THE NORTH SULAWESI SEAS
WATER MASS HEAT CONTENT IN 1995 – 2015

Fauzan L Ramadhan1, Luqman N Chairuasni3, Lamona I Bernawis2, Rima Rachmayani2, and Mutiara R Putri2
1 Department of Earth Sciences, Faculty of Earth Sciences and Technology, Bandung Institute of Technology – Indonesia
2 Research Group of Oceanography, Bandung Institute of Technology – Indonesia
3 Department of Oceanography, Faculty of Earth Sciences and Technology, Bandung Institute of Technology – Indonesia

Corresponding author: lamona@fitb.itb.ac.id

Abstract

The North Sulawesi Seas is the entrance gate of Indonesian Throughflow (ITF) which will be directly affected by the phenomenon occurring in the Pacific Ocean especially a El-Niño Southern Oscillation (ENSO). This study aims to determine the heat content of the water mass in the North Sulawesi Seas as part of ITF. Main data is a temperature data derived from the HYbrid Coordinate Ocean Model (HYCOM) reanalysis model with a resolution of 1/12°. In the North Sulawesi Seas found five types of a water masses its North Pacific Subtropical Water (NPSW), North Pacific Equatorial Water (NPEW), North Pacific Intermediate Water (NPIW), Antarctic Intermediate Water (AAIW), and Antarctic Bottom Water (AABW). The water mass heat content is calculated with the two different temperature systems for depth. Magnitudes for each heat content of water types calculated in this study for NPSW, NPEW, NPIW, AAIW, and AABW are in the range of 5,67 × 10^{13} J/m^2 - 1,04 × 10^{15} J/m^2, 22,62 × 10^{15} J/m^2 - 8,26 × 10^{15} J/m^2, 1,08 × 10^{15} J/m^2 - 9,38 × 10^{15} J/m^2, 2,17 × 10^{16} J/m^2 - 3,33 × 10^{16} J/m^2, and 8,11 × 10^{15} J/m^2 - 1,89 × 10^{16} J/m^2, respectively. The water mass heat content in the mixed and deep layer will decrease (increase) when the La-Niña (El-Niño), while in the thermocline layer will decrease (increase) when the El-Niño (La-Niña) phenomenon.

Keywords: North Sulawesi Seas; Indonesian Throughflow; Water mass; Heat content; and ENSO.

1. Introduction

For more than 50 years, the oceans have absorbed 90% of the heat produced in the atmosphere (Willis et al., 2004). According to Levitus et al. (2012) the ocean heat content in the world at a depth of 0 – 2000 m in 1995 – 2010 has increased 24 ± 1,9 x 10^{22} J which is equivalent to 0,09 °C and at a depth of 0 – 700 m has increased 16,7 ± 1,6 x 10^{22} J which is equivalent to 0,18 °C. The ocean heat content is the total heat stored in the ocean. The ocean heat content is an important component in the climate system, because will be absorb excess heat energy and reduce the impact of climate change (Levitus et al., 2012).

Ocean has a characteristic of storing heat longer than the land. The heat stored in the sea has a large role in influencing climate on earth. The heat absorbed by the oceans can cause climate change on the earth, such as melting of polar ice, changes in current patterns, and rising temperature on land. The increase in the world ocean heat content caused by increased carbon dioxide (CO2), chlorofluorocarbons.
(CFC_c), and greenhouse effect (Levitus et al., 2001). Variability of ocean heat content can be used as an indicator that can detect climate change that is still much debated. So that research about ocean heat content is needed, especially in Indonesia’s Sea.

Indonesian Seas are the tropical seas that connects the Pacific Ocean to Indian Ocean. One of the currents that connects them is the Indonesia Throughflow (ITF) that enters from North Sulawesi Sea. Sasongko (2010) states that ocean heat content at a depth of 0 – 100 m in Indonesian Sea has increase $2 \times 10^{14}$ J and at a depth of 0 – 300 m has increase $2 \times 10^{13}$ J, while for total depth in Indonesian Seas decrease $2 \times 10^{14}$ J. Positive Pacific Decadal Oscillation (PDO) effect on the decrease $1.74 \times 10^{17}$ J ocean heat content in Indonesian Seas.

ITF is one of the currents that connect tropical water mass from Pacific Ocean to Indian Ocean through Indonesian Seas, where the ITF could be a main component to climate control whether regionally or globally (Sprintall at al., 2014). ITF will carry a water mass which has its own characteristics such as temperature, salinity, nutrient, heat content, etc. Radjawane and Paundra (2014) state that there are six water mass in Sangihe Talaud Sea is North Pacific Subtropical Water (NPSW), South Pacific Subtropical Water (SPSW), North Pacific Intermediate Water (NPIW), South Pacific Intermediate Water (SPIW), and Antarctic Intermediate Water (AAIW).

