Ocean eddy detection in the Andaman Sea during April 2008

D Ardila\(^1\), Y Haditiar\(^2\), M Ikhwan\(^2\), R Wafdan\(^1\), Muhammad\(^1\), S Sugianto\(^3\) and S Rizal\(^1,2,*\)

\(^1\)Department of Marine Sciences, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia.
\(^2\)Graduate School of Mathematics and Applied Science, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia.
\(^3\)Department of Soil Sciences, Faculty of Agriculture, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia.

\(*\)Email: syamsul.rizal@ unsyiah.net

Abstract. Eddies have an important role in momentum transport, water mass, heat, and marine biogeochemical cycles. So far the information regarding eddies in the Andaman Sea is still little known. By using National Centers for Environmental Prediction (NCEP) / National Center for Atmospheric Research (NCAR) wind data, Sea Surface Height (SSH), and geostrophic currents obtained from altimeter data, this paper aimed to detect eddies during April (intermonsoon). Eddies were formed by current turbulence, gradient pressure variations, and the influence of sea surface wind. Observations showed that the SSH variations was supported by the west wind from the Andaman Sea. Spatial SSH differences caused the dynamics of geostrophic currents and eddies. During April 2008, we found six eddies scattered around the Andaman Sea, where there were four eddies cyclones and two eddies anticyclones.

1. Introduction

The Andaman Sea is deep sea waters (an average of 1100 m) located in the east of the Indian Ocean Sea, bordering Myanmar, Thailand, Malaysia and Indonesia. The area of this sea is around 6150 km stretching between Andaman Island, Nicobar Islands, Malacca Strait and up to the Bay of Bengal [1]. The Andaman Sea is connected to the Bay of Bengal through the Preparis Ten Degree Channel, and the Great Channel [2].

Most of the Andaman Sea is dominated by monsoons. Monsoons caused seasonal circulation of surface currents in the Andaman Sea [3,4]. Monsoons were also related to the intensity of rainfall [5], which could affect the stratification of Andaman sea water. Moreover, the Andaman Sea received fresh water supplies from large rivers such as the Ayeyarwady River which had high suspended sediments [6].

The transitions of monsoon also play an essential role in the surface flow of the Andaman Sea. In this period the hot peak moved north and was at the equator. This condition drove southwest winds in the Bay of Bengal and the Andaman Sea and initiates the monsoon period in Myanmar and Thailand [7]. This condition was likely to form a hydrodynamic phenomenon typical of the Andaman Sea such as eddies. Monsoon caused sea surface temperature and sea level. In south of Andaman Sea, Aceh waters was also affected by monsoon. This area had characteristic calm surface in Sabang Bay and more rough in northern and western coast of Aceh [8,9,10,11] as well as Malacca Strait [12].
Eddy is a phenomenon often seen in the Andaman Sea and the Bay of Bengal. Eddies can be formed due to current turbulence, variations in gradient pressure, and the influence of sea surface wind. Eddy had a vital role in influencing biogeochemical cycles in the sea. According to [13], Eddy cyclone formed in the northern hemisphere would cause upwelling while eddy anticyclone would cause downwelling, on the contrary in the southern hemisphere.

According to [14], the monsoon transition encouraged eddy variation in Myanmar waters. Ekman's transportation in the transitional month contributed to eddy formation on sea level [7]. Eddy could also be influenced by geostrophic anomalies [15].

Geostrophic currents are currents that occur due to a balance of pressure gradient and Coriolis forces. In a non-rotating flow, a pressure gradient force pushed water from high pressure to low pressure. The flow that rotated Coriolis forces was opposite to the pressure gradient force where water moved to the right at BBU or to the left on BBS so that the force produced was zero [16]. Sea conditions were always dynamic, so geostrophic currents were formed.

High pressure in the ocean caused a higher mass of water above the depth of observation. While the difference in pressure that occurs at sea level was caused by a mound of water relative to the geoid. Data of horizontal pressure between two different locations was used to calculate the velocity of the geostrophic currents at sea level.

So far, research on eddies had been carried out by [17] in BoB using satellite imagery and comparison of in situ observations [18], examining eddies in western BoB using the satellite altimetry method, and [19] considering eddies on the west boundary of BoB using remote sensing and in situ data. Research had also been carried out in the Andaman Sea using satellite imagery such as [15] and [20] which examined eddies on the coast of the Andaman and Nicobar Islands using the method of retrieving field data and satellite data. Eddy had been little studied in the Andaman Sea.

Along with the development of the availability of hydrographic data, this study utilized satellite altimeter data and satellite environments to observe eddy sightings in the Andaman Sea during the monsoon transition month. Also, eddy detection in Andaman was important to be studied because in that area had the best sea surface temperature and chlorophyll for fishing ground [21,22].

2. Materials and Methods

The research data used are:

1. Six hourly wind data were obtained from the National Centers for Environmental Prediction (NCEP) / National Center for Atmospheric Research (NCAR) reanalysis I [23]. The wind data obtained in interpolation were shown in the first half of the questionnaire.

