1 Introduction

Ocean currents are vertical and horizontal movements of water masses that are influenced by various factors such as wind movements on the sea surface, tidal phenomena and density differences. Water mass can be classified into surface water mass (surface), thermocline water mass, deep water mass. Water masses from the Pacific Ocean enter Indonesian waters through two pathways. The Western route starts from the Mindanao Strait moving to the Sulawesi Sea and then moves to the Makassar Strait, Flores Sea and then to the Banda Sea, the Eastern route of Arlindo enters through the Maluku Sea and Halmahera Sea [1].

The characteristics of a water mass are known through the physical and chemical properties of the water mass such as temperature, salinity, density, dissolved oxygen, and chlorophyll. Among these variables, temperature and salinity have an important role in reflecting the condition of marine water masses, this is because various aspects of parameter distribution such as chemical reactions and biological processes are a function of temperature so that temperature becomes a determining variable. While salinity is an important factor for the distribution of marine organisms [2].

Scientific cruise activities through BUDEE cruise 2023 carried out measurements and water sampling for the purpose of analyzing physical and chemical parameters in the waters of Banggai, Maluku Sea. The waters of Banggai, Central Sulawesi are very important waters because of their oceanographic conditions which are influenced by the mainland and the Banda Sea so that they are rich in marine resources [3]. This is because the waters are fertile and are a concentration of various types of fish and other marine biota in large abundance. The movement of water masses in the Banggai Waters provides unique conditions. Banggai waters are located in the Maluku Sea, which is part of the waters of Eastern Indonesia and has unique physical conditions. In addition, Maluku waters are also classified as having deep and shallow water areas. In both areas, there is a natural process of stirring or mixing surface water with water at the bottom due to the influence of waves, currents, wind and tides [4]. This is a natural phenomenon process that usually occurs in a body of water. The natural processes that occur in these waters can be studied through oceanographic parameters.

The purpose of this study was to identify the type of water mass, stratification, and currents in the Banggai-Malucca Sea. The water mass referred to in this study is based on physical characteristics such as temperature, salinity, and density. Stratification in the water column is based on temperature and density gradients, which refer to [5].

2 Methods

2.1 Research location

At the location of the research data collection was carried out in August - September 2022 in the framework of the Banggai Islands Maluku Sea Widya Nusantara Expedition (BUDEE 2022) (Figure 1). The data used are oceanographic parameter data such as temperature, salinity, density, and depth obtained from CTD tools to analyze water mass, while current data is obtained through ADCP tools to analyze current patterns at the research location. The location of the CTD drop to a depth of 1000m and ADCP to a depth of 400m was carried out in the Banggai Sea - Maluku Sea, with a total drop covering 9 station points representing the North and South, using the Baruna Jaya VIII research vessel where the cruise organizer is the National Research and Innovation Agency (BRIN) in collaboration with the Bogor Agricultural University (IPB).

