

On monitoring two major current systems of the north

Indian Ocean using an array of deep-sea moorings

Vineet Jain · P. Amol · S. G. Aparna

Abstract The region between the southern tip of the Indian subcontinent and the equator links the Arabian Sea and the Bay of Bengal. A significant exchange of mass, heat and salt occurs in the region via two major current systems: the monsoon current (dominant annual cycle), and the equatorial current (dominant semi-annual cycle). This paper presents observations from deep-sea mooring programmes and describes the rationale for maintaining a mooring array along 77.4°E to monitor both current systems. Analysis shows that the semi-annual to annual cycle transition occurs at 2–2.5°N, with the winter monsoon current peaking at 5°N, the summer monsoon current at 3–6°N, and the equatorial current at 0–1°N.

Vineet Jain · S. G. Aparna

CSIR-National Institute of Oceanography, Goa, India

P. Amol

CSIR-National Institute of Oceanography Regional Centre, Visakhapatnam, India

Corresponding author: P. Amol, E-mail: amol@nio.org

Keywords: Monsoon currents; Equatorial Indian Ocean currents; OSCAR currents; ADCPs.

1 Introduction

The monsoon current in the north Indian Ocean is a seasonally reversing current that flows eastward from the Arabian Sea to the Bay of Bengal during summer (June–September) and reverses direction during winter (November–February). Based on the season, the current is referred to as Summer Monsoon Current (SMC) or Winter Monsoon Current (WMC). In the mature phase, the monsoon current extends from the Somali coast to the eastern Bay of Bengal, but it does not form or decay over the entire region at the same time (Shankar *et al.* 2002). South of the monsoon current is the equatorial current, which reverses direction four times a year. The strong eastward equatorial current during spring (April–May) and fall (October–November) is known as the Wrytki Jet and is a unique feature of the Indian Ocean (Schott and McCreary 2001, and references therein).

In the central Indian ocean, the monsoon current flows through a bottleneck geographically constrained by the Indian subcontinent in the north and the equator in the south (figure 1b). In this region, the current has to squeeze between the equatorial and the coastal currents, whose extent depends on the deformation length scale. Shankar *et al.* (2002) noted a switch in the dominant frequency from annual (365-day) in the regime of the monsoon currents to semi-annual (180-day) in the equatorial regime at 80.5°E south of Sri Lanka;

they used geostrophic estimates from the altimeter. This switch is also evident in the direct current measurements (Schott *et al.* 1994).

The region also provides a major pathway for exchanging heat, salt and other tracers between the Arabian Sea and the Bay of Bengal (Schott *et al.* 1994; Reppin *et al.* 1999; Schott and McCreary 2001). During the summer monsoon, the SMC transports high salinity surface waters from the Arabian Sea to the Bay of Bengal and helps maintain the cold pool east of Sri Lanka. At deeper depths, the SMC advects oxygenated high-saline water masses, like Persian Gulf Water (PGW) and the Red Sea Water (RSW; Jain *et al.* 2017). Similarly, the WMC carries fresher water from the Bay of Bengal to the Arabian Sea and plays a vital role in the formation of a warm pool in the Lakshadweep Sea. The monsoon current is also known to enhance chlorophyll concentrations in the southwestern Bay of Bengal (Vinayachandran *et al.* 2004) and the southeastern Arabian Sea (Amol *et al.* 2020) through advection.

Just like the monsoon currents, the equatorial currents play an important role in the redistribution of water masses in the Indian Ocean. The observations from 80.5°E show that the zonal transport has a seasonal asymmetry and the maximum transport occurs when the fall Wyrtki jet is at its peak (Reppin *et al.* 1999). The transient undercurrent peaks during February-March. Similarly, the cross-equatorial transport has a seasonal cycle associated with anti-symmetric zonal wind stress (Wang and McPhaden 2017). The currents flowing southward during the summer monsoon and northward during the winter monsoon.

Despite the important role of the monsoon current in governing the dynamics of the north Indian Ocean, there are no long-term current measurements available in this region. The mooring programmes Current Observation and Simulation in the Indian Exclusive Economic Zone (COSINE) and Equatorial Current Observations for Indian Ocean Dynamics (ECO-IOD) monitor currents along India's coast and the central equatorial Indian Ocean (figure 1a; Chaudhuri *et al.* 2020; Jain *et al.* 2021). The Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA) and Tropical Indian Ocean Observation Network (TIOON) also maintain similar mooring networks that primarily measure currents in the equatorial Indian Ocean (McPhaden *et al.* 2009; Zeng *et al.* 2021).