2. SSH (Sea Surface Height) data obtained from monthly AVISO composites with a specified resolution $\delta y = 0.25^\circ$. This data can be accessed https://coastwatch.pfeg.noaa.gov/erddap/search/index.html?page=1&itemsPerPage=1000&searchFor=SSH

3. Geostrophic current data obtained from the monthly AVISO composite. This data is thought to be a partial expression $\delta x = \delta y = 0.25^\circ$. This data can be accessed https://coastwatch.pfeg.noaa.gov/erddap/search/index.html?page=1&itemsPerPage=1000&searchFor=CURRENT

Wind, SSH and current data downloaded were visualized and observed their relationship to compare with eddies in the Andaman Sea. Equations (1-2) showed the relationship between sea level and geostrophic currents [16]:

$$-fv = -g \frac{\partial n}{\partial x} \quad (1)$$

$$fu = -g \frac{\partial n}{\partial y} \quad (2)$$

Whereas to detect eddies the equation is used:

$$\text{Curl} = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \quad (3)$$

$u = \text{zonal current velocity (m/s)}$
\[ v = \text{meridional current velocity (m/s)} \]
\[ \eta = \text{sea level (m)} \]
\[ g = \text{gravity (m/s}^2) \]
\[ f = 2\omega \sin \phi \text{ (Coriolis parameter)} \]
\[ \omega = \text{the angular velocity (7.29 \times 10^{-5} \text{ rad/s})} \]
\[ \phi = \text{geographical latitude location} \]

3. Results and Discussion

On April 2008 strong winds were seen in the waters of Myanmar and the Indian Ocean. The wind from the Bay of Bengal moved eastward towards the Myanmar mainland, this was in accordance with the wind circulation in BoB [24], where the influence of local winds in the equator caused strong currents to the northeast collar so that the monsoon transition occurs. The wind from the Indian Ocean moved north towards the Nicobar Island and the Andaman Island and the wind was deflected towards the mainland to Thailand. Figure 2 (a) showed the movement of wind in the Andaman Sea on April 2008. It could be seen that strong winds originated in two directions, from the Bay of Bengal and the Indian Ocean towards the northeast of Andaman.

Figure 2 (b) showed the variation in SSH values on April 2008, SSH along the coast and offshore had the same amount, between 2.2 m - 2.35 m. In the eddy cyclone area, SSH values were higher, between 2.2 - 2.35 m compared to SSH values in the eddy anticyclone region, which was between 2.15 - 2.2 m. SSH varied most at Gulf Martaban and the Andaman Sea.

According to analysis [25] in the east of the Indian Ocean and BoB, SSH has different amplitude and different periods regionally. Significant SSH variations were found along the western coast of Sumatra, east of Sri Lanka, and northwest of BoB, respectively. From our results, SSH variations during April were more commonly found in the central part of the Andaman Sea.

According to [24], SSH in the BoB region and its surroundings can vary between 90-180 days due to the effects of basin resonance and strong winds. On April 2008, the west wind was stronger in the Andaman Sea. So this finding reinforced the results that the wind's strength and direction determined SSH variations.

The circulation of the geostrophic currents in Figure 2 (c) was quite strong in the waters of Myanmar, the Malacca Strait, and the west of the Sumatran Island, while the Andaman Sea was relatively quite weak. There were four cyclone eddies and two anticyclones eddies. Cyclone eddy could be seen in the Bay of Bengal, embraced by Martaban, south of the island of Andaman and north
of the island of Sumatra, while the cyclone eddy was formed near the waters of Yangon (Myanmar) and the west of Sumatra.

Our results showed that cyclone eddies had a positive curl value, between 0.2 and 0.4, while anticyclone eddies had a negative curl value with a value of curl - 0.4 to -0.2. The curl could be seen in Figure 2 (c).

Figure 2. (a) Surface wind map, (b) SSH, dan (c) geostropic currents in the Andaman Sea in April 2008.

The cyclone eddies were formed in the Bay of Bengal because of gradient instability across the coast where west currents flow towards the northeast of the Andaman Sea [18]. The Andaman Sea was directly connected with BoB and tend to have a relatively strong wind profile. According to [17], season and wind stress curls in the western basin encouraged variations in the bears that were quite strong in BoB. Our results also showed that wind encourages variations in geostrophic, eddy, and sea level currents in the Andaman Sea.
4. Conclusions
Based on the results of observations, it can be concluded that there were six eddies during April 2008. Cyclone eddies could be seen in the Bay of Bengal, in the Martaban Bay, south of the Andaman Islands and the north of Sumatra Island. The anticyclone eddies were formed near the waters of Yangon (Myanmar) and west of Sumatra Island. Cyclone eddies were the most dominant eddies occur. Data in a more extended period is needed to explore the existence of eddies.

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