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# Water mass characteristic in the outflow region of the Indonesian throughflow during and post 2016 negative Indian ocean dipole event

**A Bayhaqi[1*], I Iskandar[2], D Surinati[1], A S Budiman[1], A K Wardhana[1], Dirhamsyah[1], D Yuan[3] and D O Lestari[4]**

[1]Physical Oceanography and Climate Laboratory, Research Center for Oceanography, Indonesia Institute of Sciences (LIPI), Jakarta, Indonesia
[2]Department of Physics, Faculty of Mathematic and Natural Sciences, Sriwijaya University, Palembang, South Sumatera, Indonesia
[3]Institute of Oceanology, Chinese Academy of Sciences (IOCAS), Qingdao, People Republic of China
[4]Graduate School of Environmental Sciences, Sriwijaya University, Palembang, South Sumatera, Indonesia

E-mail: ahmad.bayhaqi@lipi.go.id

**Abstract.** Strong El Niño and positive Indian Ocean Dipole (pIOD) events in 2015/2016 followed by relatively strong negative Indian Ocean Dipole (nIOD) and weak La Niña in 2016 events have affected hydrography conditions in the Indonesian Throughflow (ITF) region. Two research cruises were conducted using RV Baruna Jaya VIII in August and November 2016. These cruises aim to evaluate possible impact of those two climate mode events on the water mass characteristic in the outflow region of the ITF. Hydrographic data from those two cruises were combined with the sea surface temperature (SST) from the Advanced Very High Resolution Radiometer (AVHRR) and surface wind data from the European Centre for Medium-Range Weather Forecasts (ECMWF). The results showed that in the 2016 anomaly year, the cooler sea surface temperature was observed during the negative IOD (nIOD) event while the warmer temperature was found in the post of nIOD event. The observed water mass characteristics in the outflow region of the ITF revealed that the upper layer was dominated by the Indian Ocean water mass, while the Pacific Ocean water mass was observed in the deeper layer. The observed current data across the Sumba Strait showed that the South Java Coastal Current (SJCC) was observed in the upper layer, propagating eastward toward the Savu Sea. A few days later, the observed currents in the upper layer of the Ombai Strait revealed the ITF flow towards the Indian Ocean. Meanwhile, the lower layer showed an eastward flow towards the Ombai Strait.

## 1. Introduction

El Niño-Southern Oscillation (ENSO) is a naturally climate mode phenomenon involving ocean temperature fluctuation and the changes in the atmosphere circulation. This phenomenon has a great impact for the life such as flood and drought. Since 1950, 23 El Nino events have been recorded and the most severe El Nino event was recorded in 1997/98. However, recent El Nino event in 2015/2016 was reported as the strongest event since 1997/98 [1]. In addition, this strong El Nino event coincidentally followed by the positive Indian Ocean Dipole (pIOD) event. During pIOD event, negative Sea Surface Height Anomaly (SSHA) could trigger upwelling anomaly in the western tropical

Pacific via Indonesian seas [2]. As an impact, sea surface temperature (SST) in south of Java was cooling during May through July as a sign of pIOD event [3].

The tropical Indonesian seas, an inter-oceanic exchange of Pacific-Indian Ocean, hold an important role to modulate the global climate through the Indonesian Throughflow (ITF), part of the global thermohaline circulation. It is clear that the ITF brings freshwater budget into the Indian Ocean along its pathways within the Indonesian archipelago via western (Makassar strait) and eastern entrance (Maluku or Halmahera Sea) [4,5,6]. The North and South Pacific water mass are the sources of the ITF water mass [7,8]. The northern water sources consist of the North Pacific Subtropical Water (NPSW) and the North Pacific Intermediate Water (NPIW) [9]. These water masses mostly exit through the Ombai Strait and the Timor Passage while the rest flows through the Lombok strait [6,10].

The outflow region of the ITF is a cross road of water masses from the Pacific Ocean, the internal Indonesian Seas and the Indian Ocean. About 15 Sv water masses flow through this region annually [10,11]. Previous study has examined the water characteristic and its variability in the ITF outflow region [12]. The authors suggested that salinity maximum of the North Pacific Water is stronger during the transition between two monsoons and there was a phase lag between the Lombok Strait and Ombai Strait as well as the Timor Passage around one and five months. Moreover, the relationship between ITF flow and the IOD event was showed the increase of ITF transport in the upper layer of outflow strait during the strong IOD positive in late 2006 while as the opposite condition in the IOD negative 2004, that upper flow showed the decrease value [10]. Thus, in this study, we will evaluate not only the the flow but also the water mass characteristic in the outflow region of the ITF during an extreme climate event in 2016 with the newer observation data than the previous study.

