IOP Conference Series: Earth and Environmental Science

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IOP Conf. Series: Earth and Environmental Science **441** (2020) 012053 doi:10.1088/1755-1315/441/1/012053

Observed snapshot condition of waters during El Niño Southern oscillation (ENSO) 2015-2017 events in the Maluku Channel

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Abstract. The Maluku Sea acts as the east gate for the Pacific transport going to Indian Ocean via internal Indonesian Seas. The observational measurement using RV Baruna Jaya VIII, which was conducted during the second transitional monsoon in the respective years 2015,2016 and 2017, aims to figure out a snapshot condition of waters including in the Maluku Sea. The results emphasize a dominant southward current in the surface layer during the period. Despite having a variation of the meridional current pattern, a greater southward transport during 2016 and 2017 (La Niña years) with the maximum –1 Sv indicates that the air-sea interaction may have influence in the subsurface layer.While three type of water mass are observed in 2015 (El Niño year) such as North Pacific Subtropical Water (NPSW), North Pacific Intermediate Water (NPIW) and South Pacific Subtropical Water (SPSW), there is an isopycnal mixing which triggers a fluctuation of the salinity value in the 200- 700 m during 2016 and 2017(La Niña years). In addition, the temperature shifting during El Niño and La Niña events contributes to the discrepancy of nutrient concentration. The higher orthophospate and nitrate are observed during El Niño event associated with the warmer temperature.

1. Introduction

Indonesian Seas are part of Southeast Asian Seas, located between the South China Sea, Western Pacific Ocean, and Eastern Indian Ocean. Circulation patterns and Indonesia's marine ecosystem are influenced by the circulation of the Western Pacific Ocean. Indonesia through flow (ITF) is one of the characteristics of the ocean current system in Indonesia. ITF is a system of current circulation in Indonesian waters where a trajectory of currents carrying water masses from the Pacific Ocean to the Indian Ocean. The Pacific water mass consists of the North Pacific and South Pacific water masses [1]. ITF's occurrence is mainly due to differences in sea level between the Pacific Ocean and the Indian Ocean, namely the surface of the tropics of the Western Pacific Ocean is higher than the Eastern Indian Ocean, resulting in a pressure gradient that results in the flow of currents from the Pacific Ocean to the Indian Ocean [2].

ITF carries Pacific Ocean water masses into Indonesian waters through two routes, namely through the western route, entering through the Sulawesi Sea and continuing to the Makassar Strait, the Flores Sea and the Banda Sea. This route is known to be ITF's main transport line [3]. The second path is the eastern path, through the Maluku Sea and the Halmahera Sea and continues to the Banda Sea. From the deep waters of the Indonesian oceans, water masses will flow out into the Indian Ocean through the main straits, such as the Lombok Strait and the strait between Alor and Timor [4,5]. Several studies indicate that the ITF have been more explored in the western path rather than the eastern path

[6,7]. Despite of being a main gate in the eastern gate, the observations of current dynamic in the Maluku Channel are still rare [8]. Thus, the information of water dynamic in the Maluku Channel is still need explored further.

Propagating from the Pacific Ocean into Indian Ocean via Internal Indonesian seas, the ITF moves the water mass and the ocean temperature as well. According to Laevastu and Haela [9], changes in temperature can cause water circulation and stratification which directly and indirectly affect the distribution of aquatic organisms. This is very closely related to biochemical processes in the body of an organism. Then, using the observational data, this study aims to figure out a snapshot condition of waters including physical and chemical properties.

2. Materials and methods

2.1. Observation

On this study, the primary data were taken from the Joint-Research cruise program between Research Center for Oceanography, Indonesian Institute of Sciences (RCO –LIPI) and Institute of Oceanology ,Chinese Academy of Sciences (IOCAS) during the second transitional monsoon from 2015- 2017. The observational data consist of ocean current, physical properties of the waters such as temperature, salinity and chemical property such as dissolved nutrients. While the ocean current data were recorded by Vessel Mounted Acoustic Doppler Current Profile (VM ADCP) along the cruise track (note: the vessel moves westward into Celebes Sea), the water properties data were taken from Conductivity Temperature Depth (CTD) SBE at five recording stations (see Figure 1). On the other hand, dissolved nutrients were determined spectrophotometrically on board.

