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Possible impact of El Niño and La Niña on water mass circulation in Ambon Bay

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Abstract. El Niño and La Niña are disruptions to the ocean-atmosphere system in the equatorial Pacific area, with significant impacts on the climate and weather throughout the world. This paper discusses the possible impact of El Niño and La Niña to the water mass circulation in Ambon bay which is directly adjacent to the Banda Sea. We used observed vertical temperature variability data in June, July, September, and October in the year of 2008 (neutral year) and 2009 (El Niño year), and July and October 2010 (La Niña year). All data have been taken with CTD instrument in 7 stations which are aligned in one straight line from inner to Ambon Outer Bay (AOB). The result shows that the water mass circulation in Ambon Bay may be affected by El Niño and La Niña. El Niño phase makes the thermocline layer from the Banda Sea to become shallower than usual and thus makes the circulation in Ambon Bay more rigorous. This is because the water mass with higher density can enter into the deep Ambon Inner Bay (AIB) through the narrow sill which separates the Ambon Bay inner from outer parts. La Niña, on the other hand, weakens the water circulation because the thermocline layer becomes deeper than usual.

Keywords: El Niño, La Niña, water mass circulation, Ambon Bay

1. Introduction

The dynamics of Indonesian Waters are affected by Indonesia's geographical position which lies between two oceans, namely the Pacific and Indian Oceans. In Eastern Indonesia, the Indonesian throughflow (ITF) advects water masses from the Pacific to Indian Oceans [1]. Some researchers show that sea surface temperature and heat in the Pacific and Indian Oceans are influenced by the ITF. The sea surface will rise in the Pacific Ocean and decrease in the Indian Ocean as much as 2 to 10 cm if ITF did not exist [2]. Water mass structure in Indonesian Waters is commonly affected by the characteristic of water mass from the Pacific and monsoon wind system [3].

The appearance of El Niño and La Niña in the tropical Pacific impacts the ocean dynamics and weather in Indonesia [4]. El Niño and La Niña arise through ocean-atmosphere interaction along the equatorial Pacific Ocean, resulting in deviations of ocean and atmospheric circulation from the normal condition. National Oceanic and Atmospheric Administration (NOAA) defines El Niño (warming phase) as an increase in sea surface temperature in Niño 3.4 region (east-central equatorial Pacific between 120°-170°W) above 0.5°C over successive 3 months. Meanwhile, La Niña (cooling phase) is



defined as a reduction in sea surface temperature in Niño 3.4 region by more than 0.5°C over successive 3 months. The impact caused by El Niño and La Niña have different characteristics in different locations, in association with their pattern, intensity and duration [5-7].

In Indonesia, the appearance of El Niño causes the sea surface temperature to become lower than normal because the warm water pool which is located in the Indonesian waters migrates eastward toward the Central Pacific. Meanwhile, the appearance of La Niña causes sea surface temperature to be higher than usual as warm water is piled up toward the Maritime Continent [8,9]. Observation for temperature variability and chlorophyll-a had been done in some locations in Indonesia such as Bali and Sunda Strait [10,11] and southern of Java Island through the Timor Sea [3].

Ambon Bay which is located in the Banda Sea ecosystem has a unique characteristic; this bay is separated into two parts, Ambon Inner and Outer Bay. Ambon Inner Bay (AIB) is a semi-enclosed part of the bay with depth of only ± 45 m, whereas the depth in Ambon Outer Bay (AOB) can reach ± 600 m at the tip of the bay and directly facing the Banda Sea. There is a narrow sill that separate Ambon Inner and Outer Bay with depth of only ± 15 m; this sill limits water mass circulation in Ambon Bay [12]. Water mass from thermocline layer in the Banda Sea shoals and can reach ± 70 m in depth when upwelling occurs in southeast monsoon [13], and is predicted to enter the AIB through tidal upwelling mechanism [14]. Water mass density from the Banda Sea is higher than water mass in AIB so it is predicted that a flushing phenomenon would occur in Inner Ambon Bay during southeast monsoon [15,16]. Water mass circulation has an important role in enriched water environment in AIB because it makes nutrient in the bottom to be transported toward the surface. Ambon Bay is known as one of the potential areas to bait fish farm. The changes in the marine environment in Ambon Bay will affect all marine organisms that live in it and eventually may affect fishing activities in the Banda Sea ecosystem.

We predicted that water mass circulation in Ambon Bay will be affected by El Niño and La Niña due to changes in the thermocline depth in the Banda Sea. Therefore, this study observes the effect of El Niño and La Niña in the southeast monsoon to water circulation through vertical temperature variability in Ambon Bay.