## 2. Method

### *2.1 Observational Data*

Observations were conducted on August and November 2016 using Conductivity Temperature Depth (CTD) SBE and Shipboard Acoustic Doppler Current Profiler (SADCP) mounted at the RV Baruna Jaya VIII. The SADCP recorded ocean data along the cruise track. During August 2016, the Widya Nusantara Expedition (EWIN) cruise recorded hydrography data at 14 CTD stations. Meanwhile, the joint research cruise between Research Center for Oceanography, Indonesian Institute of Sciences (RCO LIPI) and Institute of Oceanology, Chinese Academy of Sciences (IOCAS) recorded hydrography data at 13 CTD stations during November 2016. CTD was casted around 50-meter depth from the bottom for EWIN cruise while it was around 1000-meter depth for RCO LIPI – IOCAS joint cruise with acquisition rate of 24 Hz. It means that the CTD can record 24 data pulse in 1 second. The CTD stations are located on the outflow of ITF such as ombai strait and timor passage following the method from the previous study [13]. This figure 1 presents the stations for the CTD measurements in August and November.

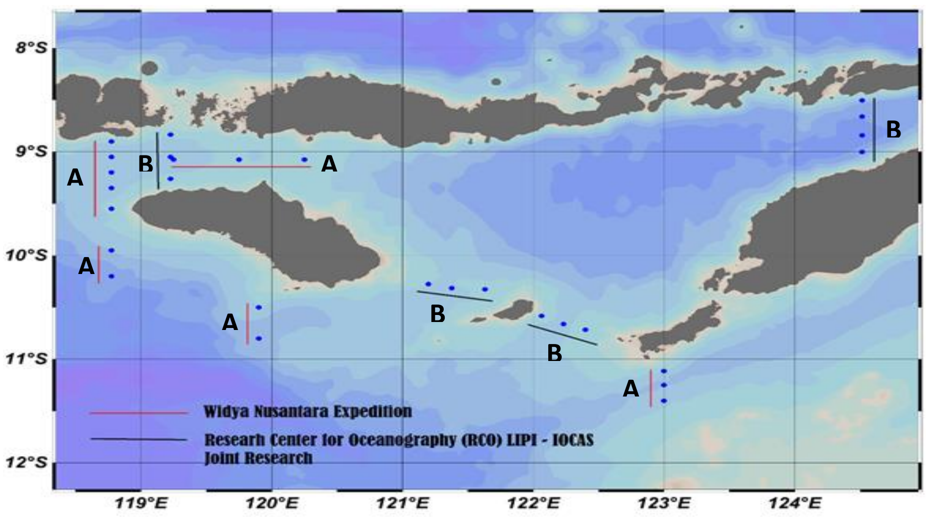


**Figure 1.** The stations for CTD measurements. The red lines (A) indicate EWIN stations while the blue lines (B) indicate RCO LIPI-IOCAS stations

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### *2.2. Satellite Data*

Monthly sea surface temperature (SST) data were obtained from the National Oceanographic and Atmospheric Information (NOAA) Optimum Interpolation (OI) SSST with a horizontal resolution of 0.25° for a period of January 2000 to December 2016. Meanwhile the European Centre for Medium-Range Weather Forecast (ECMWF) ERA Interim monthly data sets are retrieved from January 1979 to December 2016 having resolution of 0.5°. Note that the monthly climatology fields were calculated from the time series over the period of January 2001 until December 2015. The anomaly field are, then, defined as the deviation from the mean climatology. In this study, we calculate the DMI from the different value of sea surface temperature anomaly between the western pole (10°S to 10°N and 50°E to 70°E) and the eastern pole (0°S to 10°S and 90°E to 110°E) following [14].

## 3. Result and Discussion

### *3.1. Climate mode events 2015-2016*

Figure 2 shows the time series of Nino 3.4 index and Dipole Mode Index (DMI) Respectively. Note that the Nino 3.4 index is defined as averaged SST anomaly in the central equatorial Pacific Ocean over the box 170°W - 120°W, 5° - 5°N [13,15]. Meanwhile, the DMI is the east-west temperature gradient across the tropical Indian Ocean between the western equatorial Indian Ocean (50°E – 70°E and 10°S – 10°N) and the southeastern equatorial Indian Ocean (90°E - 110°E and 10°S – 0°N) [14].

