The influence of monsoon on mixed layer depth in the northern waters of Aceh in 2017

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Abstract. The research was conducted by considering the values of temperature, mixed layer depth (MLD) as a result of the analysis, and sea-level winds in the waters of North Aceh. MLD was analyzed from the results of the three-dimensional Copernicus marine environment monitoring service (CMEMS) model, which has been validated with sea surface temperature (SST) data from the monthly Aqua MODIS. The results show that SST CMEMS is relatively the same as SST Aqua MODIS with variations up to 2°C. The verification of SST CMEMS data for February, April, August and October showed quite good results with a correlation value of $r = 0.8523$. Analysis in February, August, and October shows MLD is deepest. MLD in Aceh's northern waters is 68-91 meters, and Sabang and Krueng Raya waters are 68-79 meters. However, MLD is at its most shallow in April. The waters of North Aceh is 49 meters, Sabang waters is 40 meters, and Krueng Raya is 9 meters. In February, the wind speed occurs in the northeast wind direction with a speed of 3.2 m/s. April and October occur in the direction of the transitional monsoon. The wind speed in April is 2.2 m/s, and October is 2.9 m/s. The southwest wind direction is 4.1 m/s in October. From these results, the influence of the monsoon wind is enormous in the waters of northern Aceh.

1. Introduction
The waters of North Aceh are influenced by the Andaman Sea (AS) and the Indian Ocean (IO) [1,2]. These waters are dominated by two different wind seasons, namely the northeast monsoon (NEM) from December to February and the southwest monsoon (SWM) from June to September. Rizal et al. [3] found that the monsoon causes circulating seasonal surface currents in the AS that move to IO in NEM. In SWM, flows from the north of the AS are concentrated in northern Sumatra. The currents in northern Sumatra have the highest strength. Wind movement in waters can affect seawater mass, current direction, and surface temperature [4,5]. The occurrence of monsoon winds causes seasonal circulation currents in the Aceh waters and Andaman Sea [6,7].

MLD occurs due to water masses' stirring by wind and tides at sea level. The seasons' influence causes the characteristics of the waters in the eastern part of the Indian Ocean to become warm and in the waters in the west to become very cold [8-10]. Cotroneo et al. [11] disclosed an MLD definition that
lies 20-25 meters above the thermocline layer. Several other studies have found the MLD boundary in the AS at 30 m and globally at the equator at a depth of 40 m [12,13]. Research on MLD in the waters of North Aceh is still very minimal, and this study aims to analyze changes in the depth of the mixed layer during a change in monsoon wind direction and to compare the gradient of the mixed layer at several stations in the waters of North Aceh during the transitional season. MLD’s benefits in fisheries and the environment are that information about mixed layers can be used to capture fisheries and fish distribution. The mixed layer is also useful for information on the potential distribution of plankton as fish food.

2. Materials and Methods

2.1. Data
Copernicus marine environment monitoring service (CMEMS) data is a physics model application data used to assist and make it easier to create data and analyze the data needed and often used in research. CMEMS temperature data were used in this study to determine MLD. The second data is from Moderate Resolution Imaging Spectroradiometers (MODIS) data. SST Aqua MODIS Sea Surface Temperature (SST) (11 µ daytime) level 3 SMI (Standard Mapped Image) 4 km spatial resolution was used as verification of CMEMS data. Wind data is needed to find information about wind direction and wind speed that occurs at the observation location. Sea surface wind data used is monthly wind data. This data is obtained from the National Centers for Environmental Prediction (NCEP) data [14,15].

Figure 1. Northern waters of Aceh (5.40°-5.46°N and 95.15°-95.22°BT) from SRTM30 [16-17] (https://coastwatch.pfeg.noaa.gov/erddap/griddap/srtm30plus LonPM180.html)

2.2. Analysis method
SST in Aceh Utara Waters is based on CMEMS and Aqua MODIS data. SST Aqua MODIS is also the basis for verifying CMEMS data, which will be used for MLD analysis. MLD is analyzed from CMEMS data, which is quite good. MLD is the depth with a gradient of $\Delta T / \Delta z$ 0.1°C/m, where $\Delta T$ is the change in temperature and $\Delta z$ is the change in depth [18]. The MLD results from the analysis are then compared with sea surface wind speeds in the waters north of Aceh. Verification is observed based on standard of deviation (STD) and correlation coefficient ($r$), as follows:

$$STD = \sqrt{\frac{n \sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2}{n(n-1)}}$$

