The Variability of Upper-Ocean Salinity in the Eastern Inflow Region of ITF

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Abstract. The north and south Pacific waters influenced the water mass profile in the eastern inflow region of Indonesian throughflow (ITF), including Halmahera Sea, Maluku Sea, and Sangihe–Talaud Waters. Pacific waters are characterized by the strong salinity stratification in the upper-ocean (0–300m depth). Repeated annual oceanographic observations in the eastern inflow region of ITF found anomalous upper-ocean salinity profiles during the 2014–2017 periods. At the end of 2015 (El Niño condition), saltier salinity and nearly homogeneous salinity profile (>34.6 PSU) in the upper-ocean were found, and it is expected due to the decreasing precipitation rate. Conversely, freshening of upper-ocean salinity (33.5 – 34.6 PSU) was found during the weak La Niña condition in 2017. An increased precipitation rate might cause this condition for five months in a sequence (varies within +22% to 112% higher than its monthly mean). In between, the weak El Niño and weak La Niña condition in 2014 and 2016 are more likely to show a similar salinity profile to the strong El Niño 2015 and weak La Niña 2017, respectively. There is a slight reduction (increase) of precipitation rate during 2014 (2016), but it does not lead to a drastic increase (freshening) of salinity as indicated in 2015 and 2017. This study also suggests the less effect of MJO on the precipitation rate and salinity anomalies in the eastern inflow region of ITF, especially during its active phase in 2017.

1. Introduction
The northeast part of the Indonesian region is adjacent to the western Pacific Ocean. The energetic western boundary current (WBC) modulates the ocean circulation in this area [1]. From the southern latitude, New Guinea Coastal Current/ Under Current (NGCC/ NGCUC), the elongation of South Equatorial Current (SEC) is flowing towards the equator, parallel to Papua Island. Conversely, from the northern latitude, the bifurcation of North Equatorial Current (NEC) forms Mindanao Current (MC), which is flowing to the south, towards the equatorial region [2]. These ocean current systems converged into the tropical area and deflected to the east toward the central Pacific Ocean as the North Equatorial Counter Current (NECC). However, there is part of MC which penetrates the Indonesian
Seas via Sangihe-Talaud Waters, Sulawesi Sea, and Makassar Strait. On the other way, part of NGCC/NGCUC reaches the Indonesian region via the Halmahera Sea. Hereafter, NGCC/NGCUC and MC have been known as the primary source of Indonesian Throughflow (ITF), which transported Pacific Ocean water mass towards the Indian Ocean [3, 4].

NGCC/NGCUC and MC carried South Pacific Subtropical Water (SPSW) and North Pacific Subtropical Water (NPSW). Water mass characteristics of SPSW and NPSW differ from their salinity value in the thermocline layer [4-6]. The range of salinity maximum in the thermocline layer is 35.2 – 35.5 PSU for SPW, while 34.8 – 35.0 PSU for NPSW. Both NPSW and SPSW can be identified at the ITF entrance channels, highlighting the dominance of NPSW in Sangihe-Talaud Waters, Sulawesi Sea, Maluku Sea, and SPSW dominant in Halmahera Sea [7, 4, 8, 9]. These warm and saline water masses were transported through the Indonesian Seas and exited as relatively fresher surface water towards the Indian Ocean [10-12]. Vertical mixing and isopycnal mixing of NPSW and SPSW within the Halmahera and Seram Sea and the intrusion of fresher water from the Java Sea are expected as the primary mechanism of this Pacific water salinity maxima erosion [13]. The transformed water mass then carried by ITF to the Indian Ocean and suggested has a significant impact on heat and freshwater budgets over the Pacific and Indian Ocean [14-16]. Hereinafter could affect the regional and global climate variability [8, 17, 18].

Observation of ocean circulation in the Indonesian Seas indicates the ITF core lies within the surface and thermocline layer [19-20]. Therefore, understanding the variability of upper layer ocean current and temperature and salinity profile in the eastern inflow region of ITF is necessary to quantify the heat and saltwater transport. Many factors might affect these variabilities spanned from intra-seasonal to interannual scale. On the intra-seasonal and seasonal scale, ocean circulation in the Indonesian Seas is mainly influenced by Madden-Julian Oscillation (MJO) [21-24] and the Asian-Australian monsoon system, respectively [25-27]. On the inter-annual scale, Indian Ocean Dipole (IOD) and El Niño Southern Oscillation (ENSO) are the leading regional climate phenomena that affect the ocean-atmosphere over Indo-Pacific region [28].