2. Methodology

In this observation, we use vertical temperature variability and ocean current data taken from monitoring activity of Ambon Bay which was conducted by the Ambon Technical Implementation Unit of Marine Biota Conservation Office LIPI (UPT BKBL LIPI, later known as the Centre for Deep-Sea Research, LIPI) from 2008 until 2010 in order to reveal the effect of El Niño and La Niña on water mass circulation in Ambon Bay. The main focus was on the southeast monsoon when flushing phenomenon usually occurs in the deep AIB.

Because of lack of data, we only use vertical temperature variability data in June, July, September and October 2008 and 2009, and also data in July and October 2010. The data was taken in seven stations along a straight line from AIB to AOB (figure 1) using CTD SBE Seabird 19 v2 measurements and processed by ODV (Ocean Data View) software [17]. We also use ocean current data measured on 18-19 July 2009 (24 hours observation) using current meter ALEC Compact – EM Model AEM-HR located in station 3 (1m, 5m, 30m, and 35m in depth). Observation through modelling to reveal the linkage of ENSO and monsoon with the sea surface temperature variability in Ambon Bay from 2000 until 2008 indicated that the sea surface anomaly in Ambon Bay was dominantly affected by local atmospheric condition rather than ENSO [18].

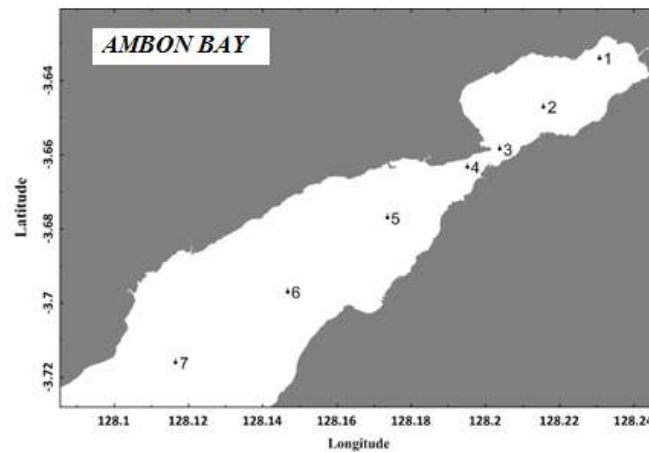


Figure 1. Map of observation location

3. Result and Discussion

Figure 2 shows the tidal prediction in Ambon Bay on 18-19 July 2009 [19], while figure 3 shows a 24-hour current measurement at station 3 starting from 16.00 pm 18 July 2009. The result shows that ocean current at the surface tends to have a different pattern with the current at deep, due to surface winds.

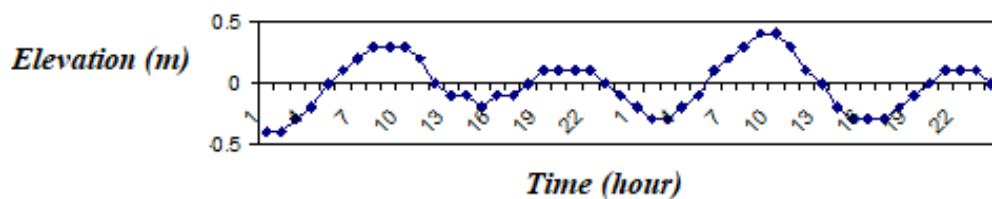


Figure 2. Tidal prediction for Ambon Bay, 18 – 19 July 2009

On 18 July 2009 at 18:00 to 24:00 local time (high tide), the ocean current at 5, 30 and 35 m depth flows into AIB (negative velocity). In contrast, the surface current flows to AOB (positive velocity). Furthermore, on July 19, 2009 at 00:00 to 06:00 am (low tide), the ocean current outflow has a maximum velocity of $0.4 \text{ m}\cdot\text{s}^{-1}$. We predict the ocean current at 30 and 35 m depth will progress upward to the surface when it is blocked by the narrow sill at station 4. Some of this current will go out to AOB, but most of it is to turn left and right back into the AIB.

The distribution of ocean current in Ambon Bay is more dominated by tidal period rather than seasons. The influence of seasons on ocean currents is only visible in the surface layer, meanwhile the influence of tidal are more dominant in the deeper layer.

