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Semi-Annual Variability In The Observed And OGCM Simulated Zonal Currents In The Equatorial Indian Ocean

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ABSTRACT: Analysis of time series of currents measured along the equator at 77°E, 83°E and 93°E locations is presented with an emphasis on the semi-annual variability of zonal currents in the Eastern equatorial Indian Ocean (EEIO) during November 2004 – July 2006. The observed currents are compared with the Ocean General Circulation Model (OGCM) simulated currents for the study period. Semi-annual Wave (SAW) harmonic is fitted to the Acoustic Doppler Current Profiler (ADCP) measured currents at each depth (at 8m depth bins) in the upper 200m time series of zonal velocity revealed i) predominant semi-annual equatorial jets in spring (April-May) and fall (September – October) with velocity ranging between 120 and 160 cm/s at 77°E and 83°E and weaker jets at 93°E with inter-annual variability, and ii) eastward flowing spring and monsoon Equatorial Undercurrents (EUC) at around 80-100 m depth. The amplitude of the SAW is large (57 cm/s) at 77°E and small (13 cm/s) at 93°E. The Observed variation of zonal velocity is compared well with the model simulations at 77°E and 83°E, but deviated at 93°E.

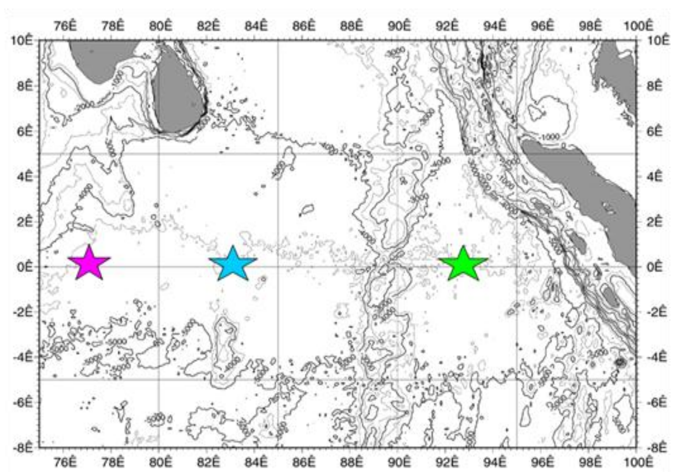
Keywords: OGCM model, Monsoon, semi-annual, ADCP, EEIO

1. INTRODUCTION:

Under the India's Ocean Observing System (OOS) program, an array of current meter moorings was deployed at 77°E, 83°E and 93°E on the equator (Fig. 1) to understand the time-variability of currents on different time scales during 2000-06. Murty et al. (2006) give the details of the long-term time series current observations generated from the OOS program and provided the preliminary results on the semi-annual variability in the zonal currents in the EEIO. Using the OOS current meter moorings data during February 2000- December 2001, Murty et al. (2002) reported the presence of intraseasonal variability in the zonal and meridional currents with periods of 10-20 day and 40-60 day at 93°E, and Sengupta et al. (2004) documented the biweekly mode (at 10-20 day period) variability in meridional currents based on the observations and model simulations. Masumoto et al. (2005) documented the intraseasonal variability in the ADCP measured zonal currents at 90°E during November 2000 – October 2001 and identified the intraseasonal bands with periods of 10-20 day (biweekly) and 30-50 day within the equatorial jets (Wyrtki, 1973). The aim of this study is to present the preliminary results on the semi-annual variability of observed currents at the 77°E, 83°E and 93°E mooring sites in the EEIO, based on the OOS deep-sea current meter moorings along the equator. We also show the comparison of observed zonal currents with the OGCM simulated zonal currents at different depths and point out the agreement and mismatch between the observations and the model simulations.