Several studies indicate IOD and MJO on the ITF variability, especially in the Makassar Strait [22, 23, 29]. Adverse IOD events reduce the seasonal ITF variability by 25 – 40% during boreal summer 2016. Elevated sea surface temperature (SST) and sea surface height (SSH) south of Sumatra and Java suppressed the pressure gradient between the Pacific and the Indian Ocean, hence weakening the ITF. The reduction of ITF transport in the Makassar Strait was also found during the active MJO phase. Approximately 4 Sv (1 x 106 m3/s) lower than its seasonal transport is expected due to the reduced outgoing longwave radiation (OLR), more intense along-strait wind stress, and increasing SSH in the south of Makassar Strait.

However, ENSO is considered one of the most prominent global climate variability sources on the inter-annual scale among those phenomena. In the Pacific Ocean, ENSO generates the movement of the western Pacific warm water pool and convection zone towards the central Pacific Ocean during El Niño and farther more to the west of the West Pacific Ocean during La Niña. ENSO modulates the ITF’s strength and the heat and saltwater transport at the corresponding region [8, 30, 31]. Weaker/more vital southward flow and deeper/shallower velocity maximum were identified during El Niño/La Niña.

This condition further raises the question, how can this climate phenomenon affect the penetration of NPSW and SPSW, especially in the eastern inflow region of ITF. Since the Halmahera Sea, Maluku Sea, and Sangihe-Talaud waters are considered the main entrance area of the ITF before entering the Indonesian Seas. Thus, the purpose of this study is to reveal the impact of ENSO and MJO on the variability of upper layer water, especially the upper ocean salinity in this area. The IOD phenomenon was not considered, assuming that it has less impact on ocean-atmosphere variability in the northeast part of the Indonesian Seas. The recent annual observation data of water mass profile (during boreal fall-winter) covered the specific ENSO condition in 2014 – 2017 periods were used in this study.
2. **Materials and Methods**

This study is part of joint research between the Research Center for Oceanography and the Institute of Oceanology Chinese Academy of Sciences to understand the ocean circulation in the western Pacific Ocean and Indonesian Seas. The hydrological survey in the Eastern Indonesian Seas observed annually during the northwest monsoon of 2014 – 2017 using Conductivity Temperature Depth (CTD) SBE 911 plus Research Vessel Baruna Jaya VIII, which was calibrated in July 2014. Three areas were investigated, including Halmahera Sea, Maluku Sea, and Sangihe-Talaud Waters, which have been considered the main entrance flow of the eastern ITF pathways. Water mass profiles within 5 – 1500 m depth were measured at each oceanographic station to figure out its characteristic at the mixed, thermocline, and deep-water layers. Specifically, the oceanographic observation in this area was conducted in December (2014 – 2016) and October 2017. Oceanographic stations observed during this study located at nearly the same location for each measurement period (Figure 1).

![Figure 1](image.png)

**Figure 1.** The distribution of CTD observation stations during the northwest monsoon of 2014 – 2017 in the Eastern Indonesian Seas, including Halmahera Sea, Maluku Sea, and Sangihe-Talaud Waters.

The ENSO and MJO activities were identified using the Oceanic Niño Index (ONI) 3.4 and Madden Julian Oscillation (MJO) index, respectively. Monthly ONI 3.4 calculated from the 3-month running mean of Extended Reconstructed Sea Surface Temperature (ERSSTv5) sea surface temperature anomalies (SSTA) in the Niño 3.4 region (5°N – 5°S, 120° – 170°W) based on centered 30-year established period data. The elevated SSTA higher/lower than +/-0.5 °C were characterized as
the El Niño/La Niña condition. This data can be downloaded from http://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php. In addition to ONI 3.4 data, the MJO indexes were obtained from the Bureau of Meteorology Australia (www.bom.gov.au/climate/mjo). The MJO index is represented by the RMM1 and RMM2 value—mathematical methods that combine the amount of cloud and winds at the upper and lower levels of the atmosphere. This combined value provides the magnitude and location of MJO. The MJO is considered weak if the RMM1 and RMM2 values are between -1 to 1.