It is shown that during 2015, a strong El Niño event took place in the tropical Pacific (figure 2a), accompanied by a positive Indian Ocean Dipole (IOD) in the tropical Indian Ocean (figure 2b). Evolution of the El Niño event was started in boreal spring 2015, peaked in boreal winter 2015 and terminated in boreal spring 2016 [16]. Meanwhile, the positive IOD event was lasting very short: started in June, peaked in September and terminated in November 2015.

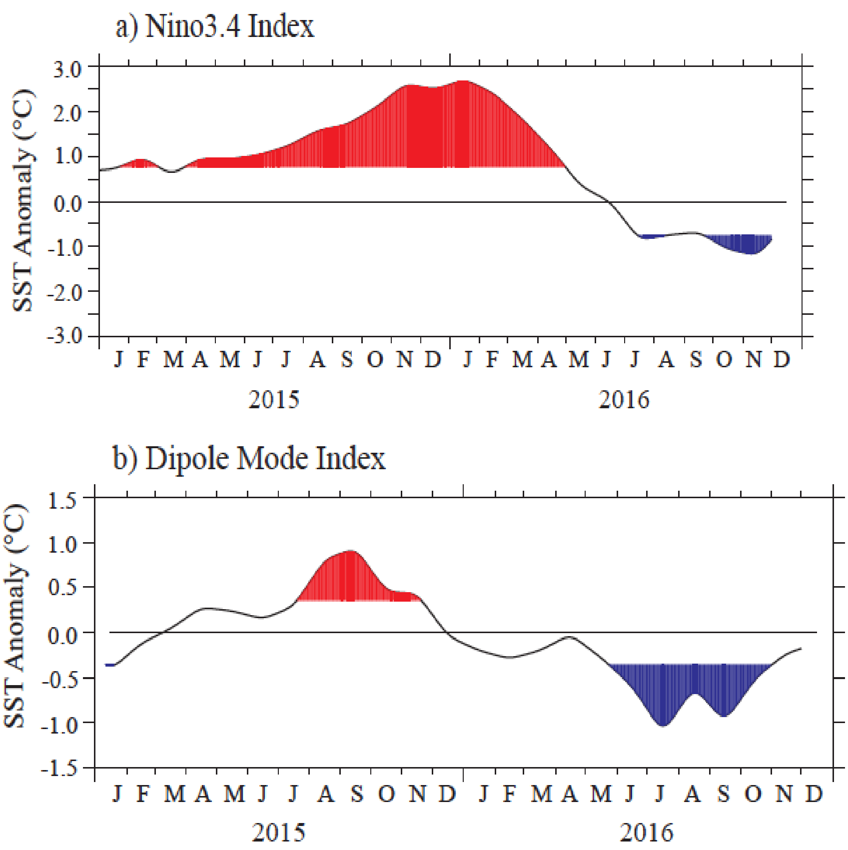



**Figure 2.** Time series of (a) Niño 3.4 index and (b) Dipole Mode Index (DMI) from January 2015 until December 2016. The red shaded-curves indicate the El Niño or positive Indian Ocean Dipole (IOD) events while the blue shaded-curves indicate La Niña or negative IOD events.

The situation was reverse in 2016. Weak La Niña event was observed at the end of 2016 (figure 2a) while relatively strong negative IOD event took place in the tropical Indian Ocean from May until November 2016 (figure 2b). Note that the EWIN and joint research observations were conducted during and post negative IOD event and during the initial phase of weak La Niña event in August and November 2016. Figure 3 shows the spatial-temporal evolutions of the SST and wind over the eastern tropical Indian Ocean and within the Indonesian seas. It is clearly shown that the EWIN observation was conducted during the peak phase of negative IOD event which is indicated by warm SST anomaly in the eastern tropical Indian Ocean associated with westerly wind anomaly (figure 3b). On the other hand, the joint research observation was conducted after termination of the negative IOD event and during the initial phase of weak La Niña. Therefore, the SST anomaly in the study area was relatively normal and the wind was south-easterly wind anomaly (figure 3e).

