7 represent the SST variation along the drifter trajectories during NEM and SWM around Sri Lanka respectively.

It is evident from the results that the presence of cold water circulation around Sri Lanka during NEM which transport from the BoB to the AS similar to the observations from the figs 4 and 5. Thus the drifter data pointed out that the water mass exchange between AS and BoB is mainly around Sri Lanka during NEM. Further, it confirms the presence of EICC and its role during NEM, which carries waters from the BoB into the AS. The previous studies carried out by Schott and McCreary (2001) suggested that the water mass transport by EICC follow the West Indian Coastal Current (WICC) after flowing around Sri Lanka. However, investigation results indicated that the drifters continue westward propagation to the AS instead of chasing WICC (Fig. 6). Figure 6 clearly illustrates the seasonality of SST, highlight the presence of cooler waters during NEM. The seasonal variation of

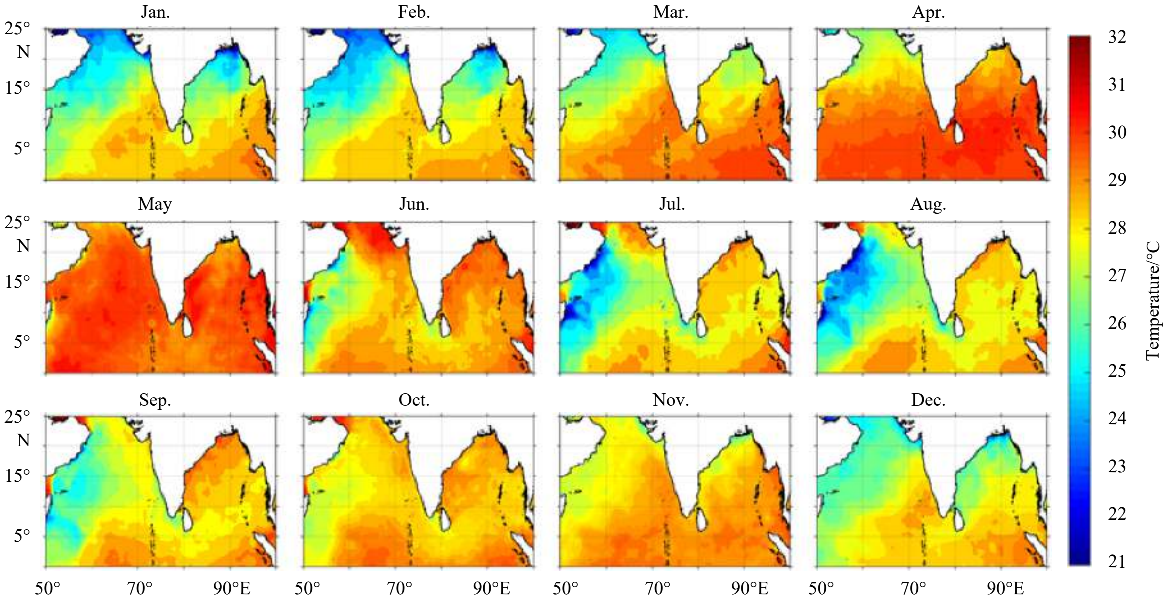

Fig. 4. Monthly average of SST variation in the Bay of Bengal and Arabian Sea during 2013. (Data source: OISST).

