Rover Publications
United International Journal of Engineering and Sciences (UIJES)
An International Peer-Reviewed (Refereed)Engineering and Science Journal
Impact Factor: 5.735 (SJIF) Vol-3, Issue- 2(July, August &September)2022
ISSN:2582-5887 www.uijes.com

Identification of Deep-Sea Meridional Currents in the Equatorial Indian Ocean Using Hybrid Coordinate Ocean Model (HYCOM) Model Simulations

***M. Anil Kumar[1], P. Suneetha[2], Sudheer Paul P[3]**
[12]Department of Meteorology and Oceanography, College of Science and Technology,
Andhra University, Visakhapatnam – 530003
[3]Department of Environmental Science, Andhra University, Visakhapatnam
*Corresponding Author: Dr. M. Anil Kumar; dranilmedi@gmail.com

Manuscript received March 03, 2022; revised April 15, 2022; accepted April 16, 2023; published April 19, 2022. DOI: 10.37854/UIJES.2022.3.2.98

Abstract

This study investigates the variability and dominant oscillatory behaviour of deep meridional currents in the Equatorial Indian Ocean (EIO) using HYCOM model simulations and supporting observational understanding. The EIO plays a crucial role in regulating regional and global climate variability through its dynamic ocean circulation, which influences heat transport, air–sea interactions, and biogeochemical processes. Understanding deep meridional current variability is therefore essential for interpreting ocean–atmosphere coupling and climate system responses. Wavelet analysis was applied to identify the dominant temporal scales of variability in meridional currents across different depths (500 m to 4000 m) and locations within the equatorial Indian Ocean. The results reveal that semi-annual oscillations represent the most dominant mode in HYCOM simulations, particularly in the central and eastern equatorial regions. These signals reflect strong seasonal reversals associated with monsoonal forcing and large-scale equatorial circulation changes. In addition, intra-seasonal oscillations (ISOs) were consistently observed and remained highly significant at both 2000 m and 4000 m depths, indicating strong vertical coherence and deep penetration of atmospheric forcing into the ocean interior. Bi-weekly oscillations were also identified as an important component of meridional current variability, especially in the upper and intermediate layers. These high-frequency signals are primarily confined to intra-seasonal time scales and are closely linked to the propagation of Madden–Julian Oscillation (MJO) activity. However, their intensity decreases with depth, where semi-annual and intra-seasonal signals become more dominant. This vertical structure suggests a transition from high-frequency surface-driven variability to more organized deep-ocean oscillatory modes.The study further highlights that meridional current variability is strongly modulated by large-scale climate teleconnections, including the El Niño–Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), and El Niño Modoki events. These climate modes influence the intensity and duration of intra-seasonal and semi-annual oscillations through changes in wind forcing, thermocline structure, and oceanic wave propagation. Overall, the results demonstrate that deep meridional currents in the equatorial Indian Ocean are primarily controlled by semi-annual and intra-seasonal variability, with significant contributions from bi-weekly oscillations in upper layers. The HYCOM model effectively captures these dominant modes, providing valuable insight into the role of atmospheric forcing and climate variability in shaping deep ocean circulation dynamics.

Key words: Current meters, HYCOM Model, MJO, Deep-Sea currents, IS Oscillations.

1. Introduction

The Equatorial Indian Ocean (EIO) plays a fundamental role in maintaining the global energy balance by acting as a key region for strong ocean–atmosphere interactions. It serves as a host to several coupled climate phenomena, including the Indian Ocean Dipole (IOD), Madden–Julian Oscillation (MJO), Indian Ocean warm pool, Quasi-Biennial Oscillations (QBOs), and biweekly oscillations (BIOs). In addition, the EIO is dynamically linked with the atmospheric general circulation through the seasonal north–south migration of the Intertropical Convergence Zone (ITCZ). The wind system over the EIO exhibits unique seasonal characteristics that distinguish it from the Equatorial Atlantic and Pacific Oceans. While the annual mean winds are relatively weak during the monsoon seasons, strong westerly wind bursts occur during the transition periods of boreal spring (April–May) and autumn (October–November) (Schott and McCreary, 2001).

Based on bathymetry and vertical structure, ocean currents are generally classified into surface, subsurface, and deep-sea currents. Each category plays a distinct role in the redistribution of momentum, heat, salt, and other oceanic properties.

One of the most prominent surface circulation features of the EIO is the occurrence of strong equatorial surface jets during the monsoon transition periods, known as Wyrtki Jets (Wyrtki, 1973). These jets appear twice a year—during spring and autumn—and are typically confined to the upper 100 m of the water column (Han et al., 1999; Iskander et al., 2011). The westerly wind bursts force strong eastward surface currents along the equator, leading to a deepening of the thermocline and a rise in sea level in the eastern basin, while the opposite conditions prevail in the west (Rao et al., 1989; Schott and McCreary, 2001; Nagura and McPhaden, 2010a). Wyrtki Jets play a crucial role in the zonal redistribution of mass, heat, salinity, and chemical and biological tracers within the equatorial and off-equatorial Indian Ocean (Reppin et al., 1999; Murtugudde and Busalacchi, 1999; McPhaden et al., 2015; Chatterjee et al., 2017). Observations from the long-term RAMA equatorial mooring array indicate that the spring jet transport in the central equatorial Indian Ocean reaches approximately 19.7 Sv, while the autumn jet transport is relatively weaker at about 14.9 Sv (McPhaden et al., 2015). Seasonal reversals in zonal current direction are also evident, with westward flow during spring and eastward flow during autumn (Nagura and McPhaden, 2016). The westward propagation during spring is associated with westward-moving surface winds linked to deep atmospheric convection migrating from the Maritime Continent toward the northern Bay of Bengal (Nagura and McPhaden, 2010b, 2016).