ITF movements strongly influenced by seasonal changes, which according Tomczak and Godfrey (2003) when the boreal winter will strengthening of ITF transport and boreal summer will be weakening of ITF transport. Resultant movement of ITF always from Pacific Ocean to Indian Ocean. In addition of seasonal influences, ITF is also strongly influenced by interannual phenomena, one of which is the El-Niño Southern Oscillation (ENSO) phenomenon, Susanto and Song (2015) state that when El-Niño (La-Niña) occurs there will be a weakening (strengthening) of ITF transport.

North Sulawesi Seas are the entry gate for ITF which will be affected by changes in ITF transport, as well as the water mass heat content. Many studies of the ocean heat content have been carried out, but in the form of total heat in one column of water. It is not known to be the heat content of each type of

![Figure 1. Indonesian Throughflow Pathways (Marked by Blue Line). (Source: Zhang P et al., 2018)](image-url)
water mass to Indonesian Sea. Because, if this can be calculated, we will know the role of each water mass in the water column in North Sulawesi Sea.

2. Methodology

In this research, the study location was in the entry gate of ITF to Indonesian Sea from the Pacific Ocean, precisely in the North Sulawesi Sea at coordinates 117° - 132° E dan 1° - 6° N.

The main data used in this research are data on temperature, salinity, and depths of 0 – 5000 m from the HYCOM reanalysis model with a daily average that will be averaged to monthly with a grid resolution of 1/12°. Data period starts from 1 January 1995 to 31 December 2015, this is needed to get a variation of the climate change. The total grid in this research is a 10.800 with a study area of 180 × 60 grid. The data is assimilation data from the Navy Coupled Ocean Data Assimilation (NCODA) system (Cummings, 2005). In addition to this data, data from Ocean Niño Index (ONI) are also used, which is represent the ENSO phenomenon.

Data this research has been conducted be processed into the heat content of each water mass using the equation by Kumar et al. (2014):

\[
Q = C_p \sum_{k=1}^{n} \rho_k (T_{h_1} - T_k) (Z_k - Z_{k-1})
\]

Where \(Q\) is the water mass heat content (J/m²), \(C_p\) is the specific heat of sea water which has a value of 4.2 x 10^6 J, \(\rho_k\) is the density of sea water at a depth (kg/m³), \(T\) is the temperature (°C), \(h_1\) is the first depth at a depth, and \(Z\) is the depth layer (m). The data to calculate this OHC is from all stations occupies the whole study area in Figure 2.

3. Result and Discussions

3.1. Water Mass

The North Sulawesi Sea are the entry gate for ITF and are affected by Pacific Ocean phenomenon, which of course the type of water mass is very affected and dominated by the water mass from the Pacific Ocean. In this research, five types of water masses were found in North Sulawesi Seas can be seen in Figure 3, is North Pacific Equatorial Water (NPEW), North Pacific Subtropical Water (NPSW), North Pacific Intermediate Water (NPIW), Antarctic Intermediate Water (AAIW), and
Antarctic Bottom Water (AABW). This is in accordance with the research of Radjawane and Paundra (2014) which states that in Sangihe Talaud Sea six types of water masses were found, is North Pacific Subtropical Water (NPSW), South Pacific Subtropical Water (SPSW), North Pacific Intermediate Water (NPIW), South Pacific Intermediate Water (SPIW), and Antarctic Intermediate Water (AAIW). SPSW not founded in North Sulawesi Seas because at a depth 70 – 250 m South Pacific Water Mass is deflected to east by Halmahera Eddy (HE) into Halmahera Sea (Martono et al., 2009). Besides that Levitus (1998) states that the water mass at the entrance gate of ITF is the water mass of NPSW and NPIW found in the Makassar Strait and the water mass of SPSW found in the Halmahera Sea and Seram Sea.

![Figure 3](image.png)

**Figure 3.** T-S Diagram at North Sulawesi Sea (Red Box= North Pacific Subtropical Water (NPSW), Yellow Box= North Pacific Equatorial Water (NPEW), Purple Box= North Pacific Intermediate Water (NPIW), Grey Box= Antarctic Intermediate Water (AAIW), and Black Box= Antarctic Bottom Water (AABW)).

The water mass found in the North Sulawesi Sea is dominated by the water mass from the Northern Pacific Ocean is the NPSW, NPIW, and NPEW and there are two water mass from the Southern Pacific Ocean AAIW and AABW, this is appropriate by Gordon (2005) research which states that 80% of the water mass of ITF originates from the North Pacific water mass. Koch-Larrouy et al. (2008) which states that the water mass of surface water and the thermocline that passes through the western path of ITF originates from the North Pacific but the water mass that is in deep layer mixing with the water mass originating from the South Pacific.