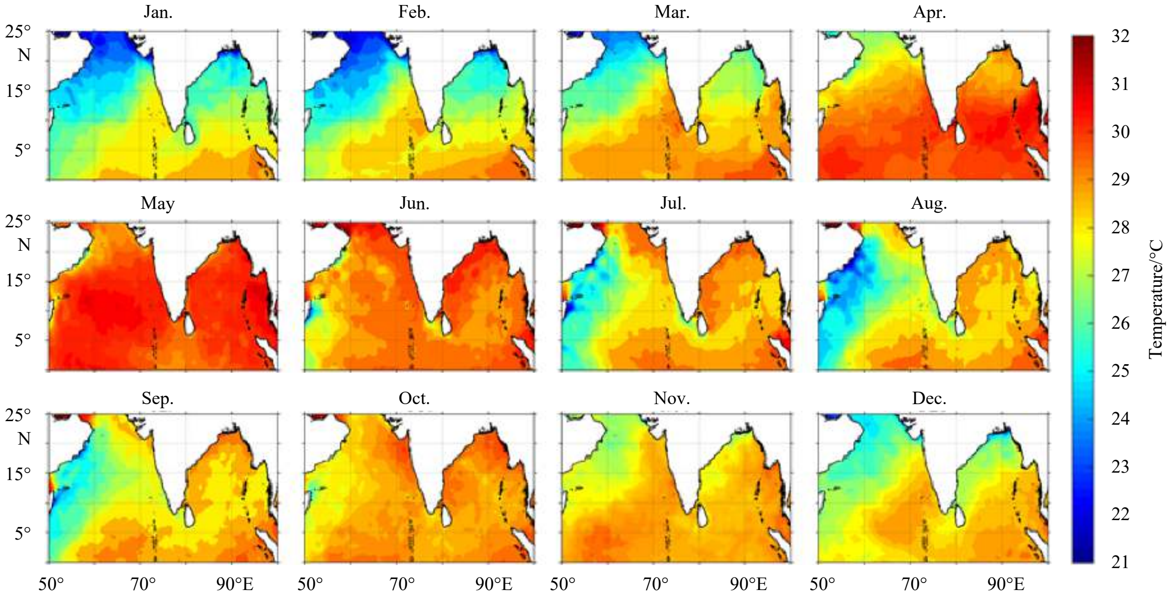

Fig. 5. Monthly average of SST variation in the Bay of Bengal and Arabian Sea during 2014 (data source: OISST).

SST within the BoB is well presented in the Fig. 7. The colder SST is a prominent feature in the northern BoB during NEM which gradually increase towards the southern BoB with the time. The warmest SSTs could be observed during 1st inter monsoon compared to other seasons in the BoB. Drifter data analysis during SWM provides the evidences for existence of eastward propagation of warmer currents in the southern BoB.

The SST variation along the drifter trajectories during 2013–2014 are presented in the Fig. 8. In consistent with remotely sensed data, drifter observations clearly indicate the existence of warmer SSTs in both basins during 1st inter-monsoon. It clearly indicates surface currents transport colder water into the AS and propagates westward after travelling around Sri Lanka during NEM. During SWM, surface currents brings warmer water into the BoB, where they change the flow direction more towards to the BoB with the progression of the SWM. Interestingly, it was noted that surface currents generated in the east of Sri Lanka flow towards to the equator during NEM, 1st inter-monsoon and SWM. Further, flow direction towards the pole ward could be observed only during 2nd inter-monsoon.

Thus, the drifter trajectories emphasize seasonal circulation between AS and the BoB more accurately.

Further, the results of the current investigation provide realistic proofs for temporal and spatial variation of surface currents and SSTs in the region. The data from RAMA moorings at 15°N, 90°E and 12°N, 90°E during January 2013 to December 2014 were analyzed for better understanding of spatial and temporal variations of observed circulation pathways. The seasonality in winds, air temperature, SST and salinity are well presented at the RAMA mooring during 2013 (Fig. 9) and 2014 (Fig. 10).

