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Variability and Characteristics of Indonesian Throughflow in Arafura and Timor Seas

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ABSTRACT

The characteristics and variability of Indonesian Throughflow (ITF) in Arafura and Timor seas are affected by monsoons and El Nino Southern Oscillation (ENSO) events. The aim of this study is to identify the types of water masses of ITF in Arafura and Timor seas, to analyze the horizontal distribution profile of ITF in Arafura and Timor seas and to analyze the variability of ITF. The data used are time series data for five years (January 2013 – Desember 2017) of u and v current, salinity and temperature dataset from HYCOM circulation model output. The datasets processed using MATLAB *software*.Water mass characteristics in the 4 study areas were dominated by water masses from the North Pacific *(Northen Pacific Subtropical Lower Water).*The seasonal circulation in the Arafura and Timor Sea dominant from the north to the southwest which is a representation of the characterisctic of the ITF. The temperature and salinity values have the highest value during northwest monsoon and the lowest during the southeast monsoon. Flow variability and salinity in the ITF pathway in the surface layer and mixed layer are dominated by seasonal (monsoonal) variability influenced by monsoons. Temperature variability in the surface layer is influenced by seasonal (monsoonal) variability while in the mixed layer is influenced by interannual variability which influenced by monsoons and global phenomena of ENSO. In the inter-annual period, the sea temperature during second transition season of 2015 and the northwest monsoon of 2016 are lower than the average due to the El Nino phenomenon.

Keywords*: *Arafura and timor seas, Characteristic, ENSO, Indonesian Throughflow, NPSLW, Variability

1. INTRODUCTION

Indonesia Throughflow (ITF) carries a water mass from the Pacific Ocean to the Indian Ocean and the components of water mass are from the North Pacific and the South Pacific. There are three main entrances from the Pacific ocean to the Indonesia ocean, there are the Straits of Makassar, the Maluku Sea and the Halmahera Sea [3][7]. The water mass that entering the Halmahera Sea will lead to the Ceram Sea and the Aru Basin [7]. Water mass in Indonesian ocean then flows into the Indian Ocean through three main leakages namely the Lombok Strait, Ombai Strait, and the Timor Sea.

Arafura sea is a part of the warm Pacific pool and has an important role, both in local and global ocean circulation. In addition, the oceanographic conditions of Arafura's western and northern sea are greatly influenced by ITF [1]. Arafura sea have unique current characteristics, highest productivity, and diverse sea surface temperatures, while the Timor Sea is ITF exits because it has the greatest depth and openness with the Indian Ocean compared to other ITF exits.

The main component of Arafura and Timor sea is a water mass that warm, has low salinity and flows from the Pacific Ocean to the Indian Ocean, the water mass then passes through the north and west of Arafura and Timor sea [1][5][6][12]. The effect of El Nino weakens ITF, and La Niña strengthens ITF [4][5][8][11][13];. The transport value of ITF's volume can change because of El Nino and La Nina [17].

The aim of this research is toto identify the types of water masses of ITF in Arafura and Timor seas, analyzing the horizontal distribution profile of ITF in Arafura and Timor seas in 2013 - 2017 and to analyze the variability of ITF.

2. MATERIALS AND METHODS

The research conducted in Arafura and Timor seas within latitude 4,5̊ S to 12̊ S and longitude 122̊ E to 142̊ E (Figure 1).

