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Stratification and Stability of Seawater Mass in Sulawesi Sea

Hadi Hermansyah[a*], Agus S. Atmadipoera[b], Tri Prartono[c], Indra Jaya[d], dan Fadli Syamsudin[e]

[a]State Polytechnic of Balikpapan, East Kalimantan - Indonesia

[b,c,d]Marine Science and Technology Department, Fisheries and Marine Science Faculty, Bogor Agricultural University (IPB), Bogor - Indonesia

[e]Agency for the Assessment and Application of Tehcnology (BPPT) - Republic of Indonesia

[a]Email: hadi.hermansyah@poltekba.ac.id

Abstract

Sulawesi waters is one of Indonesian Throughflows (ITF) tracks. Water mass shifts causing by the turbulent flows variant are able to form fluid mixing with a very high fluctuation and seawater mass stratification. This research was able to reveal water mass characteristics (temperature, salinity, and density), stratification, source and stability of seawater mass of of Sulawesi Waters. Temperature and potential density data were used to determine stratifying seawater mass layers by using threshold value method through Brunt-Vaisala Frequency to seek seawater mass in the water column. Results of this research exhibit that Sulawesi Waters possesses mixed surface layer thickness is detected in range of 0-100 meters depth with its temperature down range from 29.12 to 24.21 ^{0}C and its gradient fluctuation is about 0.01-0.02 ^{0}C. The high salinity value is located in thermocline layer (100 – 200 meters depth) which is in ranged of 34.51 to 34.83 psu, and density stratification are in three water layers such as mixed surface, thermocline, and the deeper. This is indicated by density stratification, where the waters own a high-density gradient forming in thermocline layers, while in the near surface and mid-depth layers, the stratification is relatively lower resulting an instability seawater mass.

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* Corresponding author.

The high salinity and temperature condition are in the thermocline layer manifests that both layers, surface and thermocline, are seen salinity dilution. Overall profile points out that thermocline layer tends to posesses the highest value about $0(3.2x10^{-4} – 1.8x10^{-4})$ cycl/s. The waters have a high instability water column condition is inferred relating to a high seawater current interacting with sea bottom topography and the seawater instability is located in below thermocline layers (200 – 250 meters depth form the surface).

Keywords: Characteristics; Stability; Brunt Vaisala; Sulawesi Sea.

1. Introduction

Thermohalin circulation or well known as the Great Conveyor Belt (GCB) is a global scale circulation that distributes seawater mass around the world. An important component of GCB is Indonesia Through Flow (ITF) which transfers heat from Pacific Ocean to Hindian Ocean. This through flows affects heat transfer from those oceans and atmospheric convection areas that’s why this through flows plays an important role in influencing global climate commonly and tropical climate in particular [1, 2]. Variability of ITF transferred seawater mass exemplifies there is a strong correlation of climate anomalies such as ENSO (El Nino Southern Oscillation) and monsoon system [2,3].

Sulawesi Waters is one of Indonesia Through Flows tracks or well known in Indonesia as Arlindo (Arus Lintas Indonesia). This through flows possess an important role in circulating world water mass due to it is a primary connector of water mass flows from Pacific Ocean to its origin in North Atlantic Ocean. It is added by [4] that this through flows also predisposes a lot of phenomena such as Agulhas out flow heating, Leeuwin winds system strength, East Australia Seacurrent, and warm seawater in some upwelling areas of Indonesia. The through flow carries water mass of Pacific Ocean entering Indonesia waters via two facias namely west and east paths. The west path is the main facia of ITF, where the seawater mass passes through from Sulawesi Sea to Makassar Strait, Flores Sea, and Banda Sea [5]. The second path, the seawater mass goes by Maluku Sea and Halmahera and it is continued to Banda Sea.

Sulawesi Sea is located in northern of Celebes Island, where in northern part of this sea is adjoined with Mindanao, the southernmost island of the Philippiness, and the western part is bordered by the Borneo Island. This sea is marked by steep margin slope, water depth fast increasingly from a narrow shelf. The deepest part of this sea is in eastern basin corner near to Mindanao where it reaches more than 5,700 meters depth in Cotabato trench [6]. Most of sea bottom topography of this sea is taken place in between 4,500 and 5,500 meters depth, exhibits that this basin probably is below the surface oceanic crust of Paleogene based on observing the relationship of age to depth in the main ocean floor [7].