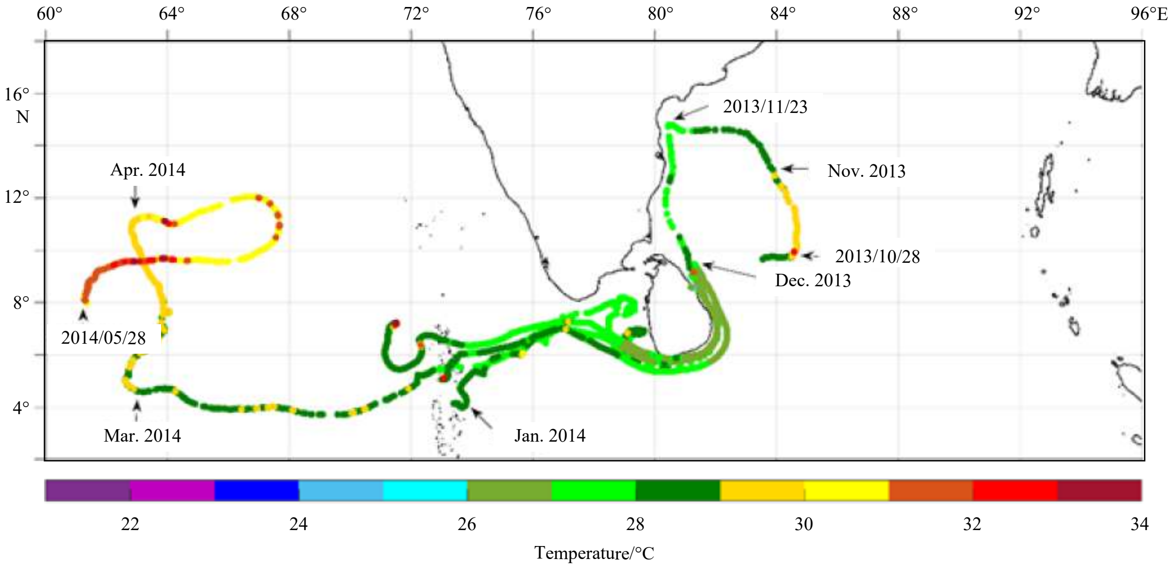

Fig. 6. Temperature variation observed along the drifter trajectories during November–February around Sri Lanka. The cold water currents along the Sri Lanka coast during NEM are well detected.

