Thermocline studies using CMEMS data in the Andaman Sea during October 2017

N Irmasyithah¹, Y Haditiar², M Ikhwan², R Wafdan¹, I Setiawan¹,², and S Rizal¹,²*

¹Department of Marine Sciences, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia
²Graduate School of Mathematics and Applied Science, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia

*Email: syamsul.rizal@unsyiah.net

Abstract. The thermocline is a sea layer with a change in temperature to depth quite quickly. We had to study this layer because it had an important contribution to thermohaline flows, upwelling, and fish migration. This paper aimed to map the vertical profiles of temperatures and thermocline gradients in the Andaman waters during the transitional season, October 2017. Analysis of the thermocline layer was based on vertical temperature data from the CMEMS model which were verified with SST from Aqua MODIS 4 km. The thermocline layer was indicated by \( \Delta T / \Delta z \geq 0.1^\circ C \) and started from the depth of 40 m. CMEMS SST verification on October 2017 showed good results (MAPE = 0.0188, \( r = 0.68 \)). The thermocline layer was found thicker off the west coast of Sumatra, the Indian Ocean (Station 1) than in the Andaman Sea. Generally, the thermocline layer was at a depth of 66 - 131 meters on October 2017. The thermocline gradients were 0.12 - 0.23. These results indicated that in the transitional season, the thermocline location in the Andaman Sea was shallower or less than 200 m.

1. Introduction

The Andaman Sea is located in the northeastern part of the Indian Ocean with deep waters below 1800 m which are separated from the Bay of Bengal by the Andaman Islands and the Nicobar Islands [1]. The average surface temperature of the Andaman Sea is 29°C, and it is almost homogeneous to a depth of 50 m that leads to stratification, which inhibits vertical mixing [2].

The Andaman Sea is in the northeastern part of the Indian Ocean which is generally characterized by low surface salinity, strong internal waves and seasonal monsoon circulation which causes circulation of surface currents and the occurrence of upwelling [3, 4, 5]. Variability of ENSO (El Nino Southern Oscillation), IOD (Indian Oscillation Dipole Mode), Monsoon and high rainfall also influence the depth and thickness of the thermocline [6, 7]. According to [8], variability such as ENSO and La Nina also causes the cumulation of water masses resulting in changes in the thermocline boundary in the Eastern Indian Ocean. In this waters, we found variation of sea surface temperature that affect the fishing ground and chlorophyll for fish feed.

The rate of decrease in temperature with increasing depth is called a thermocline. Determination of thermocline depth limits at depths of 200 and 1000 meters was found in low and medium latitudes. This is called a permanent thermocline. The permanent thermocline is not found in polar and subpolar waters because the surface water of the area is relatively cold compared to deep waters [9]. The thermocline is more shallow and strong in summer but deeper and weaker in winter. This condition is
caused by surface cooling and wind stirring. Thus, the frequency of the occurrence of thermoclines is highest in summer and lowest in winter [10].

The thermocline layer has a sharp temperature instability compared to other layers [11]. Vertical mixing of high thermoclines can affect the vertical dynamics and fluxes and nutrient levels of a water [12]. The thicker the layer, the greater the range of differences in the lowest and highest temperatures [13, 14]. The depth of the thermocline is also referred to as the maximum vertical temperature gradient depth [15]. Season and monsoon winds in the northeast and southwest can affect the location of fishing / Net Deployment (ND), Sea Surface Temperature (SST) and productivity of catches [16, 17].

2. Materials and Methods

The data used in this study was CMEMS data. CMEMS data is available and can be downloaded at [www.marine.copernicus.eu]. This data contained the temperature of the ocean with spatial resolution $dx = dy = 5$ minutes. Resolutions in vertical fields were available in the following table.

| Layers | Interval (m) | Thickness (m) | Layers | Interval (m) | Thickness (m) |
|--------|--------------|---------------|--------|--------------|---------------|
| 1      | 0.49-1.54    | 1.05          | 16     | 34.43-40.34  | 5.91          |
| 2      | 1.54-2.64    | 1.1           | 17     | 40.34-47.37  | 7.03          |
| 3      | 2.64-3.82    | 1.18          | 18     | 47.37-55.76  | 8.39          |
| 4      | 3.82-5.08    | 1.26          | 19     | 55.76-65.80  | 10.04         |
| 5      | 5.08-6.44    | 1.36          | 20     | 65.80-77.85  | 12.05         |
| 6      | 6.44-7.93    | 1.49          | 21     | 77.85-92.32  | 14.47         |
| 7      | 7.93-9.57    | 1.64          | 22     | 92.32-109.72 | 17.4          |
| 8      | 9.57-11.40   | 1.83          | 23     | 109.72-130.67| 20.95         |
| 9      | 11.40-13.47  | 2.07          | 24     | 130.67-155.85| 25.18         |
| 10     | 13.47-15.81  | 2.34          | 25     | 155.85-186.12| 30.27         |
| 11     | 15.81-18.49  | 2.68          | 26     | 186.12-222.47| 36.35         |
| 12     | 18.49-21.60  | 3.11          | 27     | 222.47-266.04| 43.57         |
| 13     | 21.60-25.21  | 3.61          | 28     | 266.04-318.12| 52.08         |
| 14     | 25.21-29.44  | 4.23          | 29     | 318.12-380.21| 62.09         |
| 15     | 29.44-34.43  | 4.99          | 30     | >380.21      | 0-1500        |

