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Response of near-surface currents in the Indian Ocean to the anomalous atmospheric condition in 2015

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Abstract. Anomalous ocean-atmosphere conditions were detected in the tropical Indian Ocean during boreal spring to boreal winter 2015. It was suggested that the anomalous conditions were characteristics of the positive Indian Ocean Dipole (pIOD) event. The purpose of this investigation was to investigate the response of near-surface currents in the tropical Indian Ocean to the anomalous atmospheric condition in 2015. Near-surface current from OSCAR (Ocean Surface Current Analyses Real Time) reanalysis data combined with the sea surface temperature (SST) data from OISST – NOAA, sea surface height (SSH) and surface winds from the ECMWF were used in this investigation. The analysis showed that the evolution of 2015 pIOD started in June/July, peaked in the September and terminated in late November 2015. Correlated with the evolution of the pIOD, easterly winds anomalies were detected along the equator. As the oceanic response to these easterly wind anomalies, the surface currents anomalously westward during the peak of the pIOD. It was interesting to note that the evolution of 2015 pIOD event was closely related to the ocean wave dynamics as revealed by the SSH data. Downwelling westward propagating Rossby waves were detected in the southwestern tropical Indian Ocean. Once reached the western boundary of the Indian Ocean, they were redirected back into interior Indian Ocean and propagating eastward as the downwelling Kelvin waves.

1. Introduction

The prior investigations have advocated that the sea surface temperature (SST) variability in the Indian Ocean is strongly tight to the ocean-atmosphere interaction and also gives contribution to the large scale atmospheric circulation [1,2]. The anomalous of warmer (colder) SST in the western (eastern) tropical Indian Ocean indicates the positive Indian Ocean Dipole (pIOD). Correlated with this SST anomaly, easterly wind anomalies were detected along the equatorial Indian Ocean and southeasterly anomalies were detected along the southern coast of Sumatra and Java [3–5]. The result of the upper ocean to the easterly wind anomalies along the equator, eastward upwelling Kelvin waves were resulted along the equator. Meanwhile, westward downwelling Rossby waves were resulted in the off equatorial region [6–8]. The intension of the IOD event is signified by the SST gradient between the western equatorial Indian Ocean (50°E - 70°E, 10°S - 10°N) and the eastern Indian Ocean (90°E - 110°E, 10°S - 10°N) [9–11].

Previous study has demonstrated that the air-sea flux is a major forcing for the outgrowth of the IOD event [12]. In addition, the pIOD event has caused hot and dry condition over Sumatera and Java [12,13]. One of the previous studies investigated the backdrop of warming and cooling SST's correlated with

ENSO and generated by the interactions internal of Ocean Atmosphere to the Indian Ocean [13]. The same studies disclosed the connection which was ensued between ENSO and Indian Ocean warming during summer [8]. While the Coastal wind and Ekman pumping possibly maintained by causing the blooms . Due to these reasons, the pattern of warming and cooling Indian Ocean became the investigation highlight to observe on the response of near-surface ocean currents to the wind field anomalies during 2015 over the tropical Indian Ocean during 2015.

2. Data and Method

In this investigation, daily surface wind data were regained from the European Centre for Medium-Range Weather Forecasts (ECMWF) which is acquire at *http://www.apps.ecmwf.int/* [15]. Data period of 1 January 2006 until 31 December 2015 with horizontal resolution of 0.25° × 0.25° were used in this observation. The daily sea surface height (SSH) data were also acquired from the ECMWF. The data were available for the period of 1 January 2006 until 15 December 2015 with horizontal resolution of 0.25°× 0.25°.

The data of daily SST were acquired from OI-SST analysis (Optimum Interpolation-Sea Surface Temperature. This dataset was created by merging all available inspections from diverse platforms (satellites, ships, buoys). The SST data were used in this investigation with the spatial resolution of 0.25°× 0.25° from 1 January 2006 until 31 December 2015.