Study about seawater mass is crucial because it is related to the water mixing. Seawater mixing is very important because it affects nutrients distribution, heat transfer, and impacting on climates. Seawater mass mixing turbulent usually deep has a significancy on transport momentum [8]. Water mass movement that is resulted by variation of turbulent flows is able to form fluid mixing with a very high fluctuation and a stratifying process which is influenced by dissimilarity of sea temperatures, salinities, and densities. Stratification process of seawater mass is caused by density variance that can create a mixing. Turbulence mixing happened is resulted by several factors such as density gradient [9], a complexity of sea floor topography and tidal waves [10].

Water mass stratification plays an important role in many sea bio-geo-chemichal processes. Stratification is defined as the density distinction between mixed layers and deep sea. Particularly, mixed layers arrange interactions such as availability light for photosynthesis and supplying nutrients from deep layers to the upper layers. Light and nutrients are two primary factors in biological productivity. Seawater mass density in mixed layers is significantly affected on water mass transport process which is important in supplying nutrients in the euphotic zone. It is added by [11] on regional scale, salinity change and stratification are affected on relating to ecological, environmental, and climate aspects. This research was aimed to reveal seawater characteristics (temperature, salinity, and density) of Sulawesi waters, the water stratification, origin mass transport and water mass stability of the sea.

2. Research Methods

2.1. Data Sampling

This research was conducted in Sulawesi Sea that was consisted on 21 observation station as shown in the Figure 1 below. Temperature and salinity data were derived from WAO (World Ocean Atlas) 2013 through site 'https://odv.awi.de/data/ocean/world-ocean-atlas-2013/'. These data are monthly average. This average value for all measured years that had been conducted by NODC (National Oceanographic Data Center) with 0.25 degree of data resolution. All data above was analyzed using some software such as ODV (Ocean Data View), Microsoft Excel, and MATLAB 2013 to profile vertical Brunt-Vaisala of the sea.

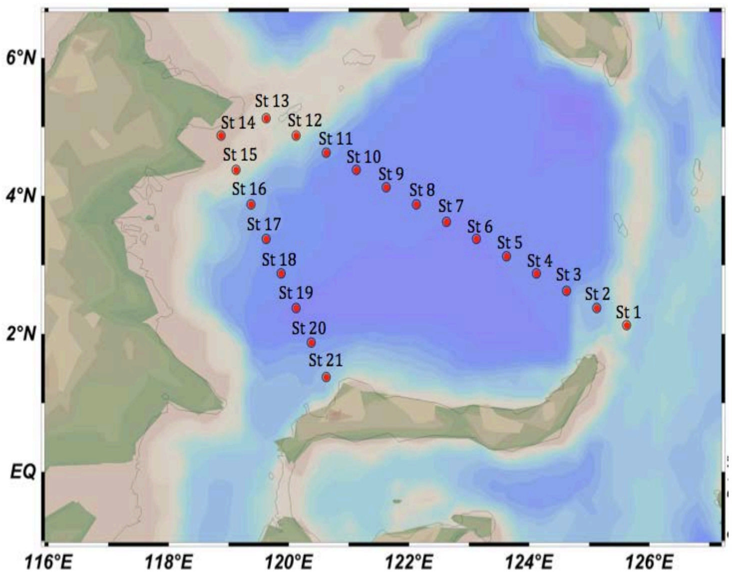

Figure 1: Map of Research Location (St.1 to St.13 is first transect, and St.14 to St. 21 is the second Line Transect)

