Ocean Currents, Temperature, and Salinity at Raja Ampat Islands and The Boundaries Seas

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ABSTRACT

Raja Ampat Islands and eastern seas influenced by water masses from the Pacific Ocean and the monsoon. The aim of the research is to study the physical condition of water column, movement, and identification of water sources. The method used in this study with spatial and temporal analysis. The results show that water movement through Raja Ampat, Halmahera, Ceram, and Banda Seas. Mix layer condition up to 71 m depth and thermocline layer up to 567 m depth. The identified water masses from T-S Diagram are SPIW (South Pacific Intermediate Water), SPSW (South Pacific Subtropical Water), NPSW (North Pacific Subtropical Water), and AAIW (Antarctic Intermediate Water). The maximum SST value occurred at the end of west monsoon (February) in the range 28.25 °C - 30.5 °C, and the minimum value occurred at the end of east monsoon (August) in the range 26.25 °C - 29.25 °C. The maximum SSS value occurred at early monsoon transition 2 (September) in the range 34.25 psu - 34.75 psu, and the minimum value occurred at early monsoon transition 1 (March) in the range 32.75 psu - 34 psu.

Keywords: Indonesian Seas, Physical Condition, Pacific Ocean, Monsoon, T-S Diagram
1. INTRODUCTION

Raja Ampat Islands are so complex that its have straits and are bordered by the waters of the Pacific Ocean, Halmahera Sea, and Ceram Sea in the eastern of Indonesia. This area is one of the main lines of water masses from the Pacific Ocean that moves towards the Indian Ocean, the water mass is known as Indonesian Throughflow [1-3]. In addition to these factors, condition of the waters is also influenced by monsoon that could affect to the value of water temperature and salinity [4, 5]. The movement of water masses and wind determines the changes in oceanographic parameter values, this results in dynamics that illustrate the condition of waters [6, 7].

Physical conditions can be explained by looking at the characteristics and variability of oceanographic parameters such as ocean current, temperature and salinity with spatial or temporal values which are important features of a waters [8]. Observations of temperature, salinity, and distribution are parameters that cannot be left behind in each study [9, 10]. Physical conditions can be seen by looking at the vertical column water stratification to explain the characteristics of the water masses, while horizontally by looking at the distribution associated with the monsoon winds on the Sea Surface Temperature and Sea Surface Salinity values.

The aim of the research is to study the physical condition of water column, movement, and identification. Considering that it is important to know the characteristics and variability where can describe the phenomena and explain the condition of a waters. This research is a follow-up study of the Baruna Jaya IV Marine Research Expedition conducted with BPPT, with the activity “Sail Raja Ampat and Deployment Ina-Triton Buoy in Pacific Ocean”.

2. MATERIALS AND METHODS

2.1. Study Area

The research area was in the eastern seas of Indonesia, from Raja Ampat Islands, Halmahera Sea, Ceram Sea, and Banda Sea with coordinates 1.5°N - 5.5°S and 124.5°E - 133.5°E. This selection station based on Sail Raja Ampat cruise line and coordination with technician and scientist form Baruna Jaya crew. The ADCP stations has 2 points and the CTD stations has 10 points according to the east pathway. Points of ADCP and CTD stations were shown in (Figure 1).
2.2. Data Source and Processing

The data was obtained with R.V. Baruna Jaya IV censors, which is CTD Sea Bird Electronic 911 Plus with data output in the form of depth, temperature and salinity values. ADCP RDI Broadband with data output in the form of direction and current velocity. GPS Sea Falcon F180 with data output in the form of coordinates of the research station. Additional data are WOA (World Ocean Atlas) data from www.nodc.noaa.gov for values of depth, temperature and salinity, and My Ocean CMEMS data from www.marine.copernicus.eu for values of direction and current velocity. Depth, temperature and salinity data were processed using Ocean Data View, with outputs in the form of salinity and temperature profiles to depth, TS-diagrams to water masses indentification, and horizontal spatial maps to see the variability of SST and SSS. Direction and current velocity data were processed using Grapher 9 for currentrose charts, and Ocean Data View for horizontal spatial maps.
3. RESULTS