Near-surface current data were acquired from the Ocean Surface Current Analyses Real-Time (OSCAR). The data were available from 21 October 1992 until present with the spatial resolution of 1° × 1°. These data represent near-surface currents at 15 m depth and on the global grid every 5 days and they were available at *http://apdrc.soest.hawaii.edu*. In order to evaluate the intensity of the 2015 pIOD event, the Dipole Mode Index (DMI) from the Ocean Observations Panel for Climate (OOPC) was used in this investigation and it was available at *http://stateoftheocean.osmc.noaa.gov.* The data was available from 4 November 1981 until 5 April 2017. Note that the DMI was defined as the SST gradient between the western tropical Indian Ocean (50°E - 70°E, 10°S - 10°N) and the eastern tropical Indian Ocean Indian Ocean (90°E - 110°E, 10°S – equator) [14].

To define the pIOD and nIOD, we defined the result of SST gradient between the eastern and the western Indian ocean to find the significant value of DMI. These values were categorized as pIOD event which had value more than +1.5 standard deviation. On the other side, the nIOD event was classified by -1.5 standard deviation [16]. From these standard deviation, the anomalous conditions of each variable can be determined by observing the evolution of pIOD during 2015. The climatology of all fields was estimated on the time sequence from January 2006 until December 2014. Then, the anomalous fields were specified as the deviation from each climatological field. The wind data, currents, and SSH anomalies were processed by a low-pass filter with cut-off period of 15 day as suggested in the previous investigation [17].

3. Results and Discussion

3.1. The evolution of 2015 pIOD event

In this section, we evaluated the evolution of pIOD event in 2015 by analyzing the time series of the DMI (figure 1). It was signified that the 2015 pIOD event was started in boreal summer (August) 2015. Interestingly, the DMI showed three DMI peaks, with weakening signals in between indicating intraseasonal disturbances. The first peak was detected in early September, the second peak was found in the mid-October, while the last peak was detected in the mid-November. The pIOD event was terminated in early boreal winter (late November/early December).

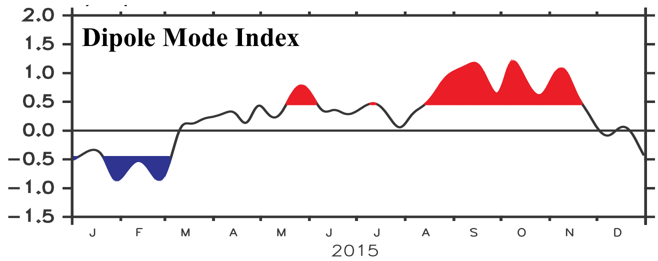

Figure 1. The Dipole Mode Index during January – December 2015

To see the mean fields of atmospheric circulation in the normal conditions, the sea surface temperature and surface wind became the variable which can be represented the atmospheric circulation. The monthly averaged climatological of sea surface temperature and surface wind was provided in figure 3 during July – December. While south-easterlies was ensued during boreal summer (July – August 2015), Boreal fall (September – November 2015) was dominated by north-westerlies and strengthened till the earliest boreal winter (December 2015). The evolutions of surface wind influenced the variability sea surface temperature in the topical Indian Ocean. Cold SST dominated in the western tropical Indian Ocean and the northern tropical Indian Ocean while the warm SST experienced in the eastern tropical Indian Ocean and the equatorial tropical Indian Ocean. The warm SST was strengthened by south-easterlies from July to October 2015.