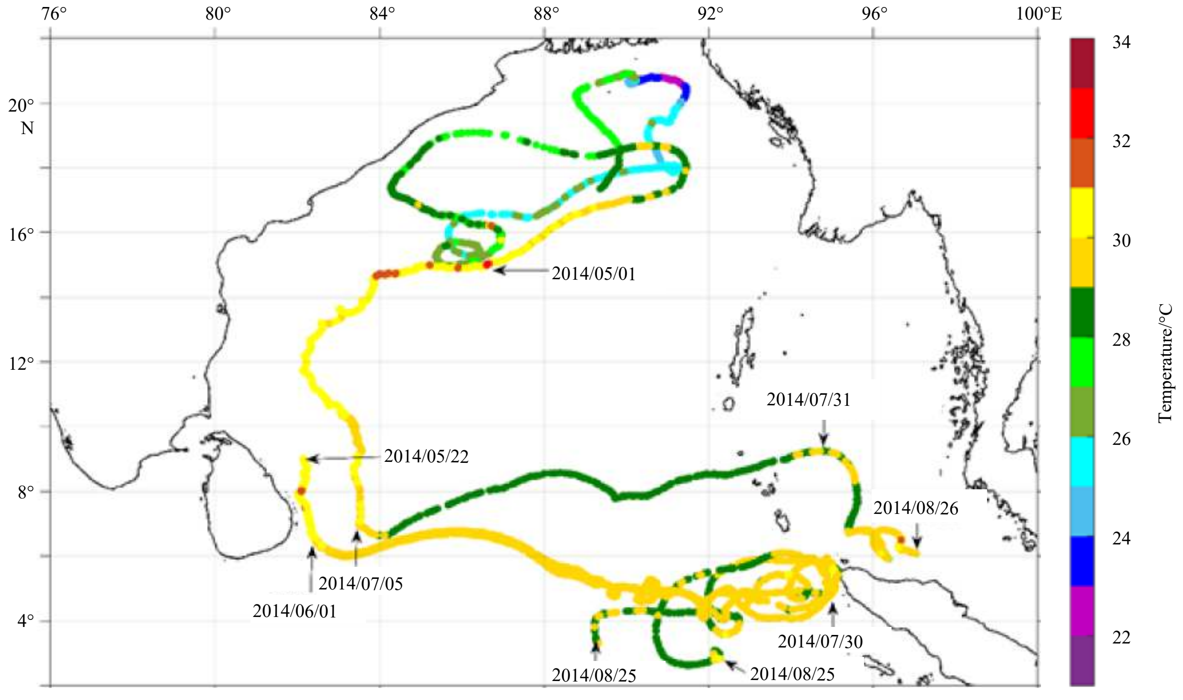

Fig. 7. Temperature variation observed along the drifter trajectories during May–August in the BoB. Eastward flowing warm water currents are well presented.

The seasonal cycle of SST observed along the drifter trajectories is well agreed with the seasonal cycle at the RAMA moorings. The highest SST could be during monsoon transitions while it was minimum during NEM (Figs 9 and 10).

3.3 *Sea surface height (SSH) anomaly controlled circulation in the BoB during summer monsoon (SM) 2014*

The monthly averaged sea surface height anomalies (SSHA) were integrated together with drifter trajectories to understand impact monsoon driven controlled factors. The daily products of SSH anomaly from Aviso data set (www.aviso.altimetry.fr/data/products/sea-surface-height-products/global) in the Indian Ocean (0°–25°N and 75°–100°E) was used to simulate during summer monsoon 2014 (July to September).

However, drifter trajectories were available only in the BoB in this time. SSH anomalies were obtained in centimeters and it is large as ±20 cm with westward propagation representing summer monsoon currents (Figs 11 and 12). The SSH anomaly diagrams clearly indicated the formation of meso scale eddies during the SM which are representing both cyclonic and anti-cyclonic status. The most of the meso scale eddies indicated the order of several hundred long and wide scales. The results further indicated the drifter trajectories are controlled by SSH anomalies in the area.

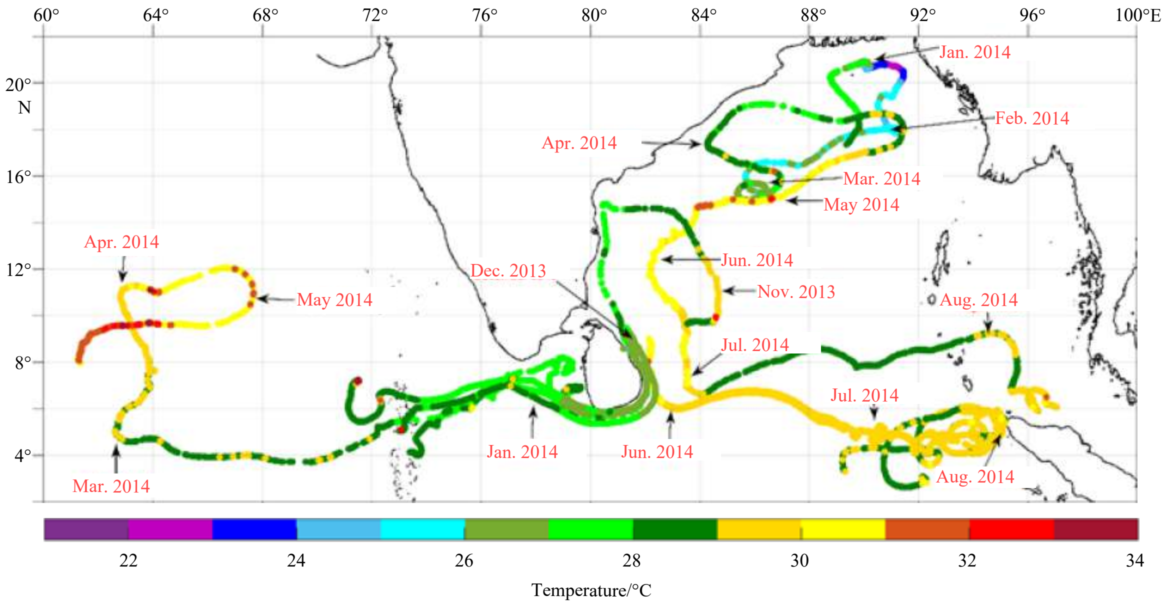

Fig. 8. Surface currents and temperature variation observed along the drifter trajectories between AS and BoB, during NEM (December–February) and SWM (June–September) period.

