Composition of Indonesia throughflow in North Sulawesi water masses and heat content

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Abstract. In this research the composition of water masses in the North Sulawesi (Sangihe Talaud) waters as part of the Indonesian Throughflow is investigated and analysed by using the Optimum Multi Parameter Analysis (OMP). The data used is the World Ocean Atlas data (WOA 13) in 1° x 1° latitude longitude resolution. Main data are the salinity, temperature and pressure. The Optimum Multiparameter analysis was used to calculate the percentage of each water mass contribution in the study waters. The contributions are 20-60% at 200-500 m depth for The North Pacific Intermediate Water (NPIW), 90-100% at around 0-100 meters depth for The North Pacific Subtropical Water (NPSW),100% at 900-1500 meters depth for the South Pacific Intermediate Water (SPIW) and 80-100% at 1100-1500 meters depth for The Antarctic Intermediate Water (AAIW). Surprisingly, the South Pacific Subtropical Water (SPSW) does not have any contribution and largest heat content comes from the AAIW. Magnitudes for each heat content of water types calculated in this study for NPIW, NPSW, AAIW, SPSW, and SPIW are in the range of 1.5 x 10^14~ 1.7 x 10^14 J /m², 2 x 10^12~ 9.9 x 10^12 J /m², 2.7 x 10^14~ 3.1 x 10^14 J /m², 0 ~ 4.3 x 10^11 J /m², and 1.8 x 10^14~ 2 x 10^14 J /m², respectively. Even though the AAIW has the lowest temperature range but its large contribution in the waters outnumbers the warmer water masses.

1. Introduction
The North of Sulawesi, or Sangihe Talaud waters is the entrance for the Indonesian Throughflow (ITF) which connects the Pacific Ocean to the Indian Ocean. The water masses of Sangihe Talaud are strongly influenced by the water mass originated from the Pacific Ocean. Therefore, the Sangihe Talaud waters is an important area to comprehend the water masses because it is the region where water masses from the Pacific Ocean travels and mixes in Indonesian waters [1].

In general, waters in eastern Indonesia are divided to three types such as subtropical, intermediate, and deepwater type. In the thermocline layer there are several water masses that flow from the Northern Hemisphere and the Southern Hemisphere which will eventually mix in the Sangihe Talaud waters including North Pacific Tropical Water (NPTW) which has maximum salinity characteristics and located at the depths of 100 - 400 m with a temperature of around 20 °C, North Pacific Intermediate Water (NPIW) which has minimum salinity characteristics and located at the depth of 500-1500 m with a temperature of around 10 °C, South Pacific Tropical Water (SPTW) which has...
maximum salinity characteristics and located at depth of 500-1000 m with a temperature of around 7-16 °C, and Antarctic Intermediate Water (AAIW) which has minimum salinity characteristics and is located at the depth of 500-1500 m with a temperature of around 6 °C which passes through the ITF [2].

Indonesian Throughflow regulates the warm pools position in the Indian Ocean and controls the depth of the thermocline, which will indirectly affect the climate in the tropics and middle latitudes. One of the factors that might influence the current climate change is the heat content inside the water [5]. The Indonesian Throughflow plays a major role on the contained heat content and the pattern of sea surface temperatures which are closely related to the events of ENSO (El-Ñino-Southern Oscillation) and the Monsoon system in Asia. In 2010 Gordon discussed that the Monsoon system in Asia and ENSO affected the ITF will influence the regional and global climate systems [6].The heat content in the sea waters can affect climate change both regionally and globally. In 2017 [7] calculated that the heat content in Indonesian sea waters is in the range of -1.04 x 10^18 J to 1.15 x 10^18 J.

In this research we would only calculate the heat content possessed by each of the water mass of Sangihe Talaud seas in order to account which of the water mass from the Pacific contributes at most to the heat budget within the waters and how the percentage and the heat content varies with seasons.