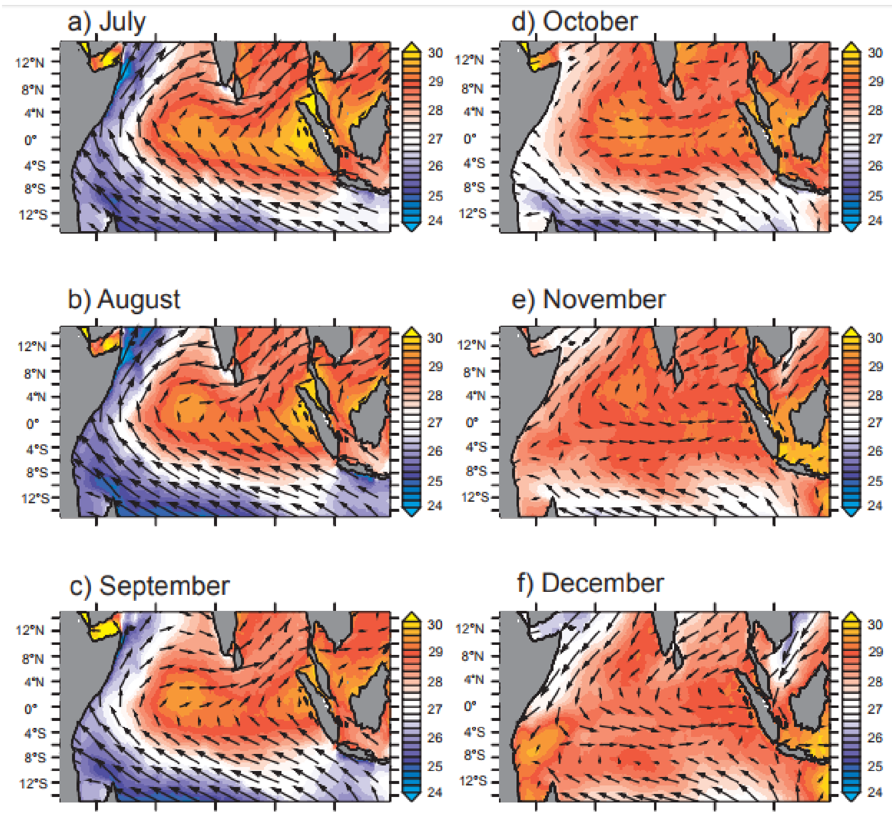

Figure 2. Monthly average of the sea surface temperature (*shaded* in °C) and the surface wind (*vector* in m/s) in the tropical Indian Ocean during July – December 2006 - 2015.

In order to evaluate the spatio-temporal evolution of the 2015 pIOD event, we then analyzed the monthly variation of the SST and wind field anomalies over the tropical Indian Ocean (figure 2). The evolution of the surface wind anomalies correlated with the 2015 pIOD event was started in July as shown figure 2a. In July, the equatorial region and off Sumatera occurred anomalous easterly winds and southeasterly winds. These easterly and southeasterly wind anomalies were correlated with the cold SST anomaly developed off South Java and warm SST anomaly occupied the western and central tropical Indian Ocean. As the anomalous winds were strengthened, the SST dipole pattern was also developed, though it did not show an extreme cold SST anomaly in the eastern tropical Indian Ocean (figure 2b-d). The pattern of SST was weakened as the wind anomaly was also weakened in November (figure 2e). Then, the SST dipole pattern was terminated and the tropical Indian Ocean experienced basin-wide warming in December (figure 2f).