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

where \( s \) is the standard deviation, \( x_i \) that is, the x value is changed to i, \( n \) the number of x and y values, \( x \) the value of the depth of the mixed layer, \( y \) the magnitude of the wind magnitude, \( r \) the correlation coefficient, \( X^2 \) squared of the x value and \( Y^2 \) squared of the y value.

3. Results and Discussions

3.1. Wind magnitude in sea surface

Figure 2 (a) shows the wind circulation in the waters of North Aceh in February 2017. Northeast winds dominate the northern part of Aceh, including the three stations, namely the waters of North Aceh, Sabang, and Krueng Raya. The wind speed in North Aceh, Sabang, and Krueng Raya waters is around 2.2 m/s. Northeast wind speed is intense due to the Northeast monsoon's peak in February, which is winter in the northern hemisphere.

Figure 2 (b) shows the wind circulation in northern Aceh waters in April 2017. The season that occurs is the transitional season, which dominates three stations, namely the waters of North Aceh, Sabang, and Krueng Raya. The wind direction that occurs at these three stations is the same: the Southwest wind.
with the wind speed in the waters of North Aceh, Sabang, and Krueng Raya waters is around 2.9 m/s.
occurs due to the influence of the transitional season where the wind moves from Southwest to east.

Figure 2 (c) shows the wind circulation in the waters of North Aceh in August 2017. West winds
dominate parts of northern Aceh waters, including the three stations, namely North Aceh, Sabang, and
Krueng Raya. The wind speed in North Aceh, Sabang, and Krueng Raya waters is around 4.1 m/s. The
west monsoon's wind speed is very high because the wind blows from the Southwest towards the
Northeast in August. Figure 2 (d) shows the wind circulation in the waters of North Aceh in October
2017. In October, there is a transition season from the Southwest direction, which dominates three
stations, namely North Aceh, Sabang, and Krueng Raya. The wind speed in North Aceh, Sabang, and
Krueng Raya waters is around 3.7 m/s. during this season, there is a strong wind coming from the
Northeast towards the Southwest.

3.2. Data verification on sea surface temperature in northern waters of Aceh
Before analyzing the mixed layer using CMEMS data, this data was verified by SST Aqua MODIS level
3 SMI with a 4 km resolution. Based on the table, it can be seen that the comparison of CMEMS data
with Aqua MODIS shows pretty good results with a correlation value of $r = 0.8523$. The mean value of
SST CMEMS with Aqua MODIS in the waters of North Aceh on February 29.1164, April 30.8611,
August 29.6750, and October 29.9965.

| Month in 2017 | MODIS (°C) | CEMEMS (°C) | STD  | R   |
|--------------|------------|-------------|------|-----|
|              | Max        | Min         | average | Max | Min | average |      |
| February     | 35.23      | 27.44       | 29.1164 | 30.834 | 28.0952 | 29.0615 | 0.4320 | 0.8523 |
| April        | 35.22      | 27.52       | 30.8611 | 31.5963 | 29.9077 | 30.2300 | 0.7453 | 0.1472 |
| August       | 34.78      | 26.13       | 29.6750 | 31.5008 | 28.7360 | 29.4118 | 0.5867 | 0.7758 |
| October      | 35.77      | 26.74       | 29.9965 | 31.3767 | 28.9589 | 29.5370 | 0.6300 | 0.6760 |

In Table 1, based on the SST comparison, it is known that the maximum SST CMEMS results are 2-4 °C lower than Aqua MODIS. At the same time, the minimum SST for Aqua MODIS is about 1 °C lower than CMEMS. It means that the SST CMEMS value range is still within the SST Aqua MODIS value range. The difference in mean SST from CMEMS is less than 1 °C with $r$ for February, April, August, and October 2017, which is entirely satisfactory in the table above. Table 1 also explains that the highest temperature was obtained in April, confirmed by the two satellite data. The lowest temperature is in February, and the values differ only slightly from August.