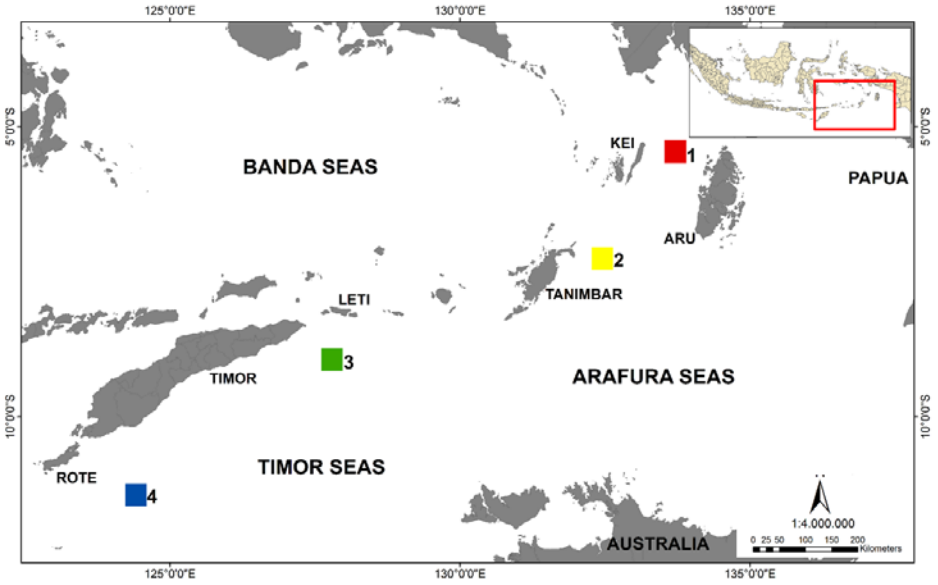


Figure 1. Map of Arafura and Timor seas, Indonesia

The data used in this research are secondary data obtained from HYCOM modeling (*Hybrid Coordinate Ocean Model*) with datasets starting from January 2013 - December 2017. The data has a daily composite and includes the current u and v (ms^{-1}), temperature (℃) and salinity (psu). The data is downloaded from the prediction of the global model HYCOM + NCODA with the website address https://hycom.org/. HYCOM has a resolution of 1/12 with 53 points. The datasets processed using MATLAB *software*for displays a TS Diagram profile and horizontal distribution profile.

3. RESULT AND DISCUSSION

3.1 Water mass Identification

The water mass in Arafura and Timor sea is dominated by a water mass from the North Pacific Ocean that flows throughout the year in each area of research. Northern Subtropical Lower Water (NSLW) flows throughout the year in all four research areas that carried by the Mindanao current to the Arafura and Timor sea through the Banda Sea [10].

3.1.1 Water mass identification in northwest moonsoon.

The characteristics of the water mass in area 1 (5 - 5.7 S and 133 - 134 E) from 2014 - 2017 have a temperature range with values 3.3 - 33.96˚C, salinity with a value range of 33.8 - 35.9 PSU and density with a value of 19.5 - 28.8 Kg/m^3. The water mass identified were NSLW, NPEW and SPSW.Water mass characteristics in Area 2 (7 - 7.5 S and 132 - 133 E) during the northwest season from 2014 - 2017, have a temperature range of 2.2 - 34.2 ℃, salinity with the value range is 33.58 - 35.88 PSU and density with values of 19.11 - 28.7 Kg/m^3. The water mass identified were NSLW, NPEW and ESPW.Water mass characteristics in Area 3 (8.4 - 9.3 S and 127 - 128 E) from 2013 - 2017, have a temperature range of 2.86 - 35.28℃, salinity with range of values 32, 2 - 36.2 PSU and density with a value of 17.6 - 29.1 Kg/m^3. The water mass identified were NSLW, WNPW, NPEW and NPIW.Water mass characteristics in Area 4 (11 - 12 S and 124 - 125 E) during the western season, the temperature range of the water mass is 6 - 34.94˚C, salinity with a value range of 32.76 -