Currently, COSINE and ECO-IOD combined have three moorings in the bottleneck (figure 1a,b). The moorings lie along 77.4°E and extends from the equator to the southern tip of India (7°N). However, these moorings do not capture the core of the monsoon currents, which is important to understand interbasin exchange between the Arabian Sea and the Bay of Bengal. It is possible to monitor these two major current systems with a minor expansion of the mooring network under these two programmes.

This paper presents data from the two mooring programmes and compares them with Ocean Surface Current Analyses Real-time (OSCAR) data. We use the data along 77.4°E to identify the regions where the monsoon and equatorial currents peak and show the transition zone between these two current systems. We further use these identified regions to describe the rationale for maintaining

a sustained mooring array to monitor current systems. The rest of the paper is organised as follows. Section 2 describes the data used. Section 3 describes the variability of currents south of India using satellite and mooring data. Section 4 summarises and concludes the paper.

2 Data

We use OSCAR currents and data from Acoustic Doppler Current Profilers (ADCPs) deployed on five moorings south of India. OSCAR product is funded by NASA Earth Science and uses satellite fields to create surface currents based on three factors: geostrophy, Ekman dynamics, and thermal winds. The data are provided on global $1/3^\circ$ grid every 5 days, and are available from 1993 to present. These data are freely available through the NASA Physical Oceanography data center (<http://podaac.jpl.nasa.gov>). The velocity terms derived using geostrophic relationships and Ekman-like formulation are singular on the equator, hence the velocity is estimated between 8°N and 8°S as a linear combination of orthogonal polynomials in the OSCAR product.

The ADCP moorings are approximately along the 77.4°E meridian and are spread from the southern coast of India to the south of the equator. The mooring locations and water depth at these locations are as follows: off Kanyakumari (77.39°E , 6.96°N , ~ 1000 m), 3°N (77.36°E , 3°N , ~ 4000 m), 1°N (77°E , 1°N , ~ 4055 m), equatorial (77.36°E , 0°N , ~ 4750 m), and 1°S (77°E , 1°S , ~ 4780 m). Hereafter, the moorings are referred to using the respective latitudes.

The data from the 7°N (off Kanyakumari) mooring have been described in detail earlier in Chaudhuri *et al.* (2020). The data from 0°N have been shown earlier in Jain *et al.* (2021) and Amol *et al.* (2022) but were not discussed in detail. The data from the other 3 moorings are being presented for the first time. These data are available for a large depth range (~ 50 m to ~ 1400 m). The data are not available above 50 m since the top 10% of the ADCP data are contaminated by the surface backscatter. The data were collected from 2 years (3°N) to 20 years (0°N; Fig 1c) and are discontinuous with data gaps varying from a few days to a few years. See Fig. S1 in supplementary material for data availability in depth.

As there are large data gaps in the ADCP data, we have used Lomb-Scargle Periodogram to estimate the power spectral density. For OSCAR data, we have used Fast Fourier Transform (FFT), except when the data are compared with the ADCP data.

3 Zonal current variability at 77.4°E

This section describes the current variability using data from five ADCP moorings deployed between the southern tip of India and the equator along 77.4°E. The near-surface ADCP currents are compared with the OSCAR currents, which is then used to highlight the annual and semi-annual transitions. We also limit our analysis to the semi-annual and annual cycles of zonal currents.

The data show that the current magnitude is strongest for the equatorial moorings between 1°N and 1°S. The values range from -2 m s^{-1} to 2

m s^{-1} , with positive values indicating eastward current (figure 2). The eastward flow is stronger than the westward at all these three locations, and the mean calculated over the available years is positive and greater than 0.25 m s^{-1} . The maximum amplitude is observed at 1°N , where the speed sometimes exceeds 2 m s^{-1} . The climatology computed using these data sets does not show any significant difference between the spring (April–May) and the fall (October–November) Wyrтки jets (figure 2). However, the westward flow during the summer monsoon (June–September) is weaker than the winter monsoon (November–February), and this difference is more prominent at 1°N . The periodogram for the three moorings show strong semi-annual peaks (figure 2).

The currents at 3°N and 7°N are relatively weak ($< 0.8 \text{ m s}^{-1}$). The eastward and westward flow have a similar magnitude, and the mean flow is close to zero at 7°N and 0.09 m s^{-1} at 9°N . The periodogram at these two locations show strong peaks for the annual cycle. The semi-annual cycle is absent at 7°N and weak at 3°N . Note that the 3°N record is only two years long, so the spectral peaks are not conclusive at seasonal timescales.

Continuous near-surface data is available from the OSCAR product at these locations, and the data correlates well (> 0.70) with the near-surface (50 m) ADCP currents (Fig 2a–e). The correlations are higher for the climatological currents. The periodograms of OSCAR data follow the trends seen in the ADCP data — 180-day peaks at 1°N , equator and 1°S locations, 365-day peak at 7°N , and both peaks in the transition zone at 3°N (red curves in Fig 2).