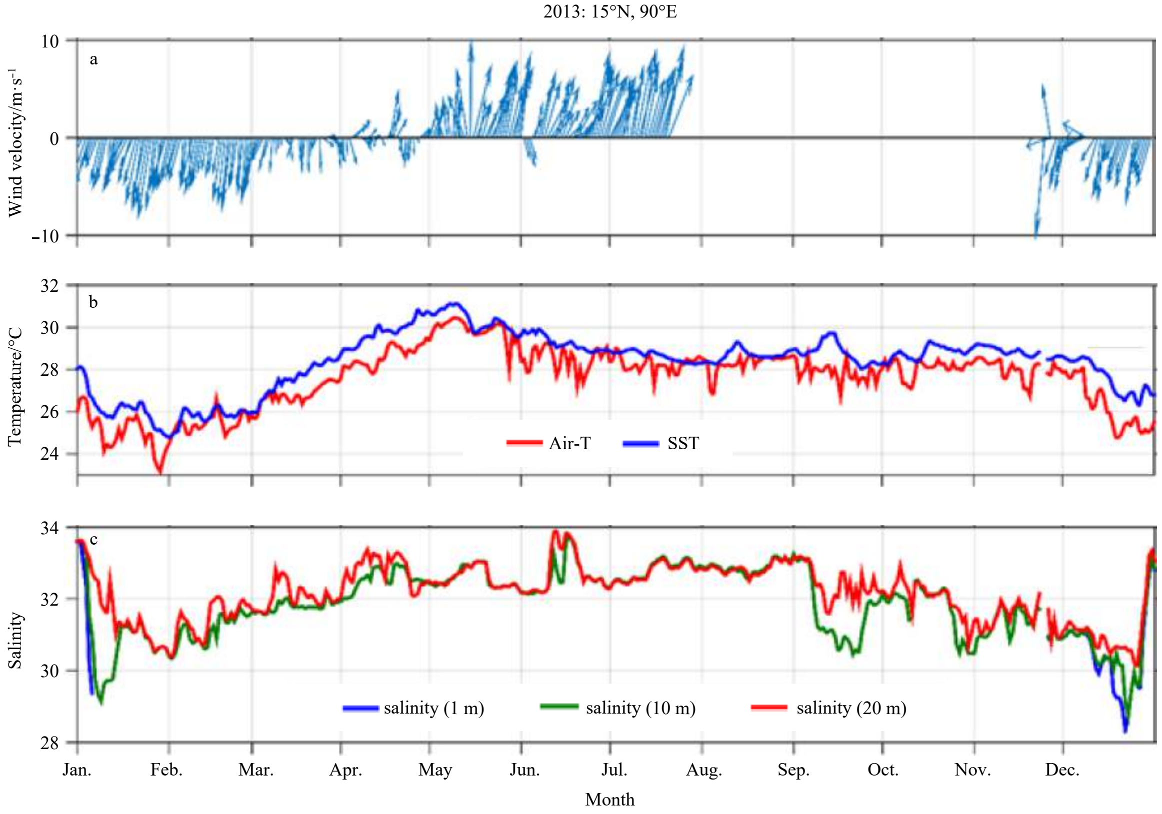

Fig. 9. Seasonal variation of wind speed (a), air temperature (Air-T: red line), SST (blue line) (b) , and SSS (blue line), salinity at 10 m depth (green line) and salinity at 20 m depth (red line)(c) at 15°N, 90°E during 2013 (data source: RAMA moorings, NOAA/PMEL).