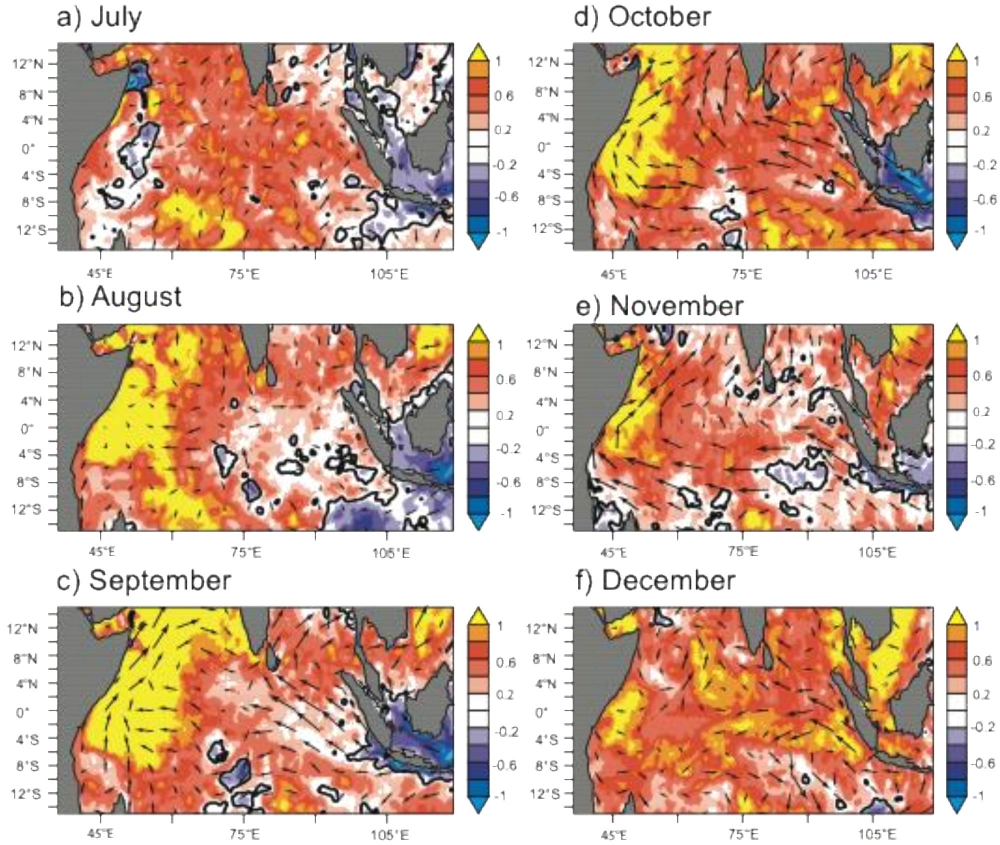

Figure 3. Anomalous evolutions of the sea surface temperature (*shaded* in °C) and the surface wind (*vector* in m/s) in the tropical Indian Ocean during July – December 2015.

3.2. Response of the near-surface currents to anomalous wind fields

In this observation, we investigated the response of near-surface currents to the anomalous wind fields over the equatorial Indian Ocean during 2015. The time-longitude diagrams of the anomalous near-surface current, SSH and surface wind was signified along the equatorial Indian Ocean in figure 3, respectively. Figure 3a showed that along the equatorial Indian Ocean indicated relatively weak easterly wind anomalies in July. From figure 3b weak westward currents along the equator was forced by those weak easterly wind anomalies.

The easterly wind anomalies in the eastern basin was strengthened from August to September 2015 (figure 3a). As a response, the eastern half of the equatorial Indian Ocean occurred relatively strong westward currents during this period (figure 3b). However, we was not detected a clear eastward propagating upwelling Kelvin waves (negative SSH anomaly) along the equator during this period (figure 3c). Instead, the SSH data revealed clear westward propagating downwelling Rossby waves (positive SSH anomaly) in the central equatorial Indian Ocean during this period (figure 3c). This downwelling Rossby wave was resulted as a response of the SSH in the off equatorial region to the easterly wind anomalies along the equator. Previous study has suggested that downwelling Rossby wave off south equator play an important role in initiating the development of pIOD event by inducing warm SST in the western pole of the pIOD.

