Schematic Model of Ocean Pacific Seawater Mass Circulation in Banda Sea

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Abstract. The Banda Sea passes through the Indonesian Throughflow (ITF), and carries seawater mass from the Pacific Ocean toward the Indian Ocean. This influx affects the variations in oceanography parameters, and the monsoon winds aggravate the water complexities. The aim of this research, therefore is to determine seawater mass movements based on temperature and salinity distribution, expressed by the schematic model. These parameters are obtained from HYCOM and processed with ODV, followed by description, using a graphical software. The schematic model created based on the waters’ vertical temperature profile, and represented by one layer each. These include the water surface or 0m, which acted as the mixed layer, while the thermocline was observed at a depth of 150m. In addition, the final deep layer was featured at 500m. Particularly, the 0m model featured irregular salinity and temperature movement, possibly due to the influx of freshwater and monsoon winds. The seawater mass at 150m is reserved for a while in the Banda Sea before exiting into the Indian Ocean. Moreover, homogenous values were recorded, with relatively similar movements at 500m.

1. Introduction
The Indonesian seas are located between the Pacific and the Indian Ocean, thus allowing for the mass flow between both water bodies [1]. In addition, a total of two seawater entry paths towards the Pacific Ocean have been identified, including the western and eastern ways, Makassar Strait and Halamhera Sea [1-3]. This network is known to affect the oceanographic parameters of Indonesian seas, and also influence seasonal changes resulting from monsoon variations [4], as observed in the Banda Sea.

The mass flow of water in this region occurs in the form of North and South Pacific waters [1-4]. These sources respectively have different temperature and salinity characteristics, known to be
influenced by seasonal monsoon variability instigated by the winds [3,5,6]. In addition, these modification have also been attributed to the island locations and the complex [5].

Moreover, the flow from the Flores Sea pours into the Banda Sea on the northwest monson, This leads to the formation of a high over Asia, and a low in the north of Australia [5,7]. Furthermore, a trough lies from the equator up to the north of Australia, while the winds blow over South China as well as the Andaman Sea, and continues to the Pacific Ocean, due to the northeast trades [5,3]. The monsoon passes the equator as a north wind, while the south is turned into the east. Subsequently, there is a reversal in wind directions because of the high and low formed in Australia and Asia, respectively. This generates the southeast monsoon, producing winds with the capacity to hit over the Banda Sea and effectively spread the water to the Flores, Java, and South China Sea [5,8].

The water mass influx also affects the Banda Sea thermocline layer, which is generated due to a drastic decline in temperature, and is characterized by a gradient of over 0.05 °C /m [9]. This phenomenon changes every season, depending on sun intensity radiation entering the water, and seasonal monsoon alterations [5,7,10]. In addition, the shallowest thermocline layer is identified at 30m depth, and extends up to a thickness of 205m [11].

The physical, chemical and biological characteristics of each water body is possibly influenced by bathymetry, season, and the geographical location. However, it is possibly to simplify the complex dynamics in the Banda Sea by creating schematic models based on changes in the movements of temperature and salinity. This assessment is handily for understanding the water flow and also to distinguish the input and output of the water mass, and the model adopted was sourced from Wardhani [12].

2. Tools and Methods

2.1. Location Determination
The research location is located in the Banda Sea, within the limits of coordinate 3° - 8° south latitudes and 123° - 133° west longitudes. Furthermore, the boundary data were created on a transects parallel to the longitude and latitude, vertical and transect to each layer at some depth. These data were further formulated into a schematic model based on the vertical profile of temperature. Therefore, three measures were selected to represent the mixed layer depths, at 0 m for surface, 150 m for thermocline, and 500 m designating the deep level.

2.2. Data Collection
This study used HYCOM as the main data object in the NetCDF format, encompassing the temperatures, coordinates, salinities, and water depth. The data is downloaded freely through the website, as the result of a global model with an NetCDF format. Therefore, salinity and temperature were obtained daily, and the monthly average was then estimated. The data downloaded over a 12 month period in 2017, show 33 depth layers (from 0 m to 5500 m) with a characteristic resolution of 1 / 12°. In addition, this research was performed in 2018 at Pusriskel KP KKP.

2.3. Data processed
The obtained data was processed with programming software to generate the average value, and was saved in the new NetCDF form. Therefore, the outcome was visualized with ODV and set for graphic plotting to create a schematic model based on temperature and salinity movements at each horizontal layer transect. The respective depth featured 3 horizontal layers, including the mixed, thermocline, and deep levels, where each transect (at 0, 150 and 500 m) contained parameter distributions at sea surface, thermocline, and deep water layers, respectively.