The high correlations with the ADCP data indicate that the OSCAR product does reasonably well in the equatorial Indian Ocean despite the underlying assumptions discussed in Section 2. The spatial coverage of OSCAR data allows the evaluation of where the currents are strongest. The daily climatological OSCAR current (Fig. 3c) shows that north of 3°N , eastward flow (SMC) is seen in May–October and westward flow (WMC) in November–April. The SMC first peaks at 6°N , which is closer to the coast, and the maxima in the amplitude slowly shift towards the equator, approaching $2\text{--}3^{\circ}\text{N}$ by October. However, the WMC peaks around 5°N without any major shift. South of 3°N , strong eastward flow (Wrytki Jets) is seen in April–May and November–December, and weaker westward flow in January–March and June–July.

Fig 3a shows the FFT annual band power of OSCAR zonal current. The annual cycle in the eastern Arabian Sea (western Bay of Bengal) is stronger near the equator ($5^{\circ}\text{N}\text{--}10^{\circ}\text{N}$). The strongest annual signal is seen between $75\text{--}85^{\circ}\text{E}$, $4.5\text{--}7^{\circ}\text{N}$. This is the region where the monsoon current is constrained by the land in the north and the equatorial regime in the south. The semi-annual FFT band (equatorial regime) is the strongest west of 80°E between 1.5°N and 1.5°S (Fig 3b). The common region of strong annual and semi-annual peaks lies between $74\text{--}79^{\circ}\text{E}$. The 77.4°E meridian passes through this region. Existing moorings and strong currents along 77.4°E , makes it an ideal region for establishing a mooring network to monitor the monsoon and equatorial current systems.

Fig 3d shows the transition between the equatorial and monsoon currents along 77.4°E . The semi-annual band is strong between 3°N and 2°S , and the annual band is strong north of 2°N (Fig. 3d). The transition occurs between 2.0°N - 2.5°N , where the magnitude of the semi-annual cycle is the same as the annual cycle. It is to be noted that the wavelet power is not uniformly strong in all years (Jain *et al.* 2021), indicating that the forcing for the currents is not entirely stationary.

What happens to these dominant frequencies with depth? The spectral analysis of the ADCP current shows that the semi-annual cycle is strong at deeper depths in the equatorial region as well as at 3°N (Fig. S2 in supplementary material). This semi-annual band extends from the surface to ~ 1000 m at these locations. However, the strongest peaks are not observed near the surface but at a deeper depth. Similar features were evident at 83°E mooring, and Amol *et al.* (2022) showed that the peaks in spectral power at deeper depths were due to the downward propagation of energy along the Rossby ray paths. The annual cycle at 7°N is seen only in top 200 m and weakens at deeper depths. The intraseasonal periods are stronger and extends till the bottom. Longer records are required in the peak monsoon current regime to analyse the influence of the annual cycle of winds on deeper currents.

4 Discussion

The monsoon current is thought to be driven by a conglomeration of different processes, whose effect varies with region (Schott and McCreary 2001). The

processes include the local wind-stress curl or Ekman pumping in the central Bay of Bengal, the reflection of the equatorial Kelvin wave in the eastern Bay of Bengal, and the Rossby wave radiation in the southeastern Arabian Sea. In addition to the change in direction, the variation in forcing mechanisms can cause differences in current magnitude between SMC and WMC. This difference is also evident at 77.4°E , which lies in the bottleneck region of the central Equatorial Indian Ocean. The climatology of OSCAR currents shows that the WMC peaks at 5°N , but the SMC peaks vary from $3\text{--}6^{\circ}\text{N}$.

As the monsoon current flows through the bottleneck, it is impacted by the coastal current in the north and the equatorial current in the south. The spectral analysis shows that the transition from semi-annual to annual occurs between $2\text{--}2.5^{\circ}\text{N}$. The transition occurs at a similar latitude south of Sri Lanka and is evident in the observations shown by Schott and McCreary (2001). In addition, the coastal current could also be in the opposite direction of the monsoon current. For example, Schott and McCreary (2001) showed a narrow westward current that carries low salinity water along the southern coast of Sri Lanka during the summer monsoon, thereby creating a shear with the eastward flowing SMC.

The annual cycle is also the strongest in this bottleneck region and east and west of this region, the monsoon currents meander, and hence the location and timing of the monsoon currents change each year (Shankar *et al.* 2002), which could lead to a weak spectral peak. The peak in the annual cycle also slopes from 0°N in the west to 10°N in the east. As the monsoon current is linked

to the Rossby waves that are generated from the eastern boundaries, this tilt of the annual cycle from west to east may be linked to the beta dispersion of the Rossby waves (Schopf *et al.* 1981). However, the westward propagation of Rossby waves will be affected by the Maldiv Islands located at 73°E .