4 Discussion

In this study, authors intended to explore the monsoonal impact on circulation pathways in the Indian Ocean using time series measurements from SVP drifters, RAMA moorings and satellite observations. Seasonality of the surface circulation between AS and BoB is well presented and agreed well with the previous studies. The *in-situ* observations illustrate the surface currents more accurately compared to that of earlier studies based on model simulations or satellite observations. This is a preliminary multi-national scientific effort to understand the circulation and mixing. However, our results provide more clear picture for understanding of the conditions in the BoB and AS.

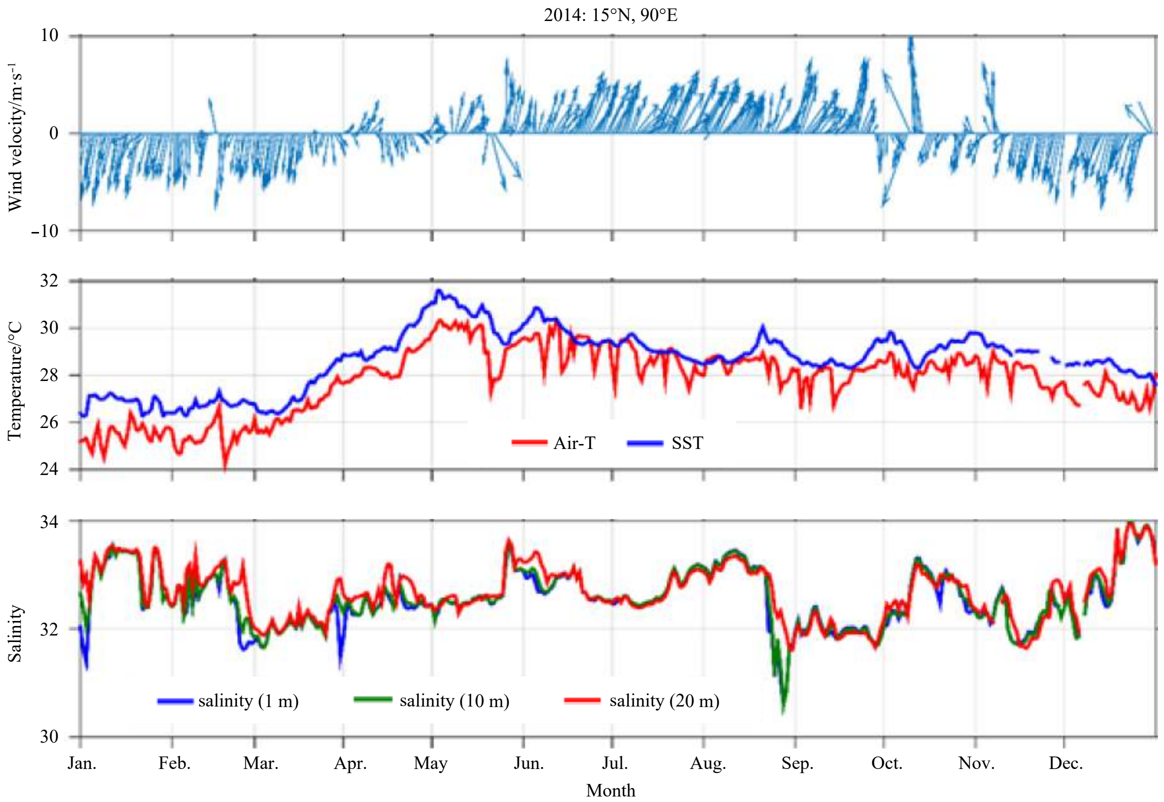

Fig. 10. Seasonal variation of wind speed (a), air temperature (Air-T: red line), SST (blue line) (b) , and SSS (blue line), salinity at 10 m depth (green line) and salinity at 20 m depth (red line) (c) at 15ºN, 90ºE during 2014 (data source: RAMA moorings, NOAA/PMEL).