36.42 PSU and density with a value of 18.34 - 28.67 Kg/m^3. The water mass identified were NSLW, SPSW, ESPW and WSPW.

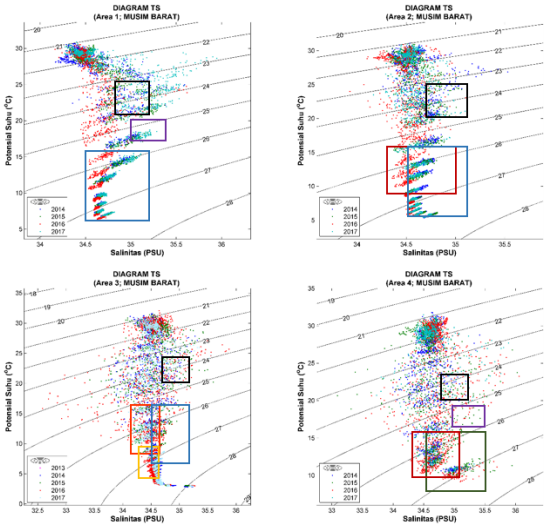


Figure 1. TS – Diagram in northwest monsoon

3.1.2 Water mass identification in first transition

Water mass characteristics in area 1 (5 - 5.7 S and 133 - 134 E), from 2013 - 2017 have a temperature range with a value of 3.7 - 33.83 ℃, salinity with the range of values is 33.18 - 36.2 PSU and density with a value of 19.06 - 28.72 Kg/m^3. The results considered the mass of water during the first transition season showed the presence of NSLW and NPEW , SPSW and ESPW.Water mass characteristics in Area 2 (7 - 7.5 S and 132 - 133 E) during the first transition season , from 2013 - 2017 have a temperature range with a value of 2.31 - 33.62˚C, salinity with a value range of 33.2 - 35.56 PSU and density with a value of 19.13 - 28.36 Kg/m^3. The water mass identified were NSLW, NPEW and ESPW .Characteristics of water masses in Area 3 (8.4 - 9.3 S and 127 - 128 E) from 2013 - 2017 have a temperature range with a value of 2.52 - 34.82˚C, salinity with a value range of 32.4 - 36.71 PSU and density with a value of 18.01 - 29.47 Kg/m^3. The water mass identified were NSLW, NPEW, WNPW and SPSW water .Water mass characteristics in Area 4 (11̊ - 12̊ S and 124̊ - 125̊ E) during the first transition season, from 2013 - 2017 have a temperature range with a value of 5.8 - 35.12˚C, salinity with a range of values 32.54 - 36.83 PSU and density with 18.18 - 29.04 Kg/m^3 values. The water masses identified were NSLW, WNPW, SPSW and WSPW.

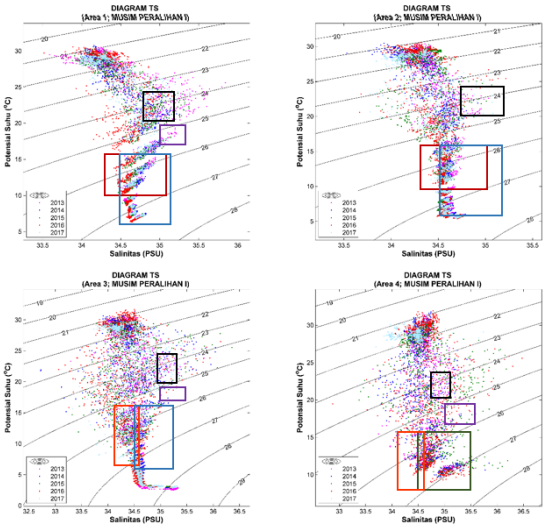


Figure 2. TS – Diagram in first transition season

3.1.3 Water mass identification in Southeast monsoon

Water mass characteristics in area 1 (5 - 5.7 S and 133 - 134 E) during East Season from 2013 - 2017 have a temperature range with a value of 3.28 - 32.51˚C, salinity with range the value of 32.94 - 36.06 PSU and density with a value of 19.61 - 28.65 Kg / m3. The results of the identification of water masses during the eastern season showed a mass of water NSLW, NPEW and ESPW.Water mass characteristics in Area 2 (7 - 7.5 S and 132 - 133 E) during the east season from 2013 - 2017 have a temperature range with a value of 3.28 - 32.51˚C, salinity with range the value of 32.8 - 35.85 PSU and density with a value of 19.16 - 28.64 Kg/m^3. The water mass identified were NSLW, NPEW and ESPW .The characteristics of water masses in area 3 (8.4 - 9.3 S and 127 - 128 E) during the eastern season from 2013 - 2017 have a temperature range of 2.8 - 32.68˚C, salinity with a value range of 32.44 - 37.4 PSU and density with a value of 18.87 - 30.07 Kg/m^3. The water mass identified were NSLW, NPEW, WNPW and SPSW .Water mass characteristics in Area 4 (11-12 S and 124 - 125 E) during the east season from 2013 - 2017 have a temperature range with a value of 6.455 - 32.83˚C, salinity with a value range of 32.27 - 37.47 PSU and density with a value of 19.10 - 29.46 Kg/m^3. The results of the identification of water masses in the east season showed the same results as the first transition season. The identified water mass were NSLW, WNPW, SPSW and WSPW.