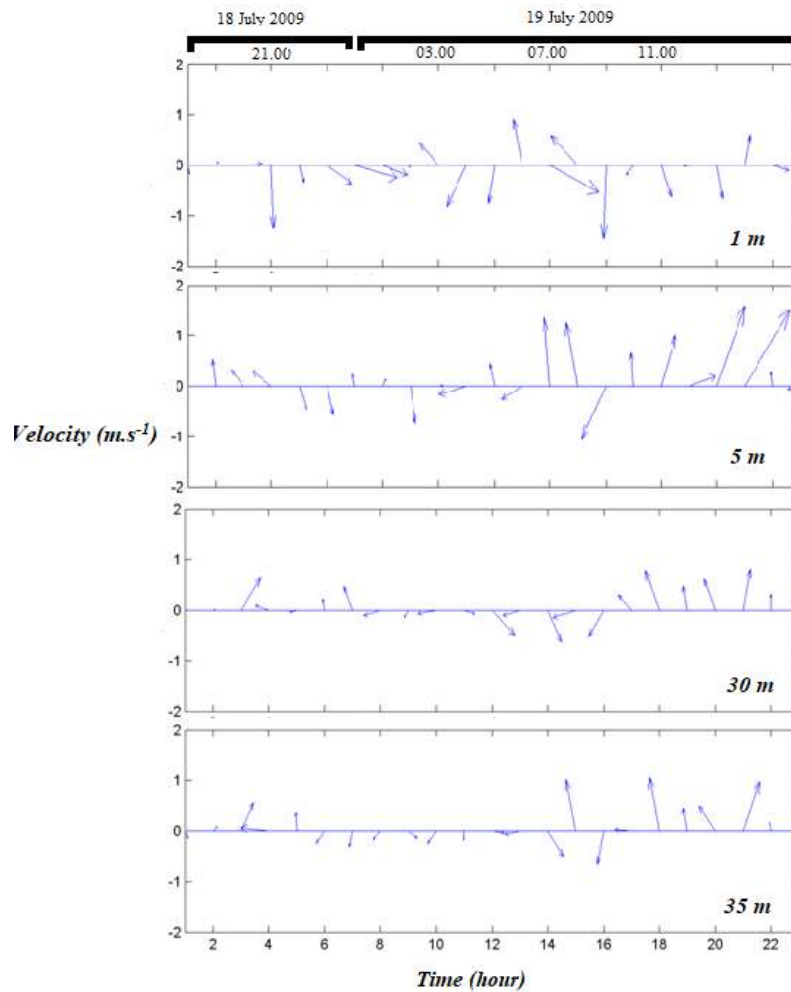


Figure 3. Ocean current in station 3

In this observation, the discussion about El Niño and La Niña refers to Niño 3.4 indices for the year 2008, 2009, and 2010 [20]. Based on figure 4, we can categorize from June to October 2008 as normal condition whereas from June to October 2009 as El Niño event, and June to October 2010 as La Niña event.

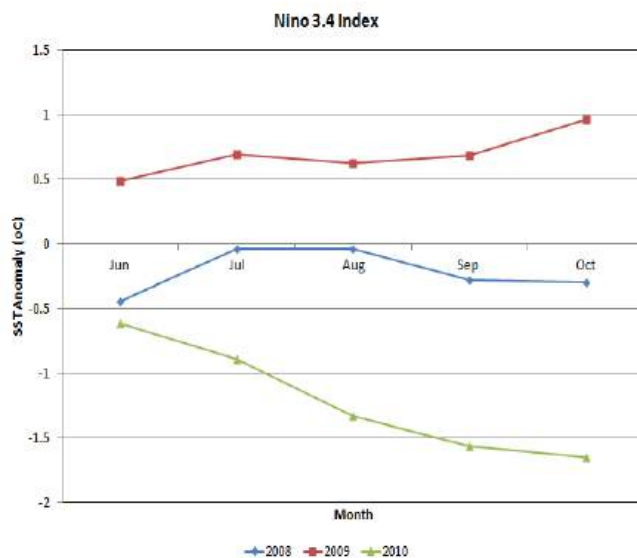


Figure 4. Niño 3.4 Index

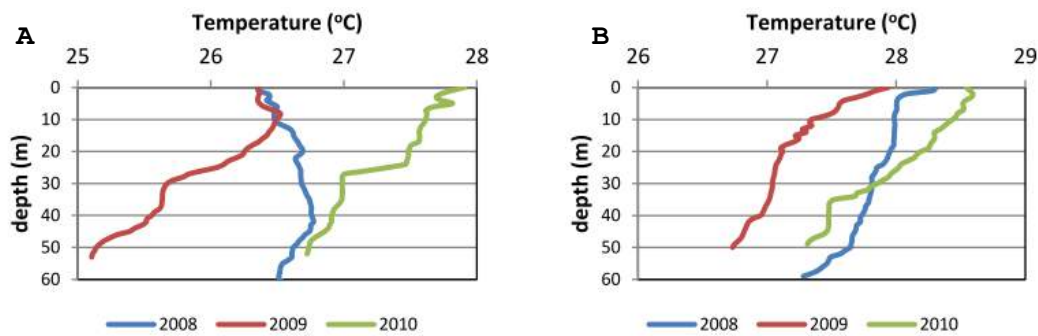


Figure 5. Vertical temperature distribution in station 7 on (a) July and (b) October 2008, 2009, and 2010.