Also, monthly rainfall intensity obtained from Tropical Rainfall Measuring Mission (TRMM) 3B43v7 (https://giovanni.gsfc.nasa.gov/) was analyzed in this study. It is used to check whether there is any relation between ENSO/MJO and precipitation over the Eastern Indonesian Seas. Monthly precipitation data were averaged over 124° – 130°E and 1°S – 5°N and obtained for 1998 – 2017. Seasonal rainfall is calculated from the monthly mean of 20-year data. This seasonal precipitation data is then used as the baseline to calculate the monthly precipitation rate anomalies.

Descriptive analysis of potential temperature ($\Theta$) and practical salinity (S) were used to identify water mass sources in the observation area. Moreover, the vertical section of the upper layer water mass within the core of ITF (in 0 – 300 m depth) was the study’s main interest. These data were then compared to the ENSO and MJO index in the corresponding observation periods. It is used to check the relation between ENSO/MJO and precipitation over the Eastern Indonesian Seas.

3. Results

Recent repeated annual oceanographic observation shows anomalous upper-ocean salinity profile during the 2014-2017 periods. The water mass observation in the Halmahera Sea, Maluku Sea, and Sangihe-Talaud Waters offers the influence of several ocean-atmospheric processes in this area.

3.1 The Potential temperature and salinity (\( \Theta \)-S) profile

Distinct $\Theta$ -S envelope shape (blue line in Figure 2) is evident either in the Halmahera Sea or Maluku Sea and Sangihe-Talaud Waters. In the Halmahera Sea, the straight-line $\Theta$-S profile was identified in 2015. It is indicating the dominance of temperature on water mass stratification. Contrary, in the following years of 2016 and 2017, the vertical salinity stratification starts to develop. There is the dissimilarity of $\Theta$-S variance within $\sigma_0 = 23$ to $\sigma_0 = 25$ in these two consecutive years. There is a broader range of $\Theta$-S envelopes in 2017 than in 2016 due to the inclusion of a hydrographic profile north of Halmahera Sea (Station 66) (Figure 2). This water mass profile at Station 66 represents the South Pacific Subtropical Water (SPSW) source, which has a higher S-max (~35.4 PSU) than the observed water mass at the south Halmahera Sea.

![Figure 2. The potential temperature and salinity profile of hydrographic data in the Halmahera Sea during 2015 – 2017 observation (black scatter point). The $\Theta$-S envelope is manually drawn to represent the variance.](image)
Unlike the Halmahera Sea, which SPSW significantly influences, the area of Sangihe-Talaud Waters and Maluku Sea is mostly influenced by the North Pacific Subtropical Water (NPSW). However, analogous to the observation in the Halmahera Sea, the higher variability of upper-layer $\theta$-$S$ was found in this area during 2014 – 2017. Wide-range of $\theta$-$S$ lied within $\sigma_0 = 22$ to $\sigma_0 = 25$. In comparison, the year 2015 shows smaller variability or a more consistent water mass profile. The smaller variability of water mass profile in this area is expected due to the stronger penetration of NPSW and less vertical mixing. On the contrary, the observed water mass in 2014, 2016, and 2017 shows higher variability in the upper and deep ocean water (Figure 3). There is a slight difference in $\theta$-$S$ steepness, which is expected due to the variability of the upper-ocean salinity profile. Thus, the detailed analysis of upper-ocean salinity (0 – 300 m depth) is explained in the following sections.

Figure 3. The potential temperature and salinity profile of hydrographic data in the Maluku Sea and Sangihe-Talaud Waters during 2014 – 2017 observation (black scatter point). The $\theta$-$S$ envelope is manually drawn to show the variance.