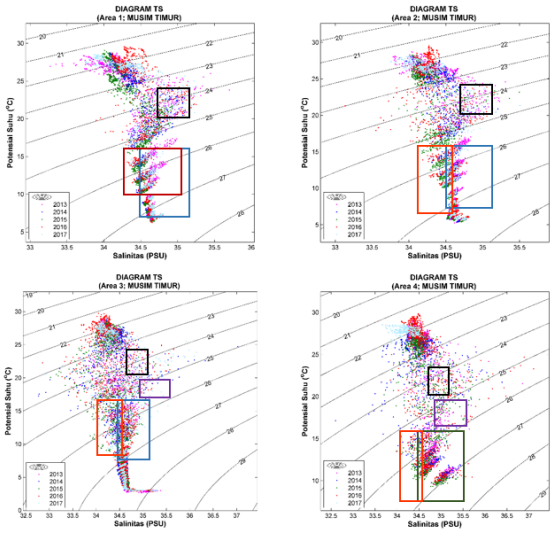


Figure 3. TS – Diagram in southeast monsoon

3.1.4 Water mass identification in second transition

The characteristics of the water mass in area 1 (5 - 5.7 S and 133 - 134 E) in the second transitionseason of 2013 - 2017 have a temperature range with a value of 3.04 - 33.75˚C, salinity with the value range of 33.73 - 36.1 PSU and density with a value of 19.04 - 28.7 kg/m^3. Result of water mass assessment when the transition season II shows the mass of NSLW and NPEW water sent from the North Pacific Ocean, when the mass of water carried from the South Pacific Ocean is the mass of ESPW water.Water mass characteristics in Area 2 (7 - 7.5 S and 132 - 133 E) during the second transition season from 2013 - 2017 in area 2, have a temperature range with a value of 2.37 - 33,77˚C, salinity with a value range of 33.66 - 36 PSU and density with a value of 19.48 - 28.7 Kg/m^3. The water mass identified is the mass of water NSLW, NPEW and ESPW.Water mass characteristics in area (8.4 - 9.3 S and 127 - 128 E) from 2013 - 2017 have a temperature range with a value of 2.8 - 35.36˚C, salinity with a value range of 32.59 - 36.58 PSU and density with a value of 17.68 - 29.35 Kg/m^3. The results assume that the mass of water in area 4 shows there is a mass of water NSLW, SPSW, ESPW and WSPW.Water mass characteristics in area 4 (11̊ - 12̊ S and 124̊ - 125̊ E) during the second transition season from 2013 - 2017 have a temperature range with a value of 6 - 34.06˚C, salinity with a value range of 33.03 - 37.16 PSU and density with a value of 18.93 - 29.98 Kg/m^3. The water masses identified were NSLW, SPSW, ESPW and WSPW.