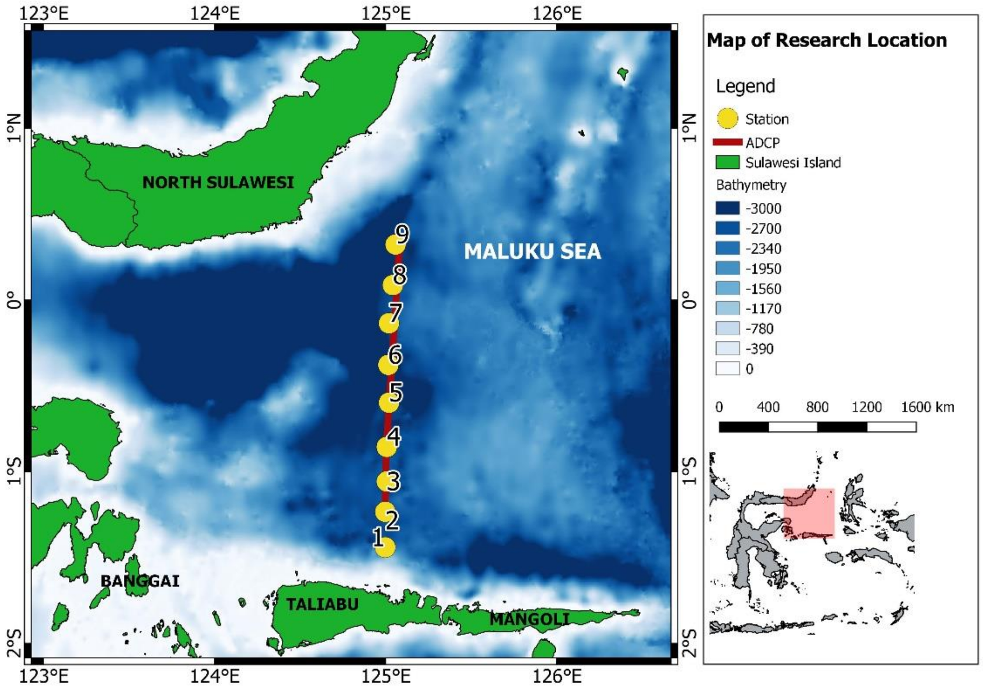

Fig 1. Map of the Banggai-Malucca Sea research site

2.2 Determination of water layer

The water column layer is divided into three layers: mixed layer, thermocline layer, and inner layer. The water mass characteristics of the mixed layer are carried out by observing a temperature gradient <0.1 °C, the thermocline layer has a temperature gradient ≥0.1 °C, and a density gradient ≥0.02 kg/m³ with reference to the surface density point [5]. The boundary between the mixed layer and the thermocline layer from the density data is cross-checked with the temperature data, the boundary is defined by the depth range where density values decrease sharply with depth.

2.3 Ocean current measurement

Ocean current measurements were carried out with a 75 KHz Acoustic Doppler Profiler (ADCP) installed on the Baruna Jaya VIII research vessel. The vertical measurement of currents is carried out starting from a depth of 50m from the surface to a depth of 400m. Measurements are taken at each station point that has been determined. Positioning is done with GPS that has been installed on the Baruna Jaya VIII ship.

Table 1. The thickness of each water mass layer in the Banggai-Malucca Sea water column

Station	Interlaced layer		Thermocline layer		Inner layer	
	Depth from the surface (m)	Temperature range (°C)	Depth/ thickness (m)	Temperature range (°C)	Depth (m)	Temperature range (°C)
1	41	28-29	41-302	11-26	302-1000	4-11
2	75	26-29	75-363	26-10	363-1000	4-10
3	49	27-29	49-327	27-11	327-1000	4-11
4	42	27-29	42-274	27-12	274-1000	4-12
5	28	29.1-29.5	28-407	29.5-9	407-1000	4-9
6	42	29-28	42-359	28-10	359-1000	4-10
7	48	28.3-28.9	48-266	28.3-12	266-1000	4-12
8	42	28.2-28.6	42-237	28.2-13	237-798	5-13
9	41	28.3-28.8	41-362	28.3-9	362-831	5-9
Mean	23	28.4	185	19.2	661	7.5

3 Results

3.1. Thickness of the water mass layer in the water column

This variation can occur due to differences in the upper and lower limits of each layer in different water columns, although it is not striking. It can be seen that there are 3 layers of water mass in the Banggai-Malucca Sea, namely the mixed layer, the thermocline layer, and the deep layer. This vertical stratification can occur due to the decreasing temperature with increasing depth, caused by the absorption of heat from the sun which decreases with increasing depth [5].

In the mixed layer, it can be seen that it has a thickness of 0-75 m with a temperature range of 27-29 °C, while the station that has the lowest thickness is at Station 34, which has the highest thickness at Station 20. In the thermocline layer, which has the lowest thickness at Station 42, while the highest thickness is at station 28, the depth range of the thermocline layer is 28-407 m with temperature values ranging from 9-28 °C. According to Nontji [6], beneath the thermocline layer is an almost homogeneous and cold layer. In the deep layer the station that has the lowest thickness is at Station 34 while the thickest is at Station 7, the depth in the deep layer has a depth range between 266-1000 m with a temperature value of 4-13 °C. The lower down the temperature will drop until the depth of 1000 m and the temperature is below 5 °C. According to Fareza Panjaitan [7] below 1000 m towards the bottom of the water, the temperature does not experience seasonal variations. In accordance with the statement of Supangat and Susanna [8], that the temperature range does not change in the deep sea both geographically (anywhere from the poles to the equator) and seasonally because it is influenced by the cold temperature of the high-density water mass flowing from the poles to the equator.