The water mass found in the North Sulawesi Sea has the characteristics of each according to the formation area. NPSW has characteristics with a temperature range of 20 °C - 23.9 °C and salinity ranges from 34.8 psu – 35.2 psu at a depth of 90 - 150 m, NPEW with a temperature range of 10 °C - 16 °C and salinity starting from 34.5 psu – 35.2 psu at a depth of 150 - 400 m, NPIW with a temperature range of 7.2 °C - 11 °C and salinity starting from 34.2 psu – 34.5 psu at a depth of 250 - 500 m, AAIW with a range temperature 4.25 °C - 7 °C and salinity starting from 34.5 psu – 34.6 psu at a depth of 500 - 1000 m, and AABW with a temperature range of 0 °C - 2 °C and salinity of 34.6 psu – 34.75 psu at a depth of > 3000 m.
Water masses from the North Pacific Ocean flow into Indonesia through the south eastern part of Papua Island (Kashino et al., 1999) and distributed by the North Equatorial Counter Current (NECC) and Mindanao Current (MC) through the North Sulawesi Sea, while the water mass from South Pacific enters Indonesian Sea carried by the flow of the North Guinea Coastal Current (NGCC) (Fine, 1994).

3.2. Water Mass Heat Content

The water mass heat content can be calculated because there are two different temperature systems in the ocean. The water mass heat content is calculated to determine the role of each mass of water in North Sulawesi Sea in climate change and its relationship with the ENSO phenomenon.

![Figure 4](image)

**Figure 4. Antarctic Bottom Water Water Mass Heat Content During Period of 1995 - 2015**

The water mass heat content for AABW at a depth of > 2500 m can be seen in Figure 4. It can be seen that AABW in the North Sulawesi Sea has a heat content around of $11 \times 10^{15}$ J/m$^2$ - $1.89 \times 10^{16}$ J/m$^2$ with an average of $1.25 \times 10^{16}$ J/m$^2$. The water mass heat content for AABW is maximum in 2004 and the minimum in 2002 is associated with the El-Niño phenomenon. The heat content for AABW has increased in the period 1995 - 2015 with an increase of $5.43 \times 10^{12}$ J/m$^2$. 
Figure 5. *Antarctic Intermediate Water* Water Mass Heat Content During Period of 1995 - 2015

Figure 5 shows the water mass heat content for AAIW which is at a depth of 600 - 1000 m in the North Sulawesi Sea. The water mass heat content for AAIW ranges from $2.17 \times 10^{16}$ J/m$^2$ - $3.33 \times 10^{16}$ J/m$^2$ with an average of $2.46 \times 10^{16}$ J/m$^2$. The maximum water mass heat content of AAIW in 2016 and minimum in 2002 coincides with the occurrence of the El-Niño phenomenon. In the period of 1995 - 2015, the water mass heat content of AAIW increased $1.35 \times 10^{13}$ J/m$^2$.

Figure 6. *North Pacific Equatorial Water* Water Mass Heat Content During Period of 1995 - 2015

Changes in temporal water mass heat content for NPEW at a depth of 150 - 350 m can be seen in Figure 6. The water mass heat content for NPEW has a range magnitude $2.62 \times 10^{15}$ J/m$^2$ - $8.26 \times 10^{15}$ J/m$^2$ with an average of $4.75 \times 10^{15}$ J/m$^2$. The water mass heat content for NPEW has decreased in 1995 - 2015 with a magnitude $2.38 \times 10^{12}$ J/m$^2$. The maximum water mass heat content for NPEW in 2003 associated on the El-Niño phenomenon and the minimum in 2008 which is associated to the La-Niña phenomenon.

Figure 7 shows the change in temporal water mass heat content for NPIW at a depth of 350 - 600 m. The water mass heat content of NPIW is around $1.08 \times 10^{15}$ J/m$^2$ - $9.38 \times 10^{15}$ J/m$^2$ with an average of $4.83 \times 10^{15}$ J/m$^2$. The water mass heat content for NPIW has increased in 1995 - 2015 with a magnitude $2.27 \times 10^{12}$ J/m$^2$. The water mass heat content for the maximum mass of NPIW
water in 1999 which was close to the La-Niña phenomenon and the minimum in 1998 was close to the El-Niño phenomenon.