3.2 Vertical section of salinity profile

3.2.1 Halmahera Sea.
Water mass profile in the Halmahera Sea was observed annually in 2015 – 2017. Oceanographic stations are placed around the Jailolo and Gabe Strait, which was suggested as the Halmahera Sea main ITF passages. During 3-year observation periods, there are three distinct water mass profiles observed in this area. Observation data in 2015 shows nearly homogeneous salinity can be identified from the surface to 200 m depth. Sea surface salinity in this area reached ~34.8 PSU, and it has increased to 35.0 PSU at 175m depth (Figure 4). The absence of a fresher surface water layer might be correlated to the super El Niño condition.
Contrary to 2015 data, the Halmahera Sea surface layer was filled by relatively fresher water in 2016 and 2017. Within the surface to 50 m depth, salinity varies in the range of 34.0 – 34.3 PSU in 2016, while 33.8 – 34.3 PSU in 2017. Below this depth, the salinity is increasing and reaches its peak of 34.9 PSU in 2016 (Figure 4) and 35.0 PSU in 2017 (Figure 4). Salinity maximum was concentrated around 128.9 – 129.4 °E and 140 – 200 m depth. Although these two salinity profiles seem similar, the salinity profile in 2017 shows a stronger vertical stratification. Furthermore, the presence of the fresher surface water layer is more evident in 2017 rather than in 2016.

Figure 4. Vertical section of salinity profile in the Halmahera Sea (0 – 200m depth) at latitudinal section 1°S to 0°S during the observational periods of 2015 – 2017. The vertical black dashed line represents the depth-coverage by CTD measurement.

3.2.2 Maluku Sea.

Water mass observation in the Maluku Sea during the 2014 – 2017 periods covered the longitudinal section of 2 °N. Relatively fresher surface water of 34.1 – 34.3 PSU spread from the surface to 50 m depth in 2014 and 2016 (Figure 5). Below this layer, the salinity of 34.6 – 34.7 PSU stretched over this area. Conversely, the saltier upper-ocean water was evident in the Maluku Sea during the El Niño condition in 2015. Nearly homogeneous high-salinity of 34.5 – 34.8 PSU were extended from the surface to 200 m depth (Figure 5). This condition is slightly different from 2014 and 2016 data, which has a salinity of 34.5 PSU below 50m depth.

Whereas the most distinct profile was identified in 2017 observation data. Fresher water was dominating the upper layer of the Maluku Sea. A relatively low salinity of 33.8 PSU was stretched from the surface to 75 m depth. Below this layer, a strong salinity stratification is developed. A fast increase of salinity from 34.0 to 34.5 PSU lies within 75 to 100m depth (Figure 5). The very saline (fresh) upper-ocean water in 2015 (2017) was expected due to the distinct ENSO and MJO condition occurring in this area.
Figure 5. Vertical section of salinity profile in the Maluku Sea (0 – 200m depth) at latitudinal section 2°N during the observational periods of 2014-2017. The vertical black dashed line represents the depth-coverage by CTD measurement.

3.2.3 Sangihe-Talaud Waters.
Northwest to the Halmahera Sea, the Talaud Waters is known as one of the ITF inflow channels. Previous studies suggest the dominance of NPW flowing into this region originated from the Mindanao Currents and the retroreflection flow from the Sulawesi Sea and Sangihe Water [33]. The very thin mixed layer was identified from 0 to 30 m depth, with the salinity range of 34.2 – 34.3 PSU in 2014. Strong salinity stratification was recognized under this layer, increasing salinity from 34.3 to 34.8 PSU (Figure 6). Typically, the stratification is more robust in the northern part of Talaud water than in the southern region. We suggested that the distance of the observation station to the North Pacific Subtropical Water (NPSW) might affect this variability. The core of NPSW with a salinity of 35.1 PSU was detected in 50 – 100 m depth.