3.2. Vertical profile of temperature, salinity, and density

The temperature graph shows that the temperature value decreases with increasing depth, the surface layer shows the maximum temperature value, while in the thermocline layer, the temperature value decreases significantly and is relatively homogeneous in the deep layer (Figure 2). The vertical temperature profile of the Maluku Banggai Sea can be divided into three layers, namely the mixed layer, thermocline layer, and deep layer. In the mixed layer, the temperature value ranges from 25-30 °C at a depth of 1-40 m, while in the thermocline layer, the temperature value ranges from 12-26 °C at a depth of 40-322 m. In the thermocline layer, the vertical profile of the water mass looks irregular and Step-like, this condition is thought to occur due to the stirring process in the thermocline layer. The deep layer has temperature values of 5-12 °C, with depths ranging from 322-1000 m. According to Indrayanti [9] in this layer, the penetration of light obtained is very small and the influence of the current is small, causing the conditions to be stable and the temperature tends to be constant. Mean MLD 45.3 (±12.6) m, shallower toward the mid-section; mean thermocline 276.6 (±57.6) m; tend to deepen toward both the end of section. Step-like structure of temperature is evident in the upper 400 m depth; salinity profiles: salinity max near 75-125 m (center thermocline layer) and salinity min near 300m depth. Large meridional variation of S max and S min is found.

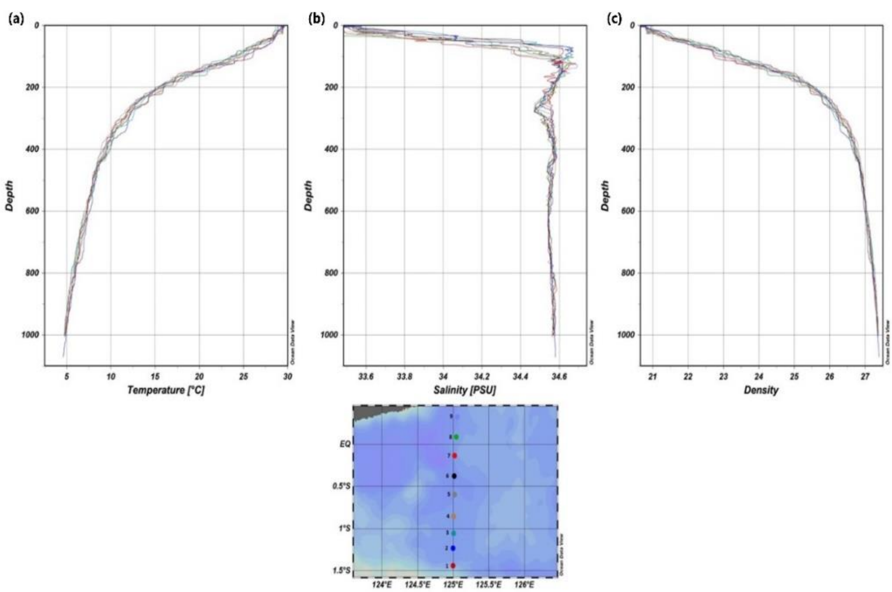

Fig 2. Vertical profiles of temperature(a), salinity (b), and density (c) from 9 CTD cast measurements in the Banggai-Maluku Sea at 1000m depth

Through the vertical distribution of salinity, the pattern of water mass layering from the surface to the deep layer can be seen, which is divided into three layers, namely the mixed layer, the halocline layer, and the deep layer. The salinity profile shows that the surface has a low salinity value due to freshwater dilution and the maximum is in the thermocline layer at a depth of 75-180 m is the maximum salinity depth with salinity values ranging from 34.6-34.7 psu. At a depth of 280 m there is a decrease in salinity value of 34.5 psu, this is indicated by the input of low salinity water masses from the Pacific Ocean, then in the deep layers the salinity value forms a value profile that tends to be homogeneous.