Below the surface layer, the Equatorial Undercurrent (EUC) develops in the EIO due to basin-wide pressure gradient forces. Unlike the Pacific EUC, the Indian Ocean EUC is comparatively weaker and exhibits strong seasonal variability, primarily driven by reversing monsoon winds (Reppin et al., 1999; Schott and McCreary, 2001). The EUC is typically observed during boreal winter and spring, aligned with the thermocline core (Chen et al., 2015, 2019), although it occasionally appears during summer and autumn at depths between 90 and 170 m, as recorded by RAMA moorings (Iskandar and McPhaden, 2011). The forcing mechanisms of the EUC vary seasonally. During summer, eastward pressure gradients generated by downwelling Rossby waves reflected from the eastern boundary dominate, whereas in winter, the EUC is influenced by upwelling Kelvin and Rossby waves in combination with seasonal easterly winds. On intraseasonal timescales of 30–70 days, EUC variability is largely controlled by lower-mode baroclinic Kelvin and Rossby waves (Iskandar and McPhaden, 2011). Interannual variations in the undercurrents are also closely linked to the IOD, affecting heat and mass redistribution and contributing to sea surface temperature variability (Zhang et al., 2014; Nyadjro and McPhaden, 2014).The semi-annual cycle of zonal winds over the equator arises mainly from the meridional advection of easterly momentum by cross-equatorial monsoon winds (Ogata and Xie, 2011). Intra-seasonal variability of Wyrtki Jets is influenced by internal instabilities as well as local wind forcing (Sengupta et al., 2001, 2007; Masumoto et al., 2005). On interannual timescales, equatorial current variability is associated with large-scale climate models such as ENSO and the IOD, with the positive phase of the IOD weakening zonal winds and the negative phase strengthening them (Gnanaseelan et al., 2012). Biweekly oscillations with periods ranging from 10 to 30 days have been widely observed in meridional velocities and are attributed to mixed Rossby–gravity (Yanai) waves (Yanai and Maruyama, 1966; Smyth et al., 2015). These waves play a critical role in meridional heat transport and energy redistribution within the equatorial region.

While surface and subsurface currents are primarily wind-driven, deep-sea currents are governed by thermohaline processes arising from temperature and salinity gradients, basin-scale density variations, bottom friction, and turbulence. Despite their importance in heat and carbon sequestration, deep-sea currents in the EIO remain poorly studied due to observational limitations. Most existing studies focus on surface and subsurface layers, leaving a significant knowledge gap in understanding deep-ocean circulation. Recognizing this gap, the present study aims to investigate the characteristics and dominant oscillations of equatorial deep-sea currents in the EIO using both observations and HYCOM model simulations. Wavelet analysis is employed to identify significant variability at depths ranging from 2000 to 4000 m. This work represents one of the few attempts to comprehensively describe equatorial deep-sea current behaviour in the Indian Ocean using combined observational and modelling approaches

2.Data and Methodology

2.1. Wave Let Analysis:

Wavelet analysis mathematical representation: Wave let analysis become a common tool for analysing localized variations of power with time series. By decomposing time series in to frequency space are is able to determine both dominant modes of variability and how these modes vary with time. The wave let analysis transform has been used to for numerical studies in geophysics including tropical convection (Wang and Han 1994), El Nino southern oscillations (ENSO; Gu and Philander 1995), (wang and wang 1996), and Dispersion Oceanic waves (Meyers et al.1993), wave growth and breaking (Lia 1994), coherent structure of turbulent flow (Farge 1992). Fourier transformation gives limited amount of information on characteristics of time varying signal. A FT reveals frequencies present in the whole time series information about an individual event would be lost (Kantha &Clayson, 2000). Wave let transform expands time series in to frequency –space in to time-frequency space and can find localized intermittent periodicities.

(Grims et al..2004).

https://paos.colorado.edu/research/wavelets/

The total energy conserved in wavelet transform (Parseval’s theorem) , Wavelet analysis is

$$\sigma^2 = \frac{\delta j \delta t}{c\delta . N} \sum_{N=0}^{N-1} \sum_{j=0}^{j} \left| w_n s_j \right|^2 / s_j$$

σ^2 is variance, σ summed of reconstructions, the distribution for Fourier spectrum is

$$\frac{N\left|\widehat{X_K}\right|^2}{2\sigma^2} \rightarrow \frac{1}{2} p_x x_2^2$$

k-each frequency Index, → *distributed as* , the corresponding distribution for local wavelet power spectrum is

$$\frac{\left|w_{n(s)}\right|^2}{\sigma^2} \rightarrow \frac{1}{2} p_x x_2^2$$

At each time new scale $|\widehat{x_k}|^2$ is Chi-Square distributed with two DF’s denoted by x_2^2 , p_k mean spectrum at Fourier frequency k that to be corresponding scale s.