3.3. Mixed layer depth in northern waters of Aceh
In the northern waters of Aceh, the deepest MLD occurs in February, August, and October. MLD that
occurs is the same for 68-91 meters. However, in April, the MLD was the shallowest at 49 meters. In
the waters of Sabang, the deepest MLD occurs in February, August, and October. MLD that occurs in
Sabang waters every month is the same as 68-79 meters, and the lowest MLD is 4 meters. The deepest
MLD in Krueng Raya waters occurs in February, August, and October. MLD that occurred was the same
at 68-79 meters. However, in April, the MLD was the shallowest at 59 meters.

It can be simplified that the results of the MLD depth and shallowness are mostly influenced by the
wind, which causes similarities and differences at each station. In Aceh waters, the MLD that occurred
was 68-91 meters, while the MLD value in the waters of Sabang and Krueng Raya was the same, namely
68-79 meters. Meanwhile, the shallowest MLD occurs at each station, not much different by 40 to 59
meters. It occurs due to the influence of the western season and the transitional season.

The wind strength that occurs in each month is different because of the influence of seasonal winds.
The correlation to MLD in this transitional season is good. It can be seen from the temperature in the
transitional monsoon season. The depth and shallowness of the MLD that occurs at each station are not all the same because the waters are affected by the circulation of the seasonal winds that occur.

| Month  | Station | Thickness (m) | Magnitude of Wind (m/s) |
|--------|---------|---------------|------------------------|
| February-01 | 66 | 1.393743753 |
| February-02 | 66 | 2.326833868 |
| February-03 | 78 | 3.660568516 |
| April-01 | 47 | 3.277199587 |
| April-02 | 41 | 2.640943578 |
| April-03 | 56 | 3.077805382 |
| August-01 | 92 | 4.224740793 |
| August-02 | 66 | 3.779494544 |
| August-03 | 66 | 5.40219926 |
| October-01 | 78 | 3.885964282 |
| October-02 | 78 | 3.700949176 |
| October-03 | 78 | 4.170289406 |

The results of this study can be seen in the relationship between SST and MLD winds that affect the three stations. In February, when the Northeast wind occurred, the MLD got deeper and was directly proportional to the very low SST. As for April, there is a west wind which causes the MLD to be very shallow but inversely proportional to the SST, which is very high. In August and October, there are Southwest winds which cause very deep MLD and slightly different SST values. Monsoon winds mostly influence the Andaman Sea. The occurrence of monsoon winds causes the circulation of seasonal currents in the Andaman Sea waters [3]. Monsoon winds occur due to seasonal changes in air pressure in mainland Asia and the Indian Ocean. Monsoon winds have a wind pattern that changes direction within half a year.

There is a thickness MLD value that is not linear with wind strength, meaning that many other influences determine the MLD value. We propose wind as the primary influence but do not rule out the addition of topographic and weather variables. MLD occurs due to the stirring of water masses by wind and tides at sea level which causes the temperature of the layers in the area to be the same, in this study the MLD conditions that occur in the waters of North Aceh are closely related to wind and sea surface temperature (SST). In a 2017 study [18], it stated that the MLD conditions in AS were quite good; only the shallowness of the thermocline could support the productivity of AS.

4. Conclusion

The results showed that the Northeast and Southwest Winds influenced the depth of MLD and SST. It is due to the influence of the different seasons in each month. The absence of obstacles when the wind passes through the three stations to propagate is also a factor. Wind speed in the waters of North Aceh, waters of Sabang and Krueng Raya is influenced by the Northeast monsoons, Southwest monsoons and transitional seasons. SST that occurred in February, August and October was equal to a value of 29. While in April it was 30. The deepest MLD occurred in February, August, and October in the waters of North Aceh amounting to 68-91 meters. Waters of Sabang and Krueng Raya are the same, which is 68-79 meters. The shallowest MLD occurs at each station, not much different from 40 meters to 59 meters. This study has similarities with previous studies on wind and MLD. This research can be used as information for the field of capture fisheries and fish distribution. MLD is also useful for information on the potential distribution of plankton as food for fish.
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