Water mass heat content for NPSW at depths of 60 - 150 m while can be seen in Figure 8. The water mass heat content for NPSW has a range magnitude \(5,67 \times 10^{13} \text{ J/m}^2\) - \(1,04 \times 10^{15} \text{ J/m}^2\) with an average of \(4,02 \times 10^{14} \text{ J/m}^2\). The water mass heat content for NPSW has decreased in 1995 - 2015 with a magnitude \(1,96 \times 10^{10} \text{ J/m}^2\). The maximum water mass heat content for NPSW in 2003 associated on the El-Niño phenomenon and the minimum in 2008 which is close to the La-Niña phenomenon. In addition, the results of the total heat content of all water masses always have a positive value, this is consistent with studies from Levitus et al. (2012) which states that since 1990 the global ocean heat content always has a positive value and tends to increase.

![Figure 7. North Pacific Intermediate Water Water Mass Heat Content During Period of 1995 - 2015](image)

It can be seen that the water mass heat content of AAIW has the highest fluctuation with a variance of \(4,75 \times 10^{30}\) and the lowest variant is owned by NPSW water mass heat content with a variance of \(3,34 \times 10^{28}\). AABW has a variance \(2,94 \times 10^{30}\), the NPEW has a variance of \(1,27 \times 10^{30}\), and the NPIW has a variance of \(2,37 \times 10^{30}\). Variances indicate fluctuations in data. The highest fluctuation of water mass heat content founded in the thermocline layer, it is the heat content of AAIW, NPIW, and NPEW, because the thermocline layer has a very sharp change in sea water temperature, besides ENSO phenomenon plays an important role in changing the thermocline depth. In mixed layers, temperature changes tend to be uniform and tend to be influenced by atmospheric interactions.
Figure 8. *North Pacific Subtropical Water* Water Mass Heat Content During Period of 1995 - 2015

Figure 9 and Table 1 show a correlation lag between ENSO and the heat content of each water mass, it can be seen from the table that heat content of each water mass has a p-value <0.05 with a Pearson correlation threshold of $r > 0.123$ and $r < -0.123$ which indicates that for each parameter there is a relationship both directly or inverse. Each water mass heat content has different correlations, a positive correlation indicates a directly relationship, which means that when the El-Niño phenomenon occurs in the Pacific Ocean will increase the water mass heat content in North Sulawesi Seas, while when the La-Niña phenomenon occurs will reduce the water mass heat content. Negative correlation indicates an inversely relationship, where when El-Niño occurs it will reduce the water mass heat content and when La-Niña occurs it will increase the water mass heat content. It can be seen in Table 1 that for each water mass heat content it has a lag (delay) in the ENSO phenomenon except for the water mass heat content of NPIW. The lags that indicates that the ENSO phenomenon does not directly affect the water mass heat content, but this phenomenon will affect the water mass heat content after 0 - 12 months occurs. This is in accordance with Turner *et al.* (2004) which states that the ENSO phenomenon will affect SST in the Ross Sea (Antarctica) with a lags of about 2 - 4 months.

Table 1. Lag Correlation between ONI Index and Water Mass Heat Content

| Water Mass | Correlation | Lag (Month) | $P$-Value       |
|------------|-------------|-------------|-----------------|
| NPSW       | 0.51        | 4           | $3.73 \times 10^{23}$ |
| NPEW       | 0.385       | 3           | $1.08 \times 10^{8}$  |
| NPIW       | -0.57       | 0           | $3.73 \times 10^{23}$ |
| AAIW       | -0.306      | 2           | $6.8 \times 10^{7}$   |
| AABW       | 0.291       | 12          | $25.4 \times 10^{8}$  |

In addition, it can be seen that the water mass heat content in mixed layer and the top thermocline layer (0 - 350 m), it is NPSW and NPEW has a relationship that is directly to the ENSO phenomenon in the Pacific Ocean. In the lower thermocline layer (500 - 1500 m) the water mass heat content of NPIW and AAIW has an inverse relationship with the ENSO phenomenon in the Pacific Ocean. In the deep layer (> 2500 m) the water mass heat content of AABW water has a direct correlation with the ENSO phenomenon in the Pacific Ocean.
4. Conclusion

They are five types of water masses founded in the North Sulawesi Sea with different heat content in each type, it is the North Pacific Equatorial Water (NPEW) with a heat content of $4.75 \times 10^{15}$ J/m$^2$, North Pacific Subtropical Water (NPSW) with a heat content of $4.02 \times 10^{14}$ J/m$^2$, North Pacific Intermediate Water (NPIW) with a heat content of $4.83 \times 10^{15}$ J/m$^2$, Antarctic Intermediate Water (AAIW) with a heat content of $2.46 \times 10^{16}$ J/m$^2$, and Antarctic Bottom Water (AABW) with a heat content of $1.25 \times 10^{16}$ J/m$^2$.

The water mass heat content in the mixed and deep layer will decrease (increase) when the La-Niña (El-Niño), while in the thermocline layer will decrease (increase) when the El-Niño (La-Niña) phenomenon.

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6. Reference

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