2. Data and Method
The data used in this study is obtained from the World Ocean Atlas 2013 which is a climatological data that has been processed statistically using the interpolation method. The data used is temperature, salinity, and density at the depth of 0 m - 1500 m with a resolution of 1° x 1° taken from this climatological data from January to December. The location of the data used is located in Makassar Sea to Sangihe Talaud Waters with coordinates 1° - 6° North Latitude and 117° - 132° East Longitude with a total of 96 observation stations as displayed in Figure 1.

To find out what water masses occupy our study waters, we set up 6 line transects (figure 1) to draw the T-S diagram and vertical distribution of the salinity and temperature against the depth as shown in Figure 2 and 3. Firstly, T-S diagram and the vertical distribution of S,T,P were drawn to identify the water masses occupying the area. Then the distribution of each water masses were calculated by means of the Optimum Multiparameter analysis. The data of transect 4 and 5 were chosen in order to represent the most entrance of the Indonesian Throughflow.

The Optimum Multi Parameter (OMP) analysis was developed by Tomczak and Karstensen (1998). In this research the OMP analysis method used is the advanced version (2013) which includes the range value of the dissolved oxygen, Phosphate and Nitrate – not only the temperature and salinity.
Further detail of the OMP analysis may be read in the website http://omp.geomar.de/node1.html. The processed data were averaged for each season, which is divided into 4 seasons namely the west season represented by December-January-February (DJF), the first transition season represented by March-April-May (MAM), the east season represented by June-July-August (JJA), and second transitional season represented by September-October-November (SON).

To calculate the heat content, a formulation was proposed by [9] is used:

$$H = C_p \int_{z_1}^{z_2} \rho_z T dz$$

where $C_p$ is the specific heat of sea water which has a value of 4.2 x 10^6 J, $\rho_z$ is the density of sea water at a depth (z) (kg / m^3) and $T$ is the average temperature depth (°C). The data to calculate this OHC is from all stations occupies the whole study area as in rectangle 6 in figure 1.

3. Result and Discussion

3.1. Water Mass

In this research, by means of T-S diagram in the waters of Sangihe Talaud is found five types of water masses: NPIW (North Pacific Intermediate Water), NPSW (North Pacific Subtropical Water), SPSW (South Pacific Subtropical Water), SPIW (South Pacific Intermediate Water), and AAIW (Antarctic Intermediate Water).

![Figure 2](image)

**Figure 2.** (a). Vertical distribution of temperature in transect 4 of January. (b). As (a) for July.
We see in figure 2 that the isotherms of 15°C and warmer varies in depth along with different monsoon (as January for the west and July for the East monsoon). The core of high salinity from the NPSW is clearly seen in the depth range of 100 – 250m in figure 3 (b). The salinity vertical distribution is also varied with the monsoon seasons. There is different pattern of salinity distribution from transect 1 and 4, whereas transect 1 is the West Pacific and transect 4 is the North Sulawesi waters.

The AAIW is a water mass formed between the subpolar and polar regions in the Atlantic Ocean known as the Atlantic Polar Front Zone (Gordon, 1971). The mass of water in the Sangihe Talaud Seas is possible to be carried out from the Atlantic Ocean and Pacific Ocean through a thermohaline cycle that enters Indonesian waters through the waters of Sangihe Talaud as the entrance of the Indonesian Throughflow.

Table 1. Water Masses in Sangihe Talaud Seas

| No | Type of Water Mass | Depth (m) | Temperature (°C) | Salinity (‰) |
|----|-------------------|-----------|-----------------|--------------|
| 1  | NPSW              | 100-200   | 20-24           | 34.8-35.2    |
| 2  | SPSW              | 150-200   | 17-19           | 35-35.6      |
| 3  | NPIW              | 400-700   | 7-11            | 34.1-34.5    |
| 4  | SPIW              | 500-800   | 5-8             | 34.45-34.65  |
| 5  | AAIW              | 750-1000  | 4-7             | 34.4-34.7    |

3.2. Contribution of Water Masses
In this study to calculate the contribution of water mass in a region of waters, the OMP (Optimum Multi Parameter) method developed by Tomczak and Karstensen (2013) is used. The calculation was based on the average of 4 seasons in the 2 zones used, namely the 4th transect zone and the 5th transect zone (Figure 1).
The contribution of the water mass varies on different depth from the four seasons, the west monsoon can be seen in Figures 4 represented by December-January-February. There is no significant change in contribution with east monsoon represented by June-July-August (not shown).