2.2. Data Analysis

Potential temperature and density data were used to specify seawater mass layers by using threshold value method. In temperature point of view for mixed surface layer and surface layer has a distinction about $\Delta T \leq 0.5^{O}$C, while the differentiation between mixed layer and thermocline is about $\Delta T > 0.5$ [12]. Furthermore, these potential data were used to identify water mass using T-S diagram (Temperature-Salinity), where the origin of the water mass referred to [13]. This analysis is useful and able to provide the best explanation for recognizing water types with specific temperature, salinity and water mass [8]. Static stability of this research is stated by Brunt-Vaisala frequency to seek water mass stratification in the water column through the following formula.

$$N^2 = -\frac{g}{\rho_0}\frac{d\rho}{dz} \quad (1)$$

Where ρ_0 is an average density of determined water (1026.52 kg m^{-3}), $d\rho$ is density gradient on depth changes dz (1m), and g is earth gravitation (9.79423 m s^{-2}). The used density value of N^2 above is derived from arranged density data in stable condition [14].

3. Results and Discussion

3.1. Temperature Profile

Vertical profile of temperature in Sulawesi waters possesses mixed surface layer thickness that has been found in the depth between 0 to 100 meters are in range down of 29.12 to 24.21 ^{0}C and temperature gradient fluctuation about 0.01 to 0.02^{0}C as shown in the Figure 2 below. This range is lower than derived by [15] in the east monsoon in the southern Makassar Strait that has ranged from 21 to 28 ^{0}C, and that has been found by [16] as 26.10-27.50 ^{0}C in the Flores Sea, Western Banda, and Timor Sea. This distinction is caused by the dynamics of the Sulawesi Sea that has a complex sea floor, where there is a sill and to be Indonesia Through Flows (ITF) resulting input internal waves and kelvin waves. Based on previous research [8] points a strong turbulent mixing that temperature do not decrease sharply on depths. Decreasing temperature on the homogeneous depths range in 350 meters depth until the measured deepest depth 1,500 meters depth. This condition is relatively low finding by [17] in Makassar Strait with temperature profile which divide deep layer according to average vertical temperature gradient that is more specific into mixed surface, thermocline, middle, and deep layers.

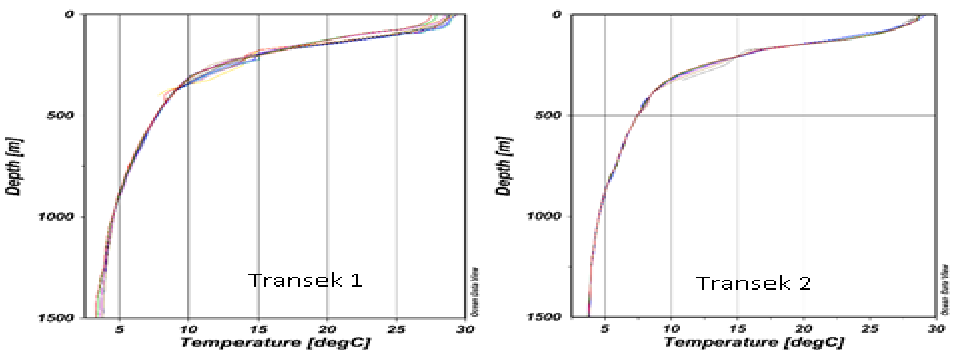

Figure 2: Temperature Profile of Sulawesi Waters in Transect 1 and Transect 2

3.2. Salinity Profile

Salinity profile vertically is seen that low salinity value is found in the mixed layer, where this is indicated by diluting of freshwater as shown in the Figure 3 as follow. The surface salinity value of this research is in ranged between 34.12 psu and 34.26 psu. Farther, a high salinity value in thermocline layer (100 – 200 meters depth) is in ranged of 34.51-34.83 psu. Then, the salinity decreases coming back to the homogeneous layer with value about 34.54-34.60 psu. This fact denotes insignificant variation in each layer. It is caused by fresh water input from Java Sea with salinity characteristics that is relatively low. Result of research conducted by [18] states that low value of salinity on the seawater surface is supposed due to a conflux of low and high seawater densities from open sea to forming transition zone. It is added by [15] that salinity and density of seawater mass along the observed station in South Makassar Strait are higher than the outlet track of water mass to Hindian Ocean at southern Java. The condition of a very high density and temperature at the research location is almost the same with Makassar Strait than Ombai Strait, Lombok Strait, Dao, and Timor which are lower. It is shown by [19] through data analysis using model exhibits that both layers, surface and thermocline, are seen salinity dilution in some areas resulted from more rain intensity in Java Sea, whilst the Ombai is more saline finding in surface layer that has a lower salinity. It is induced by any seasonal effects.