3.1. Current Profile

The current profile uses ADCP data and CMEMS My Ocean data, with direction and current velocity. The current profile is represented by the currentrose chart for ADCP data, and a horizontal spatial map for CMEMS data. The current profile at the A01 station (Sagewin Strait) is dominant to the west and southwest direction. Have an average of speed less than or equal to 100 mm/s with a percentage of about 2%, speeds of 101-200 mm/s around 6%, speeds of 301 - 400 mm/s around 7%, and speeds of more than 401 mm/s around 7.5% as seen in Figure 2 (a).

The current profile at A02 station (Dampir Strait) is dominant to the southwest direction. Have an average of speed less than or equal to 100 mm/s with a percentage of less than 1%, speed of 101 - 200 mm/s around 4%, speed of 201 - 300 mm/s around 6%, speed of 301 - 400 mm/s around 7.5%, and above 401 mm/s around 10% as shown in Figure 2 (b).

![Figure 2. Current Rose of CTD Stations](image)

(a) A01 Station (b) A02 Station

The current profile of CMEMS My Ocean data is depicted with a horizontal spatial map using monthly averages in August 2014 with a resolution of 0.028°. The current profile describes the strong water mass movement from the Pacific Ocean entering through the Halmahera gap, this water mass flows into the Ceram Sea and Banda Sea as seen in (Figure 3). In August, where the southeast monsoon was strengthening, the North and South Pacific water masses flowed through the Halmahera Sea and flowed into the Banda Sea [3].
The current profile in the study area has an average speed below 1 m/s with quite varied water mass movements. In Raja Ampat waters the dominant movement to the west is the Halmahera Sea and southwest to the Ceram Sea. In the waters of Halmahera the dominant moves to the south and part of the water mass moves towards the north because it is influenced by Eddy's current [11]. In Ceram Sea the direction is more varied because there is an intake of water mass from the Banda Sea that enters through the gap between Ceram and Papua Island, and also the intake of water masses from the Halmahera Sea and Maluku Sea that are heading south. The strong movement of water masses from the Pacific Ocean that enters Indonesian waters in according to [12, 13] where in June - August is the transport of the Indonesian Cross Flow with the highest water mass gradient value.

3.2. Water Masses Stratification

Condition of the stratification of the water mass layer calculated using temperature parameters with the threshold value where the mixed layer has a value of $\Delta T = \leq 0.5$ °C and for the thermocline layer has a value of $\Delta T = \geq 0.5$ °C [14, 15]. The depth value of the calculation results is not the actual limit of the mixed layer or thermocline layer, but the calculation result is the temperature data retrieval limit from CTD, where the temperature value at the depth indicates the condition of the mixed layer and thermocline layer of the 10
CTD stations. The results of the calculation of temperature parameters have mixed layers up to a depth of 71,892 m, with a thermocline layer thickness of up to 502,175 m, where the lower boundary layer is up to a depth of 567,688 m. The mixed layer can increase as the wind blows which causes stirring so that the upper limit gets deeper, but the thicker the thermocline layer will decrease the temperature gradient will be smaller [16, 17].

3.3. Temperature and Salinity Profile

Temperature profile at the study area has a sea surface temperature in the range of 27 - 30 °C. The mixed layer is in the depth 0 - 71 m with temperature value in the range 30 - 25 °C, and the thermocline to a depth of 567 m with temperature value in the range 25 - 7 °C. The temperature profile of the 10 CTD stations illustrates the unstable conditions in the thermocline layer at stations 3-5 because of the movement of the water mass from the direction of station 10 which causes the rise of the mixed layer as seen in (Figure 4).