2.4. Analysis
Plot each variable in a time series, observe the direction of its movement and, then plot it schematically into an arrow. This method was adopted from a study conducted by Wardhani [12]. In addition, the model is used to describe the pattern of horizontal or vertical oceanography parameters.
These horizontal temperature and salinity distributions are expected to provide information on the pattern, input, and output of the Banda Sea.

3. Results and Discussions

The schematic model transect is determined from the temperature profile. Based on the graph, the thermocline layer (75 - 200 m depth) was observed to change monthly, depending on the ocean parameters. Furthermore, the table on NWM and TS1 show similarity in depth for upper and lower limits, although the latter demonstrated the lowest and deepest value for an upper and lower limit, respectively, amongst other seasons. The thermocline layer has the least thickness during the southeast monsoon, compared to others, with a range of 75 - 150 m. These values also vary with reference to sunlight radiation intensity.

| Thermocline layer | NWM | TS1 | SEM | TS2 |
|-------------------|-----|-----|-----|-----|
| Upper Limit (m)   | 75  | 75  | 75  | 50  |
| Bottom Limit (m)  | 200 | 200 | 150 | 200 |
| Temperature at the upper limit (°C) | 27,31 | 26,85 | 25,89 | 27,44 |
| Temperature at the bottom limit (°C) | 16,25 | 15,512 | 18,21 | 15,73 |

3.1. Schematic model at 0m

The seawater mass with high-temperature (29-30 °C) enters into the Banda Sea on instances where the NWM originates from the Maluku Sea, through the gap between Sulawesi Island and Buru Island. Meanwhile, those with low-temperature (28-28.5 °C) originate from the Flores Sea, and spreads northeast of Banda Sea. However, some part of these variants merge onto the Arafura Sea.
In addition, a high-temperature seawater mass (29-30 °C) originating from the Maluku Sea moves into the Banda Sea and partly towards the Arafura Sea. However, the low-temperature variant in the SEM, entered the Banda Sea from the Seram Sea through gaps between Papua and Seram Island. In addition, most of the high-temperature seawater mass allegedly originates from the Maluku Sea to the Banda and then the Flores Sea with a temperature range of 28 - 28.5 °C, while the low-temperature variant at 26.5 - 27.5 °C, entered the Banda Sea from Seram Sea.

The salinity movement also differs with each season, as low-salinity of about 34 psu enters the Banda Sea from the Flores Sea in the NWM. This pushes the volume with high-salinity, 34.25 PSU, out into the Arafura Sea. Moreover, the value recorded on the surface was only about 33.75 - 34 PSU during the TS1. This was estimated to have originated from the Flores and Maluku Seas. The SEM comparably has a higher value, at 34.25 PSU, which enters the study location from the Maluku Sea. This is achieved at the gap between Buru and Seram Island, as well as between Seram and Papua Islands. The mass with lower levels (34 PSU) entered from the Seram Sea, while the water body with high-salinity moved out toward the Flores and Timor Seas.
The movement of temperature and salinity on the water surface is irregular. Fig. 1 and Fig. 2 show higher temperature and low salinity input to the Banda Sea during NWM, while the freshwater from Java Sea brings contributes warmness and low-salinity, due to an accumulation responsible for the thermocline depression [14]. The maximum inflow from freshwater sources occurs in the presence of winds from the South China Sea. This subsequently produces moist water [3], while those from surrounding islands influence the salinity [5].

Furthermore, the water mass entered from the north at the SEM, due to the New Guinea Coastal Current extension, flowing from the Halmahera and New Guinea [14]. This possessed the lowest temperature range, and relatively high salinity, due to the incidence of upwelling and reduced evaporation rate instigated by dry air winds blowing from southeast [3]. The most significant temperature range was observed from November to mid-May, while the least was recorded in August [2]. In addition, the changing parameters on the sea surface were influenced by wind movements during the monsoon season, characterized by the capacity to modify the thermocline uplift depth [6,7].

3.2. Schematic model at 150m

The seawater mass with high-temperature transited from the Seram Sea, through gaps between the Kei Islands at 20.5 - 23 °C. This further mixed with those possessing low-temperatures (18-20 °C) and originating from the Seram Sea, through Buru and Sulawesi Islands. The value recorded in the TS1 is lower compared to NWM. In addition, a range of 19.5 - 20.5 and 17-19 °C were respectively reported, despite the similar origin, as in NWM. However, additional low-temperature seawater mass was received from Flores Seas in the TS1.