In general, the density of a water mass increases with depth. In the absence of disturbance, a low-density water mass will always be above a high-density water mass. It can be seen on the vertical profile that the density value in the mixed layer ranges from 20.95-21.30 σ_0 with a depth of 1-40 m. While in the thermocline layer, the density value ranges from 21.30-26.29 σ_0 with a depth of 40-322 m, based on previous research the density value of the thermocline layer ranges from 22-26 σ_0 [7]. In the inner layer the density value ranges from 26.29-27.37 σ_0, the value is in accordance with previous research [11].

3.3. Transverse profile of temperature, salinity, and density

The transverse profile of the mixed layer temperature tends to be higher than the layer below, where the mixed layer of each station has a different thickness (Figure 3). This is because the mixed layer can be influenced by several factors such as wind pressure, solar heating, and particles that limit the penetration of heat at depth [9]. The mixed layer of each station has a different thickness at Station 5 is the thinnest compared to other stations, ranging from 0-28 m with a temperature range of 29 °C, while the thickest is at Station 2 with a thickness of 0-75 m with a temperature range of 26-29 °C, stations in the isotherm bounded layer the temperature is relatively stable although interspersed with some fluctuations. In previous research, the temperature value of the mixed layer had a value ranging from 29.6-30.3 °C [11]. The upper limit thermocline layer is represented by the 26 °C isotherm while the lower limit is represented by the 9°C isotherm, in the very thin thermocline layer station is represented by station 8 thickness ranging from 42-237 m with a temperature range of 13-28 °C, while the very thick is represented by station 5 with a thickness of 28-407 m temperature range ranging from 9-29 °C, in the lower boundary inner layer represented by isotherm 4°C, a very thin station is at station 8 with a thickness of 237-798m with a temperature range of 5-13 °C, while the very thick is represented by Station 4 with a temperature range of 4-12 °C and in the inner layer represented by isotherms that are below the thermocline layer, namely 5 °C. Previous research on the Maluku Sea thermocline layer has a value range of 11.8-29 °C [11]. Center of thermocline (isotherm of 20 °C) near 150 m depth, and is slightly deepen toward the north; salinity less than 34.0 psu in the upper 50 m depth. Salty water S max ~34.6psu is found within the thermocline layer, centered between 100-175 m depth and thicken toward the north; the first three station from the south, S max slightly shallower between 50 m and 175 m with two cores; S min (<34.5 psu) appear between 250-300 m depth, but it weakens in the first four stations from the south.

Through the transverse distribution presented in (Figure 4), it can be seen the condition of the salinity profile and the characteristics of the water mass in the Banggai Waters of the Maluku Sea. The transverse profile of salinity in the mixed layer tends to be low, this can be seen from the color change gradient in the transverse salinity profile on the 33.5 psu isohaline line, in previous studies the range of salinity values of the mixed layer ranged from 34.25-34.45 psu [12]. This can be indicated by the mixing of water masses from land influenced by various factors, namely evaporation, precipitation, freshwater inflow (runoff), and changes in currents due to seasonal changes. Below the surface layer of the thermocline layer, the salinity value increases until the range at isohaline 34.58 psu, not only an increase in salinity value but also a decrease in salinity value which reaches 34.5 psu, in previous studies found extreme salinity values in the Maluku Sea reaching more than 34.6 psu [11]. In the deep layer, the salinity value tends to be homogeneous with a salinity value of 34.6 psu.