2. Data and methods:

The OOS array consists of 3 deep-sea current meter moorings located at 77°E, 83°E and 93°E in the EEIO (Fig. 1). During September 2004 current meter mooring deployment, one up looking ADCP (Acoustic Doppler Current Profiler (300 kHz ADCP, RD Instruments, Norway) was placed on each mooring at a 100 m nominal depth. The designed range of velocity profile is 80 m from the ADCP sensor depth. The swings in the mooring line caused data gaps in the upper layer in the ADCP data, but provided data well below 100 m depth in these occasions. The closest common depth from the surface where data is available at all the three sites is 48 m during 9 November 2004 – 28 June 2006. The ADCP has been quality controlled with the 4 beams mean Percentage Good. The ADCP currents were obtained with 8 m bins during 9 November 2004 - 31 July 2006 at 77°E, 83°E and 93°E. The total length of record was slightly different for each time-series depending upon the times of deployment/retrieval at the mooring sites besides the ADCP internal battery power. After initial processing of the data, the 15 min. Interval profiles were averaged to hourly current profiles (to minimize the data gaps at a given depth bin) and then daily averaged and weekly (6-day) averaged. The weekly zonal currents at each depth at each site Fig. 1 OOS Current Meter Mooring and weekly model zonal currents were fitted with sites 77°E, 83°E and 93°E in EEIO. The computed Semi-annual wave (SAW) harmonic with a period of 180 day is used to understand the semi-annual variability of zonal currents in the EEIO. Fast Fourier Transportation (FFT) analysis was carried out to obtain the spectral estimates using the Origin7.5 Professional software.



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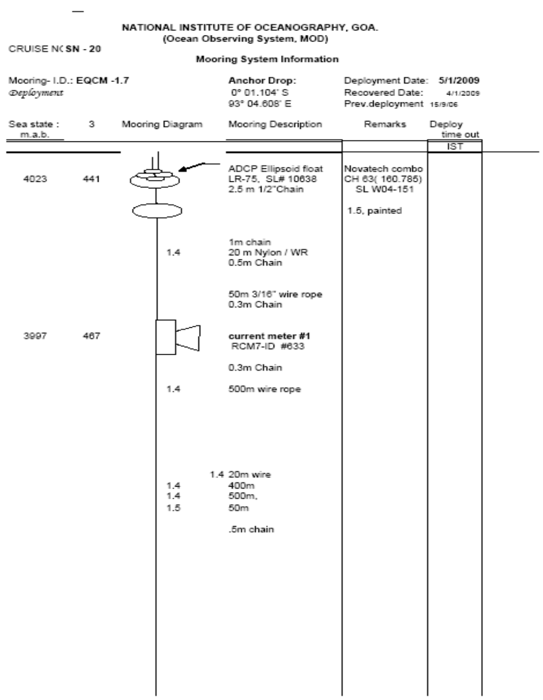

***Figure 1** OOS Current Meter Mooring sites CEIO (77°E, 83°E) and EEIO (93°E) in EEIO (left) and engineering structure of the mooring design. (Right).*

Model description

The OGCM is a reduced gravity, primitive equation, sigma coordinate model with a variable depth surface mixed layer. The model domain covers 32°E-76°W and 30°S-30°N with a 5 degree sponge layers at the meridional boundaries (Murtugudde e al., 2000). The model has been spun up for over 200 years starting with the World Ocean Atlas (WOA) hydrography and climatological weekly (6-day a week and 360 days in a model year) winds and the interannual run is initialized from this spun up state. The interannual simulation is forced with weekly mean 10 m NCEP reanalysis winds from 1948 through 2006 and weekly model outputs were analyzed for this model-data intercomparison. The latent and sensible heat fluxes in the model are computed interactively by an advective atmospheric mixed layer whereas climatological solar radiation and cloudiness are prescribed from ERBE and ISCCP, respectively. Inter-annual precipitation is the reconstruction of Xie and Arkin (1995).

3. Results and discussion:

3.1. Zonal velocity structure:

Fig 2a-c show the zonal velocity structures in the upper 200 m at 77°E, 83°E and 93°E during 9 November 2004 – 31 July 2006 constructed using the daily averaged data. This unique data set along the equator reveals that the equatorial jets lasted longer at 77°E and 83°E and shorter period at 93°E. Low-frequency variability is dominant at 77°E and 83°E, while intra-seasonal variability is dominant at 93°E towards the eastern basin. The velocity structures at 77°E and 83°E show the occurrence of strong eastward flowing shallow (<120 m) equatorial Wyrtki jets. Fig 2. Zonal velocity structure at CEIO (77°E, 83°E) and EEIO (93°E) mooring sites in the EEIO. Within the equatorial jets, intense intra-seasonal (biweekly) bands of eastward flow are seen. In November 2004, the fall jet extended gradually up to 140 m and Fig. 2 Zonal velocity structure at 77°E, 83°E and 93°E mooring sites in the EEIO. Shoaled up to 50 m by January 2005 at both 77°E and 83°E. In 2005, the fall jet (September –December) is stronger than the spring jet (April – June).