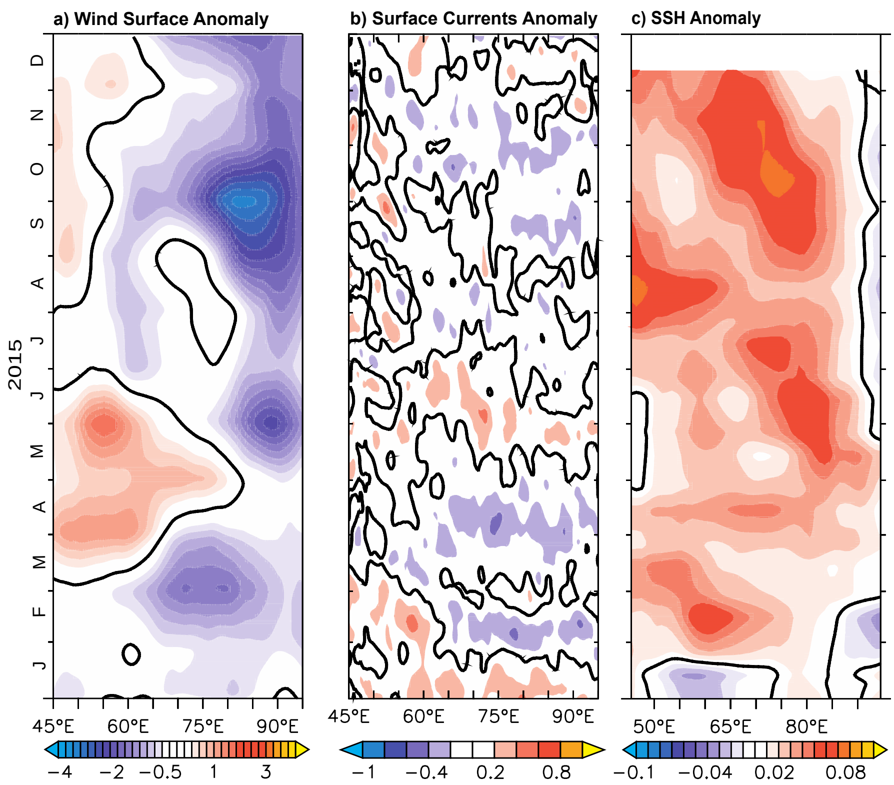

Figure 4. Hovmuller diagram of the a) surface wind anomaly (m/s), b) surface currents anomaly (m/s), and c) sea surface height anomaly (m) along the equator during January – December 2015.

To see the mean fields of ocean circulation in the normal conditions, the sea surface height (SSH) and surface current became the variable which can be represented the ocean circulation. Figure 3 showed the climatology of SSH and surface current during July – December. From figure 5, the western tropical Indian Ocean experienced the Negative SSH and the positive SSH was ensued in the eastern tropical Indian Ocean. However, the equatorial Indian Ocean did not show the significant indication of upwelling and downwelling signals during July 2015. In the western tropical Indian Ocean experienced downwelling Rossby waves during July till December and was strengthened in October. On the other side, the upwelling Kelvin waves occurred in the eastern tropical Indian Ocean and was intensified in October. In the southern of Java, the positive SSH occurred from July – October and the peaked signal took place in the September. The dynamic of surface current dominated westward current during July – September and the eastward current controlled during October – December which was illustrated by vector in figure 5.