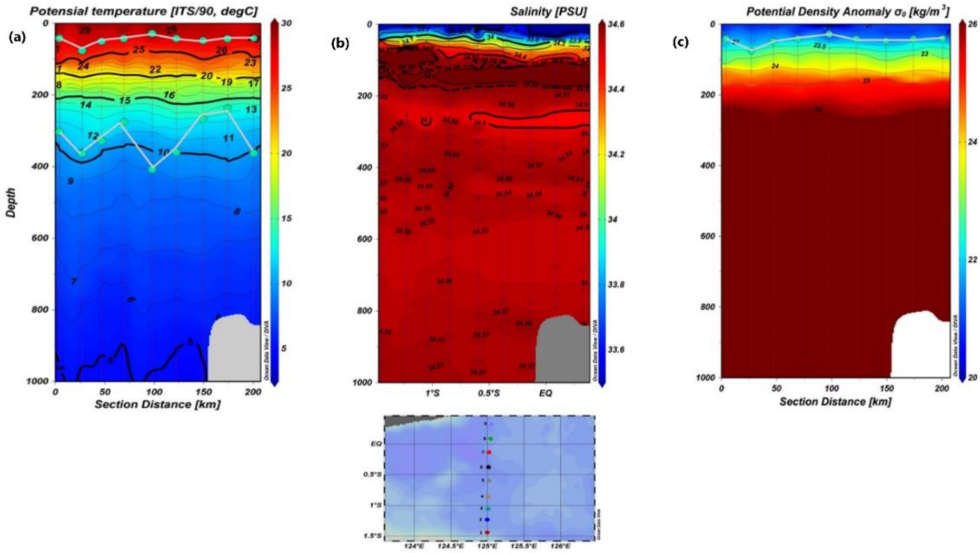

Fig 3. Horizontal section profiles of temperature (a), salinity (b), and density (c) from 9 CTD cast measurements in the Banggai-Maluku Sea at 1000 m depth.

The transverse density profile can be seen that the density conditions in the surface layer have a density value of 20 σ_0 thickness value that matches the transverse temperature graph, while the layer below the mixed layer is a pycnocline layer, in this layer the density value is 22.5-26.5 σ_0, according to research [13]. in the pycnocline layer ranges from 22-26 σ_0. The layer located below the pycnocline layer is the inner layer of this layer formed starting from the lower limit of the pycnocline layer in the range of 26.5-27.5 σ_0, in previous research the density value of the inner layer had a range of 26-27 σ_0 [11]. The density value is used to determine the mixed layer because to get the density value how to calculate it is obtained from the temperature and salinity values.

3.4. Water mass characteristics of Banggai waters, Maluku Sea

The TS diagram was used at 9 observation stations in the Malaku Sea (Figure 4) to identify water mass characteristics. The measurement results of the TS diagram of this study show the existence of three types of water masses at a depth of 80-163 m, there is a North Pacific Subtropical Water (NPSW) water mass with a temperature value of 20-24 °C, salinity ranging from 34.8–35 psu and DO value of 169-179 μmol/kg. The North Pacific Intermediate Water (NPIW) mass at 273-393 m depth is characterized by temperature values of 10-11 °C and salinity of 34.5 psu, DO values of 113-121 μmol/kg. South Pacific Intermediate Water (SPIW) is found at a depth of 408-920 m with temperature values of 8-5 °C and salinity values of 34.54-34.56 psu and DO values of 112 μmol/kg – 109 μmol/kg. Figure 4 displays the TS diagram of the study site, which illustrates the water mass structure. The NPSW Smax varies significantly (~0.6 psu) between isopycnal surfaces 21-24. The first three southern stations exhibit maximum salinity, while the remaining stations have fresher water with higher DO levels of approximately 160-180 umol/kg. Additionally, the minimum salinity of NPIW was slightly different between the three southern stations and the remaining station in the north. This was observed near the >27 isopycnal surface and corresponded to a much higher dissolved oxygen level between 130-140 umol/kg. At the study site, a slight minimum salinity of 34.4 psu was identified as Antartic Intermediate Water (AAIW), with temperature values ranging from 4-7 °C. This was associated with a slight increase in dissolved oxygen. Figure 4 shows a diagram of potential temperature and salinity (TS diagram), which is consistent with previous studies [11, 12, and 14]. These studies identified four characteristics of Pacific Ocean water masses, including their distinct oceanographic parameters such as temperature, salinity, and density. These studies identified four characteristics of Pacific Ocean water masses, including their distinct oceanographic parameters such as temperature, salinity, and density. It is important to note that water masses moving through the ocean have unique characteristics. It is worth noting that this text excludes any subjective evaluations. These water masses can also impact the chemical properties of the water.