The penetration of NPSW extended farther to the south towards 2.9 °N in 2015. It is expected due to the strong El Niño condition during the observation periods. The core of maximum salinity 35.0 PSU was stretched out from 50 to 90 m depth. Above this layer, the salinity was relatively high, in the range of 34.4 – 34.7 PSU (Figure 6). In contrast, the observation in December 2016 was conducted during weak La Niña conditions. As the impact, the thicker freshwater layer was observed in this area. Within the surface to 50 m depth, salinity varies in 34.1 to 34.4 PSU (Figure 6). Below this layer to 100 m depth, salinity increases to 34.6 PSU in the south part while salinity increases to 35.1 PSU in the north part of Talaud Waters. The core of salinity maxima 35.1 PSU, which was previously noticed at 50 – 100 m depth during 2014 – 2015, lay within 100 – 150 m depth in 2016.
Figure 6. Vertical section of salinity profile in the Talaud Waters (east of Talaud Islands) within 0 – 300 m depth at longitudinal section 126° to 128° E during the observational periods of 2014 – 2017. The vertical black dashed line represents the depth-coverage by CTD measurement.

Entirely different for 2014 – 2016 data, a thicker layer of low-salinity water was observed in the upper 50 m of the Talaud Waters in 2017 (Figure 6). This layer has a salinity range between 33.5 and 34.2 PSU. To the north of 3.0 °N, strong salinity stratification was recognized within 50 – 100 m depth. Conversely, there is a very weak stratification or nearly homogeneous salinity profile towards the equator area. A distinct salinity profile was also found in the core of maximum salinity (S-max). The saline water tongue (S-max) could not reach more than 34.8 PSU in 2017. It was 0.3 PSU lower than the observed value in the previous years.

Almost identical condition to salinity profile in the Talaud Waters is Sangihe Waters (Figure 7). The upper water layer of high-salinity was observed during the El Niño condition in 2015. In contrast, the freshening of the upper water layer was found during weak La Niña in 2017. However, these two areas have a slight difference in the vertical distribution of maximum salinity. The core of maximum salinity in Sangihe Waters lies at the deeper layer (within 100 – 150 m depth) than observed data in Talaud Waters. Also, a high-salinity core is more evident in Sangihe Waters than Talaud Waters.
Figure 7. Vertical section of salinity profile in the Sangihe Waters (west of Sangihe Islands) within 0 – 300 m depth at longitudinal section 124° to 126° E during the observational periods of 2014 – 2017. The black dashed line represents the depth-coverage by CTD measurement.

3.3 Atmospheric setting and its impact in the Indonesian Region

Water mass observation in the eastern Indonesian Seas occurs annually from October to December, which is considered the alteration of transitional monsoon to northwest monsoon in the Indonesian Seas. The northwest monsoon reaches its peak during boreal winter from December to February (DJF). It is characterized by the strong wind blowing from Asia towards the Australian continent and carried huge water vapor originated from the South China Seas. Conversely, the peak of the southeast monsoon occurred during boreal summer (June to August – JJA), characterized by its robust and dry wind blowing from Australia to the Asia continent. In between, weaker wind speeds are noticed during boreal spring from March to May (MAM) and boreal fall from September to November (SON) due to the decreasing of atmospheric pressure gradient over Asia and Australia [24].

In addition to the seasonal pattern of wind direction, the monsoonal system is responsible for changing the spatial and temporal pattern of rainfall intensity over the Indonesian region, especially in the eastern Indonesian area. The 20-year mean of monthly precipitation rates shows a seasonal pattern with two rainfall peaks. The highest peak of 287.85 mm/month is identified in June. There is a lower-secondary rainfall peak of 223.23 mm/month identified in January (Figure 8), while the precipitation rate reaches its lowest value in September with 144.75 mm/month.
Figure 8. Comparing seasonal variability of precipitation data based on 20-year periods monthly means (1998 – 2017) and monthly precipitation data averaged over corresponding oceanographic observation areas.

From 2014 to 2017, the precipitation rate varies in the range of 10.67 mm/month at the lowest to 444.54 mm/month at the highest. Very high variability of precipitation data was expected due to the activity of ENSO or MJO. There are distinct ENSO phases from 2014 through 2017, including weak El Niño, strong El Niño, and weak La Niña conditions (Figure 9). Generally, the influence of ENSO is reflected in the precipitation rate data. Weak and strong El Niño conditions in November 2014 – May 2016 correspond to fewer precipitation rates than the weak La Niña conditions in the following years. The decreasing amount of precipitation rate during weak (December 2014) and strong El Niño (December 2015) was -54% to -92%, respectively (Figure 9). In 2015 only, the percent decrease in precipitation rate was varied from -18 to -92%. Slightly lower than 2015, the year 2014 was also dominated by the reduction of precipitation rate (-8.7% to -61%), except for August 2014 (+40%).