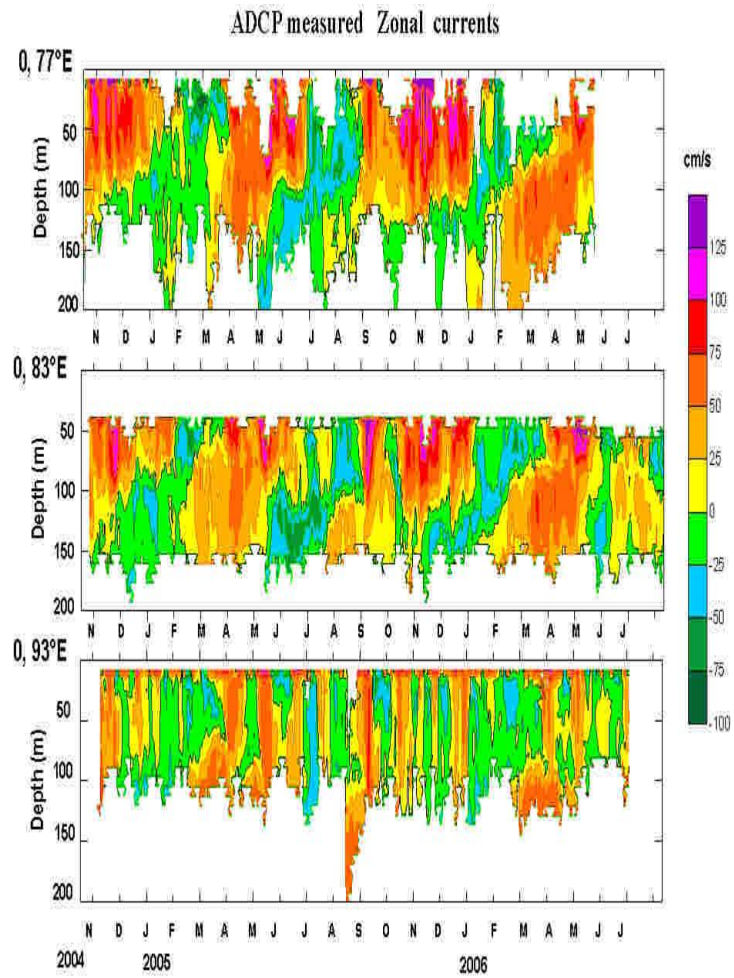

***Fig 2:** Zonal velocity structure of the WEIO, CEIO& EEIO location over Equatorial Indian Ocean (EIO).*

While strong velocity shear is present below the shallow equatorial jets at 77°E and 83°E, intraseasonal band structure is noticed at 93°E. The zonal velocity structure in 2006 clearly shows upward propagation of the eastward velocity from subsurface depths beginning in February to the surface by May, coinciding with the occurrence of spring jet. Typical EUC, with surface westward flow in the upper 50 m, is noticed in the thermocline in late January and March 2005 (25-50 cm/s) at 77°E, during mid-July – August 2005 (0-25 cm/s at 77°E and 25-50 cm/s at 83°E), during February-April 2006 (75-100 cm/s both at 77°E and 83°E). The EUC is also seen between 100 and 150 m in March – April 2006 and in mid-August in the depth range of 125-200 m at 93°E. The monsoon EUC is also seen during mid-June – July at 83°E in the depth range of 100 – 125 m. The fall jets in 2001254 and 2005 have stronger cores (>70 cm/s) compared to spring jets (50-70 cm/s) in 2005 and 2006. One can also see the upward rise in the velocity contours, suggesting the upward phase propagation (discussed below). At 93°E, one can also see the reduction in the speed of the jets (compared with those at 77°E and 83°E), with no clear-cut upward phase propagation. The observations are lacking beyond May 2006 at 77°E when the zonal velocity associated with the 2006 spring jet reached to about 100 cm/s. At the 83°E, the observations beyond May 2006 do suggest abrupt collapse of the spring jet (140 cm/s) by mid-May followed by a reverse in the direction of flow towards west. Then the direction of flow further reverses to ADCP measured Zonal currents Eastward from June to July. At 93°E, the spring jet in 2006 is weak (40 cm/s) in May (compared to that at 83°E and 77°E) and the eastward velocity is further reduced to lower values (10 cm/s) in June. This eastward decrease might be associated with the westward flow driven by the easterlies associated with the development of the Indian Ocean Dipole off Sumatra coast in 2006. Figure 3 shows the low-pass (> 90 days) filtered zonal velocity at 88 m depth at the mooring sites. The amplitude of low-frequency variation is almost same at all the sites from November 2004 to April 2005, but from April 2005 onwards, low-frequency variation continues to dominate at 77°E and 83°E while its amplitude drops rapidly at 93°E, during September 2005 - June 2006. This is more evident in the power spectra of zonal velocity at 40 m depth at the mooring sites (not shown) in which the spectral peak at 170 day

