Analysis of Equatorial Currents Observed by Eastern Indian Ocean Cruises in 2010 and 2011

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Abstract

Hydrographic and direct current measurements were made in the Eastern Equatorial Indian Ocean in May 2010 and April 2011 as part of the Eastern Indian Ocean Cruises (EIOC) organized by the South China Sea Institute of Oceanology (SCSIO). Analyses of the ship-drift Acoustic Doppler Current Profiler (ADCP) data indicate that the equatorial currents observed in May 2010 are characterized by a strongly eastward surface current (Wyrtki Jets, WJs) with a maximum velocity of 0.9 m s⁻¹, while that observed in April 2011 is weak and without a consistent direction. The strongly eastward WJ transports the surface water eastward, resulting in a deeper upper mixed layer, as shown in the temperature and salinity profiles. However, it was found that the Equatorial Undercurrent (EUC) in the Eastern Indian Ocean is strong in April 2011 and weak in May 2010. The EUC was located approximately at the position of the thermocline, and it had higher salinity (up to approximately 35.5 psu) than the upper and lower waters.

Keywords: equatorial currents, equatorial undercurrents, Eastern Indian Ocean


1 Introduction

The surface currents in the equatorial Indian Ocean reverse their directions four times a year with the transition of the Indian Ocean monsoons. These currents flow westward during the winter, weakly westward in the central and western Indian Ocean during the summer, and strongly eastward during the spring and fall (Mariano et al., 1995; Han et al., 1999; Schott and McCreary, 2001). The strongly eastward equatorial Indian Ocean Currents, which have an amplitude of approximately 1 m s⁻¹, are known as the Wyrtki Jets (WJs) in recognition of Wyrtki's discovery of the currents (Wyrtki, 1973). Han et al. (1999, Fig. 1) showed that the WJs' zonal component, averaged from 1°S to 1°N, can exceed 30 cm s⁻¹ in a large meridional range (55°E–90°E) from March to July. Wyrtki (1973) suggested that the eastward jets are forced directly by the equatorial westerlies between the summer and winter monsoons. His opinion was quickly supported by a two-layer model (O’Brien and Hurlburt, 1974), which showed that a strong eastward jet develops as a direct response to the switched-on westerlies. Other model results indicate the WJs' intensity is sensitive to the sea surface wind fields in the Indian Ocean (Anderson and Carrington, 1993; Han et al., 1999). WJs transport surface water eastward, leading to an increase of the upper mixed layer and sea surface height in the Eastern Indian Ocean (EIO) and a decrease in the west. The WJs show large seasonal variability, with a monthly eastward transport of 35 Sv in November 1993, but only 5 Sv in May 1994 (Reppin et al., 1999).

Another important current in the equatorial Indian Ocean is the Equatorial Undercurrent (EUC). This undercurrent is located in the thermocline and is of low magnitude (Knauss and Bruce, 1964), similar to the EUC in the Pacific Ocean and Atlantic Ocean. Compared with the quasi-permanent EUC in the Pacific and Atlantic (Yu and McPhaden, 1999; Stalcup and Metcalf, 1966), however, the EUC in the Indian Ocean is highly transient because of the large, seasonally varying force. For its highly transient nature, Schott and McCreary (2001) suggested viewing the EUC in the Indian Ocean as a transient equatorial wave phenomenon rather than a mean circulation. The EUC in the Indian Ocean was first reported by Knauss and Bruce (1964). Subsequently, other observations, most of which were located in the western and central Indian Ocean, confirmed its existence in different months (Swallow, 1967; Knox, 1976; Leetmaa and Stommel, 1980; Schott et al., 1997; Reppin et al., 1999, Figure 1 Route (line) of the EIOC for the equatorial section and the CTD sites for 2010 (cycle) and 2011 (star).
Iskandar et al., 2009). The latest month in a year when the EUC is observed is August (Reppin et al., 1999). Surprisingly, this undercurrent is absent during some years, such as 1974 (Knox, 1976) and 2003 (Iskandar et al., 2009). It is generally believed that the EUC is driven by the eastward pressure gradient force caused primarily by upwelling equatorial Kelvin waves excited by prevailing easterlies (Iskandar et al., 2009).