The ADCP has frequency of 76.8 kHz and can record the ocean current data until 128 bins. Starting with the first bin range of 13 meters and the bin size (range) of 5 meter, it means that we have the ocean current data until ~600 m depth below the surface. However, due to technical matters during the measurement in 2015 revealing many blank data, we only use the upper 15 bins (~80 m) for all periods. Using a simplification of box area, the distance of station 1 into station 5 is assumed as the length of Maluku Sea while the maximum bin is interpreted as bottom column. Then, the simple calculation of snapshot transport can be calculated. On the other hand, the CTD measures the ocean physical properties until 1000 m in each stations revealing the T-S diagram which indicates the water mass characteristic in the Maluku Sea.

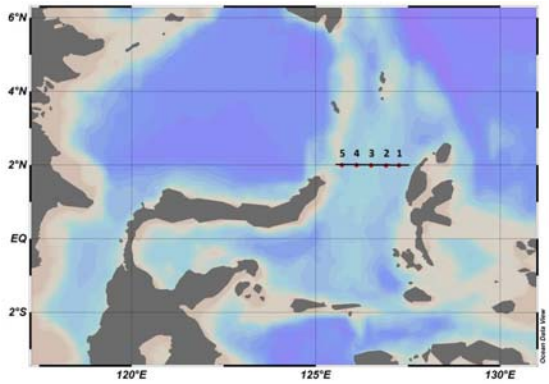

Figure 1. Research Location; red circle indicates the CTD stations and black line shows the cruise track.

2.2. Satellite data

In order to define the climate event in the periods, monthly sea surface temperature from National Oceanographic and Atmospheric Information (NOAA) Optimum Interpolation (OI) with the resolution of 0.25º for period of January 2000 to December 2018 are used to calculate the climate index such as Nino 3.4 index and Dipole Mode Index (DMI). In this study, the climate indices are calculated using the averaged SST anomaly in the defined region. While Nino 3.4 index is described as the average of SST anomaly in the central equatorial Pacific Ocean, the DMI index is the temperature gradient between western and southeastern equatorial Indian Ocean. The term of anomaly comes from the deviation of mean climatology. Then, in this study, the monthly climatology is defined as the time series over the period of January 2001 until December 2017.