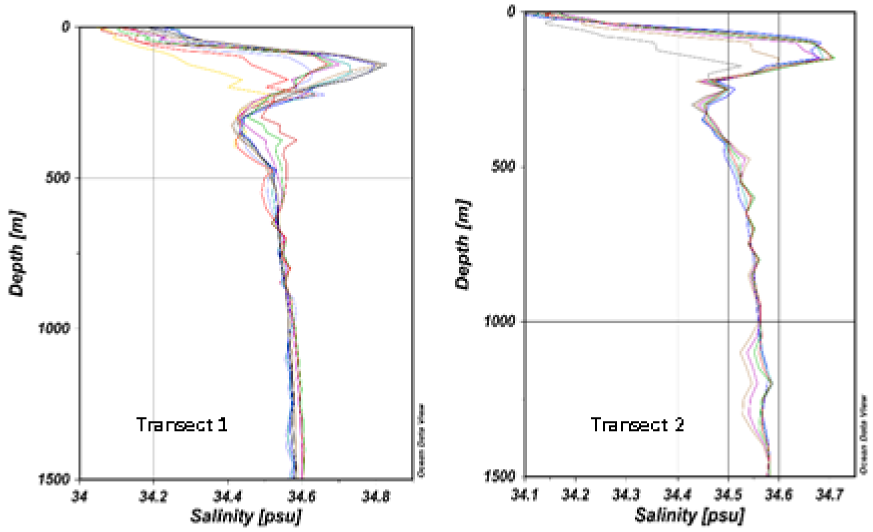

Figure 3: Salinity Profile of Sulawesi Water Areas in Transect 1 and 2

3.3. Density Profile

Figure 4 shows that there are density stratifications in three layers such as mixed surface layer, pinocline layer, and deep layer. Stratification of salinity and temperature is indicated by density stratification, where the Sulawesi Sea has a high-density gradient forming in thermocline layer such shown in the figure below. Moreover, in the near surface and in the deep water, stratification becomes relatively lower that resulted instability of water mass which is potential to form turbulent mixing process. Mixed surface layer thickness and pinocline in density profile are almost coincide with the temperature profile. This is caused the seawater density is a function of temperature and salinity. [20] explains that relationship between density, salinity and temperature is not linear, however density is hugely influenced by temperature than salinity. The higher temperature with constant salinity, the water particle will expand and enlarge volume with the same mass, so the density will decrease.

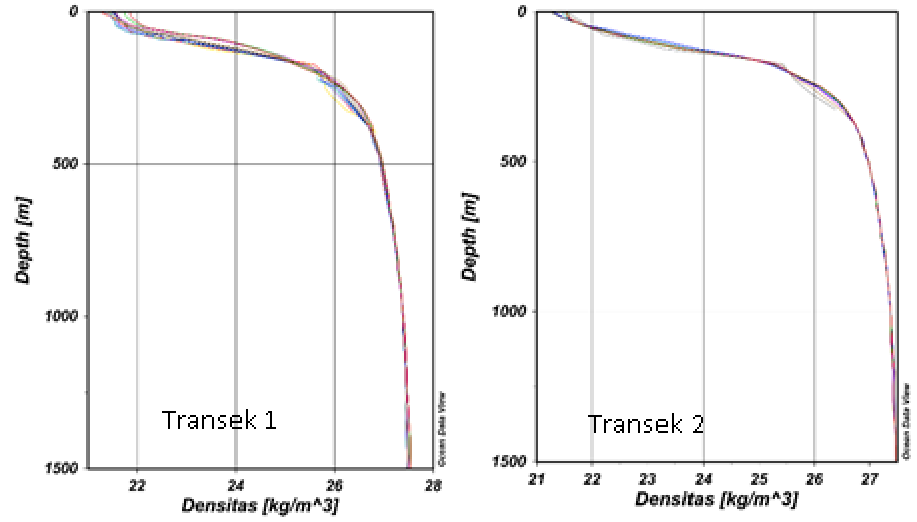

Figure 4: Density profile of Sulawesi Sea in transect 1 and 2.