Th etime averaged wavelet spectrum (Global wavelet spectrum) over a certain period

$$\bar{w}_n^2\,(s) = \frac{1}{n_a} \sum_{n=n_1}^{n_2} |w_n\,(s)|^2$$

N is index arbitrary assigned to mid-points n_1 and n2 ; n_a= n_1-n_1 no.of points averaged over .

Global wavelet spectrum

$$\overline{w}^2(s) = \frac{1}{n}\sum_{N=0}^{N-1}|w_n\ s|^2$$

2.2. The Hybrid Coordinate Ocean Model (HYCOM):

HYCOM is a council of a multi-institutional effort supported by the National Ocean Partnership Program (NOPP) in part of the Global Ocean Data Assimilation Experiment (GODAE). The HYCOM model is the data-assimilative hybrid isopycnal-sigma-pressure (generalized) coordinate ocean model. The HYCOM model provides real time three-dimensional Ocean state. The HYCOM model considered boundary conditions of coastal and regional models and boundary conditions for the atmospheric coupled prediction models. In the Hybrid model, the coordinates are isopycnic in the open and stratified ocean and terrain following coordinates in the shallowcoastal region. The z-level coordinates to study the mixed layer and unstratified ocean. The HYCOM will provide the fixed depth intervals near shore data. For handling the heating and cooling cycle in both deep and shallow regions, the above said coordinates were chosen with the collaboration of the University of Miyami Modeling group and the Naval Research Laboratory. In order to provide the physical processes in the mixed layer and its non-local effect, slab-typeKraus-Turner mixed layer such as K-profile parameterization (KPP) (Large et al., 1994) schemewas used for the model mixed layer study. To study the deep-sea currents validation with deepsea currents of RCM with the HYCOM Model, the wavelet and filtered band-pass analysis wereperformed for zonal and meridional currents. The contribution of background internal wavebreaking, shear instability wave mixing, and double diffusion in the Ocean interior isparameterized. In the surface boundary Layer, the influence of wind-driven mixing, surfacebuoyancy fluxes, and convective instability is parameterized. The KPP algorithm alsoparametrizes the influence of non-local mixing of T and S, which permits the development ofcounter gradient fluxes. The required zonal and meridional currents daily data at 77^0E, 83^0E, and 93^0E along the Equator during 2002 was downloaded from the website. http://tds.hycom.org/thredds/catalogs/GOMl0.04/GOMl0.04_022_agg.html Hybrid coordinate Ocean Model (HYCOM) is a primitive–equation model which is containing 5 prognostic governing equations. Two equations meant for horizontal velocity components, a mass continuity of layer thickness tendency equation, and two conservation equations for pair offthermodynamics variables, such as salt and temperature or salt density.

The model equations written in (x, y,z) coordinates, where s is an unspecified vertical coordinate are

$$\frac{\partial v}{\partial t_s} + \nabla_s \frac{v^2}{2} + (\zeta + f)k \times v + (s\frac{\partial p}{\partial s})\frac{\partial v}{\partial s} + \nabla_s.\mathrm{M}\text{-}\mathrm{P}\nabla_S\ \alpha = \text{-g}\frac{\partial \tau}{\partial p} + (\frac{\partial p}{\partial s})^{-1}\nabla_s\ (\mathrm{v}\frac{\partial p}{\partial s}\nabla_s\ (\mathrm{v}\frac{\partial p}{\partial s}\nabla_s\ \mathrm{v})$$

$$\frac{\partial}{\partial t_s}(\frac{\partial p}{\partial s}) + \nabla_s(v\frac{\partial p}{\partial s}) + \frac{\partial}{\partial}(\mathrm{s}\frac{\partial p}{\partial s}) = 0$$

$$\frac{\partial}{\partial t_s}(\frac{\partial p}{\partial s}\theta) + \nabla_s.\left(v\frac{\partial p}{\partial s}\theta\right) + \frac{\partial}{\partial s}(\mathrm{s}\frac{\partial p}{\partial s}\theta) = \nabla_s(v\frac{\partial p}{\partial s}\nabla_s\ \theta) + \chi_\theta$$

Where $\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$ relative vorticity

3. Results and Discussions:

3.1. Study of deep-sea currents from HYCOM model currents

To study the validation between deep sea currents of RCM with the HYCOM model, the wavelet and filtered band-pass analysis were performed for zonal and meridional currents. The required zonal and meridional currents daily data at 77^0E, 83^0Eand 93^0E along the equator during 2002 was downloaded from the http://tds.hycom.org/thredds/catalogs/GOMl0.04/GOMl0.04_022_agg.html.

3.2. HYCOM Meridional Currents at WEIO, CEIO & EEIO

The variability of meridional currents simulated by the HYCOM model was investigated at 77°E (WEIO), 83°E (CEIO), and 93°E (EEIO) along the equator during 2002 using wavelet analysis. The study aimed to identify dominant oscillatory modes, including intra-seasonal oscillations (ISOs), seasonal oscillations (SOs), and bi-weekly variability across multiple depth levels ranging from 500 m to 4000 m. The results demonstrate strong spatial and vertical variability in meridional current dynamics, with ISOs emerging as the most persistent and dominant signal across most regions and depths.