3. Results and discussion

3.1. Climate event

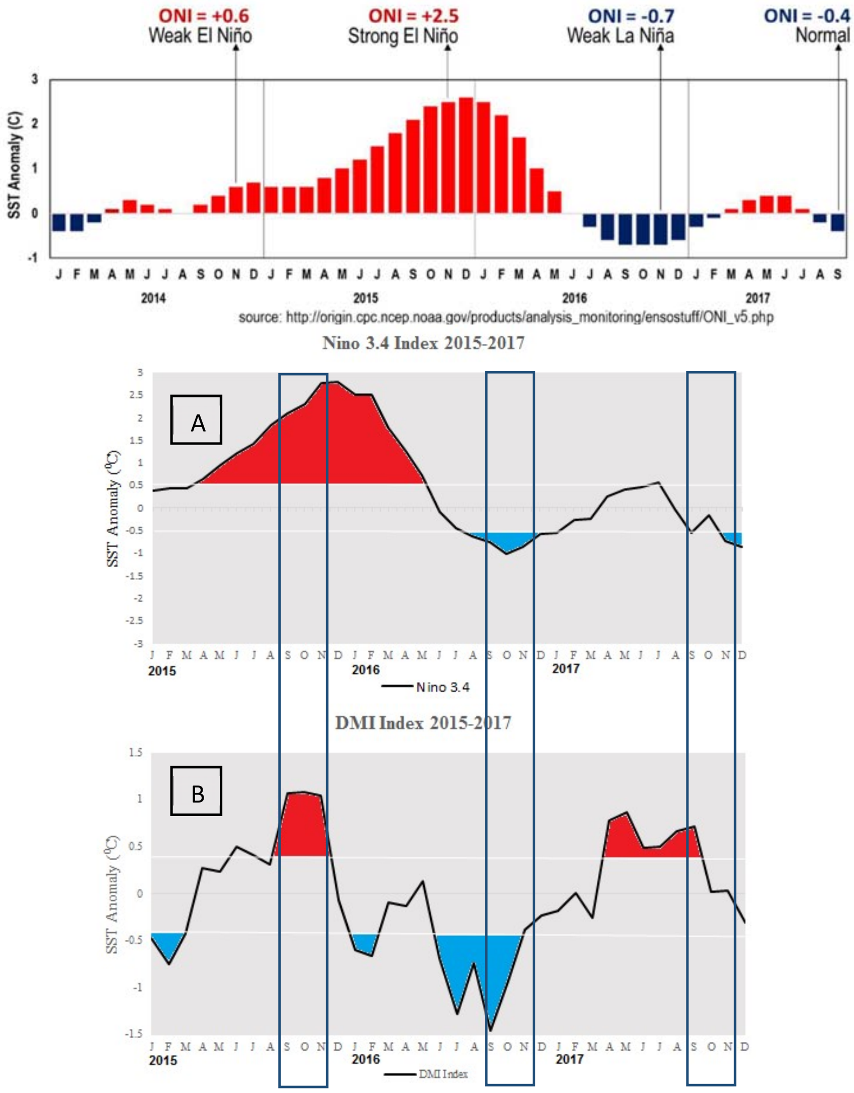

Figure 2. Time series of ENSO condition (upper panel and A) and DMI index (B) from January 2015 until December 2017. The red-shaded curves signify the El Niño and positive Indian Ocean Dipole

(IOD) events and the blue-shaded curves show La Niña and negative IOD events.

In order to identify the climate events during the observation periods, figure 2 shows a time series of climate indices; Nino 3.4 index and DMI from 2015-2017. It indicates a sea surface temperature anomaly as y-axis while the x-axis refers to the time. The El Niño (positive Indian Ocean Dipole) and La Niña condition (negative Indian Ocean Dipole) can be determined with the red and blue-shaded curves in Nino 3.4 (Figure 2a) and DMI (Figure 2b) respectively. As revealed in Figure 2, a strong El Niño and positive IOD event occurred in 2015, followed by La Niña event in the next two years with the 2016 strong negative IOD.

The El Niño onset was observed in March 2015. It reached a peak in boreal winter months and terminated in boreal spring months 2016. The reversal condition occurred in 2016 and 2017 when weak La Niña was found at the last months of those years respectively. On the other hand, the short lasting of 2015 positive IOD was begun in June and stopped November. The opposite situation also happened in 2016 when strong negative IOD was seen from May until November. Since the joint cruise was organized during second transitional monsoon (October-November), then it is definitely shown that the observation was conducted in the strong El Niño+positive IOD (2015), weak La Niña+strong Negative IOD (2016) and La Niña+ normal IOD phase (2017).

3.2. Water mass characteristic

Physical properties data such as temperature and salinity, which was taken using CTD, reveal the characteristic of water mass. Its characteristics can be identified using T-S diagram (figure 3). Based on the results, generally, the Pacific water mass is a dominant input for Maluku Sea. It can be seen from the observed water mass in the T-S diagram. There are three types in this region namely North Pacific Subtropical Water (NPSW), North Pacific Intermediate Water (NPIW), South Pacific Subtropical Water (SPSW). These Pacific water masses potentially come from the recirculation of Mindanao current and Halmahera retroflection. Based on the results, the water mass in Maluku Channel is mainly dominated by North Pacific Water while the trace of South Pacific water mass may come from Halmahera Sea.

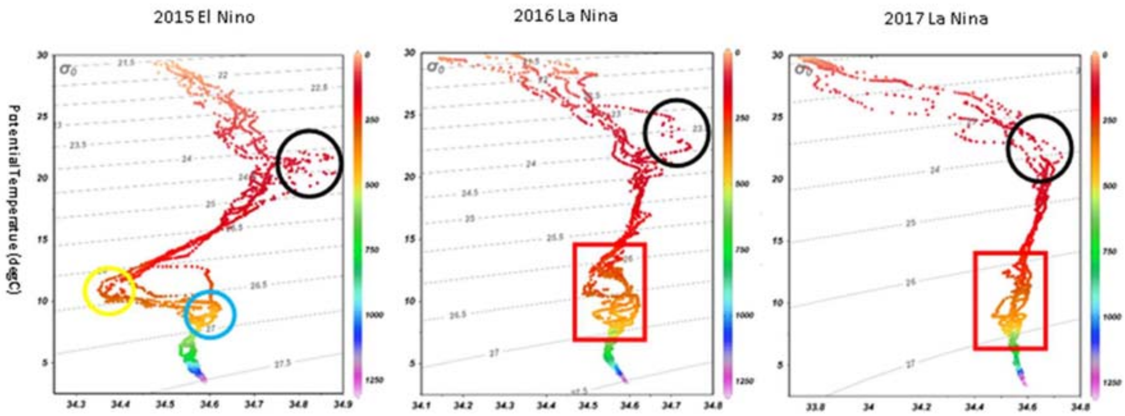

Figure 3. Snapshot T-S diagram represents the type of water mass in the Maluku Channel during ENSO condition 2015-2017. The water mass consist of NPSW (black circle), NPIW (yellow circle), SPSW (blue circle) and the fluctuation phenomenon of salinity value which potentially signifies the isopycnal mixing.