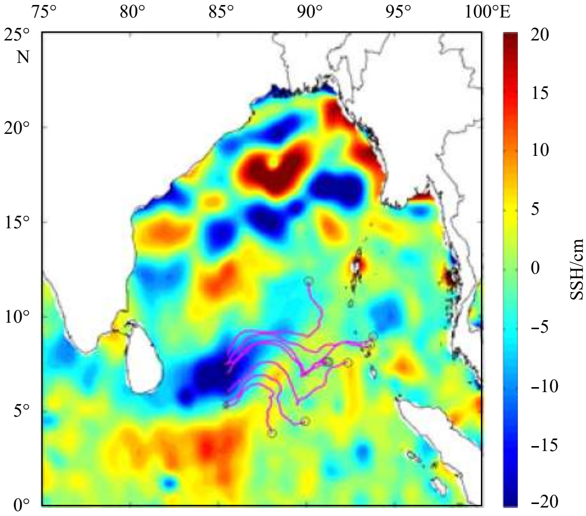

Fig. 11. SSH anomaly map for July 2014. The lines indicate drifter tracks for month of July 2018. The crosses and circles indicate starting and ending points (source: www.aviso.ltimery.fr).

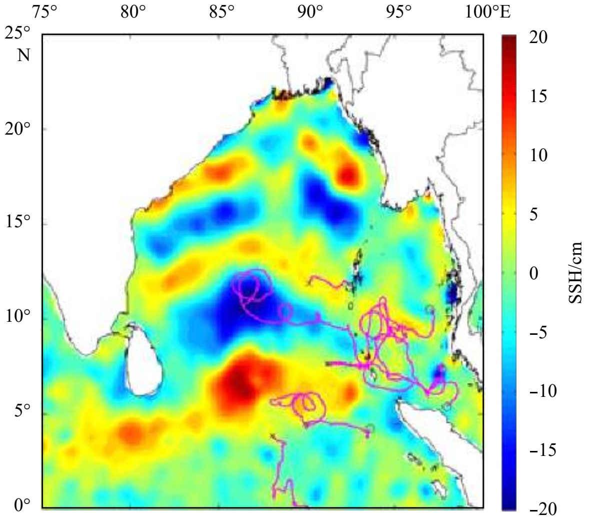

Fig. 12. SSH anomaly map and drifter tracks for August–September 2014. Some drifters moved southward, and some moved eastward (source: www.aviso.altimetry.fr).

Further, the observations provide well established platform to enhance the model simulations and predictions in the region.

Monsoon onset, tenor and breakdown vary in time. It was noted that year to year variability of the monsoons in the region during this investigation. The seasonal changes of surface circulation response to the monsoon condition in the region. Therefore, it is important to understand the onset, tenor and intensity of the monsoon for accurate predictions of the monsoon derived surface circulation. Stronger wind is observed during SWM than the NEM and the impact of this is well presented in the surface currents. The formation of eddy like features was prominent during SWM which is leading to the mixing in the region. Absence of eddy like features during monsoon transitions is suggesting the weaker winds. The *in-situ* observations from RAMA moorings clearly indicate the changes in the monsoon cycle in the region. During the NEM western boundary currents of the Bay of Bengal tends to flow along the east coast of India and Sri Lanka (SL) as part of the EICC (Vinayachandran et al., 2005). It is evident that in the results, surface currents flow from the BoB towards AS during NEM along the east and south coasts of Sri Lanka. But it is interestingly noticed that the surface currents tends to flow towards more westward instead of chasing the path of WICC after passing the south of Sri Lanka during NEM. However, none of the drifters were travelled around Laccadive High (LH) due to the influence of winter monsoon current. The drifters travel southwest direction after passing south of Sri Lanka around 70° during NEM instead of travelling towards the northwest direction similar to that stated in Schott and McCreary (2001).The seasonality followed by the changes in the monsoons and the year to year variability of the conditions emphasize the complexity of the region. Further, the real time drifter observations demarcated that the EICC is closer to the east coast of India and Sri Lanka as NEM progresses and shifts further away from the coast as the NEM disappears.