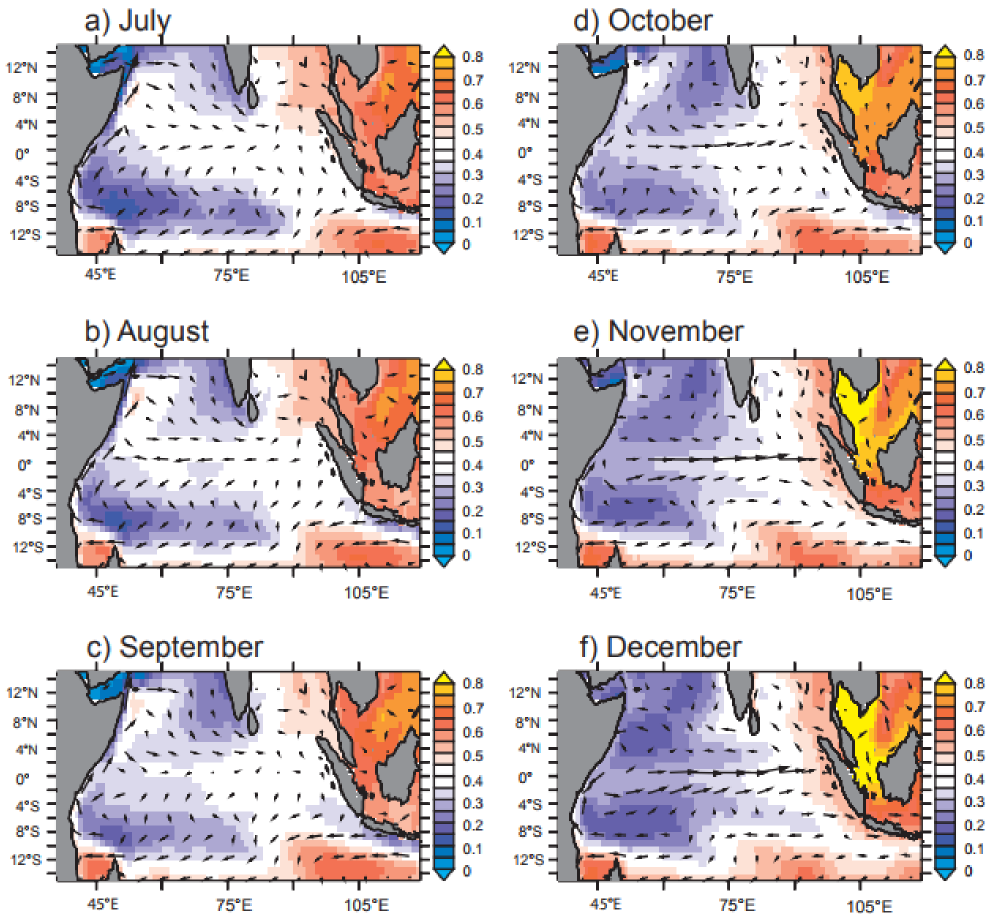

Figure 5. Monthly average of the sea surface height (*shaded* in meter) and the surface current (*vector* in m/s) in the tropical Indian Ocean during July – December 2006 - 2015.

To have a better view of spatio-temporal evolution of the near surface current and SSH to the wind field anomaly, the monthly evolution of the near-surface current and the SSH in the tropical Indian Ocean was specified in figure 3. As expected, there was no clear sign of the upwelling Kelvin waves along the equatorial Indian Ocean in response to the easterly wind anomalies (figure 6a-b). However, westward propagating downwelling Rossby waves were clearly detected from the development phase until the termination phase of the pIOD event, in particular in the southern hemisphere. Once the downwelling Rossby waves reached the western boundary of the Indian Ocean, part of the energy was redirected back as eastward propagating downwelling Kelvin waves (figures 6c-d). In the eastern equatorial Indian Ocean off west Sumatra coast, however, we detected upwelling signals (negative SSH anomalies) during the peak phase of the pIOD event starting from September (figure 6c). This negative SSH signal was strengthened in October and propagated northward and southward (figures 6d). In contrast to the SST pattern (figure 4), the SSH has signified a clear dipole pattern during the peak phase of the pIOD event in September-October 2015 with negative (positive) SSH anomalies occupied the eastern (western) tropical Indian Ocean (figures 6c-d).