3.4. T-S Diagram

Seawater mass characteristics passing out Sulawesi Sea are able to seek through T-S diagram as shown in the Figure 5, where characteristic of each seawater mass can be cognized by taking a look at temperature, salinity and density parameters. The water mass water is coming from north Pacific Ocean. High temperature and salinity condition are in thermocline layer that is similarly with the condition of salinity and temperature in Makassar Strait and it is higher than other Sea such as Ombai Strait, Lombok Strait, Dao and Timor Strait. This result is alike with the resulting by [19] through data analysis using KL07 model that represents surface layer to thermocline layer are seen salinity dilution in some location as impact of excessing rain fall in Java Sea, while in Ombai strait, the surface layer is less saline (low salinity).

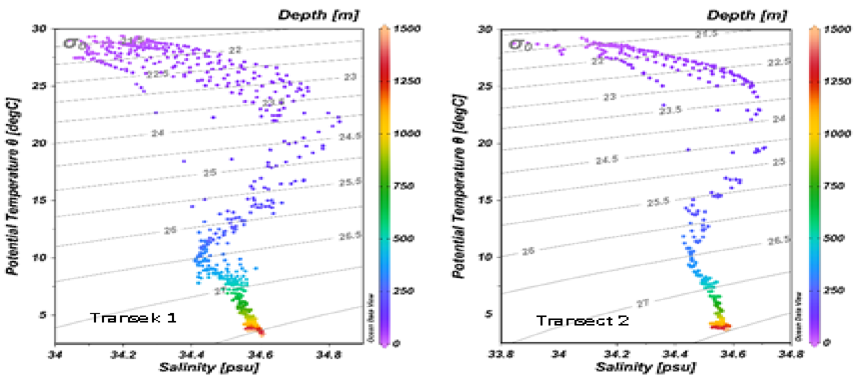

Figure 5: T-S Diagram in Transect 1 and 2 of Sulawesi Waters

3.5. Seawater Mass Stratification

Instability of seawater column is able to trig happening mixed turbulent where it can be identified by calculating Brunt-Vaisala (N^2) frequency. The N^2 results of all observing stations is figured in Figure 6 below. All research point stations are grouped into two transects, namely first transect that consists of station 1 to 13 and the second transect which consists of station 14 to 21. Result of all profiles are seen that thermocline layer tends to possess higher value about 0($3.2x10^{-4}$ – $1.8x10^{-4}$) cycl/s. [20] explains that in the thermocline layer, there is a pinocline layer where density gradient increasing sharply on depths, so it resulted a huge instability of the determined waters. Furthermore, the lower layer has a very low value of density as shown in the Figure 6. It is supposed holding a highest static stability rate resulting inversion value of seawater mass to becomes low. The N^2 in the station 10 at first transect has high value in the thermocline layer. In this condition, it is indicating that there is a threshold and supposed happening high internal waves [21]. A high instability water column of Sulawesi Sea is presumed relating to high wave condition and sea floor topography. Moreover, both transects have no significant differentiation of N^2 in all layers. The instability above also is presuming related to current condition, where in canal system, the increasing waves enough interacts with sea floor is potential to distorse the water column stability. This condition implies that disrupted seawater mass stratification is resulted by flow turbulent triggering from topography threshold in the strait. Supposing the high current shear backdrop is potential to produce turbulent flow that disturbs seawater mass stability.