Based on vertical temperature measurement in one of the outer stations in Ambon Bay (Station 7) in July (figure 5a) and October (figure 5b) in the year of 2008, 2009, and 2010, it is apparent that El Niño and La Niña had an impact on vertical temperature compared with normal condition. When El Niño event occurred in 2009, the temperature in AOB became cooler, whereas, during the 2010 La Niña, the temperature was warmer than the 2008 normal condition.

The temperature in Indonesian waters tended to be colder than usual when El Niño occurred due to the eastward shift of the warm pool toward the central Pacific, which elevated the ocean temperature there. This condition made the air pressure above the sea surface lower than usual, resulting in occurrences of eastward wind anomaly against the westward blowing Trade Winds. This wind anomaly moves water mass in the West Pacific region to the eastern Pacific, triggering upwelling in the West Pacific region. Water mass with lower temperature and high density moves upward to the surface when upwelling happens, and thus making sea surface temperature in the western Pacific region to be cooler than usual [21].

On the contrary, when La Niña occurs, sea surface temperature in the Niño 3.4 region becomes cooler than usual due to the pile-up of warm water over the Maritime Continent caused by the stronger Trade Winds. This makes the thermocline layer to remain at depth, and the mixed layer could become thicker than usual [22].

The most effective water mass circulation in Ambon Bay happens in the Southeast monsoon when there is upwelling in the Banda Sea [23]. At this time, water mass in the thermocline layer is lifted to the surface until it reaches ± 70 m depth, which previously was at ± 150 m [14]. This water mass is thought to get into the deep AIB through tidal upwelling mechanism, replacing the resident water mass because the density is higher than the host density. Observation using 3D hydrodynamic modelling suggests that water mass from the Banda Sea gets into the deep AIB through the narrow sill between June to August [14,15].

Figure 6a shows the vertical temperature distribution in all stations in June 2008 and 2009. The temperature in June 2008 was apparently warmer than in 2009. In June 2008, the water mass circulation in Ambon Bay was not seen, and based on the T-S diagram (figure 6b and 6c), it was seen that there was a different water mass characteristic between Ambon Inner and Outer Bay. This condition explains that water mass exchange only happened at the surface and flushing phenomenon was predicted not to occur at this time.