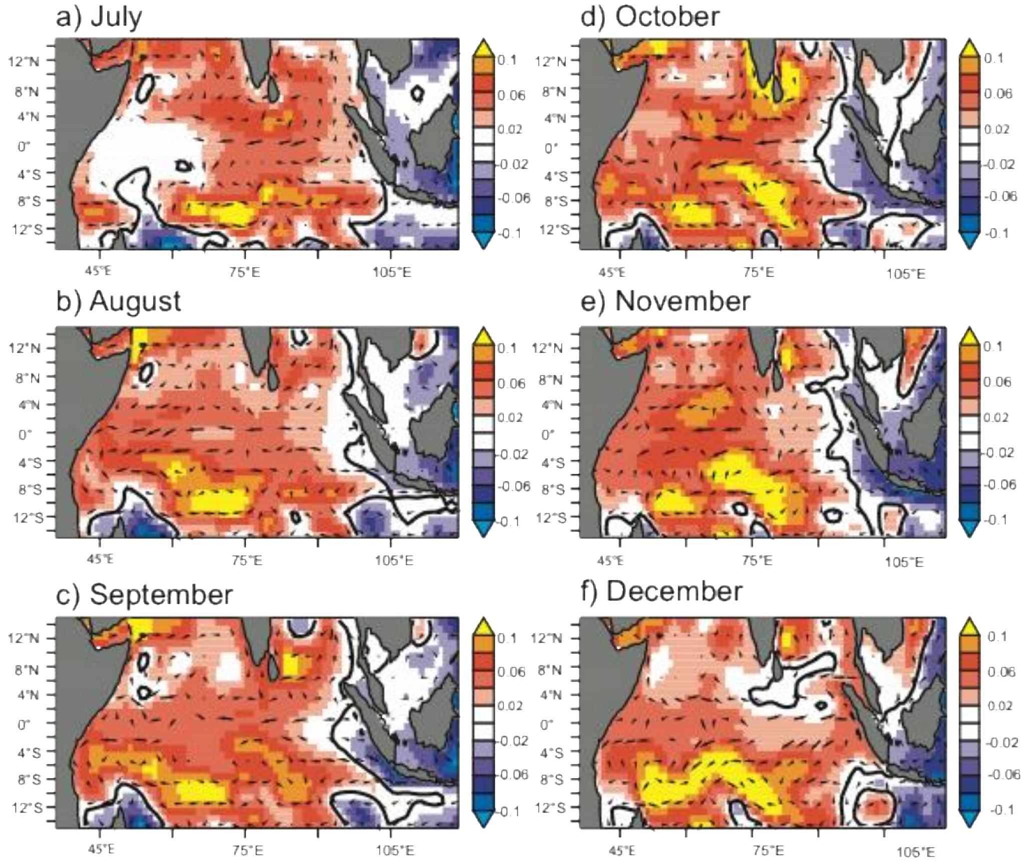

Figure 6. Anomalous evolutions of the sea surface height (*shaded* in meter) and the surface current (*vector* in m/s) in the tropical Indian Ocean during July – December 2015.

Meanwhile, the response of near-surface currents to the anomalous winds along the equator was obvious. Anomalous westward currents were detected along the equator during the peak phase of the pIOD in from August to October 2015 (figures 6b-d). These anomalous westwards currents were terminated in November as the easterly wind anomalies were weakened (figure 6e). The near-surface currents were reverse their direction in December although in the eastern equatorial Indian Ocean still occurred the easterly wind anomalies (figure 6f). These observations were the same analysis which was done by Nababan (2009) that there was the anomalous of surface current in the equator Indian Ocean during October – December. The northern-southeastern of tropical Indian Ocean took place the reverse direction of surface current.

4. Conclusion

A short-lived pIOD event took place in the tropical Indian Ocean, which was developed in August. The highest intensity occured in September/October and ceased in late-November/early December. Correlated with this pIOD event, strong easterly wind anomalies along the equatorial Indian Ocean perceived strong easterly wind anomalies during the peak phase of the event. The effect of easterly wind anomalies to the oceanic dynamic, along the equatorial Indian Ocean detected strong westward current anomalies.