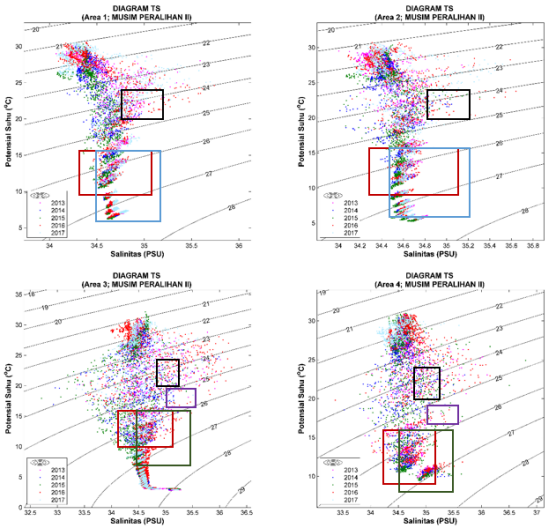


Figure 4. TS – Diagram in second transitional season

3.2Oceanography Characteristic

3.2.1 Current

The velocity of sea surface current on the ITF pathway in the northwest season of 2014-2017 has a range of values 0,1 – 0,2 m/s. At a depth 100 m the velocity has decreased to 0,04 – 0,18 m/s. At that depth, there was recirculation both *anticyclonic* and *cyc*lonic. This is due to the reversal of the flow direction so there is recirculation of currents in the southeast of Tanimbar Island and southeast of Timor Island. The meeting between ITF water mass that carried from the Seram Sea and the Banda Sea also resulted in turbulence which formed an *anti-cyclonic* recirculation. This is consistent with the research conducted by Pranowo (2012) [14]. The velocity of sea surface current on the ITF pathway in the first transition seasons of 2013 – 2017 has a range of values 0,05 – 0,3 m/s. At a depth 100 m the velocity has decreased to 0,05 – 0,15 m/s. The velocity of sea surface current on the ITF pathway in the southeast season 2013 – 2017 has a range of values 0,1 – 0,35 m/s and decreased to 0,05 – 0,27 m/s at a depth 100 m. In the southeast season the velocity at 100 m has a higher value compared to other seasons, this is caused by differences in sea level between the Pacific Ocean and the Indian Ocean which reaches the maximum value in the southeast season [15][19]. The velocity of sea surface current on the ITF pathway in the second transition season 2013 – 2017 has a range of values 0,1 – 0,3 m/s, and decreased to 0,05 – 0,2 m/s at a depth 100 m.

3.2.2 Sea Temperature

Distribution of SST in the northwest season in Arafura and Timor Sea from 2014 - 2017 has a range of 28.5-30.5˚C. At a depth of 100 m sea temperature on the ITF pathway from 2014 - 2017 has a range between 21-26˚C. The temperature at this depth has a lower value of ± 7˚C compared to temperatures at a depth of 10m. The temperature distribution in the northwest season of 2016 at a depth of 100 m is lower compared to the other years, this is due to the influence of strong El Nino phenomena that occur from August 2015 - March 2016 [2]. During first transition season , the range of SST in Arafura Sea and Timor from 2013 - 2017 is 28.2 - 30.2˚C. At a depth of 100 m the sea temperature in the Arafura Sea and Timor from 2013 - 2017 has a temperature range of 20 - 26˚C. Distribution of SST in the southeast

season in Arafura and Timor Sea from 2013 - 2017 has a range of 25.5-28.5˚C. At a depth of 100 m the range of ocean temperature values is 20-26˚C. The distribution of sea surface temperature in the southeast season has a lower value than the other seasons, because of there was an input of cold water masses from the east (Torres Strait) and the Banda Sea which are carried by the currents [9][18]. During the second transition season SST in the Arafura and Timor Sea from 2013 - 2017 have a range of 27.2 - 29.7˚C. Distribution of temperatures at a depth of 100 m from 2013 - 2017 in the Arafura and Timor Sea has a range of 19 - 25˚C.