In 2015, the maximum salinity value of 34.88 psu with the temperature 21.70^{0}C were observed at 105 m depth while the minimum salinity of 34.35 psu with the temperature 10.67^{0}C were found at 306 m depth. In addition, there is also found the maximum salinity at 390 m depth with 34.62 psu and temperature 9.43^{0}C. In this year, there are a strong signal for all three water mass types; NPSW, NPIW and SPSW. They are found in the surface layer (100 m), intermediate layer (300 m) and lower later respectively. While the NPSW has the characteristic with the salinity maximum in the range of 34.6 -35.1 psu and temperature 15-23^{0}C, the NPIW consists of salinity range of 34.3 -34.6 psu and temperature 9-12^{0}C. Then, the SPSW has a salinity maximum below the homogen layer with the salinity range of 34.6 – 35.3 psu.

The water masses profile in the surface layer until 500 m depth are observed to be widely vary during the distinct ENSO condition. The clear profile of NPSW, NPIW and SPSW in Maluku Channel can be found at the strong El Niño 2015. While, on the following years of La Niña events, the penetration of NPIW and SPSW are not as strong as on 2015. In the strong El Niño 2015, there are relatively saline water at the surface area which is affected by the low precipitation in Indonesian Seas. On the other hand, while the salinity profile in 2016 shows a similarity with 2015, a fresher surface water is observed in 2017 creating a strong stratification. Furthermore, a unique phenomenon occurred in 2016 and 2017 showing a fluctuation of salinity value in 200 m – 700 m depth. The isopycnal mixing in this layer might responsible for this phenomenon.