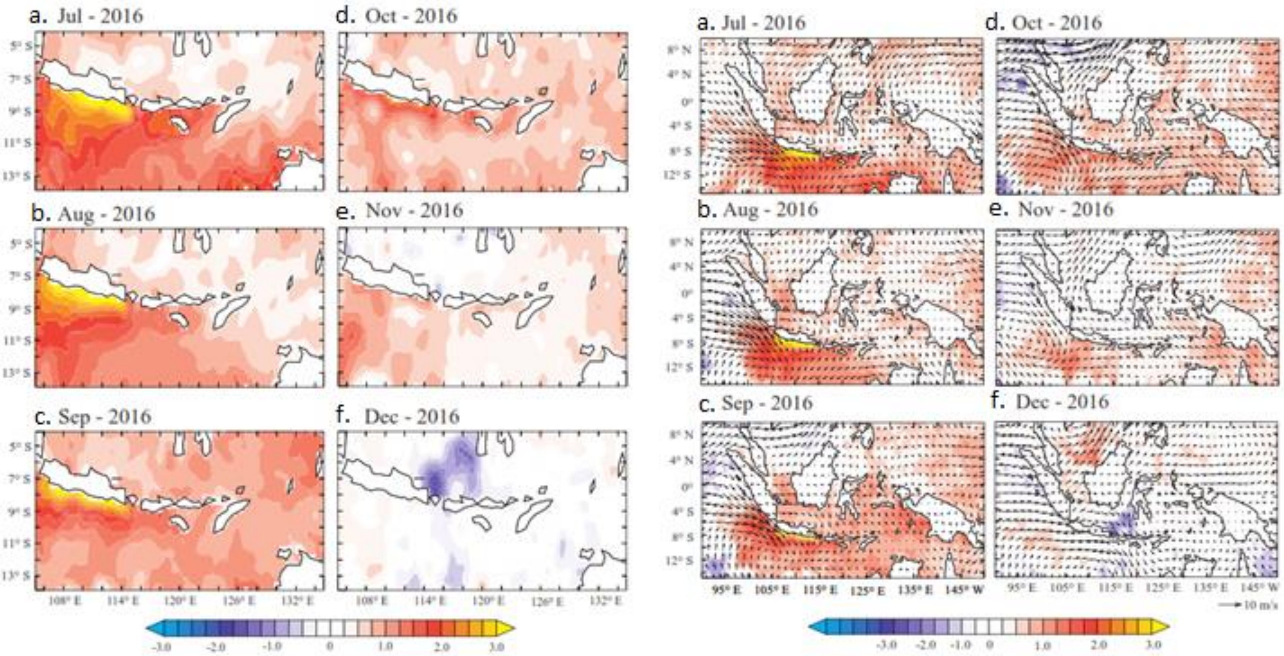



**Figure 3.** Monthly spatial-temporal evolution of the sea surface temperature (SST) and wind anomalies in the eastern tropical Indian Ocean and within Indonesian seas during July – December 2016

### *3.2. Water mass characteristics*

Figure 4 shows the T-S diagram of the water mass observed during both observational cruises in August and November 2016. There were six kinds of water masses observed in the research area. In the upper layer (0-500 m) we found the Bay of Bengal Water (BBW) from the Indian Ocean, Indian Equatorial Water (IEW), Indonesian Upper Water (IUW) and Western North Pacific Central Water (WNPCW). Meanwhile, in intermediate layer between 500-1500 m, the Antarctic Intermediate Water (AIW) and the Indonesia Intermediate Water (IIW) were identified. It is also shown that the water mass has divided the water column into three regions. Firstly, the surface layer (<50 m) was dominated by water mass from the Indian Ocean, secondly several water mass resources from the Indonesian water and the Pacific Ocean trigger mixing within 100-500 m depth and lastly the Antarctic and the Indonesian water are dominant resources in the intermediate layer.