At 77°E (WEIO), the wavelet power spectra show that at 500 m depth, ISOs were significant during July and October 2002, while seasonal oscillations dominated from March to December 2002 (Figure-3.17a). A similar pattern was observed at 1000 m depth, where seasonal oscillations remained prominent throughout most of the year, with ISOs also present (Figure-1.b). This indicates that at intermediate depths, meridional currents are strongly influenced by both seasonal forcing and intra-seasonal atmospheric variability.

At 2000 m depth, two distinct ISO modes were identified at 32–42 days and 64–128 days, while seasonal oscillations disappeared completely (Figure-1c). This highlights a transition toward intra-seasonal dominance in deeper layers, suggesting that abyssal meridional currents are primarily driven by short-period atmospheric and oceanic forcing mechanisms. At 4000 m depth, only a single significant ISO mode was observed during September to October 2002 in the 32–90-day band (Figure-3.17d), indicating reduced variability but persistent intra-seasonal influence even at abyssal depths.

At 83°E (CEIO), meridional current variability exhibited strong ISO dominance at multiple depths. At 500 m depth, ISOs were the primary oscillatory mode during May to November, February to April, and October to December 2002, while bi-weekly oscillations (8–16 days) were also observed during February–March and July–September 2002. This indicates strong high-frequency variability in upper layers. At 1000 m depth, seasonal oscillations dominated with low spectral power, while ISOs were still present but weaker (Figures- 2 a & b). At 2000 m depth, only ISOs were observed during April–May and September–October 2002, showing episodic deep variability. At 4000 m depth, ISOs became dominant from April to September 2002, while seasonal oscillations were also present from February to September 2002 (Figures-2 c & 2 d). This indicates a coexistence of seasonal and intra-seasonal forcing at abyssal depths in CEIO.

At 93°E (EEIO), meridional currents showed the strongest and most persistent intra-seasonal variability across all depths. ISOs were consistently dominant at all levels of the water column. Importantly, bi-weekly oscillations were absent at this longitude, indicating a smoother but more coherent ISO signal structure (Figures-3.a–3.d). The persistence of ISOs across all depths suggests strong vertical coupling and enhanced atmospheric forcing influence in the eastern equatorial region.

To further understand the flow characteristics associated with ISO and SO variability, a 20–90-day band-pass filtered analysis was performed for meridional currents at different depths during 2002 (Figure-4). At 500 m depth, two distinct seasonal flow regimes were identified (Figure-4 a). From March to July, eastward flow dominated at 77°E and 83°E, while from July to November, westward flow prevailed across 77°E, 83°E, and 93°E. Transitional phases showed mixed behavior, with eastward flow at 77°E and westward flow at 83°E and 93°E.
At 1000 m depth, eastward flow was observed from February to June at 77°E, while westward flow dominated at 83°E and 93°E (Figure-4 b). Strong current magnitudes were observed at 77°E during March–April and at 93°E during November–December, indicating seasonal intensification of meridional circulation. At this depth, 77°E and 83°E generally followed eastward flow patterns, while 93°E exhibited more variable and predominantly westward behaviour except during winter periods.

At 2000 m depth, winter currents exhibited greater variability at 93°E compared to 77°E and 83°E (Figure- 4 c & 4 d). Eastward flow was observed at 77°E and 83°E from August to December, while westward flow dominated across all three longitudes from May to July. Only one eastward flow event was detected at 83°E during January to March, highlighting strong temporal asymmetry in deep meridional circulation.

Overall, HYCOM meridional current analysis demonstrates that intra-seasonal oscillations are the dominant and most persistent mode of variability across all regions and depths, particularly at 93°E where ISOs remain coherent throughout the water column. Seasonal oscillations dominate at intermediate depths in certain regions, while bi-weekly variability is confined mainly to upper layers at 83°E. The results clearly indicate strong vertical coupling and zonal differences in meridional current dynamics across the equatorial Indian Ocean.