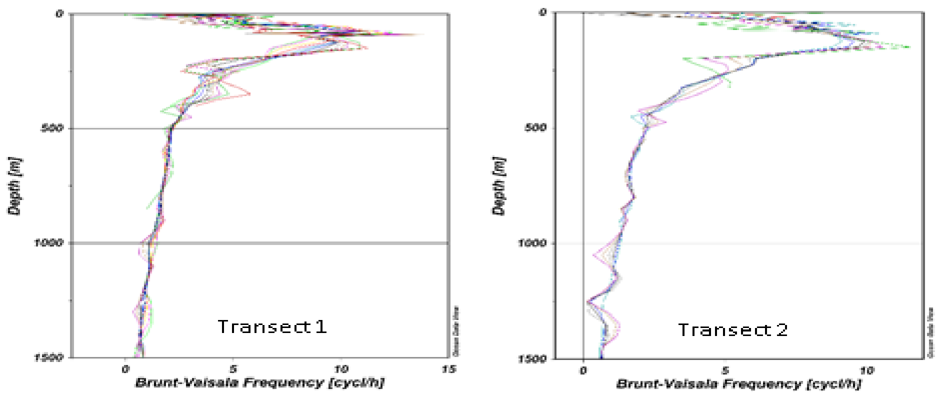

Figure 6: Vertical Profile of Brunt-Vaisala (N^2) in Sulawesi Waters areas

In general, seawater mass instability is in the layer below thermocline (200 – 250 meters depth). Based on [8] there are effects of current and topography which is causing seawater mass parcel distortion. In particular, it is seen that transect 2 (western part of Sulawesi Sea) has more instabilities than middle part of the ocean. This is supposed there is a strong mixing resulted by tides in the western part of the ocean. Research conducting by [22] signifies that the western part of the strait happening single daily internal tide which has a high value. Besides that, seawater mass mixing can be generated by tides with internal wave background. In station 9, Brunt-Vaisala frequency has a negative value (very instable) in 90 meters depth. It is probably caused by this station is an entrance for breaking current flows. In that place, the turbulent flows always are happening as a result of turbulent mixing that distorses seawater mass (lower density of seawater mass would be above the higher one).

4. Conclusion

Sulawesi Waters possesses mixing surface layer thickness that is found in the range of 0 to 100 meters depth with temperature lowering range from 29.12-24.21 ^{0}C and temperature gradient fluctuation about 0.01 – 0.02 ^{0}C. This condition is caused by the dynamic of the sea which has a complexity topography with a sill and the sea also is being one of Indonesia Through Flow (ITF) as an entrance for internal and kelvin waves. Salinity fluctuation of the research location is varied where in surface layer starts from 34.12 psu to 34.26 psu, thermocline layer in 100 to 200 meters depth is in ranged of 34.51-34.83 psu, and it decreases in the homogeneous layer about 34.54 psu to 34.60 psu. Those numbers testify the variance of each layer is small due to freshwater input from Java Sea with salinity characteristics which has relatively lower.

Density stratification is happening in three layers such as surface, pinocline, and deep layers. Stratifying temperature and salinity is indicated by density stratification, where the sea holds a high-density gradient in thermocline layer, whilst in surface and middle layers the stratification is relatively lower resulting instability seawater mass that is potential to forming turbulent mixing process. Mixing layer thickness and pinocline layers in density profile is almost coinciding with temperature profile.

Characteristics of seawater mass in Sulawesi Sea comes from North Pacific Ocean. Salinity and temperature condition in thermocline layer at this sea is similar with Makassar Strait, and it is higher than Ombai Strait, Lombok Strait, Dao, and Timor Strait. It is alike with have been found by [19] that surface layer until thermocline layer are seen salinity dilution in some location as result of high intensity in Java Sea. All profile results evidences that thermocline layer tends having a higher value about $3.2x10^{-4}$ – $1.8x10^{-4}$ cycl/s and the down layer possesses lower values. It is presumed this layer hold highest static stability rate that's why the inversion value of seawater mass to becoming low. The value of N^2 in station 10 at the transect one is high in thermocline layer. This condition is indicated there is a threshold and presuming high internal waves. It infers that the Sulawesi Sea has a high instability seawater column that is supposed relating to high current flows interacting with sea floor topography. In general, instability seawater column happens in nether layer under thermocline (200 – 250 meters depth).

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