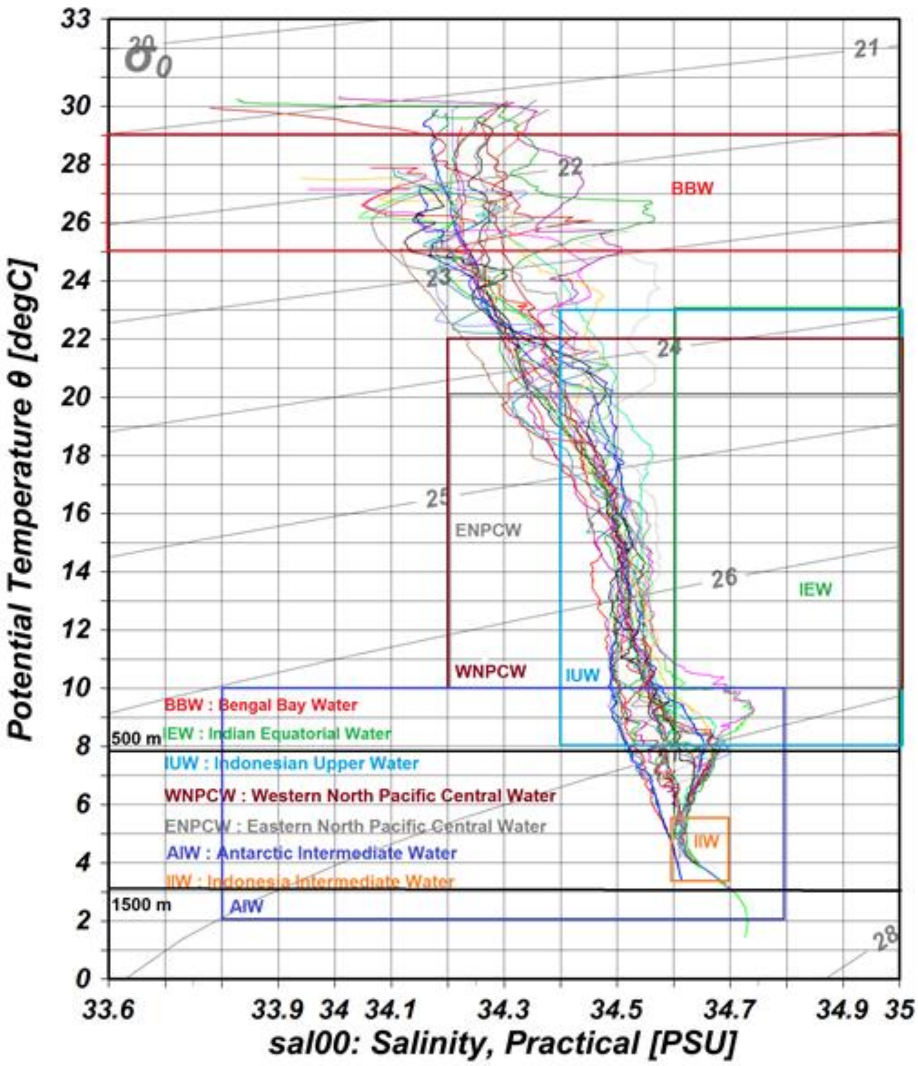



**Figure 4.** The T-S diagram for all CTD stations from August and November 2016 measurements.

*3.3 Spatial Distribution of Observed water mass*

Figure 5 shows the observed water mass in the northern parts of the ITF outflow region while figure 6 presents the observed water mass in the southern parts of ITF outflow region. In the western Savu sea, we found the BBW and IEW water masses (figure 5, *left panel*). Fresh water mass was observed in the upper layer within the Savu sea (figure 5, *upper panel*). On other hand, in the Ombai strait, the Pacific water mass in the upper layer (figure 5, *right panel*). In the southern parts of ITF outflow region, the observed water masses were saltier than those observed in the northern parts (figure 6). In the western part, water masses from the equatorial Indian (IEW) and Bay of Bengal Water (BBW) are found (figure 6, left panel). On other hand, the water masses observed in the Timor Passage and in the southern part of Savu sea were dominated by water massed from the Pacific Ocean (figure 6, lower and right panels).