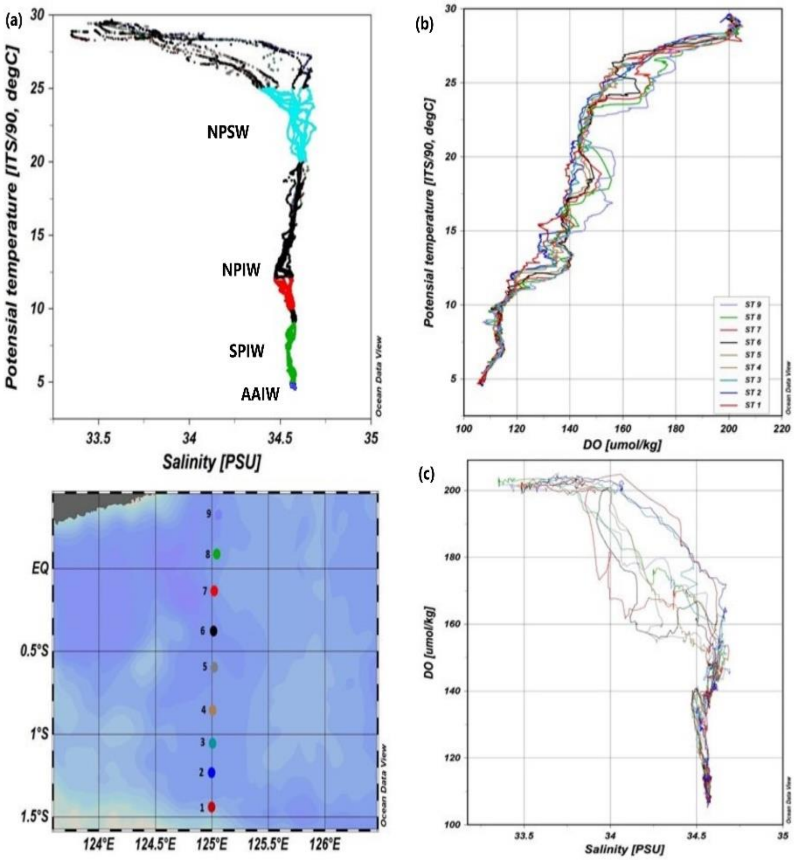

Fig 4. Diagrams of Temperature-Salinity (a), Temperature-Dissolved Oxygen (b), and Salinity-Dissolved Oxygen (c) at Banggai station-Malucca Sea

3.5. Vertical pattern of tidal and non-tidal currents

Measurement of ocean currents using ADCP at a depth of 50 m in Banggai waters, where there are 9 current measurement stations. In principle, ADCP works by transmitting sound waves to the water column with a certain pattern and then receiving back the reflection. Based on the results of surveys that have been carried out in the Banggai Sea Maluku by the BUDEE 2022 team, simulation of current movement patterns using ADCP software obtained differences in current vectors between tidal currents and non-tidal currents. In the display of current processing can be seen, the tidal current (image) LU at a depth of 20-52 m (b) shows the movement of the current direction is more dominant towards the Northeast with a current speed of 30 cm/s. while the area where the station is located 0º-0.5° LU depth of 20-52 m tidal current direction is more dominant towards the North with a speed of 30 cm/s. The station located at 1-0.5° LS has a more dominant current direction towards the Southeast with a speed of 30 cm/s at a depth of 20-50 m.