3.3. Snapshot ocean current and transport dynamic

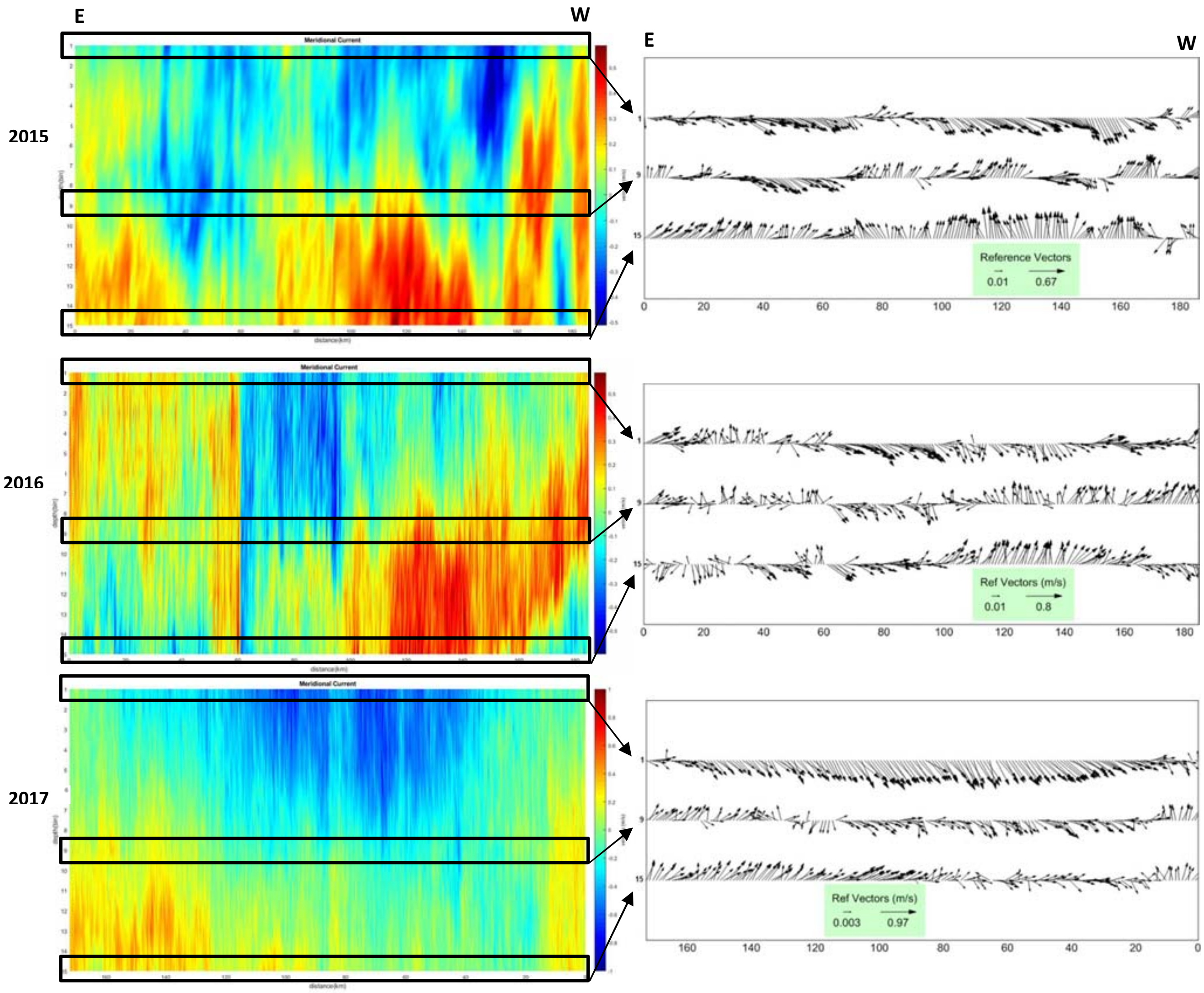

Figure 4. Time series of snapshot meridional current in Maluku Channel; Section plot (left-handed panel) and vector plot (right-handed panel). The initial of E means eastern side of the track while W indicates the western side.

To figure out the ocean current dynamic in the Maluku Sea, we also evaluate the ocean current data from the VMADCP revealing the snapshot condition of ocean current pattern in this region. Figure 4 illustrates the time series of meridional current in the Maluku Sea with the bin as Y-axis and x-axis indicating the distance. Since the vessel moves eastward into the Celebes Sea, then a starting point (zero km) of distance in the figure indicates the eastern side of the track. In this study, the vector plot are presented in the certain bin (depth); bin 1, bin 9 and bin 15.

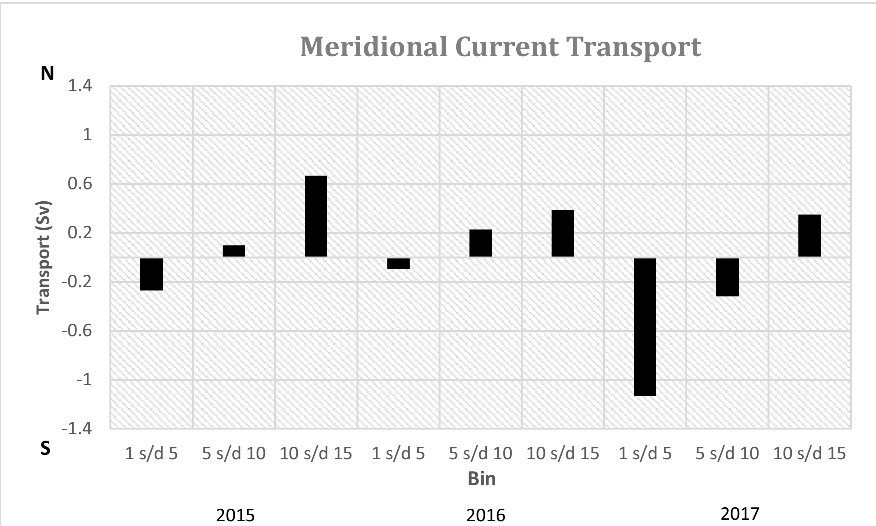

Figure 5. Time series of snapshot current transport in Maluku Channel. The plus value indicates northward current while the minus value shows southward current.