3.2.3 Salinity

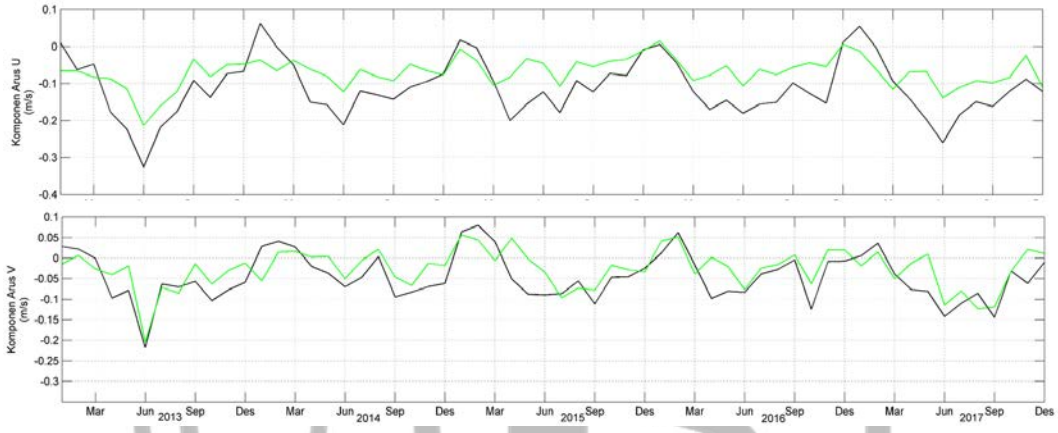
The distribution of sea surface salinity during the northwest season has a range of values of 30.5 - 34.7 PSU. The distribution of salinity during the western season at a depth of 100 m has a range of values from 28 - 34.8 PSU. The distribution of salinity during the northwest season at a depth of 100 m has a range of values from 28 - 34.8 PSU. The distribution of sea surface salinity in the first transition season in the Arafura and Timor Sea from 2013 - 2017 has a range of values of 31.5 - 34.7 PSU. Salinity at a depth of 100 m in the Arafura and Timor Sea from 2013 - 2017 has a range of values of 30-34.7 PSU. The distribution of salinity during the southeast season in the Arafura and Timor Sea in 2013 - 2017 has a range of 34 - 34.4 PSU. The salinity value at a depth of 100 m from 2013 - 2017 has a range between 34.2 - 34.7 PSU. The distribution of sea surface salinity in second transition season the distribution of salinity values at a depth of 10 m in the Arafura Sea and Timor has values ranging from 34 - 34.7 PSU. At a depth of 100 m the salinity value has a range of 34.4 - 35 PSU tends to increase by ± 0.4 PSU when compared to the salinity value in the surface layer. In 2013 salinity had a value of around 34.4 - 35 PSU. The value of salinity tends to decrease along ITF parthway.

3.3 Variability of ITF

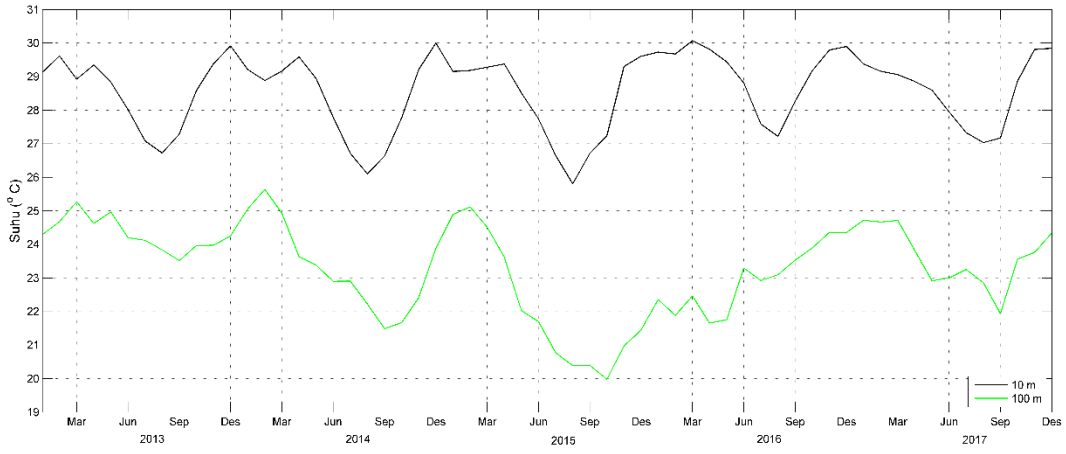
At depths of 10 and 100 m the current components u and v have a pattern that repeats every year. The components of the u (zonal) current are strong and flow to the southwest in the northeast season and weaken during the southwest season. The dominant component of v (meridional) flows to the south, and strengthens when the northeast season flows and weakens during the southwest season. The results of time series analysis in the ITF pathway indicate that the current has a variability with a seasonal (monsoonal) period.