Despite the monsoon current playing a significant role in the north Indian Ocean dynamics, no long-term current measurements, similar to RAMA, are available away from the coastal region. Stronger equatorial and monsoon currents along 77.4°E and existing moorings, under COSINE and ECO-IOD projects, along this meridian provide a unique opportunity to extend the mooring network to include observations to map both the equatorial and monsoon currents. Currently, three moorings are collecting data along 77.4°E . On a priority basis, the first new mooring could be deployed at 5°N , and this mooring would capture both the WMC and SMC (See figures 1, 3). The mooring at 6°N and the existing mooring at 3°N will cover the SMC. The remaining two moorings can be deployed at 1.5°N and 1.5°S for the equatorial currents. The 3°N mooring will also pick the currents at the transition zone. The existing 7°N mooring on the continental slope will measure the boundary currents.

The monsoon current can also be mapped south of Sri Lanka. In this case, the network would require a fewer number of moorings. Currently, one mooring each from RAMA (0°N , 80.5°E) and TIOON (2.5°E , 80°E) are in this region. Extending this mooring network, which includes measurements in the Sri Lankan Exclusive Economic Zone, requires international collaboration.

In addition to transport of water masses, long-term monitoring of these currents is of interest to understand the effect of climate modes like the Indian Ocean Dipole (IOD) and El Niño on the current variability and its subsequent implications for the weather and rainfall patterns on the Indian subcontinent. The data from these moorings will add to developing the operational ocean forecast and reanalysis system for the north Indian Ocean (Francis *et al.* 2020).

Acknowledgements

The authors thank D. Shankar for his critical comments. The support from A. Chaudhuri, CSIR-NIO mooring group (V. Fernando, N. P. Satelkar, S. T. Khalap, S. Ghatkar, P. A. Tari, and M. G. Gaonkar), A. Kankonkar, ship cell members, officers, crew, and seamen from various cruises is gratefully acknowledged. The mooring operations were carried out on the research vessels ORV Sagar Kanya, RV Sindhu Sadhana, and TDV Sagar Nidhi. VJ acknowledges funding support from ESSO-INCOIS. We acknowledge the following sources for data: The OSCAR-current products were obtained from the NASA EOSDIS Physical Oceanography Distributed Active Archive Center (PO.DAAC) at the Jet Propulsion Laboratory, Pasadena, CA. Python modules were used for analysis and graphics. This is CSIR-NIO contribution XXXX.

Author statement

Vineet Jain, and P. Amol drafted the manuscript. Vineet Jain and P. Amol processed, analysed, and interpreted the data. Vineet Jain, P. Amol, and S. G. Aparna conceived and designed the study.

References

- Amol P, Bernal S, Shankar D, Jain V, Thushara V, Vijith V and Vinayachandran P 2020 Modulation of chlorophyll concentration by downwelling Rossby waves during the winter monsoon in the southeastern Arabian Sea; *Progress in Oceanography* **186** 102,365; <https://doi.org/10.1016/j.pocean.2020.102365>.
- Amol P, Jain V and Aparna S 2022 Blue-shifted deep ocean currents in the equatorial Indian Ocean; *Climate Dynamics* 1–11; <https://doi.org/10.1007/s00382-021-06125-9>.
- Chaudhuri A, Shankar D, Aparna S G, Amol P, Fernando V, Kankonkar A, Michael G S, Satelkar N P, Khalap S T, Tari A P, Gaonkar M G, Ghatkar S and Khedekar R R 2020 Observed variability of the West India Coastal Current on the continental slope from 2009–2018; *Journal of Earth System Science* **129**; <https://doi.org/10.1007/s12040-019-1322-3>.
- Francis P A, Jithin A K, Effy J B, Chatterjee A, Chakraborty K, Paul A, Balaji B, Shenoi S S C, Biswamoy P, Mukherjee A, Singh P, Deepsankar B, Reddy S S, Vinayachandran P N, Kumar M S G, Bhaskar T V S U, Ravichandran M, Unnikrishnan A S, Shankar D, Prakash A, Aparna S G, Harikumar R, Kaviyazhahu K, Suprit K, Shesu R V, Kumar N K, Rao N S, Annapurnaiah K, Venkatesan R, Rao A S, Rajagopal E N, Prasad V S, Gupta M D, Nair T M B, Rao E P R and Satyanarayana B V 2020 High-resolution operational ocean forecast and reanalysis system for the Indian Ocean; *Bulletin of the American Meteorological Society* **101** E1340 – E1356; <https://doi.org/10.1175/BAMS-D-19-0083.1>.