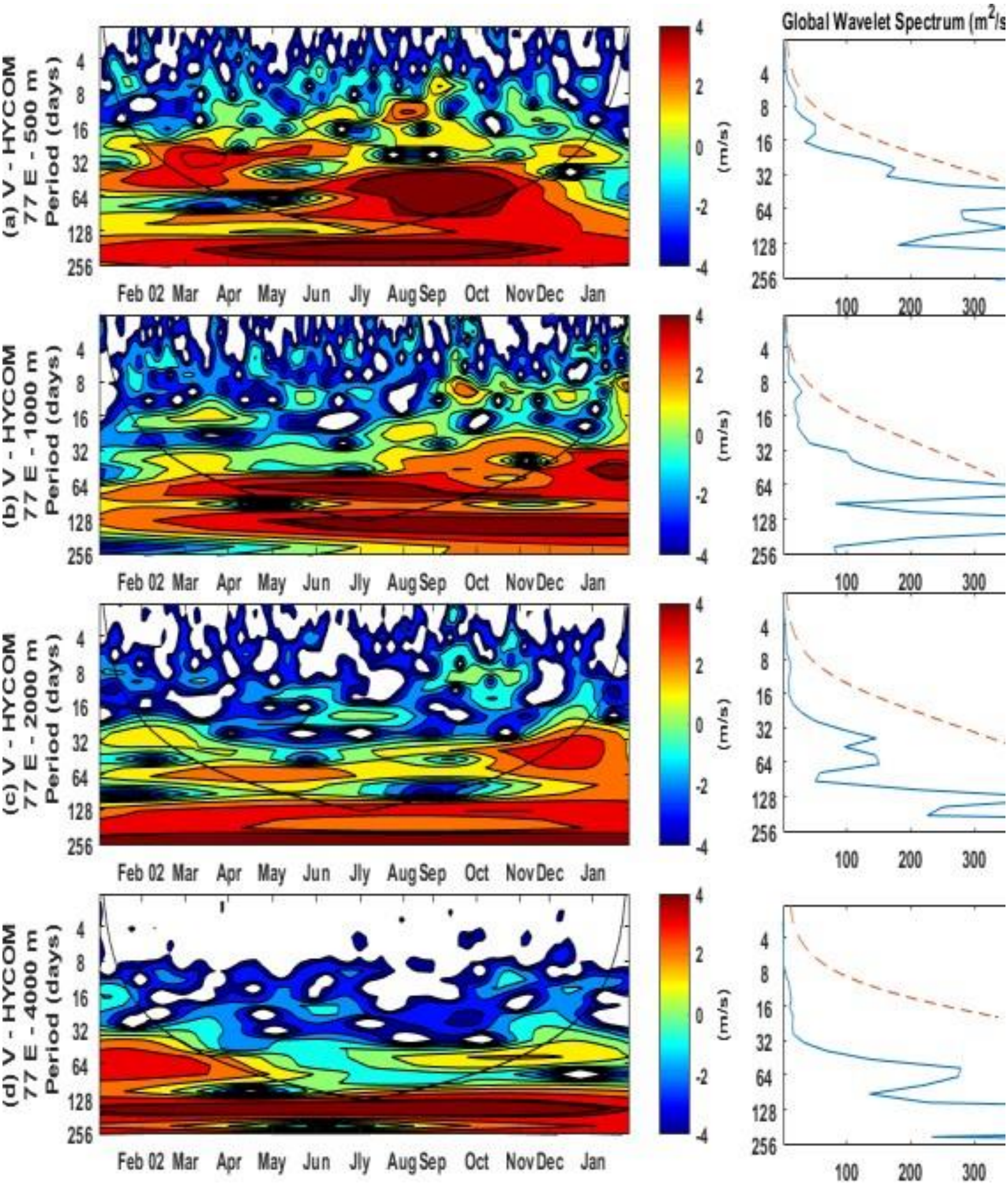

Figure-1: Wavelet power spectra and global spectra of HYCOM model meridional currents (m/s); a) WEIO (77^0E) in 500 m depth from January 2002to December 2002, b) 1000 m depth, c) 2000m depth, and d) 4000 m depth from January 2002 to December 2002.