Interestingly, the SSH pattern did not show a clear pattern of the upwelling Kelvin waves as a response of the surface ocean to the wind fields. However, in off equatorial Indian Ocean, in particular in the southern hemisphere, robust westward spreading downwelling Rossby waves were detected from the development phase until the cessation phase of the pIOD event. These westward downwelling Rossby waves induced warm SST to the western pole of the pIOD in agreement with previous investigation [16]. Once reached the western boundary of the Indian Ocean, these downwelling Rossby waves were delineated back into the interior Indian Ocean as eastward propagating downwelling Kelvin waves.

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References

[1] Schott F A, Xie S-P and McCreary Jr J P 2009 Indian Ocean Circulation and Climate Variability *Rev. Geophys.* **47** 1–46
[2] Cherchi A, Gualdi S, Behera S, Luo J J, Masson S, Yamagata T and Navarra A 2007 The influence of tropical Indian Ocean SST on the Indian summer monsoon *J. Clim.* **20** 3083–105
[3] Ajayamohan R S, Rao S A and Yamagata T 2008 Influence of Indian ocean dipole on poleward propagation of boreal summer intraseasonal oscillations *J. Clim.* **21** 5437–54
[4] Dwivedi S 2012 Forecasting the peak anomalies of dominant intrinsic modes of Indian Ocean Dipole Deep. *Res. Part I Oceanogr. Res. Pap.* **70** 73–82
[5] Jarvis C, Darbyshire R, Eckard R, Goodwin I and Barlow E 2018 Influence of El Niño-Southern Oscillation and the Indian Ocean Dipole on winegrape maturity in Australia *Agric. For. Meteorol.* **248** 502–10
[6] Nagura M and McPhaden M J 2010 Dynamics of zonal current variations associated with the Indian Ocean dipole *J. Geophys. Res. Ocean.* **115** 1–12
[7] Deser C, Alexander M A, Xie S-P and Phillips A S 2010 Sea Surface Temperature Variability: Patterns and Mechanisms *Annu. Rev. Mar. Sci.* **2** 115–43
[8] B A, Cherchi A and Ratna S B 2017 ENSO and the recent warming of the Indian Ocean *Int. J. Climatol.* **1**
[9] Saji N H, Goswami B N, Vinayachandran P N and Yamagata T 1999 A dipole mode in the tropical Indian Ocean *Nature* **401** 360–3
[10] Ashok K, Guan Z, Saji N H and Yamagata T 2004 Individual and Combined Influences of ENSO and the Indian Ocean Dipole on the Indian Summer Monsoon *Am. Meterological Soc*. **17** 3141–55
[11] Saji N H and Yamagata T 2003 Possible impacts of Indian Ocean Dipole mode events on global climate *Clim. Res.* **25** 151–69
[12] Li T, Wang B, Chang C-P and Zhang Y 2003 A Theory for the Indian Ocean Dipole-Zonal Mode* *J. Atmos. Sci.* **60** 2119–35
[13] Murtugudde R, McCreary J P and Busalacchi A J 2000 Oceanic processes associated with anomalous events in the Indian Ocean with relevance to 1997–1998 *J. Geophys. Res.* **105** 3295
[14] Nababan B 2009 Unusual upwelling evidence along easten part of equator in Indian Ocean during 1997-1998 El-Niño event *J. Kelaut. Nas.* **4** 16–31
[15] Gupta N and Bhaskaran P K 2017 Inter-dependency of wave parameters and directional analysis of ocean wind-wave climate for the Indian Ocean *Int. J. Climatol.* **37** 3036–43
[16] Sun S, Fang Y, Feng L and Tana 2014 Influence of the Indian Ocean Dipole on the Indian Ocean Meridional Heat Transport *J. Mar. Syst*. **134** 81–8
[17] Kanzow T, Cunningham S a, Rayner D, Hirschi J J-M, Johns W E, Baringer M O, Bryden H L, Beal L M, Meinen C S and Marotzke J 2007 Observed flow compensation associated with the MOC at 26.5 degrees N in the Atlantic. *Science* **317** 938–41