- Jain V, Amol P, Aparna S G, Fernando V, Kankonkar A, Murty V S N, Almeida A M, Sardar A A, Khalap S T, Satelkar N P, Ghatkar S, Tari P A, Gaonkar M G and Khedekar R 2021 Two decades of current observations in the equatorial Indian Ocean; *Journal of Earth System Science* **130**; <https://doi.org/10.1007/s12040-021-01568-4>.
- Jain V, Shankar D, Vinayachandran P N, Kankonkar A, Chatterjee A, Amol P, Almeida A M, Michael G S, Mukherjee A, Chatterjee M, Fernandes R, Luis R, Kamble A, Hegde A K, Chatterjee S, Das U and Neema C P 2017 Evidence for the existence of Persian Gulf Water and Red Sea Water in the Bay of Bengal; *Climate Dynamics* **48** 3207–3226; <https://doi.org/10.1007/s00382-016-3259-4>.
- McPhaden M J, Meyers G, Ando K, Masumoto Y, Murty V S N, Ravichandran M, Syamsudin F, Vialard J, Yu L and Yu W 2009 RAMA: The Research Moored Array for African–Asian–Australian Monsoon Analysis and Prediction*; *Bulletin of the American Meteorological Society* **90** 459–480; <https://doi.org/10.1175/2008BAMS2608.1>.
- Reppin J, Schott F A, Fischer J and Quadfasel D 1999 Equatorial currents and transports in the upper central Indian Ocean: Annual cycle and interannual variability; *Journal of Geophysical Research* **104** 15,495–15,514; <https://doi.org/10.1029/1999JC900093>.
- Schopf P S, Anderson D L T and Smith R 1981 Beta-dispersion of low-frequency Rossby waves; *Dyn. Atmos. Oceans* **5** 187–214; [https://doi.org/10.1016/0377-0265\(81\)90011-7](https://doi.org/10.1016/0377-0265(81)90011-7).
- Schott F A and McCreary J P 2001 The monsoon circulation of the Indian Ocean; *Progress in Oceanography* **51** 1–123; [https://doi.org/10.1016/S0079-6611\(01\)00083-0](https://doi.org/10.1016/S0079-6611(01)00083-0).
- Schott F, Reppin J, Fischer J and Quadfasel D 1994 Currents and transports of the Monsoon Current south of Sri Lanka; *Journal of Geophysical Research* **99** 25,127–25,141; <https://doi.org/10.1029/94JC02216>.
- Shankar D, Vinayachandran P N and Unnikrishnan A S 2002 The monsoon currents in the north Indian Ocean; *Progress in Oceanography* **52** 63–120; [https://doi.org/10.1016/S0079-6611\(02\)00024-1](https://doi.org/10.1016/S0079-6611(02)00024-1).
- Wang Y and McPhaden M J 2017 Seasonal cycle of cross-equatorial flow in the central Indian Ocean; *Journal of Geophysical Research* **122** 3817–3827; <https://doi.org/10.1029/2016JC012441>.

1002/2016JC012537.

Vinayachandran P, Chauhan P, Mohan M and Nayak S 2004 Biological response of the sea around Sri Lanka to summer monsoon; *Geophysical Research Letters* **31**; <https://doi.org/10.1029/2003GL018533>.

Zeng L, Chen G, Huang K, Chen J, He Y, Zhou F, Yang Y, Liang Z, Peng Q, Shi R, Gamage T P, Chen R, Li J, Zhang Z, Wu Z, Yu L and Wang D 2021 A Decade of Eastern Tropical Indian Ocean Observation Network (TIOON); *Bulletin of the American Meteorological Society* **102** E2034 – E2052; <https://doi.org/10.1175/BAMS-D-19-0234.1>.

Figure captions

Fig 1: Panel (a) shows the mooring locations in the north Indian Ocean, with triangle, circle, square and plus symbols marking COSINE, ECO-IOD, RAMA and TIOON moorings, respectively. Panel (b) shows the mooring array along 77.4°E south of India along with a schematic representation of the major current regimes in the north Indian Ocean. Monsoon current regime is shown in light-green color with arrows representing the approximate current direction. The red arrows are for the Summer Monsoon Current (SMC) and blue for the Winter Monsoon Current (WMC). The equatorial current regime is shown in light-red color with green arrow for the Wrytcki Jets and olive arrow for the westward Equatorial Current (EC). The coastal current regime is shown in light-blue color with black double-headed arrows marking the current direction. The hatched area marks the bottleneck and gray region marks the transition zone. Panel (c) shows the time period for which the respective moorings have been deployed. In panels (a) and (b), colors indicate mooring status — black for active, yellow for discontinued, and red for new proposed moorings.