The currents in the equatorial Indian Ocean have been depicted by some moorings and ship-drift Acoustic Doppler Current Profilers (ADCPs). However, most of these moorings and ship-drift ADCPs are located in the western and central Indian Ocean, and observations in the EIO are still limited. This paper gives a general description of the equatorial currents in the EIO in May 2010 and April 2011, based on observations along the EIO in these months. The paper is organized as follows: the data sources are given in the next section; section 3 describes the currents, temperature, and salinity in the equatorial EIO; finally, a conclusion is given in section 4.

2 Data

The Eastern Indian Ocean Cruise (EIOC) organized by the South China Sea Institute of Oceanology (SCSIO) was successfully performed in 2010 and 2011. The EIOC collected a number of hydrological and meteorological data to understand the oceanic and atmospheric state of the EIO. The equatorial section is a routine observation section in this cruise. Because of the weather conditions, the route and the observation sites (Fig. 1) along the equatorial section in these two years are not exactly the same, but are still highly valuable for understanding the currents in the EIO.

The data that we use in this paper include currents from a ship-drift ADCP; temperature and salinity from Conductivity, Temperature, and Depth (CTD) and wind vectors from an Advanced Scatterometer (ASCAT). The sampling frequencies of ADCP and CTD are set to 12/hour and 24/second, respectively. ADCP provides current data with a vertical resolution of 8 m from 22 m to 574 m at an extremely high horizontal resolution. CTD (5 in 2010 and 15 in 2011, Fig. 1) provides temperature and salinity data with an extremely high vertical resolution (approximately 0.2 m, processed by the CTD processing software SBEDataProc) from the surface to 1500 m. The ASCAT data we used are the daily winds, with a spatial resolution of 0.25° × 0.25°.

3 Equatorial currents in the Eastern Indian Ocean

A typical WJ with a strong eastward velocity was observed from 80°E to 92.5°E in the equatorial Indian Ocean on 10–14 May 2010 (Fig. 2). This WJ developed better in the east and with a greater velocity than in the west. The maximum eastward velocity reached 0.9 m s⁻¹ at the surface at approximately 91°E. The maximum speed of WJs can exceed 1.5 m s⁻¹, as observed at an equatorial mooring from September 1993 to January 1994 (Reppin et al., 1999). The jet also tends to occupy a deeper layer in the east because of an increased upper mixed layer (Fig. 3) induced by strong eastward surface transports (Schott and McCreary, 2001). The jet reached a depth of 80 m in the east but a depth of only 50 m in the west. Another weaker eastward current with a maximum speed of 0.5 m s⁻¹ is seen below the WJ (at a depth of 90 m to 150 m) from 82°E to 92°E. To discuss the position of the undercurrent, the 28°C and 20°C isotherms are shown in Fig. 2 as a proxy for the top and bottom of thermoclines, respectively (Iskandar and McPhaden, 2011). Noting that this current coincides approximately with the thermocline as indicated by the 28°C and 20°C isotherms (Iskandar and McPhaden, 2011) as well as a slow westward current separating this eastward current and the WJ (Fig. 2), we infer that this weak eastward current is a weak equatorial undercurrent, not an extension of the WJ in the subsurface. One can see that this current has the typical characteristics of equatorial undercurrents in the Indian Ocean, including the strong eastward velocity, and is located in the thermocline with May as the time of occurrence.