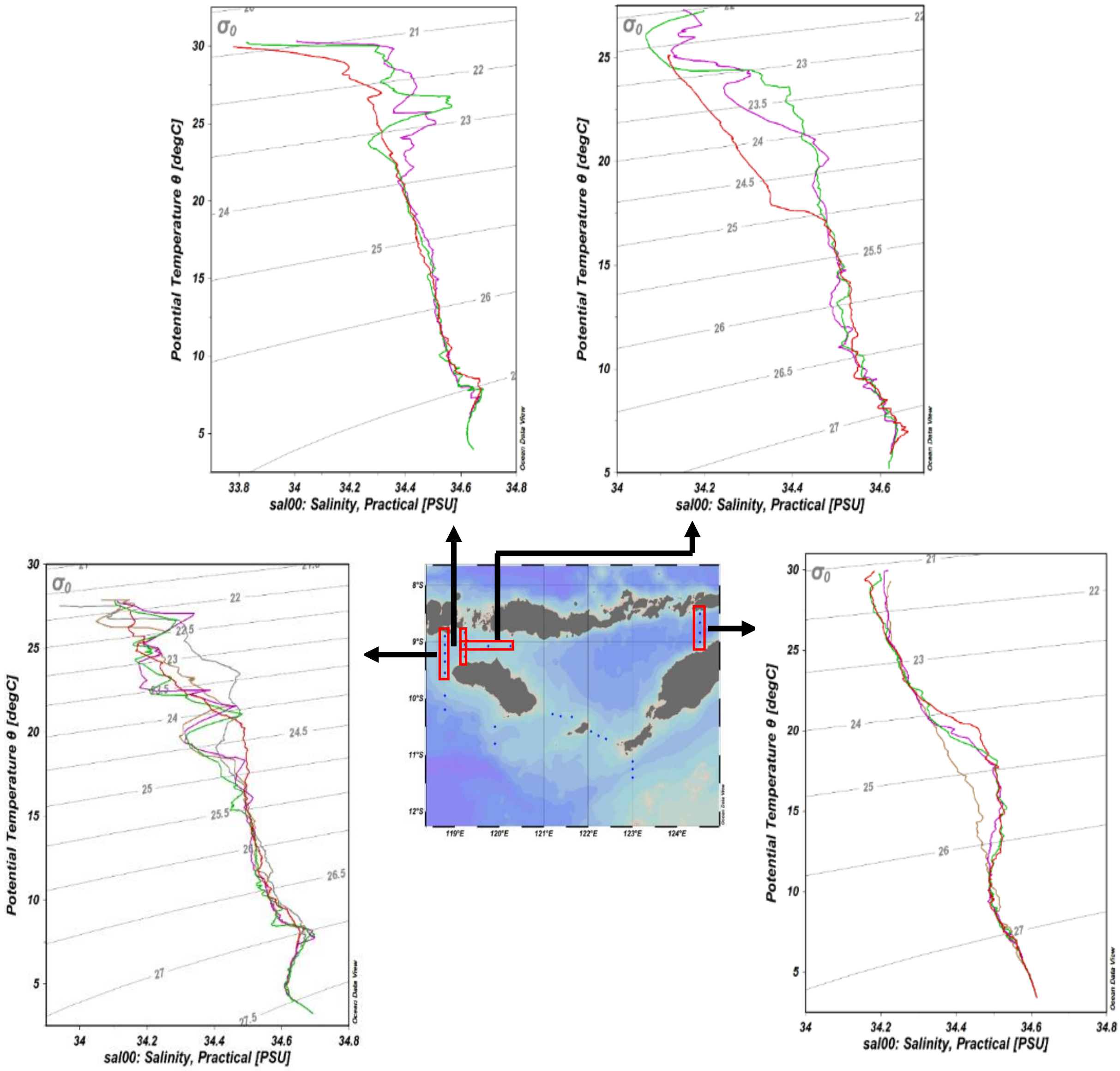



**Figure 5.** The T-S diagram of observed water mass in the northern area of ITF outflow region

The observed water in this area has unique characteristics. The maximum salinity value ~34.60 psu indicating the North Pacific Subtropical Water (NPSW) water mass be inivisible. Vertical mixing in this region is estimated affecting the water mass. Thus, it has the same characteristic with Banda and Timor sea water mass which is marked by the maximum salinity ~34.50 and the same profile until the bottom layer. The difference value 0.1 – 0.2 psu between them is resulted from the intrusion of Indian Central Water which has high salinity. This water mass is one of the primary sources for the ventilation of permanent thermocline in the Indian ocean. It is formed by the subduction in the region of negative wind stress curl and moves eastward with the south Indian current [17]. This water mass result also showed that there is the Indian ocean water trace which enters the Sumba strait. On the other hand, figure 6 showed the distribution of water mass in the southern region of ITF outflow. That figure illustrated the southern region is slightly more influenced by Indonesian Intermediate Water (IIW) which characterised by the range of temperature value from 3.5°C – 5.5°C and the value of salinity 34.6 psu – 34.7 psu

Related to the sea surface temperature (SST), both figure 5 and 6 provided the different value in temperature during two cruises. The maximum value of SST in the EWIN cruise and Joint research cruise is 27.8°C and 30°C respectively. The monsoonal condition potentially contributes in making that difference since August is still in the southeast monsoon where in this period can trigger the upwelling phenomenon and reduce the sea temperature. In the opposite way, the temperature can be warmer when the northwest monsoon. That condition indicates that during 2016 anomaly year, the cooling temperature is followed by nIOD event coincidentally and the temperature will increase after the nIOD phase in this region.