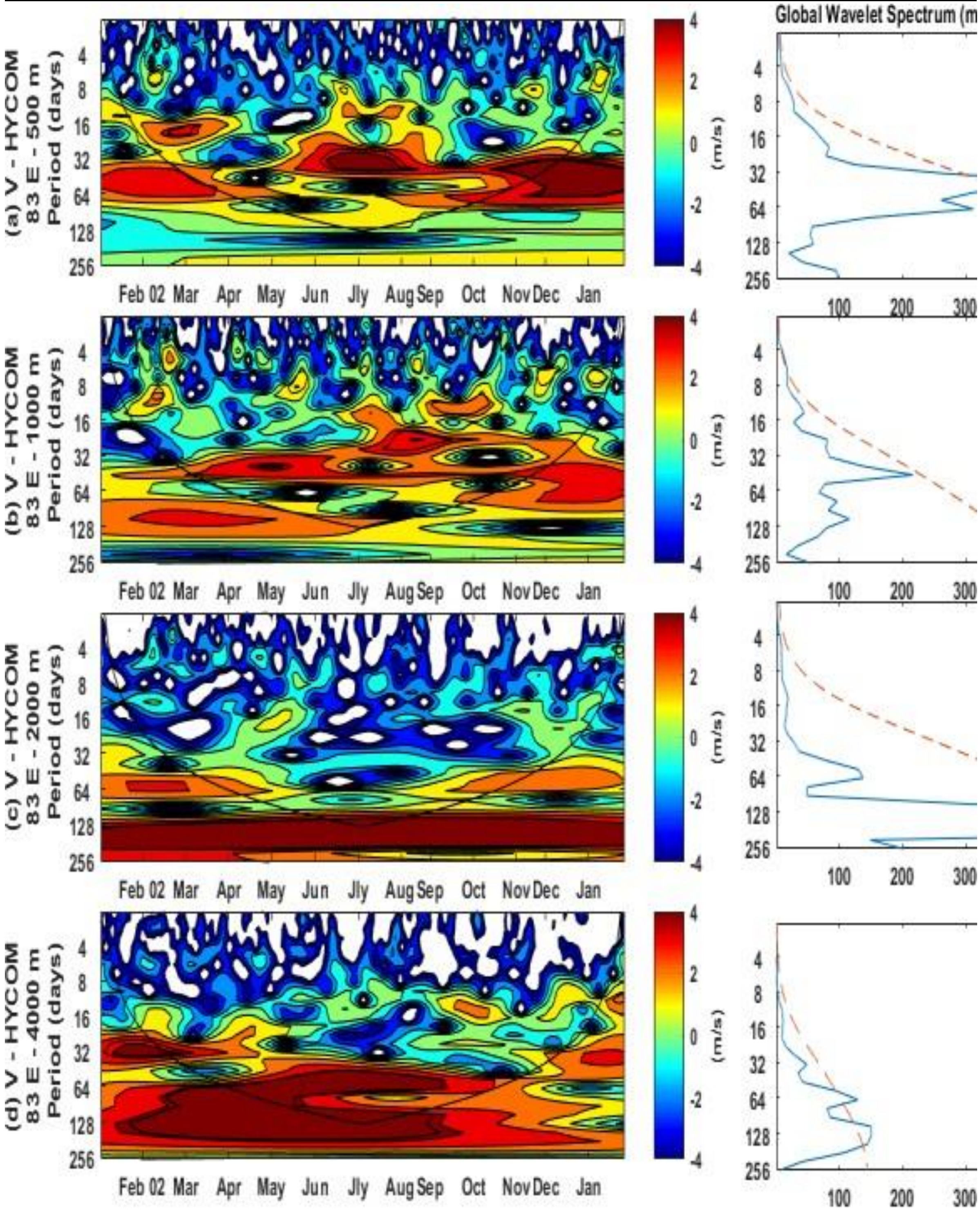

Figure-2: Wavelet power spectra and global spectra of HYCOM model meridional currents (m/s); a) CEIO 83^0E, a) in 500 m depth from January 2002 to December 2003, b) 1000 m depth, c) 2000 m depth, and d) 4000 m depth from January2002 to December 2002

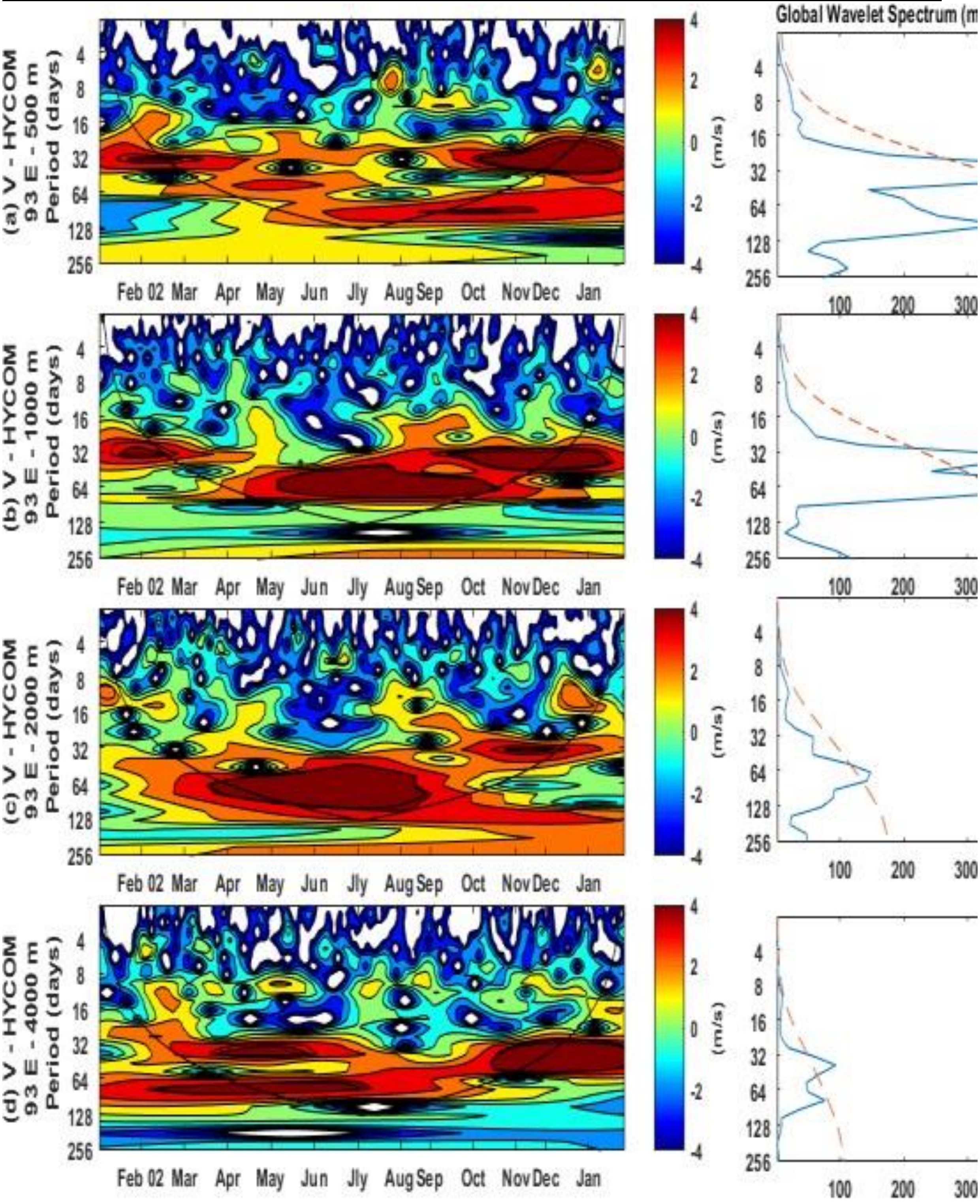

Figure-3: Wavelet power spectra and global spectra of HYCOM model meridional currents (m/s); a) EEIO(93^{0}E) in 500 m depth from January 2002 to December 2002, b) 1000 m depth, c) 2000 m depth and d) 4000 m depth from January 2002 to December 2002.