In contrast to the phenomenon in May 2010, the ship-drift ADCP data indicate a strong equatorial eastward undercurrent from 80°E to 95°E on 15–22 April 2011 (Fig. 2). This undercurrent is located at a depth of 100 m to 150 m but not exactly in the thermocline. The core of the EUC was below the 20°C isotherms in the east, which is inconsistent with the description given by Knauss and Bruce (1964). This undercurrent reached the same strength as
the surface current in May 2010. In contrast, the surface 
current, which is westward in the east and eastward in the 
west, is weak in April 2011. This current pattern is similar 
to the results observed from March to May 1994 (Reppin 
et al., 1999). An obvious decreasing of the upper mixed 
layer depth in the east of the EIO is shown in Fig. 4. Is-
kandar et al. (2009) pointed out that the onset of the EUC 
coincides with the shoaling of the thermocline, and they 
supposed that the eastward surface currents depress 
the development of the EUC so that a strong eastward equa-
torial undercurrent is always accompanied by a westward 
surface current, the same as a typical equatorial under-
current in the Pacific Ocean and Atlantic Ocean (Yu and
McPhaden, 1999; Stalcup and Metcalf, 1966) or a weak 
eastward surface current (as observed by Reppin et al.,
1999) in the Indian Ocean.

The EUC has a higher salinity (up to 35.5 psu) than the 
upper or lower waters (Figs. 3 and 4) whether it is strong 
(in 2011) or not (in 2010). Previous studies have shown 
that high salinity waters originating in the Arabian Sea are 
adverted along the equator to the Eastern Indian Ocean
(Han and McCreary, 2001; Hase et al., 2008) and have 
noted that the zonal transport of the EUC is considerable. 
Reppin et al. (1999) reported that the EUC had a large 
transport of 17 Sv in March and April 1994. Iskandar et al. 
(2009) calculated the zonal transport per unit width within 
the depth of the EUC, which reached to 35 m² s⁻¹ in April. 
Such a transport is important because it balances the salt 
budget between the western and Eastern Indian Ocean. 
Other studies (Hase et al., 2008) have suggested that the 
high salinity water in the thermocline after the onset of 
the EUC may be responsible for the formation of a barrier 
layer in the eastern Indian Ocean.

It is generally believed that the WJs are directly forced 
by the equatorial westerlies (Wyrtki, 1973; O’Brien and 
Hurlburt, 1974; Anderson and Carrington, 1993; Han et 
al., 1999). Figure 5 shows the difference of the wind field 
during 10–14 May 2010 and 15–22 April 2011. Obviously, 
the wind during 10–14 May 2010, which is strong and 
eastward, is beneficial to the development of equatorial 
surface currents, while the wind during 15–22 April 2011, 
which is weak and without a consistent direction, is not.

4 Conclusion

The upper layer equatorial current system in the EIO is 
investigated by analyzing the ADCP and CTD data col-
lected by the EIOC. A typical strong eastward equatorial 
surface current (WJ) and a typical strong eastward equa-
torial undercurrent in the EIO are clearly observed in May 
2010 and April 2011, respectively. Another weak eastward 
equatorial undercurrent below the strong eastward surface 
current was observed in May 2010. The EUCs are located 
in and below the thermocline in May 2010 and April 2011, 
respectively. The strong eastward-WJ transported the sur-
face water eastward and deepened the upper mixed layer. 
The salinity profiles in these two years both show a high 
salinity core in the EUC. This high salinity water is im-
portant because it balances the salinity budget across the 
basin and may be responsible for the formation of barrier 
lays in the EIO.

These observations, along with those collected by the 
EIOC in the future, will be further investigated to obtain a 
full understanding of the current system in the EIO.

![Figure 3](image-url) Observed temperature (top, units: °C) and salinity (bottom, units: psu) profiles in the equatorial Indian Ocean from 5 m to 500 m on 10–14 May 2010. The black curve shows the mixed layer depth (MLD). The MLD is defined as the depth of the density, which is calculated by the surface salinity and a temperature 0.5°C lower than the surface temperature (Sprintall and Tomczak, 1992).

![Figure 4](image-url) Same as Fig. 3, but on 15–22 April 2011.

![Figure 5](image-url) Averaged wind fields during the cruises (top: 10–14 May 2010, bottom: 15–22 April 2011).
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References