To ascertain the accuracy of this data, a verification between SST CMEMS and Aqua MODIS Sea Surface Temperature (SST) (11 µ daytime) level 3 SMI (Standard Mapped Image) was previously carried out. MODIS data used is monthly composite data with a spatial resolution of 4 km (https://coastwatch.pfeg.noaa.gov/erddap/griddap/erdMH1sstdmday.html).

Verification is executed by Mean Absolute Error (MAE), Mean Squared Error (MSE), Mean Absolute Percentage Error (MAPE), Standard Deviation (STDev) and correlation coefficient ($r$).

\[
MAE = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{x_{i1}-x_{i2}}{n} \right|
\]  

(1)

\[
MSE = \frac{1}{n} \sum_{i=1}^{n} \left( \frac{x_{i1}-x_{i2}}{n} \right)^2
\]  

(2)

\[
MAPE = \frac{1}{n} \sum_{i=1}^{n} \left( \frac{x_{i1}-x_{i2}}{x_{i1}} \right) \times 100\%
\]  

(3)
\[ s = \sqrt{\frac{n \sum_{i=1}^{n} x_i^2 - \left( \sum_{i=1}^{n} x_i \right)^2}{n(n-1)}} \]  \hspace{1cm} (4)

\[ r = \frac{n \sum_{i=1}^{n} x_i y_i^2 - \left( \sum_{i=1}^{n} x_i \right) \left( \sum_{i=1}^{n} y_i \right)^2}{\sqrt{n \sum_{i=1}^{n} x_i^2 - \left( \sum_{i=1}^{n} x_i \right)^2} \sqrt{n \sum_{i=1}^{n} y_i^2 - \left( \sum_{i=1}^{n} y_i \right)^2}} \]  \hspace{1cm} (5)

After the data was known to be quite good, the thermocline analysis was carried out at seven stations spread across the Andaman Sea (Figure 1). Andaman Sea is located at 1.5° – 10° N and 90° – 100° E. The determination of the thermocline in Andaman Sea was based on the gradient temperature \( \Delta T/\Delta z \geq 0.1 \, ^\circ C/m \).

![Figure 1](https://coastwatch.pfeg.noaa.gov/erddap/griddap/srtm30plus_LonPM180.html)

**Table 2.** Research station

| Stations | Coordinates     | Depths (m) |
|----------|----------------|------------|
| 1        | 93.08 °BT-3.41 °LU | -4504      |
| 2        | 94.25 °BT-5.08 °LU | -2184      |
| 3        | 95.16 °BT-6.58 °LU | -1543      |
| 4        | 92 °BT-6.75 °LU    | -4053      |
| 5        | 91.33 °BT-8.91 °LU | -3692      |
| 6        | 95.58 °BT-7.75 °LU | -1086      |
| 7        | 97 °BT-6.08 °LU    | -1230      |

3. Results and Discussion

3.1. Data verification of CMEMS and Aqua MODIS SST

Before analyzing the thermocline layer using CMEMS data, this data was verified by SST Aqua MODIS level 3 SMI 4 km resolution. Figure 2 (a) showed the SST from CMEMS and Figure 2 (b)
showed the SST data from Aqua MODIS. The results of the verification of CMEMS and SST Aqua MODIS data were shown in Figure 2.