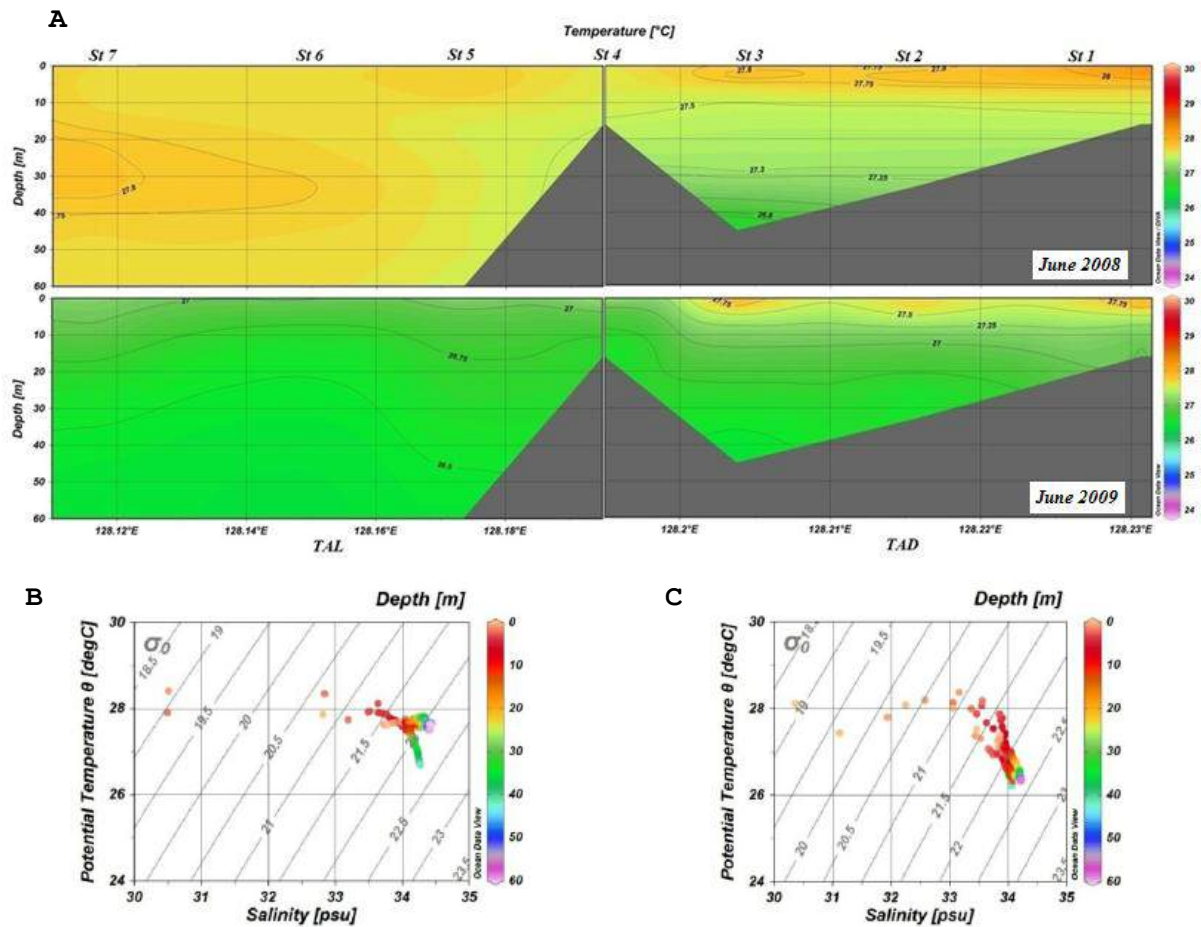


Figure 6. a. Vertical temperature distribution based on locations: Ambon Outer Bay (TAL) and Ambon Inner Bay (TAD) on June 2008 and 2009 and T-S diagrams on (b) June 2008 (c) and 2009.

Observation on July 2008, 2009, and 2010 showed that there was an obvious difference in vertical temperature variability (figure 7). In July 2008, it can be seen that vertical temperature distribution was almost the same in all stations and this observation was shown by the T-S diagrams (figure 7b-d). It was estimated that the water mass from AOB had filled most of AIB.

Both of vertical temperature profiles (July 2009 and July 2010) showed water mass stratification, but there was an obvious difference in the value of temperature distribution (figure 7). The temperature distribution in July 2010 (La Niña) was higher than on July 2009 (El Niño) at which temperature in the surface was still warm even it had entered the Southeast monsoon. In July 2009, vertical temperature profile showed that the appearance of El Niño could strengthen the upwelling process in the Banda Sea where water mass with low temperature ($\pm 25^{\circ}\text{C}$) could rise into shallower depth ($\pm 40\text{m}$). Water mass from the Banda Sea then entered the AOB. It was predicted that flushing phenomenon began to happen at this time.