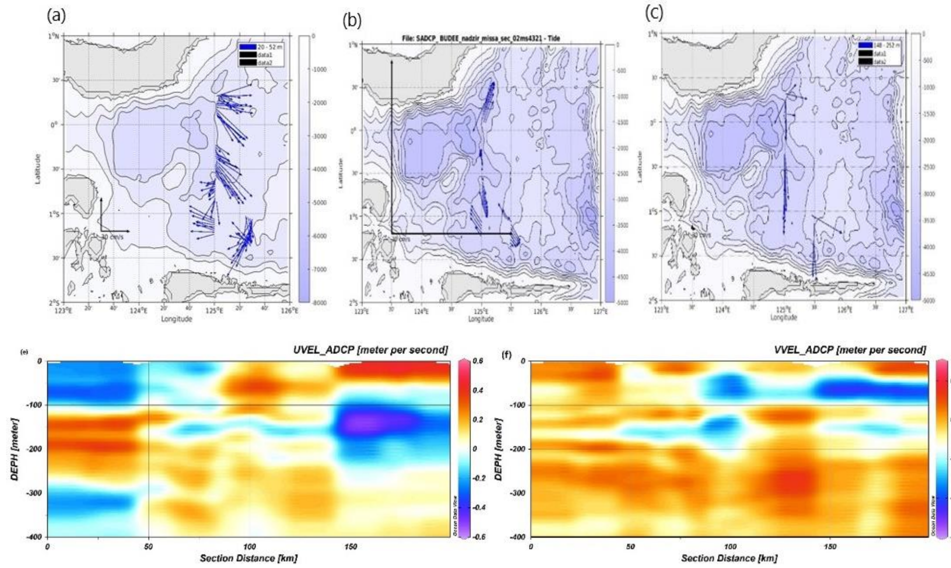

Figure 5. Current patterns at multiple depth layers: Non-tidal 20-52m (a), tidal 20-52 (b), non-tidal148-252m (c), non-tidal 252-404m (d), uvel (e), vvel (f).

Non-tidal currents of LU at depths of 20-50 m (a) show the movement of the current direction is more dominant towards the Southeast with a speed of 30cm/s at a depth of 20-52 m, while the station located at 0-0.5 ºLU is more dominant towards the Southwest with a speed of 30 cm/s. The station located adjacent to Taliabu Island at 1-0.5 °N is more dominant towards the Northwest with a speed of 30 cm/s at a depth of 20-52 m. While at a depth of 148-252 m shows a change in current pattern, the station located at LU the current pattern is more dominant towards the South with a speed of 30cm/s, the station located at 0-0.5 °LU the current direction is more dominant towards the South with a speed of 30cm/s, the station located adjacent to Taliabu Island 1-0.5 °N is more dominant towards the South. At 148-400 m depth, the current direction tends to be the same as the previous depth, the current direction pattern dominates to the South, as well as the station located with Taliabu Island. The images in section (e) and (f) serve to reinforce the current direction.

4 Conclusion

The Banggai-Maluku Sea exhibits a stratification of water masses with varying thicknesses at each station. Stations in close proximity to the island have a lower water column thickness compared to those further away. Additionally, four types of water masses were identified in each layer of the sea, including North Pacific Subtropical Water (NPSW) with a temperature range of 20-24 °C, salinity ranging from 34.8-35 psu, and a dissolved oxygen (DO) value of 169-179 µmol/kg. The North Pacific Intermediate Water (NPIW) water mass is found at a depth of 273-393m and is characterized by temperature values of 10-11°C, salinity of 34.5 psu, and DO values of 113-121 mol/kg. The South Pacific Intermediate Water (SPIW) is located at depths of 408-920 m and has temperature values of 5-8 °C, salinity of 34.54-34.56 psu, and DO values of 109-112 mol/kg. Antarctic Intermediate Water (AAIW) is found at a minimum salinity of 34.4 psu and a temperature range of 4-7 °C, which is associated with a slight increase in dissolved oxygen. The current pattern in the Banggai-Maluku Sea at a depth of 20-52 m is still influenced by tidal currents. The station's location in the LU indicates a dominant current movement towards the Northeast. In the area between 0° and 0.5° LU, the tidal current direction is more dominant towards the North. At 1-0.5 °LS, the current direction is more dominant towards the Southeast. The non-tidal current is more dominant towards the South at a depth of 52-400 m, while the tidal current remains unchanged in direction.

We as authors are very grateful to the National Research and Innovation Agency (BRIN) and the crew of Baruna Jaya VIII for supporting data collection. we also thank the reviewers for suggestions in improving this manuscript.

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