Fig 2: Rows (a)–(e) show 50 m zonal current from moorings at 7°N , 3°N , 1°N , equator and 1°S along 77.4°E , respectively. Columns show the 30-day smoothed currents, the climatological currents, and the Lomb-Scargle periodogram from left to right. In all panels, ADCP data are shown in black color and OSCAR data are in red color. The numbers inside the panels indicate the correlation coefficients for 5-day smoothed (black color) and 30-day smoothed

currents (blue color) in first column, and between climatological currents in second column. OSCAR data time range is taken from September 2003 to August 2021 for calculating the periodogram and climatology at all 5 locations to match the maximum range available for ADCP data. The vertical dashed lines in periodogram panels mark the 90, 120, 180 and 365-day periods.

Fig 3: OSCAR zonal current variability. Panels (a) and (b) show the annual and semi-annual FFT power of the OSCAR zonal current in the Equatorial Indian Ocean. Panels (c) and (d) show the climatological current and FFT power along 77.4°E meridian, respectively. The new and existing mooring locations are marked by black crosses in panels (a)–(b) and by gray dashed lines in panels (c)–(d). The black solid vertical lines in panel (d) mark 90, 120, 180 and 365-day periods.

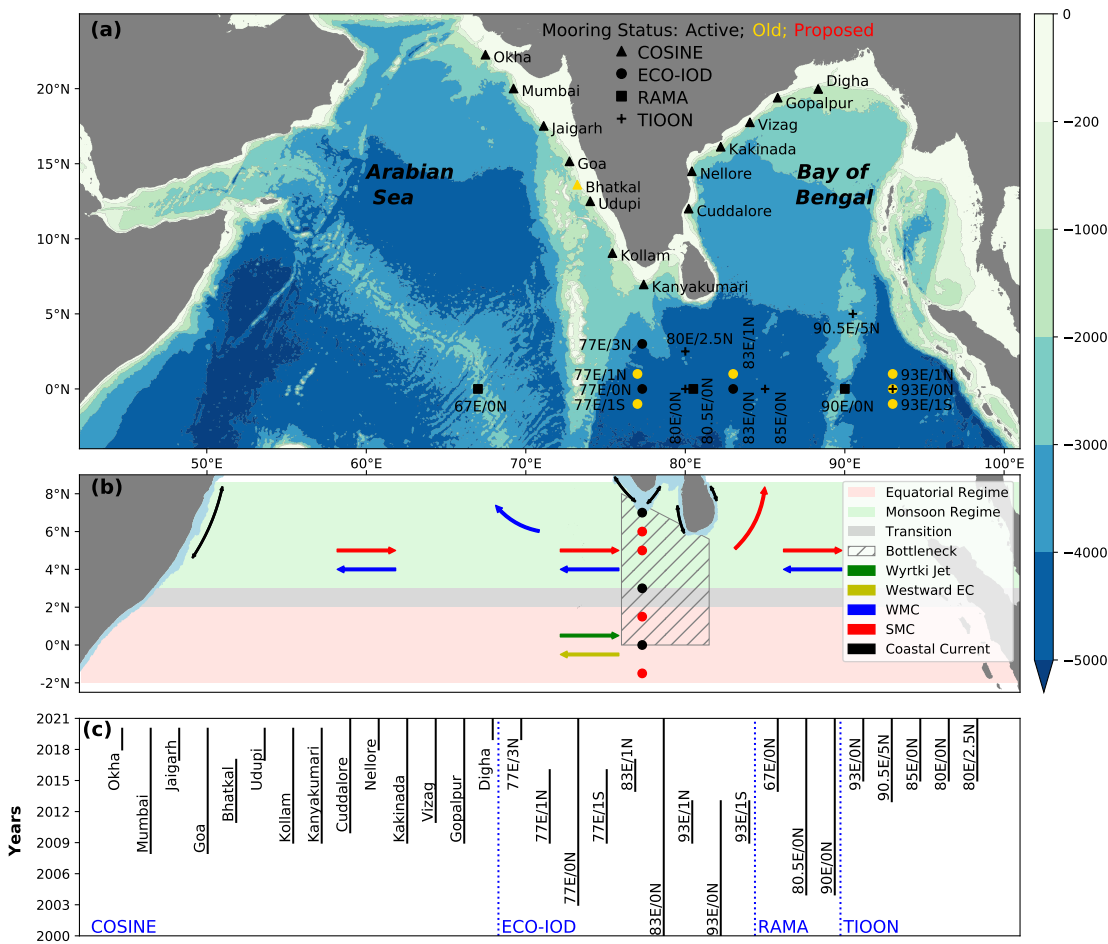


Fig. 1 Panel (a) shows the mooring locations in the north Indian Ocean, with triangle, circle, square and plus symbols marking COSINE, ECO-IOD, RAMA and TIOON moorings, respectively. Panel (b) shows the mooring array along 77.4°E south of India along with a schematic representation of the major current regimes in the north Indian Ocean. Monsoon current regime is shown in light-green color with arrows representing the approximate current direction. The red arrows are for the Summer Monsoon Current (SMC) and blue for the Winter Monsoon Current (WMC). The equatorial current regime is shown in light-red color with green arrow for the Wyrтки Jets and olive arrow for the westward Equatorial Current (EC). The coastal current regime is shown in light-blue color with black double-headed arrows marking the current direction. The hatched area marks the bottleneck and gray region marks the transition zone. Panel (c) shows the time period for which the respective moorings have been deployed. In panels (a) and (b), colors indicate mooring status — black for active, yellow for discontinued, and red for new proposed moorings.