Conversely, increasing precipitation rates were identified during normal conditions and weak La Niña. The highest precipitation anomaly reaches 112% larger than its seasonal values in September 2017, coincided with weak La Niña conditions (ONI= -0.7). The weakening of trade winds during El Niño induces the movement of the convection zone from the western to the central Pacific Ocean, decreasing the precipitation rate in the west of the Pacific Ocean. In reverse, the strengthening of trade winds during La Niña pushes the convection zone to the far western Pacific Ocean, which increases precipitation in the west of the Pacific Ocean.

In the intra-seasonal timescale, MJO expected plays an essential role in affecting the rainfall variability over the equatorial Pacific and the Indian Ocean. There are eight phases of MJO, where the fifth and sixth phases represent the Eastern Indonesian Seas and Western Pacific Ocean. The MJO index obtained from the Bureau of Meteorology Australia for October – December (2014 – 2017) periods shows the active MJO phase (in the eastern Indonesian Seas) occurred in 1 – 10 Dec 2014; 18 – 31 Dec 2015; 3 – 7 Nov 2016; and 12 – 23 Oct 2017. Comparing the MJO index and precipitation data, we can see that the peak of MJO is not significantly correlated to the height of precipitation in the corresponding periods. There are decreasing precipitation rates of -19% and -66% during the MJO peaks in December 2014 and 2015. Later, there is a reduced precipitation rate of -27.95% and an increasing precipitation rate of 6.72% during the MJO peaks in November 2016 and October 2017.
Discussion

The complex ocean circulation and vigorous vertical mixing in the eastern ITF pathways made the study of water mass variability in this area challenging. Previous studies in the Maluku Sea suggested that the ocean current at this area was flowing from the Indonesian Seas’ internal space to the Pacific Ocean [34]. The Sulawesi Sea recirculation is known to have a significant contribution to force the water mass at Maluku Sea to flow to the Pacific Ocean. As for the impact, there is less influence of NPSW on the salinity profile of Maluku seawater. The surface layer (mixed layer) was dominated by lower salinity than others found at Halmahera Section. Recent studies in this area using the results of the ocean general circulation model suggests the dominance of NPSW in the Maluku Sea and mix of SPSW at 24.5σ₀ of Halmahera Sea during El Niño [9]. Completely different from the El Niño condition, SPSW dominates the subsurface water in Maluku and the Halmahera Sea during La Niña.

Heading to our study results, the water mass preview in the ϴ-S diagram could not identify the source of upper-ocean water beneath this region. In general, the upper-ocean water of the Maluku Sea and Sangihe-Talaud Waters are originated from NPSW, while the water mass of the Halmahera Sea is originated from SPSW. This opinion is based on the identification of the isopycnal position of salinity maximum. The peak of S-max of NPSW is mostly found in 24σ₀, while the S-max of SPSW is primarily found in 25σ₀ [32, 35]. In this study, the S-max peak is located at 23σ₀ and 24σ₀ for the water mass observed in the Maluku Sea and the Halmahera Sea, respectively. The sign of SPSW on the water mass profile of the Halmahera Sea is similar to the observation from Levitus 98 quoted in the previous study [32]. The lower S-max at the south of Halmahera Sea was suggested due to the horizontal

Figure 9. a) Oceanic Nino Index 3.4 (ONI3.4) during the 2014 – 2017 periods and annotated points indicate oceanographic observation periods in the determined location. b) Percent of difference in monthly precipitation data, compared to its seasonal mean. A positive value indicates the increasing precipitation rate (in percent), while a negative value indicates the decreasing precipitation rate. The scatter points indicate the MJO amplitude in the eastern Indonesian region, classified as phases 5 and 6. Active MJO phase characterized by the MJO amplitude >1.
advection of different salinity waters and vertical mixing process, which eroded the S-max as the ITF flowing through these passages.