Generally, there is a dominant southward current in the surface layer with the magnitude range of 0.01 – 0.67 m/s for all periods. This result emphasizes that the source of water mass in the Maluku Sea comes from the northern region. However, looking at the subsurface layer (bin 9), the variation of meridional current (southward and northward) is observed during 2015 and 2016. The clear sign of dominant southward current occurred during 2017 in the bin 1 and bin 9 layer. Although 2016 and 2017 are the La Niña years, there is a different condition between them. The La Niña event in 2016 is coincided with the strong negative IOD. Thus, there is an intrusion of northward current in the subsurface layer during 2016 while southward current dominates in 2017. The northward current is also seen in the lower layer (bin 15) in the consecutive three years (2015-2017) indicating the reversal current. Similar with the vector plot, the variation of snapshot transport current (figure 5) in the Maluku Sea shows a maximum southward transport in 2017. As La Niña develops, the transport of Indonesian Throughflow going into internal Indonesian Seas via inflow passages increases due to the stronger eastern trade wind.

3.4. Dissolved nutrients

The concentration of dissolved nutrients is one of the most important properties of seawater. Nutrients play a role in stimulating primary production and hence have a significant effect on life in the oceans.

Two of the most critical dissolved nutrients in seawater are phosphorus and nitrogen in the form of orthophosphate and nitrate respectively. During three years observation in three stations (st.1, st.3 and st.5), nutrient concentrations in the sea surface were significantly different (Figure 6). Concentrations of orthophosphate as well as nitrate in 2015 were higher than in 2016 and 2017. Since the observations were conducted in the same season, it was likely that the shift in seawater temperature during El Niño (2015) and La Niña (2016 and 2017) contributed to that discrepancy. El Niño is associated with warmer temperature. During this event, plankton at the surface might migrate down to the deeper and cooler water column. As a result, nutrients at the surface were not used up by phytoplankton leading to high nutrient concentration at the surface. In contrast, La Niña is associated with cooler temperature. During this event, plankton at deeper water column might migrate up to the surface with warmer temperature. As a result, nutrients at the surface would be consumed by phytoplankton leading to low nutrient concentration at the surface.

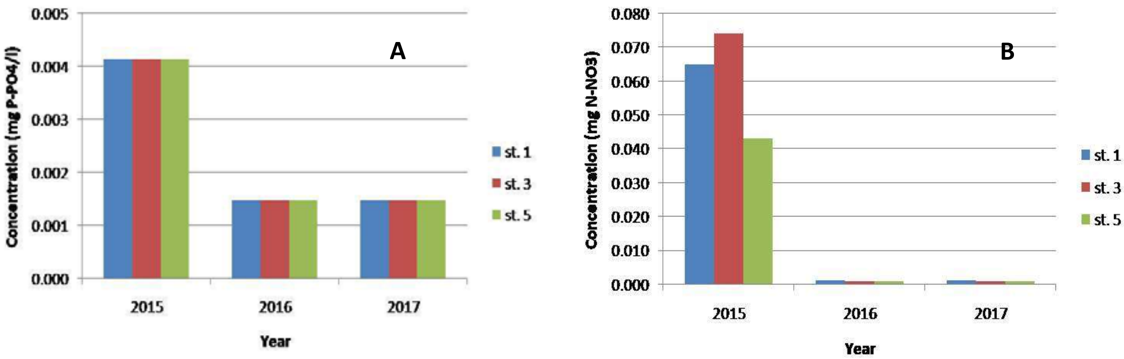

Figure 6. Dissolved nutrient in the form of orthophosphate (A) and nitrate (B).

4. Conclusion
The observed dominant southward current in the surface layer of Maluku Channel brings the Pacific water masses, mainly from North Pacific Ocean. A greater southward transport which is marked by maximum transport of -1 Sv occurs during La Niña event, revealing a unique fluctuation of salinity value in the subsurface layer 200 m – 700 m depth. In the eastern Indonesian Seas, there are shallower salinity maximum of subsurface Pacific waters identified during El Niño, while deeper and fresher subsurface water identified during La Niña. Furthermore, concentrations of dissolved nutrients in surface layer are higher during El Niño event. Low phytoplankton consumption on nutrients during warmer temperature might responsible for this phenomenon.

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Acknowledgements

This study is part of joint research cruise between Research Center for Oceanography, Indonesian Institute of Sciences (LIPI) and Institute of Oceanology, Chinese Academy of Sciences (IOCAS). The gratitude of thanks are sent to the crew of R/V Baruna Jaya VIII for the help during the cruise.