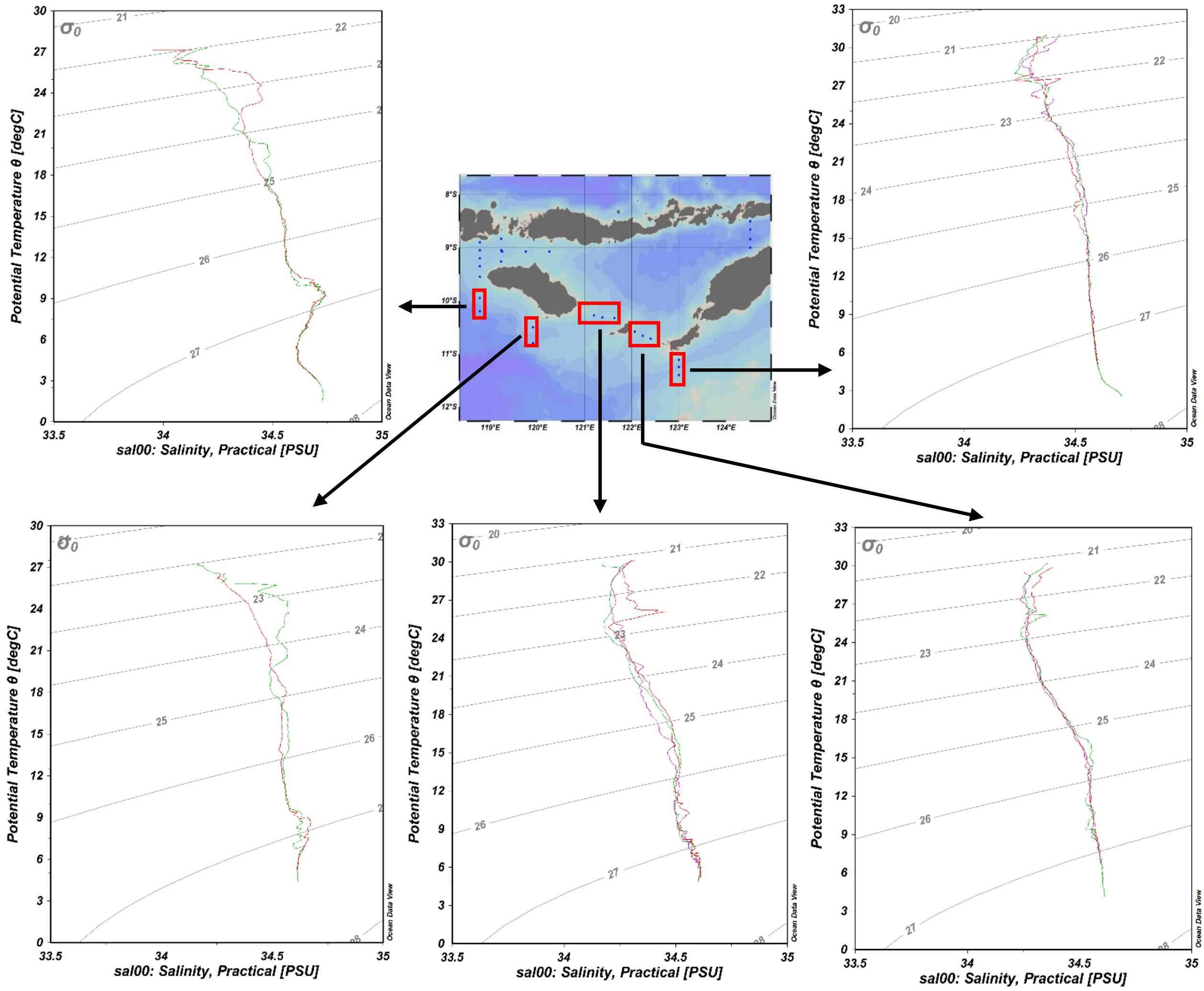
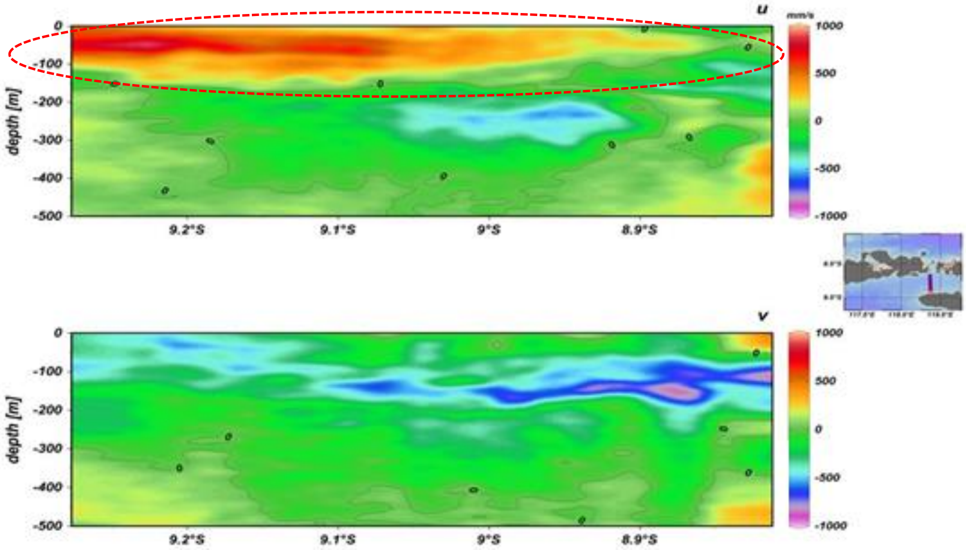
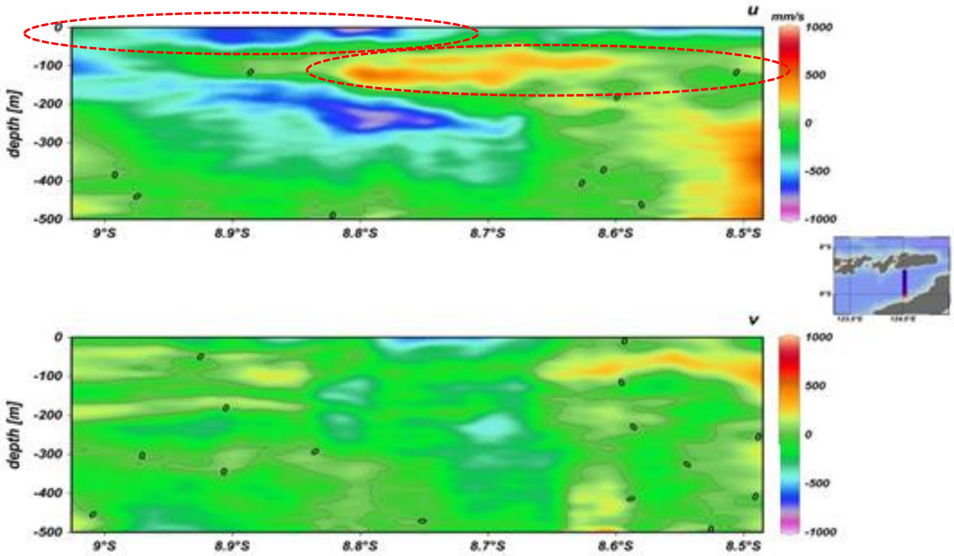