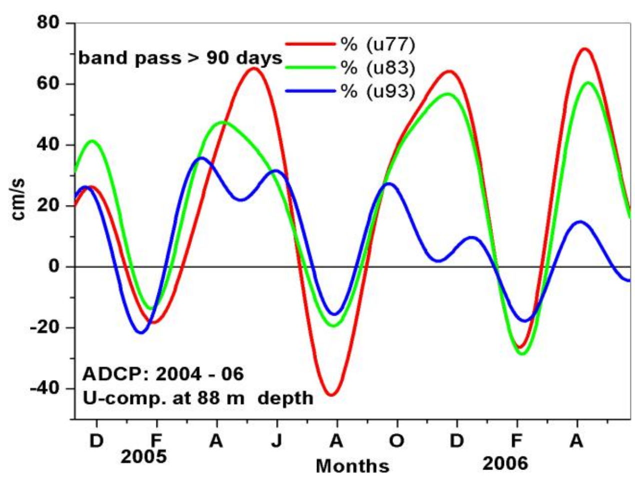

Fig 3. Lower-pass (>90 days) filtered zonal semi-annual period is nearly absent at EEIO (93°E) compare with velocity at 88 m depth at mooring sites.

3.2 Temporal variation of observed and model simulated zonal velocity at different depths

Figure 2&3 presents the temporal variation of weekly (6-day) averaged zonal velocity at the mooring sites at 48 m and 104 m depths together with the superposition of the model simulated weekly zonal velocity at these depths. In general, the pattern of simulated currents agrees well with the observed currents at all the depths; however, the simulated currents at 93°E in spring 2005 and 2006 are overestimated than the observations. On most occasions, the peaks in the zonal velocity coincided both in the observations and model simulations. One can also see mismatch in certain seasons (example, at 104 m depth at 77°E) in the magnitudes and phase of the zonal velocity. However, the model simulates well the low frequency variability as that seen in observations. **Fig.3**. Weekly averaged ADCP measured and OGCM, It is interesting that the model simulates simulated zonal currents at 48 m (left panel) and 104 m well the occurrences of intraseasonal (right panel). The Peaks as that was also seen in the observations, however the simulated magnitudes are large. The model simulated well the fall jets and the westward flows during winter (February-March) and summer (July-August). At deeper depths, the model simulations agree well with the observations. Since the model simulations represent well the annual cycle of currents as that in the observations for the study period, the model simulated zonal velocity time-series are also fitted with the semiannual harmonics to compare the amplitude and phase values with that obtained from the observations. Table 1 shows the amplitude and phase of the semi-annual harmonic fitted to the time series of observed and model simulated zonal currents at each depth. The time series begins from 15 November 2004 and the phase is referenced to 1 January 2004. Gradual decrease of SAW amplitude with depth is seen in the observations, whereas the amplitude of model SAW decreased rapidly with depth both at 77°E and 83°E and the differences in phases (observed minus model) increased with depth at these 3 sites. However, one can see the upward phase propagation at each site in both the measured and simulated currents suggesting the vertical propagation of equatorial waves forced by winds at the sea surface. At 77°E, an excellent comparison is noticed in both the phase and amplitude values at 48 m depth. The model SAW leads by 5° (equivalent to 2.5 days). This good agreement points out that the model performance is good in the region of weaker intraseasonal variability in NCEP wind forcing, i.e., the central EIO. At 83°E, the model amplitude is higher (18 cm/s) than in the observations and model SAW leads by 20° (10 days). On the contrary, at 93°E, in the eastern basin, the amplitude of the SAW in the measured currents are 3 times lower than the model currents without any appreciable shift in the phase (model SAW leads by 3.5 days). This points out that the mismatch in the model simulations, particularly with large spring jets (Higher than the observed jets), contributed to the higher model amplitude of the SAW at 93°E site. The higher differences in the model SAW amplitudes at 83°E and 93°E might be related to the errors in the NCEP wind forcing and the missing of high frequency intraseasonal events in the NCEP winds during the study period. At the depths between 48m and 72m, the phase of the SAW both in observations and model simulations decreased eastward (from 77°E to 93°E) suggesting the westward propagation of SAW. At depths between 80 m and 104 m, the phase of SAW increases eastward between 77°E and 83°E and decreases eastward from 83°E to 93°E, both in the observations and model simulations. The model studies indicate that the semi-annual equatorial jets driven by the semi-annual westerlies over the equatorial Indian Ocean are the manifestation of eastward propagating Kelvin Waves in the equatorial wave guide. These semi-annual