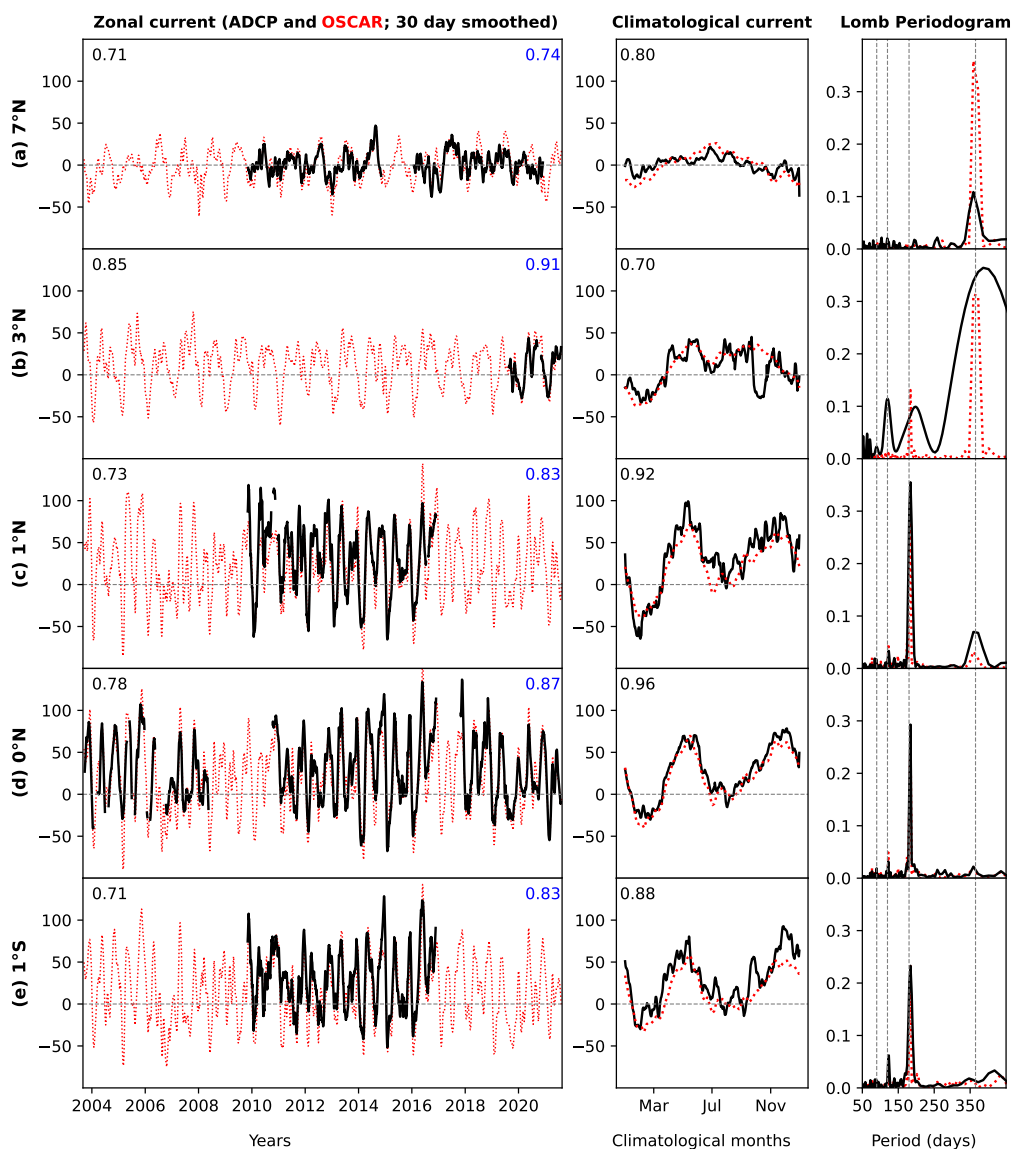


Fig. 2 Rows (a)–(e) show 50 m zonal current from moorings at 7°N, 3°N, 1°N, equator and 1°S along 77.4°E, respectively. Columns show the 30-day smoothed currents, the climatological currents, and the Lomb-Scargle periodogram from left to right. In all panels, ADCP data are shown in black color and OSCAR data are in red color. The numbers inside the panels indicate the correlation coefficients for 5-day smoothed (black color) and 30-day smoothed currents (blue color) in first column, and between climatological currents in second column. OSCAR data time range is taken from September 2003 to August 2021 for calculating the periodogram and climatology at all 5 locations to match the maximum range available for ADCP data. The vertical dashed lines in periodogram panels mark the 90, 120, 180 and 365-day periods.