The motion direction observed was different with the SEM, as high-temperature seawater mass entered and spread over the Banda Sea through gaps between Buru and Seram Islands, ranging from 18.5 to 20 °C. This input successfully pushed out those with low-temperature toward the Arafura Sea. In addition, high-temperated samples of around 19-21.5 °C originated from the Halmahera Sea and transited through gaps between Buru and Seram Islands, and also between the Kei Islands at TS2. However, those with low-temperature (17 -18.5 °C) moved out onto the Flores Sea.

The salinity range at 150m was within the range of 34-35.4 PSU, and low-salinity values were reported in NWM (34.2 - 34.7 PSU). This water body moved into the studied location from Flores as well as Maluku Seas. In addition, others with similar range (34.8 – 35.2 PSU) entered through the Seram Sea. Hence, the low salinity values extend from 34 to 34.7 PSU. Conversely, samples with
high-salinity were predominantly collected in transition season 1 (34.8 - 35.1 PSU). This is characterized by the ability for low-salinity seawater mass from Maluku and Flores Seas to push the high-salinity sample area towards the south of Seram Island. Hence, there is a massive exit from Banda to Arafura Sea through gaps between Tanimbar and Tayando Islands, as well as Tanimbar and Islands Babar. The water body with high salinity enters the Banda Sea through Flores and Maluku Seas in the SEM, with values ranging from 34.8 - 35.2 PSU. This influx instigates the exit of low salinity seawater mass through the southeast side and towards the Arafura Sea. In addition, the Seram Sea was the only low-salinity (34.2 - 34.5 PSU) source, while Flores Sea provides high-salinity (34.6 - 35 PSU). Conversely, water from the Seram sea moved and spread south of Seram Island and towards the Arafura Sea, through gaps between Tanimbar and Kei Islands.

The schematic model at 150m depth illustrated the distribution of temperature and salinity in the thermocline layer. This area of the Banda sea moved through the North and South Pacific water mass (Gordon et al 2010). Conversely, South Pacific enters the Banda Sea through Halmahera and Seram Sea, while the North penetrates via the Flores Sea, spreads north to south, and exits towards the Indian Ocean [3]. Also, there have been reports on movements through the Makassar Strait to the Flores Sea, and towards the Banda Sea, through the ITF western gate [1].

Based on the temperature and salinity schematic model in NWM, no visible mass of seeping water was observed. However, there is a possibility of accumulation or removal in the Banda Sea, featuring the propensity to cause downwelling [13]. This phenomenon also instigates upwelling in the water column. In addition, monsoon winds variation maximally strengthens from February and April to December, respectively [6].

3.3. Schematic model at 500m
The monsoon variations had no significant effect on the movement of existing oceanographic parameters. Moreover, seawater mass collected at 500m depth in the schematic model demonstrated a fixed salinity value of 34.6 PSU. This water body originated from the south pacific via the Halmahera Sea and spread through the southwest of Banda Sea to the southeast of Arafura Sea. In addition, the south pacific water mass, in the form of SPSW and SPIW has been mixed, due to the presence of energetic internal waves spread from Seram to Banda Sea [7]. This result also show the occurrence of

![Figure 5. Schematic Model of Salinity in Banda Sea at 150m](image-url)
an isopycnal mixing at this depth, alongside the formation of isohaline seawater mass [3]. Moreover, the schematic model showed no spatial temperature difference, as 8°C temperature enters the study location through Maluku and Flores Seas. This value was not as high as the reports obtained at the surface and 150m depth, due to the inability for sunlight to penetrate successfully. The light rays are a significant part in temperature distribution [10].

Figure 6. Schematic Model of Temperature in Banda Sea at 500m

Figure 7. Schematic Model of Salinity in Banda Sea at 500m

4. Conclusion
The schematic model created to observe and simplify the distribution and movement of salinity and temperature in the Banda Sea. In addition, the temperature at sea surface level is irregular, due to direct heating by sunlight and monsoon variations. This particularly influenced the salinity distribution, which was also affected by freshwater inputs from surrounding sources. The schematic model at 150m depth indicated the presence of reserved water mass during NWM and TS1, which is
released only after transition season ends. Furthermore, there was an upwelling and downwelling process, signifying the restrained prior to discharge into the Indian Ocean [6].

The schematic model parameters tend to not change after seasonal changes at 500m depth, including after an exposure to monsoon variations. In addition, flow at this level emanates from the Halmahera Sea, and moves towards the Arafura Sea. This is a mass of mixed south pacific water, observed due to the internal waves present, and isopycnal combination [2,3].

Based on the schematic model research of Pacific Ocean, further evaluation is needed for the seawater at Banda Sea. This is expected to generate more information on distribution and also to assess the profile.

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