![Figure 4. Temperature Profile to Depth](image)

The reason is not because of the wind because it requires large energy to be able to stir the thermocline layer which tends to be more stable [6]. The reason is the intrusion of water masses from the Pacific, where the Pacific water masses traveling along the northern coast of Papua and enter through Halmahera gap then move towards the Ceram Sea which causes water masses intrusion [1, 18, 19].

Salinity profile at the study area has a sea surface salinity in the range of 34 - 34.25 psu. The salinity profile of the 10 research stations has a high salinity value in the thermocline layer but tends to be homogeneous in the inner layer, and low in the mixed layer due to the influence of monsoon winds and run-off of river streams. The salinity profile illustrates the presence of high salinity water mass intrusion towards low salinity at stations 4-10, this is characteristics of high salinity from the Pacific Ocean in the waters of Halmahera and Raja Ampat which lead to the waters of Ceram Sea and the banda Sea which tend to homogeneous as seen in (Figure 5).
The Halmahera Sea is a gap for the North Pacific and South Pacific water masses that moves towards the Ceram Sea to the Banda Sea with high salinity characteristics [3, 10]. High salinity values in the upper thermocline layer indicate the characteristics of the subtropic water mass of the Pacific Ocean [1, 18].

3.4. Water Masses Identification

The water masses identification of 10 CTD stations using TS-diagram during the southeast monsoon precisely in August. TS-diagram can be used to define and locate water masses [21]. The water masses characteristic in the study area had a mixed layer with a depth range of 0 - 71 m, a value of $\sigma_o$ in the range of 21 - 23, and a temperature value of 30 - 25 °C. The thermocline layer has a depth range of 71 - 500 m, $\sigma_o$ value is in the range of 23 - 27, and temperature value is 25 - 7 °C. The deep layer with a depth of up to 1000 m has a $\sigma_o$ value below 28, and the temperature value is below 4 °C tend to be more homogenous and minimum value [22]. The identified water masses are SPIW (South Pacific Intermediate Water), SPSW (South Pacific Subtropical Water), NPSW (North Pacific Subtropical Water), and AAIW (Antarctic Intermediate Water).

SPIW water masses was identified at stations 1 - 8 at a depth of 250 m - 850 m with a characteristic value of $\sigma_o$ in the range of 26.5 - 27.5, minimum salinity value 34.55 psu and maximum salinity 34.65 psu. AAIW water masses was identified at stations 1 - 6 at a depth of 750 - 1000 m with characteristics of values $\sigma_o$ 27 - 27.5, minimum salinity 34.58 psu and maximum salinity 34.63 psu. NPSW water masses was identified at stations 5 - 10 at a depth of 70 - 150 m with characteristic values $\sigma_o$ 23.5 - 24.5, minimum salinity 34.8 psu and maximum salinity 35.2 psu. SPSW water masses was identified at station 10 at a depth of 130 - 200 m with characteristic value of $\sigma_o$ 25-26, minimum salinity 35.2 psu and maximum salinity 35.34 psu as seen in (Figure 6).
SPIW water masses presumed entering Halmahera Sea, but has been shifted to Ceram Sea because it wasn’t found at station 9 - 10. AAIW water masses is estimated entering through the Maluku Sea and its condition is still strong because it is found in almost all the Ceram Sea CTD stations. SPSW water masses is estimated entering only through the Papua gap because this water mass is only found at station 9. NPSW water is estimated to move Halmahera Sea towards the Banda Sea because this water masses is found in stations 5 - 10. SPIW water mass entered the Halmahera Sea along the northern coast of Papua, the AAIW water mass entered through the Maluku Sea and then headed for the Ceram Sea, Banda Sea to the Indian Ocean, the SPSW water mass moved from the South Pacific through coastal Papua and enter through the Halmahera Sea, the NPSW water mass moves from the South Pacific, entering through the Sulawesi Sea si and Halmahera and spread through water gaps [1, 3, 20].