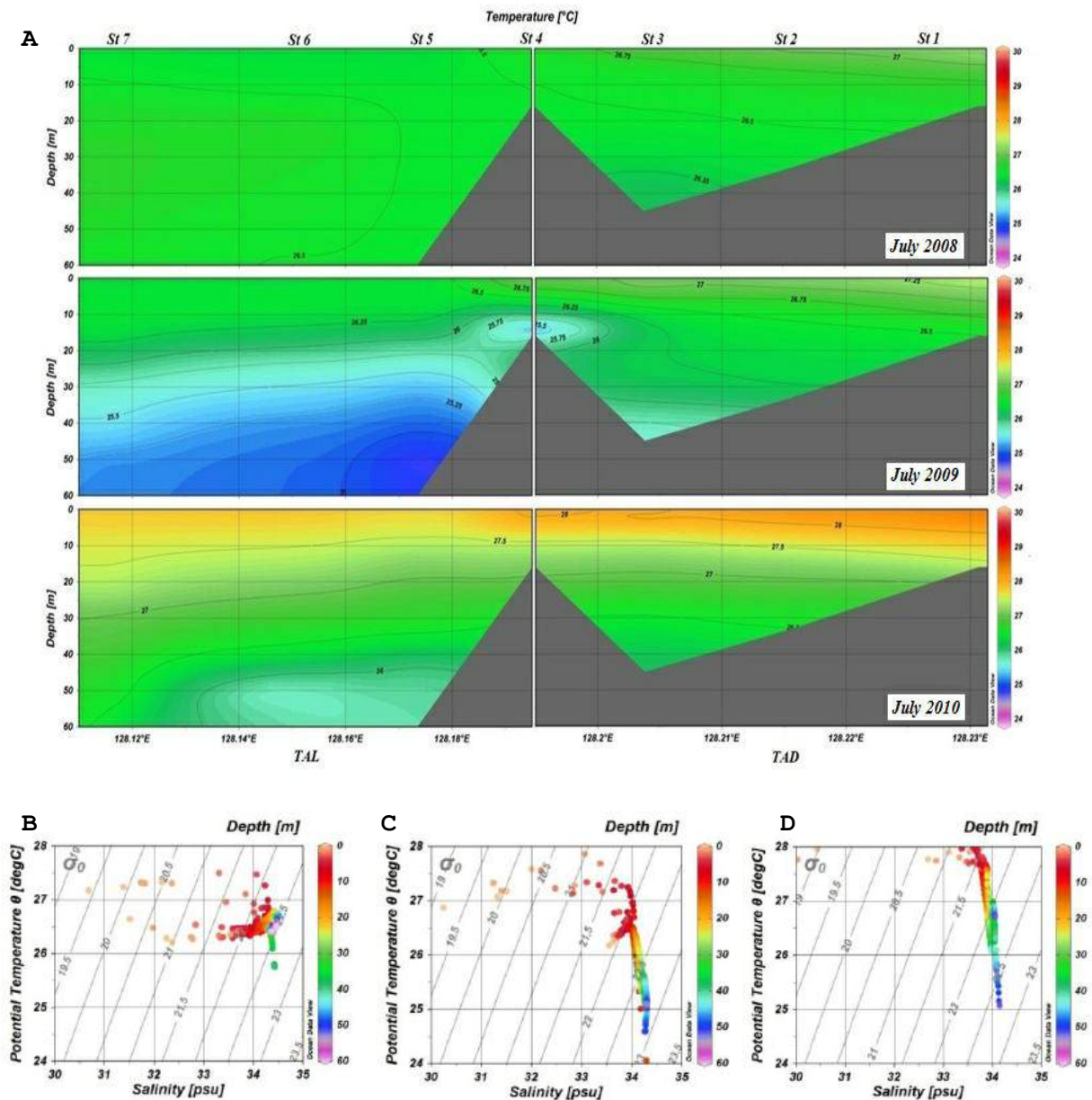


Figure 7. a. Vertical temperature distribution on July 2008, 2009 and 2010 and T-S diagrams in (b) July 2008, (c) 2009, and (d) 2010.

The vertical temperature profile in AOB on September 2009 was warmer than on September 2008 (figure 8a), and flushing phenomenon in Ambon Bay was not seen at this time. This was due to the water mass, which passed through the narrow sill, had a lower density than the water mass in the deep AIB and thus made water mass in the deep AIB trapped and could not exchange with water mass from AOB. We may observe these conditions on the T-S diagram for September 2009 (figure 8b and 8c), where water mass from AOB had a different characteristic to that in AIB.

Based on figure 9, it can be seen that the vertical temperature distributions for October 2008, 2009, and 2010 are different. According to Wyrтки [23], there was a sinking phenomenon where water mass was going down into the bottom of the Banda Sea when entering transition season II until northwest monsoon (October – March). This condition made the water mass density which passes through the bottom of the sill had a lower value than water mass in the deep AIB, and it was estimated that flushing did not happen at this time.