Kelvin waves impinge on the coast of Sumatra and reflect westward as propagating semi-annual Rossby Waves along the equator (Blanc and Boulanger, 2001). The presence of reflected Rossby Waves is noticed both in the observations and model simulations in the depth interval of 48 m to 72 m from 93°E to 77°E. With depth, propagation of both Kelvin waves between 77°E and 83°E and westward propagation of reflected Rossby waves from 93°E to 83°E are noticed in both the measured and simulated currents.

Table-1: *Depth wise amplitude and phase of semi-annual wave harmonic fitted to the data. Depth (m) Weekly averaged **ADCP** observations and **Model** simulations 77°E 83°E 93°E Amp (cm/s) Phase (referenced to 1 Jan. 2004) Amp (cm/s).*

Depth (m)	ADCP and Indo-Pacific run weekly data (the phase is referenced to 1 January 2004)					
	77(15 Nov 2004-9 May 2006)		83(15 Nov 2004-26 July 2006)		93(15 Nov 2004-20 June 2006)	
	Zonal Amp (cm/s)	Phase	Zonal Amp (cm/s)	Phase	Zonal Amp (cm/s)	Phase
48	55 59	266 269	42 60	254 241	15 44	251 250
56	53 47	263 267	45 54	256 240	14 39	245 251
64	52 34	260 262	44 47	256 240	13 31	234 252
72	52 23	254 256	41 40	254 240	13 23	225 248
80	49 15	246 238	36 33	245 236	12 16	219 236
88	44 10	233 216	32 26	231 231	14 13	214 223
96	39 9	216 188	31 20	214 221	17 11	193 212
104	36 9	200 163	30 15	195 209	21 9	182 199
112	33 10	187 151	31 12	180 186	22 8	177 191
120	29 11	179 145	32 12	168 158	19 6	176 180
128	24 12	172 139	32 13	158 136	13 4	166 150
136	20 13	166 134	30 14	152 117	7 5	134 110

Further analysis of model simulations obtained from Quick scat wind forcing is in progress.

4. Conclusions:

Based on the recently acquired observed ADCP currents in the eastern equatorial Indian Ocean, the semi-annual variability of zonal currents is presented. We have also compared the observed zonal current variability with the OGCM simulated zonal currents to understand the Dynamics associated with the semi-annual variability. The comparison between the observed Currents with model simulations at 77°E and 83°E is excellent in the central equatorial Indian Ocean, where the intraseasonal variability in the NCEP reanalysis winds is weak. However, in the far eastern equatorial Indian Ocean (93oE), the model simulated currents mismatch with the observations, particularly the 3-fold overestimated equatorial jets in the model simulations. We interpret the mismatch between the observations and model simulations at 93°E as due to the missing of intraseasonal events in the NCEP reanalysis winds in the model forcing.

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References:

[1] Wyrtki, K. (1973) An equatorial jet in the Indian Ocean. Science, 181, 262-264

[2] Blanc, Le, J.L. and Boulanger, J.P. (2001): Propagation and reflection of long equatorial waves in the Indian Ocean from TOPEX/ POSEIDON data during the 1993-1998 periods. Climate Dynamics, 17, 547-557.

[3] Xie, P. and P. Arkin (1995) An inter-comparison of gauge observations and satellite estimates of monthly precipitation. J. Appl. Meteor., 34, 1143-1160.

[4] Masumoto, Y., H. Hase, Y. Kuroda and H. Matsuura and K. Takeuchi (2005) Intra-seasonal variability in the upper layer currents observed in the eastern equatorial Indian Ocean. Geophys. Res. Lett., 32, L02607, doi:10.1029/2004GLL021896.

[5] Murtugudde, R.,J.McCreary, and Busalacchi (2000), Oceanic processes associated with anomalous events in the Indian Ocean with relevance to 1997 - 1998, J. Geophys. Res.,105, 3295-3306.

[6] Sengupta, D., Retish Sensan, V.S.N. Murty and V. Fernando, 2004: A biweekly mode in the equatorial IndianOcean.J.Geophys.Res.,109,doi:10.1029/2004JC002329.

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