The HYCOM-simulated zonal currents in the equatorial Indian Ocean exhibit clear multi-scale oscillatory behaviour, primarily governed by intra-seasonal oscillations (ISO), seasonal oscillations (SO), and semi-annual oscillations (SAO). These oscillations are not isolated dynamical features but are strongly linked to large-scale climate teleconnections, including ENSO (El Niño–Southern Oscillation), Indian Ocean Dipole (IOD), and El Niño Modoki, which modulate their intensity, persistence, and vertical structure. The dominance of ISO in HYCOM zonal currents across 77°E, 83°E, and 93°E at multiple depths (500–2000 m) is closely associated with variability in tropical atmospheric convection driven by ENSO-related circulation anomalies. During El Niño and La Niña phases, changes in Walker circulation and wind stress over the Indian Ocean enhance or suppress equatorial wave activity, thereby modulating ISO strength. In particular, strong ISO signals in the model during 2002 are consistent with periods of active ENSO–IOD coupling, which intensifies equatorial wind forcing and promotes enhanced intra-seasonal variability.

The presence of strong seasonal oscillations in HYCOM zonal currents, especially at 77°E and 83°E, reflects the direct influence of the monsoon system and IOD-related basin-wide SST gradients. Positive and negative IOD phases modify zonal wind stress across the equatorial Indian Ocean, leading to strengthened or weakened seasonal current reversals. For example, enhanced SO activity in the model corresponds to periods when IOD-induced SST anomalies reinforce monsoonal wind patterns, intensifying seasonal flow transitions. The semi-annual oscillations (SAO) observed particularly at CEIO are linked to the twice-yearly reversal of monsoon winds and associated equatorial wave adjustments. These SAO signals become more pronounced under combined ENSO–IOD interactions, where basin-scale SST anomalies reinforce semi-annual forcing mechanisms.

At 93°E (EEIO), the persistent and vertically coherent ISO signal throughout the water column indicates strong sensitivity to Madden–Julian Oscillation (MJO)-driven atmospheric convection, which itself is modulated by ENSO and Modoki events. Enhanced ISO activity during specific periods reflects active MJO phases combined with favourable ENSO background conditions.

Bi-weekly oscillations observed in upper layers are also indirectly linked to short-period atmospheric variability associated with MJO propagation and wind bursts, which are often intensified during ENSO–IOD transition phases. Overall, HYCOM zonal current variability demonstrates that intra-seasonal, seasonal, and semi-annual oscillations are not purely oceanic features but are dynamically forced by large-scale climate teleconnections. ENSO, IOD, and Modoki events regulate wind stress, SST gradients, and equatorial wave propagation, thereby controlling the amplitude, duration, and vertical penetration of zonal current oscillations across the equatorial Indian Ocean.