Water mass exchange between AS and the BoB is well presented in the results. Normally, whole drifters follow the path ways around Sri Lanka and none of the drifters cross the pathway through the Palk Strait during NEM. This suggests that the major exchange pathways between AS and the BoB is around Sri Lanka during NEM. Though drifter derived pathways are exactly similar to the model simulations, systematic and detail *in-situ* measurements along the Palk Strait are required for confirmation. The study of drifter derived water mass exchange through Palk Strait is not an easy task. However, alternative routines are required due to the importance of studying the exchange through Palk Strait.

The sea surface height (SSH) observations do not coincide with the drifter trajectories. Thus, it brings the importance of an observation system for a complex region like northern Indian Ocean. AS and the BoB are well noted in the literature due to their remarkable differences in salinity. Though the drifter trajectories pointed out the seasonal surface circulation with SSTs accurately, still they are lack with salinity observations. The salinity observations along the drifter trajectories will be a very good indicator to point out the exchange pathways between AS and the BoB. Divergence of currents (Potemra et al., 1991) and decrease of SST (Rao et al., 2010) together suggest a possibility of upwelling phenomenon associated with Sri Lanka coast. Earlier studies based on ocean color images on chlorophyll distribution in the region suggests the potential upwelling areas close to west and south coast of Sri Lanka during SWM (Vinayachandran et al., 2004; de Vos et al., 2014).Thus, the accurate observations of surface currents and SSTs from the drifters are the potential out puts to improve the biological studies, search and rescue missions and mitigation of hazards in the region.

The investigation reveals that major controlling factor for the circulation in the BoB is cyclonic and anti-cyclonic eddies represented by SSH anomalies. The well develop cyclonic (negative SSH anomaly) and anti-cyclonic (positive SSH anomaly) eddies could be observed in the SSH anomaly simulation with 250–400 km long and 200–300 km width. Drifter trajectories follow the direction of eddies during most of the time. The meso-scale cyclonic feature observed (Fig. 10) in the east of Sri Lanka appears during summer monsoon is identified as well-known Sri Lanka Dome (Vinayachandran and Yamagata, 1998; Wijesekera et al., 2015).

5 Conclusions

The research findings of monsoon onset, tenor and strength of monsoons over the northern Indian Ocean indicate a yearly shifting during the study period. In consistent with previous studies, surface circulation follows a seasonal cycle responding to the variability of monsoonal conditions in the region. Surface currents during NEM trace the wintertime freshwater exchange between the BoB and AS while it reverses the direction forming more cyclonic and anti-cyclonic eddies along the pathways during SWM. Surface currents during SWM are much stronger than NEM which influence the mixing and stirring of the basin. During NEM, EICC flowing around Sri Lanka, trail the west/southwest direction, instead of passing through Laccadive High to connect with the WICC. SST indicates a prominent seasonal cycle and the spatial variability of SST during NEM is higher than that noted during SWM in the region. The drifter trajectories provide a thorough understanding of the major circulation pathways between the AS and the BoB and further highlight the connection with the coastal currents. However, no evidences were found for water exchange through Palk Strait during the investigations. Hence, it requires more systematic *in-situ* measurements to understand the water mass exchange via Palk Strait. Further, some mis-matches in drifter trajectories and SSH anomalies measurements were observed (Figs 11 and 12). However, results indicated that drifter trajectories were controlled by SSH anomalies following eddy circulations. Further, negative anomaly of SSH (cyclonic feature) appears in Fig. 12 is well known Sri Lanka Dome which form during summer monsoon in the BoB. The overall results of the current investigation imply the importance and necessity of an accurate observation system for this complex region as an alternative approaches.

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