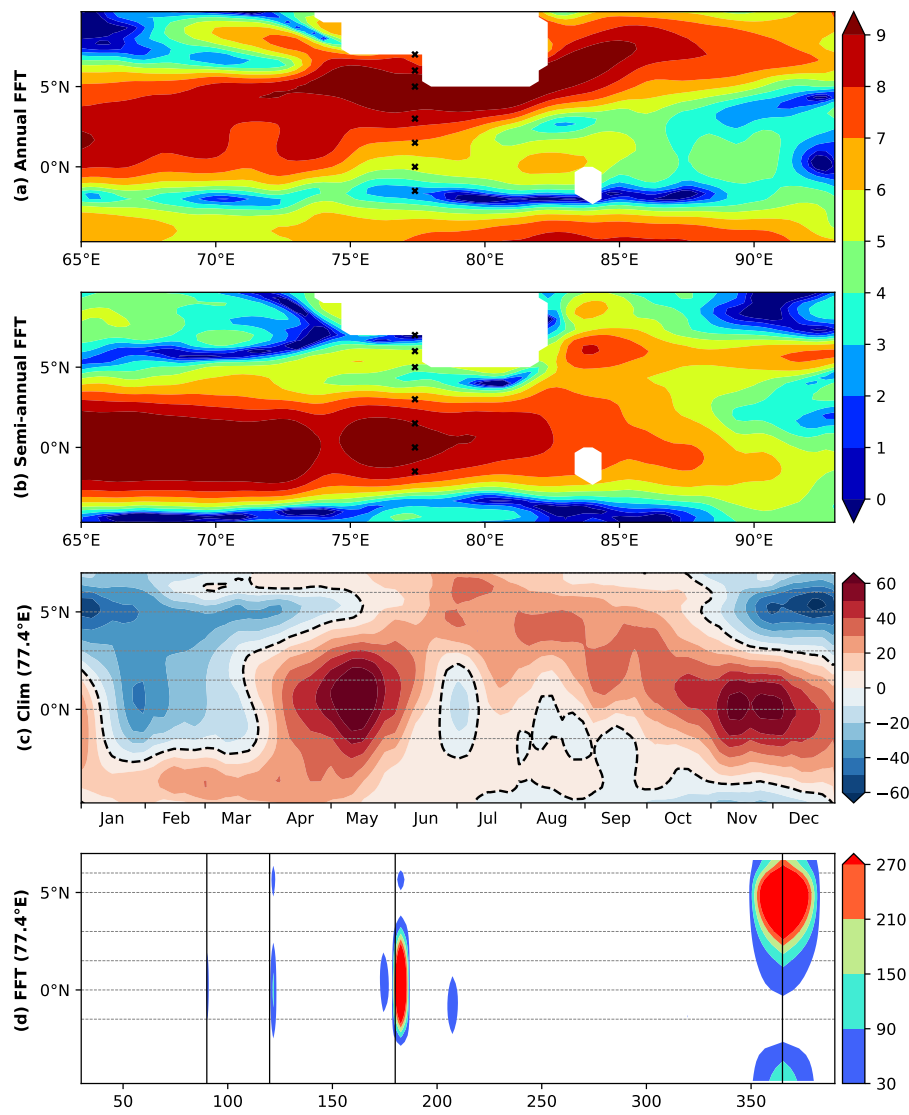


Fig. 3 OSCAR zonal current variability. Panels (a) and (b) show the annual and semi-annual FFT power of the OSCAR zonal current in the Equatorial Indian Ocean. Panels (c) and (d) show the climatological current and FFT power along 77.4°E meridian, respectively. The new and existing mooring locations are marked by black crosses in panels (a)–(b) and by gray dashed lines in panels (c)–(d). The black solid vertical lines in panel (d) mark 90, 120, 180 and 365-day periods.

Research highlights

1. Ocean current observations are shown in the monsoon and equatorial currents regime at 77.4°E
2. The transition between monsoon and equatorial current occurs at 2-2.5°N
3. Summer (winter) monsoon current is strongest at 3-6°N (5°N)
4. Minor expansion of existing mooring programmes to monitor two major current systems in the North Indian Ocean is proposed