Some distinct upper-ocean salinity profiles were noticed in the several phases of ENSO and MJO. We could suggest several explanations to understand these phenomena. During weak and strong El Niño conditions, the western Pacific Ocean’s water mass flows to the central Pacific Ocean. Consequently, to balance these dynamics, the upwelling process, which brings colder and saltier water from the deeper layer must occur in the western Pacific Ocean. Above the ocean, the decreasing precipitation rate was also associated with the weak and strong El Niño condition [36-38], except in June 2015. Monsoonal rainfall activity during June 2015 might minimize the effect of ENSO in this area. As a result, a slight increase in the precipitation rate of 2.89% is higher than its seasonal mean. However, overall, the El Niño condition leads to the distribution of relatively high salinity at all observation areas in the eastern Indonesian Seas. Furthermore, the distribution of upper-ocean water with salinity maxima reached further a distance to the internal water of the Indonesian Seas.

Contrary, during weak La Niña, the decreasing salinity was found in the surface and subsurface layer. It is possible because of the higher rainfall intensity in the western Pacific Ocean [36, 38]. The higher precipitation rate than its seasonal mean shows the intense rainfall from June 2016 to November 2017, except for several months such as August 2016, November 2016, and April 2017. The rainfall intensity reached 112.98% higher than its seasonal value in September 2017. This data explains the existence of the fresher surface salinity layer in 2016 and the intense freshening of upper-ocean salinity in 2017.

Compared to ENSO, there is no significant impact of MJO on rainfall intensity and upper-ocean salinity in the Indonesian Seas. The increasing precipitation rate from the end of 2016 to 2017 is suggested by the post-El Niño and weak La Niña conditions. These conditions lead to the movement of the surface warm water layer and convection zone from the central to the western Pacific Ocean. Therefore, it shows the heavy rainfall in the eastern Indonesian Seas and hence freshening the upper-ocean salinity. The minimum effect of MJO can be seen in October 2017, where the peak of MJO coincided with a very slight increase in the precipitation rate. It has been noticed in the previous study that the active phase of MJO was not simultaneously increasing the precipitation rate in the Indonesian region [21].

Despite that, further explanations are still needed to understand this phenomenon. It remains unclear how the nearly homogeneous salinity in the Halmahera Sea can be formed during the super El Niño condition. It might be the combination of minimal precipitation rate and strong diffusivity from the upwelled subsurface saline water. It has not been analyzed whether vertical mixing has a significant role in producing a homohaline profile at 22σ0 - 24σ0. A previous study indicated that El Niño weakens the ITF and shallows the depth of maximum velocity [8]. Analogous to the El Niño condition, it also remains unclear how weakens the ITF and swallows thick surface water layer formation in this area during weak La Niña conditions. The heavy precipitation, which lasts for five months (May – September 2017), might be the main factor. The vast amount of freshwater loaded into this area is expected to lead freshwater diffusion into a deeper layer. As the La Niña condition was found to strengthen the ITF and deepen the maximum velocity, it might also affect the vertical mixing energy. Also, tidal mixing needs to be considered since it significantly affects the water mass transformation in the ITF region [13, 39]. The numerical approaches found the tidal mixing erode SPSW salinity maxima for more than 0.4 PSU were identified when the water mass was entering the Halmahera Sea [40].

5. Conclusion
Recent observation of upper-ocean water in the eastern inflow region of ITF indicates the significant role of ENSO in affecting the salinity variability. Nearly homogeneous high-salinity profiles have been found in the upper layer of the Maluku Sea and the Halmahera Sea, an evident sign of southward
extension of NPSW in the Sangihe and Talaud Waters during super El Niño condition in 2015. The reduction of the precipitation rate in the western Pacific Ocean might contribute to this phenomenon. Conversely, the significant freshening of the upper-water layer was identified during the weak La Niña condition in 2017. The increasing precipitation rate, which lasts for five months, might induce vertical diffusion of the freshwater layer hereafter found as very fresh upper-ocean water at almost all observation areas. These findings also suggested less impact of MJO activity on the precipitation rate in the eastern Indonesian region, especially in October 2017. Slightly similar to the super El Nino (2015) and weak La Nina (2017) was the condition of weak El Nino (2014) and weak La Nina (2016), respectively.

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