**Figure 6.** The T-S diagram of observed water mass in the southern area of ITF outflow region




(a)




(b)

**Figure 7.** Vertical section of Zonal (*upper panel*) and meridional (*lower panel*) current in (a) Sumba Strait (b) Ombai Strait

To evaluate a possible dynamic underlying the spatial distribution of water masses during the observational periods, we analyse the observed currents in two straits, namely Sumba and Ombai Strait (figure 7). It is shown that the penetration of the Indian Ocean water into the ITF outflow straits was associated with strong eastward zonal current observed in Sumba Strait (figure 7a, *upper panel*). This eastward zonal current is possibly propagation of South Java Coastal Current (SJCC). The Pacific and Indian Ocean water masses observed in the southern part of ITF outflow area associated with strong eastward current in between two westward ITF cores (figure 7b, *upper panel*). This subsurface eastward current is known as South Java Coastal Under Current (SJCUC). These results fit with [18] where observation measurement from 2004-2006 showed the trace of SJC moving to the east into the Savu sea. From this condition, the flow in the Sumba strait confirms that there is a contribution from the Indian Ocean water mass through the SJC.

## 4. Conclusion

Warm SST anomaly in the ITF outflow region was detected during the negative IOD phase. As the opposite, SST anomaly was cooling down after the stoppage of negative phase. The cooler sea sea surface temperature was observed during the EWIN cruise in southeast monsoon (nIOD event 2016) while warmer temperature was found during joint rsearch cruise RCO LIPI-IOCAS in north monsoon (post nIOD event 2016) indicating that there is a monsoonal contribution in this region. The upper layer of western ITF outflow region was dominated by the Indian Ocean water mass induced by South Java Coastal Current while the deeper layer was dominated by Pacific origin water masses induced by ITF. Meanwhile, in the eastern ITF outflow region, Pacific Ocean water mas via ITF was the biggest resource both in upper and deeper layer.

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