3.5. Sea Surface Temperature Variability

Variability of SST values in west monsoon and transition 1 tends to be higher as seen in (Figure 7). In the west monsoon the value is in the range 28.25 - 30.5 °C, with the variation of SST in December 28.5 - 30 °C, January 28.75 - 29.75 °C, and February 28.25 - 30.5 °C. In transition 1 monsoon the value is in the range of 28.25 - 29.75 °C, with the variation of SST
in March 28.5 - 29.75 °C, April 29.25 - 29.75 °C, and May 28.25 - 29.75 °C. SST values can be higher due to the position of the sun in the southern hemisphere, as well as gusts of wind from the Asian Continent to the Australian Continent that has warm characteristics [1, 3]. In the west monsoon the wind tends to be weak that affect to transfer of heat weak from the surface so the sea surface temperature is warmer [23].

Variability of SST values in east monsoon and transition 2 is lower than west monsoon and transition 1. In east monsoon the value is in the range of 26 - 29.5 °C, with the variation of SST in June 27.25 - 29.5 °C, July 26 - 29.5 °C, and August 26.25 - 29.25 °C. In transition 2 monsoon the value is in the range of 26.25 - 29.5 °C, with the variation of SST in September 26.25 - 29.25 °C, October 27.75 - 29.5 °C, and November 28.75 - 29.75 °C. SST values tend to be lower because the sun is in the northern hemisphere, as well as wind gusts from the Australian Continent towards the Asian Continent which has cold characteristics [1, 3]. The low SST value in the study area indicates upwelling phenomenon [23, 34].

![Figure 7. Maps of 12 Month Sea Surface Temperature](image)

3.6. Sea Surface Salinity Variability

Variability of SSS values in west monsoon and transition 1 tends to be lower as seen in (Figure 8). In the western monsoon the values is in the range of 33 - 34.75 psu, with the variation of SSS in December 33.5 - 34.75 psu, January 33.5 - 34.5 psu, and February 33.5 - 34.75 psu. In the transition 1 monsoon the value is in the range 32.75 - 34.25 psu, with the variation of SSS in March 32.75 - 34 psu, April 33 - 34.5 psu, and May 32.75 - 34.25 psu. SSS values are lower due to high rainfall which causes low salinity waters values, but in the northern part of the study area the SSS value is quite high due to the influence of the water mass of the Pacific Ocean which has high salinity characteristics [1, 3].
Variability of SSS values in east monsoon and transition 2 tends to be higher than west monsoon and transition 1. In the eastern monsoon the value is in the range of 33.25 psu - 34.75 psu, with the variations of SSS in June 33.25 - 34.25 psu, July 34 - 34.75 psu, and August 34 - 34.5 psu. In transition 2 monsoon the value is in the range of 33.75 - 34.75 psu, with the variation of SSS values in September 34.25 - 34.75 psu, October 34 - 34.75 psu, November 33.75 - 34.25 psu. SSS values are higher due to low rainfall, and the strengthening of southeast trade winds above sea level which causes shifting in water masses, so the low water masses will be filled by the water masses from the bottom of the water column and make the SSS value higher [23].

In the eastern monsoon there is upwelling phenomenon in the Ceram Sea, where August is the peak time of the upwelling phenomenon in the Ceram Sea [24-35].

4. CONCLUSIONS

The results of research that has been carried out, it can be seen the movement of water masses from the Pacific Ocean through the Halmahera Sea, Raja Ampat, Ceram Sea, to the Banda Sea. Raja Ampat Island and the boundaries seas have mixed layers to a depth of 71 m, and thermocline layer to a depth of 567 m. The identified water masses are SPIW (South Pacific Intermediate Water), SPSW (South Pacific Subtropical Water), NPSW (North Pacific Subtropical Water), and AAIW (Antarctic Intermediate Water). The variability of the maximum SST value occurs at the end of west monsoon (February), and the minimum occurs at the end of the east monsoon (in August). The maximum SSS value occurs at the beginning of transition 2 monsoon (September), and the minimum at the start of the transition 1 monsoon (March).
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