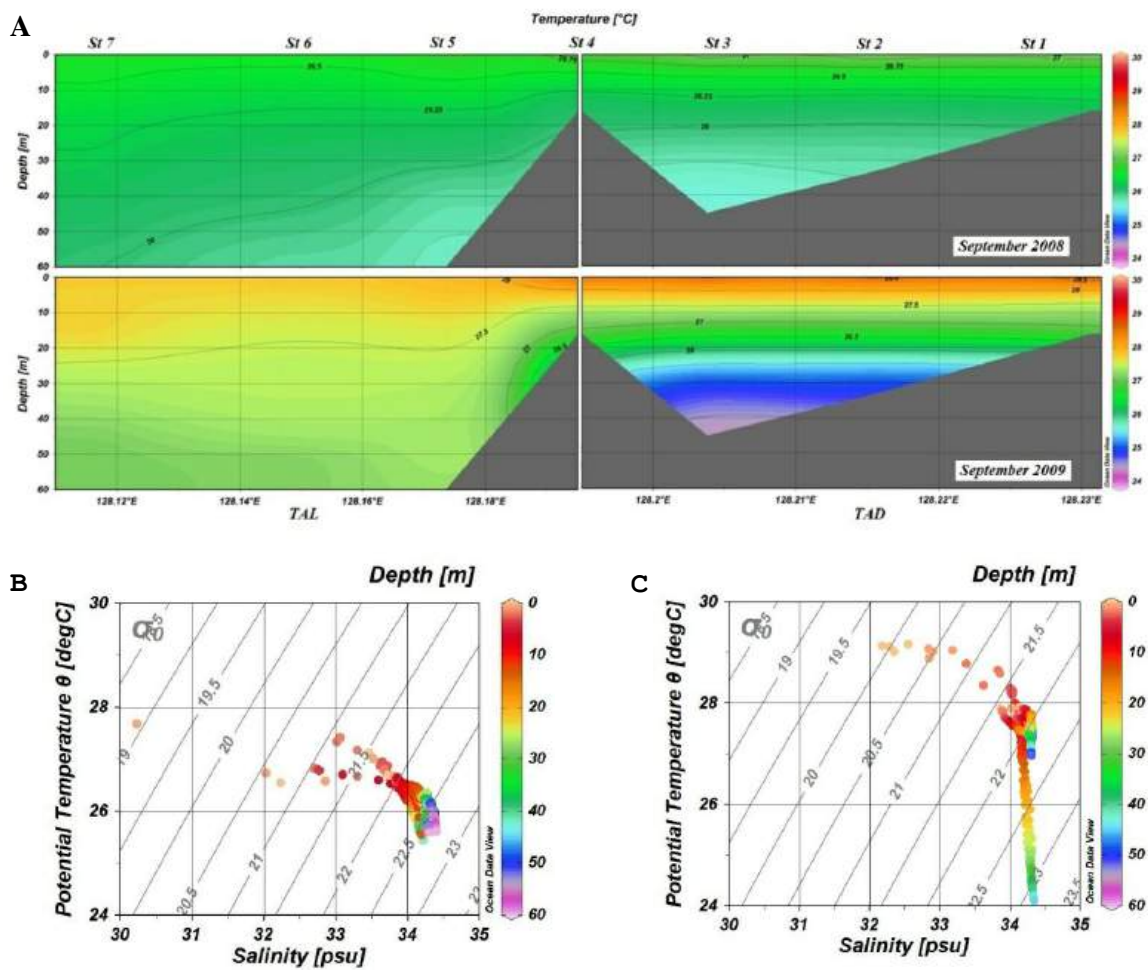


Figure 8.a. Vertical temperature distribution in September in the year of 2008 and 2009 and T-S diagrams in (b) September 2008 and (c) 2009.

It looked as though this condition happened in October 2008 where the temperature in AOB had risen compared with September 2008. This made water mass in AIB trapped and could not go out to AOB, due to water mass density passing through the sill being lower than water mass in the deep AIB (figure 9a). Similar condition also occurred in October 2010, but at this time there was an anomaly in temperature distribution in AOB. At the depth of ± 50 m, water mass with lower temperature and high density increased to the surface again and it was estimated that this condition happened because of higher than normal Niño 3.4 SSTs for October 2009. This condition made the temperature in Ambon Bay Waters lower than in September 2009 even when it was entering the transition season II (figure 9b).

The vertical temperature profile in October 2010 showed a higher value than in October 2008 and 2009. This condition did not just happen only in AOB but also in AIB. It is predicted that there was heat diffusion from the surface to the bottom of AIB.

Ambon Bay is a potential fishing area and known as bait fish farm especially in AIB. Most of the fisherman in this area caught small pelagic fish such as *Sardinella* sp., *Rastreliger* sp., *Decapterus* sp., and *Selar* sp. [25]. The changes in the marine environment affect marine organisms that live in it and later affect the fishing activity in this area. Phytoplankton as the basis of life is one of the marine organism that plays an important role in the aquatic productivity. We use the abundance of phytoplankton to assess the water fertility in Ambon Bay. In July 2008, the density of phytoplankton reached 51,701–853,333 cell.m⁻³ [26], this number was higher for July 2009 with phytoplankton density reaching 263,540–5,697,576 cell.m⁻³ [19]. We predict that the higher amount of phytoplankton in July 2009 is related to El Nino which occurred at that time. El Nino triggered flushing in AIB as

mentioned above and thus changed the marine environment. Nutrient in the bottom of AIB would be lifted up into the surface when flushing occurred, and might enhance productivity in Ambon Bay.