![Figure 2. Verification of CMEMS and Aqua MODIS SST, a) CMEMS SST October 2017; b) SST MODIS October 2017](image)

Based on the SST comparison, it was known that the maximum CMEMS SST results were about 3°C from Aqua MODIS. The Aqua MODIS minimum SST were around 2°C lower than CMEMS. However, the average SST differences from CMEMS are less than 1°C with MAPE and r for October 2017. This fact was quite satisfying. A detail description could be seen in Table 3.
### Table 3. Accuracy measuring instrument

| No. | Year | SST Maximum (℃) | SST Minimum (℃) | SST Average (℃) | MAE     | MSE     | MAPE   | STD   | r    |
|-----|------|------------------|------------------|------------------|---------|---------|--------|-------|------|
|     |      | CMEMS MODIS      | CMEMS MODIS      | CMEMS MODIS      |         |         |        |       |      |
| 1   | 2017 | 31.37            | 35.77            | 28.95            | 26.74   | 29.53   | 29.99  | 0.5741| 0.608|
|     |      | 0.63             | 0.0188           | 0.63             | 0.68    |         |        |       |      |

The Andaman Sea is directly connected to the Bay of Bengal. SST in the Bay of Bengal is gradually influenced by the El Niño Southern Oscillation (ENSO) and Indian Mode Dipole Mode Index (IODMI) [18]. SST can determine the variability of the depth of the thermocline layer. Vertical stratification of temperatures in the ocean caused the formation of thermocline layers which affect nutrient distribution. Because the verification results obtained were quite satisfactory, the CMEMS data were analyzed to determine the thermocline layer.

### 3.2. Thermocline layers in October 2017

Analysis of the thermocline layer was shown in Figure 3. The analysis was based on CMEMS temperature data from surface 0.49 to 380.21 meters in several Andaman Sea stations, as shown in Figure 1. The thermocline location is determined based on $\Delta T / \Delta z \geq 0.1$ °C/m.
Figure 3 showed information about the thermocline vertical profile on October 2017 for seven stations. The figure also showed about the mixed layer, the thermocline layer, and the deep layer.

On October 2017, the thermocline layer was varied. The shallower thermocline layers occur at stations 1, 3 and 6. The deeper thermocline layers occur in stations 2, 4, 5 and 7. All stations in 2017 the thermocline layer was closer to the surface. Generally, on October 2017, the thermocline layer was at a depth of 66-131 meters. The thermocline gradient was 0.12-0.23 °C/m. These results indicated that in the transitional season (October), the thermocline location in the Andaman Sea was shallower or less than 200 m.

According to [13], the shallow thermocline layer supported aquatic productivity. During a vertical mixing process, nutrients in the shallow thermocline layer were more easily reaching the surface layer than the deeper thermocline layer. High rainfall also caused the lower limit of the thermocline to become shallow [7]. Temperature and thermocline depth profiles were characterized by mixed layer depth, thermocline depth, and thermocline thickness [19]. The layer data and thermocline thickness on October 2017 could be seen in Table 4.
Table 4. Thermocline layer for October 2017

| No. | Station | October Layers (m) | Thickness (m) | ΔT/Δz (°C/m) |
|-----|---------|--------------------|---------------|--------------|
| 1   | 1       | 66-131             | 65            | 0.1216       |
| 2   | 2       | 78-131             | 53            | 0.171725     |
| 3   | 3       | 66-110             | 44            | 0.19175      |
| 4   | 4       | 78-110             | 32            | 0.2178667    |
| 5   | 5       | 78-131             | 53            | 0.172        |
| 6   | 6       | 66-110             | 44            | 0.181        |
| 7   | 7       | 78-110             | 32            | 0.2287667    |

Table 4 showed the range of the thermocline layers with their upper and lower limits. The upper limit of the thermocline was the border area between the mixed layer and the thermocline layer, and the lower limit was the border area between the thermocline layer and the deep layer.

The distribution of the thermocline layer at each station illustrated changes in temperature to depth. The layer indicated as the thermocline layer was \( \Delta T / \Delta z \geq 0.1 \, ^\circ C/m \). This fast transition zone \( (\Delta T / \Delta z) \) was below the mixed layer. Fast transition zones were zones where temperature decreases rapidly with depth. Seasonal changes and monsoon winds in the northeast and southwest affected the location of fish catch / Net Deployment (ND), Sea Surface Temperature (SST) and catch productivity [16, 17].

4. Conclusions
From the results of this study, it can be concluded that CMEMS data could be used in conjunction with MODIS images because the difference in temperature values was not much different. The verification results showed that SST CMEMS data was close to MODIS satellite data, and the verification instrument presented the good category. CMEMS maximum SST result was lower around 3°C than Aqua MODIS, while the Aqua MODIS minimum SST was around 2°C lower than CMEMS. However, the average CMEMS SST difference was less than 1°C with MAPE and \( r \) for October 2017, which was quite satisfying. On October 2017, the thermocline layer was shallower at three different stations at stations 1, 3 and 6 (66-131 m) and the deeper thermocline layer was at stations 2, 4, 5 and 7 (78 - 131 m). These results indicated that in the transitional season (October), the thermocline location in the Andaman Sea was shallower or less than 200 m.

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