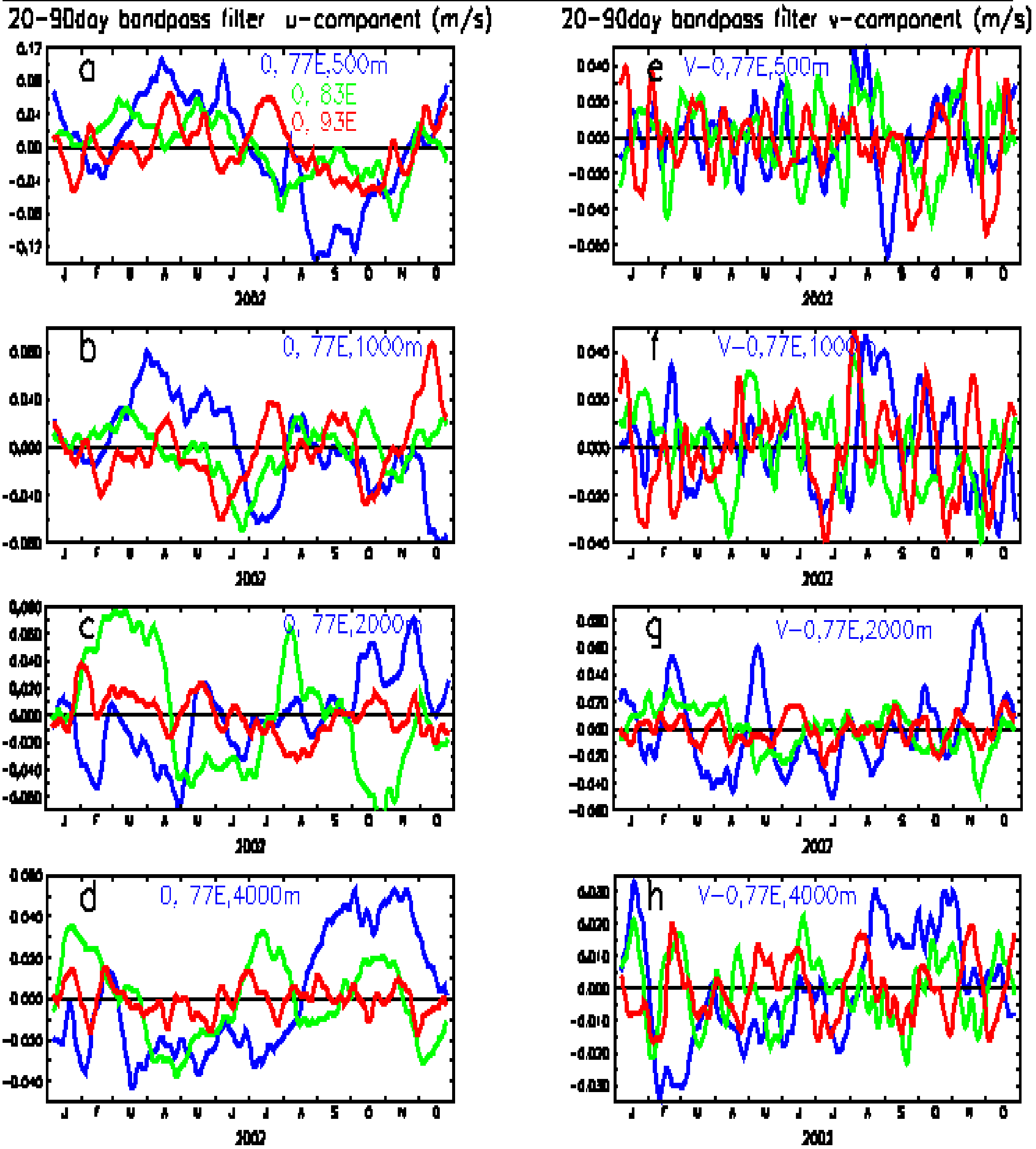

Figure-4: 20–90-day band pass filtered HYCOM model zonal and meridional (m/s) currents among 77E, 83E&93E along the Equator. a) U-500m b) U-1000m, c) U-2000mand d) U-4000m and e) V-500m, f)1000m, g) 2000m and h) 4000m depths during 2002 year

4.Conclusions:

The analysis of HYCOM-simulated meridional currents in the equatorial Indian Ocean clearly demonstrates that intra-seasonal oscillations (ISOs) and semi-annual oscillations (SAOs) are the most dominant modes of variability across all regions and depths. At 2000 m depth, combined ISO and SAO signals with high spectral power were observed at both the Central Equatorial Indian Ocean (CEIO) and Eastern Equatorial Indian Ocean (EEIO) during multiple periods, particularly from 2000 to 2002. These results indicate strong and persistent coupling between atmospheric forcing and deep meridional circulation.

At 2000 m depth, SAOs emerged as the primary dominant mode during January–July 2004, while seasonal oscillations represented the second most significant variability. ISOs were intermittently dominant during 2002–2004, highlighting the episodic but recurring influence of intra-seasonal atmospheric variability on deep meridional currents. At 4000 m depth, ISOs remained the foremost and most persistent signal, especially during February 2003 to October 2004 at EEIO, confirming that intra-seasonal forcing extends effectively into abyssal ocean layers.

Bi-weekly oscillations were also identified as an important secondary mode at 4000 m depth during February–June 2004, along with concurrent ISO activity during January–March 2004. These high-frequency signals indicate the influence of short-period atmospheric disturbances and mesoscale variability on deep meridional circulation, although their intensity decreases with depth compared to ISOs and SAOs.

In addition, ISOs were observed to persist from January to April 2007, while seasonal oscillations dominated from December 2006 to February 2007, further confirming the alternating dominance of intra-seasonal and seasonal forcing mechanisms. Long-duration ISO events from 2006 to 2007 at WEIO (2000 m depth) also highlight the sustained influence of intra-seasonal variability in meridional current structure.

The variability of meridional currents is strongly modulated by large-scale climate teleconnections, including ENSO, El Niño Modoki, and the Indian Ocean Basin Mode (IOBM). These climate modes significantly influence the intensity and duration of ISOs and SAOs, demonstrating a strong link between global climate variability and deep ocean circulation.

Overall, the study concludes that meridional currents in the equatorial Indian Ocean are primarily controlled by persistent intra-seasonal oscillations, supported by semi-annual variability and intermittent bi-weekly fluctuations. HYCOM model results effectively capture these dominant modes, confirming their reliability in representing deep ocean meridional current dynamics and their response to large-scale climatic forcing.

5. Recommendations:

On basis of the important of Deep-Sea currents role, the deep-sea currents are playing significant role on bio-geo-and physical aspects of oceans. The deep-sea currents can measure and estimate the CO_2 variations over depth wise in interior of the ocean, that can be possible by attaching the chemical and biological sensors with mooring systems. In additions to that the study of deep-sea currents is very useful to underwater security purpose for the country in Military. The study of deep-sea currents can possible to understand the link with various intrusion water from south and northern part of the Indian Ocean.

6.Acknowledgements:

The authors are very much thankful to the Inian National Centre for Ocean Information services (**INCOISE, Hyderabad**), Under Ministry of Earth Science for providing **HYCOM** model data and Director of National Institute of Oceanography (**NIO**), Council of Scientific and Industrial Research for providing the Mooring measured zonal currents. I am indebted to Colorado research Institute for providing **MATLAB/Python** program for wavelet analysis https://paos.colorado.edu/research/wavelets/

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