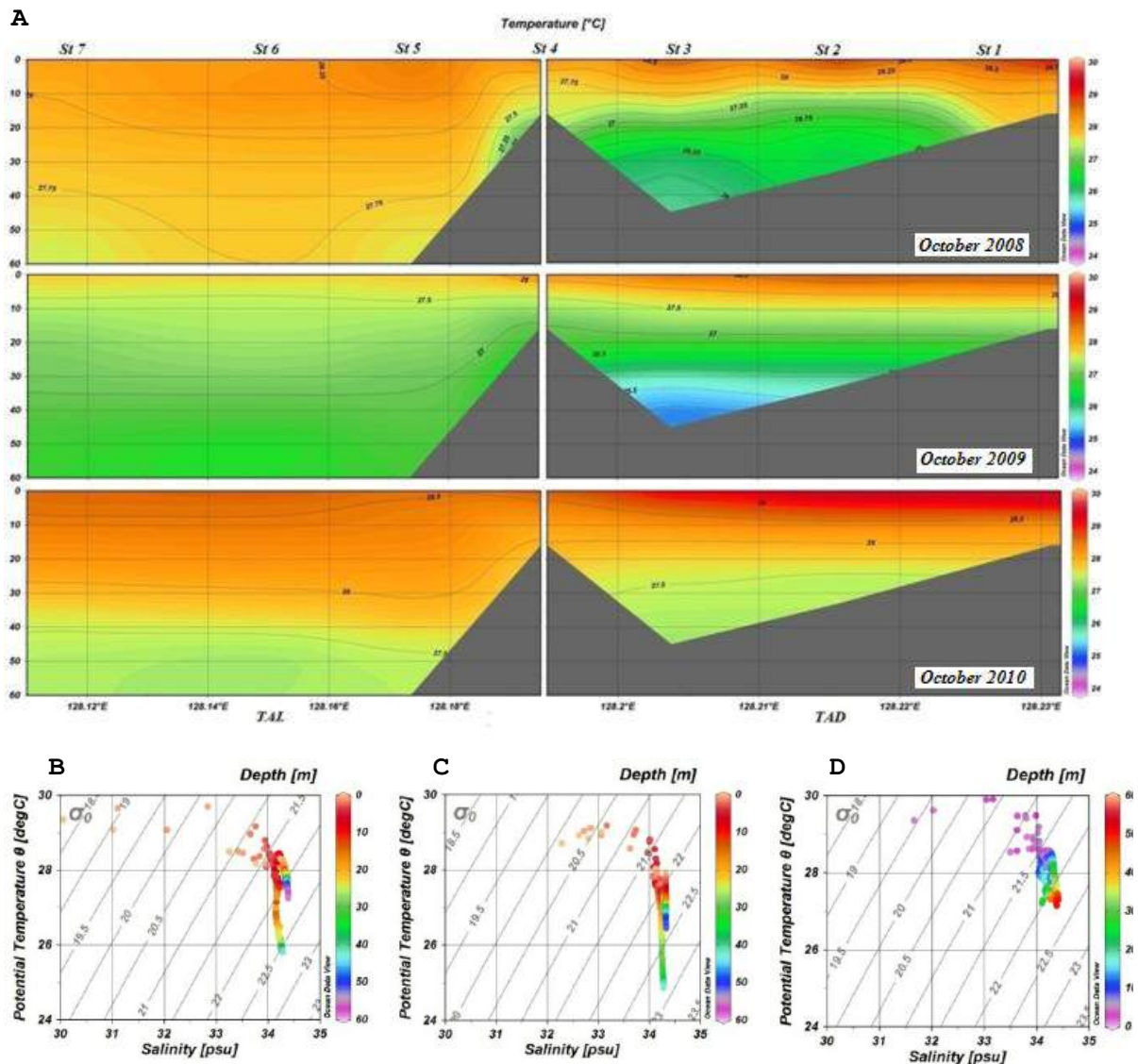


Figure 9. a. Vertical temperature distribution in October 2008, 2009, 2010 and T-S diagrams in October (b) 2008, (c) 2009, and (d) 2010.

4. Conclusion

El Niño and La Niña effect may be observed in temperature variability data in Ambon Bay, and this phenomenon may affect the water mass circulation in Ambon Bay. Water mass circulation in Ambon Bay typically occurs in the southeast monsoon (July). El Niño makes water mass circulation in Ambon Bay to occur earlier, and La Niña makes the circulation to be slower than usual. We still need more data in order to confirm the effect of El Niño and La Niña on water mass circulation in Ambon Bay and how these water mass circulation changes would affect its marine environment.

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