The SPIW is captured at a depth of about 900-1500 meters with a contribution of about 100%, while the contribution of the SPIW water mass tends to disappear to the surface, even in surface or depth of 0 meters the contribution of SPIW water mass is around 0%. The SPSW does not play a role in the contribution (0% contribution for each depth, therefore not shown). The NPIW water mass is found to be maximum at 200-500 meters depth with varied contributions around 20-60%. While for the NPSW water mass it is found to be maximum on the surface of 0-100 meters with the contribution in the range of 90-100% and its contribution will decrease along with the increase in depth, and for the AAIW water mass is captured maximum at a depth of around 1100-1500 meters with a contribution in the range of 80-100% and reduced along the way to the surface.

4. Ocean Heat Content (OHC) of the Water Masses

The value of OHC varies for each water mass, the more volume of water mass found in the study area (Sangihe Talaud Sea) the greater the value of the OHC. Eventhough the water masses of the surface is having warmer temperature, but the volume of contribution from the deeper water mass AAIW outnumbered the warmer water masses. Figure 5 exhibit the magnitude of the OHC; for the water mass NPIW is in the range of $1.5 \times 10^{14} - 1.7 \times 10^{14}$ J/m$^2$, for the water mass NPSW is in the range of $2 \times 10^{14} - 9.9 \times 10^{12}$ J/m$^2$, for water mass AAIW is in the range of $2.7 \times 10^{14} - 3.1 \times 10^{14}$ J/m$^2$, for the SPSW water mass is in the range of $0 - 4.3 \times 10^{11}$ J/m$^2$, for the water mass SPIW is in the range of $1.8 \times 10^{14} - 2 \times 10^{14}$ J/m$^2$.

Almost all of the water masses have the highest value of heat in the second transition season, namely September-October-November to the western season, namely December-January-February (figure 5). This is due to the abundant of hot water input from the Pacific Ocean which will affect the size of the Ocean Heat Content in the area and hence will cause the amount of rainfall in Indonesia.
Figure 5. The Ocean Heat Content of each water masses (SPSW, SPIW, AAIW, NPSW and NPIW).

The Ocean Heat Content (OHC) in total for the whole waters is very dependent to the contribution of the water mass in the area due to the variation of the range of temperature of each water masses. In this case it can be seen that in the waters of North Sulawesi has the largest contribution of Ocean Heat Content from the AAIW water mass and the low contributing water mass is SPSW. In other words, the contribution of heat content from the mass AAIW water plays a major role here, even though the temperature range is smaller than the near surface water masses, but the volume of contribution is much larger than other water masses. The amount of heat content at the entrance of the Indonesian Throughflow will have implications for regional climate change and global climate.

5. Conclusion
Based on the results of data processing from the 2013 World Ocean Atlas, 5 types of water masses have been identified in North of Sulawesi (Sangihe Talaud waters), namely North Pacific Intermediate Water (NPIW), North Pacific Subtropical Water (NPSW), and South Pacific Subtropical Water (SPSW), South Pacific Intermediate Water, and AAIW (Antarctic Intermediate Water).

The contribution of the water mass in the Sangihe Talaud waters varies with depth. The amount of variation that occurs starts from 0-100% for each depth. Ocean Heat Content for each water mass in the Sangihe Talaud waters has different quantities. The value of Ocean Heat Content of water mass has a range of 0 - 3.1 x 10^{14} J / m^2. The water mass of AAIW (Antarctic Intermediate Water) has the highest heat content in Sangihe Talaud Waters and the water mass that has the lowest heat content is SPSW (South Pacific Subtropical Water).

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