The results of the analysis using a time series show that at a depth of 10 m, the distribution of temperature values in the Arafura and Timor Sea is dominated by seasonal (monsoonal) variability. In the annual period the fluctuations of sea temperature are affected by the monsoon system. Fluctuations of sea temperature values at a depth of 100 m are influenced by the presence of ENSO phenomena, so that at this depth the dominating variability is interannual periods. This is consistent with Schiller (2011) statement that the variability of sea temperature in North Australian (Arafura and Timor sea) is dominated by monsoon winds and is influenced by large-scale inter-annual variability [16]. The results of the analysis using a time series shows that at a depth of 10 m and 100 m depth, the distribution of salinity in the Arafura and Timor Sea is dominated by variability with seasonal periods (monsoonal). In the annual period the fluctuations in the value of sea salinity are affected by the monsoon system.

(A)


Komponen Arus U (m/s)
Komponen Arus V (m/s)
Mar Jun 2013 Sep Des Mar Jun 2014 Sep Des Mar Jun 2015 Sep Des Mar Jun 2016 Sep Des Mar Jun 2017 Sep Des

(B)


Suhu (° C)
10 m
100 m
Mar Jun Sep Des Mar Jun Sep Des Mar Jun Sep Des Mar Jun Sep Des Mar Jun Sep Des
2013 2014 2015 2016 2017

(C)

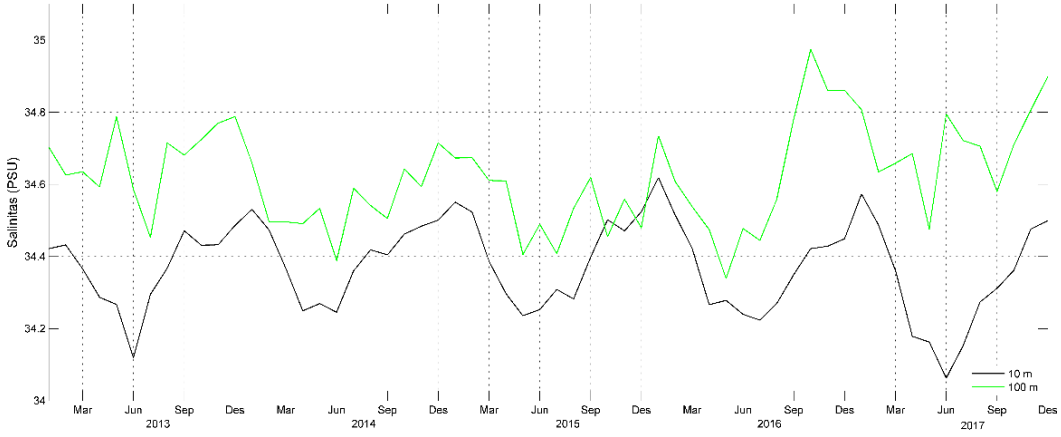


Figure 5.**(A)** monthly average zonal and meridional component **(B)** monthly average of sea temperature **(C)** monthly average of sea salinity

4. CONCLUSIONS

The seasonal circulation in the Arafura and Timor Sea dominant from the north to the southwest which is a representation of the character of ITF. The distribution of temperature and salinity values has the highest value during northwest monsoon and the lowest during the southeast monsoon. Variability of salinity and current in the ITF pathway in the surface layer and mixed layer are dominated by seasonal (monsoonal) variability. Temperature variability in the surface layer is influenced by seasonal (monsoonal) variability while in the mixed layer is influenced by interannual variability which influenced by monsoon and global phenomena ENSO. In the inter-annual period, the value of temperature in the second transition season of 2015 and the northwest monsoon of 2016 is lower than the average due to the El Nino phenomenon.

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