The relationship between monsoon and sea surface temperature in the western part of Aceh Waters, Indonesia

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Abstract. The western part of Aceh waters is part of the eastern Indian Ocean. This waters is a dynamic region where there is differences in sea surface temperature (SST) and significant chlorophyll-a concentrations between the southwest (SW) monsoon (June-September) and the northeast (NE) monsoon (December-February). Analysis of SST and chlorophyll-a concentration were used to determine upwelling events in the region. We found that SST in the NE monsoon is lower than that of in the SW monsoon.

1. Introduction
Upwelling is the vertical movement of the water mass from the bottom layer to the surface layer [1]. This movement transports mass of water with a low temperature. Upwelling is caused by Ekman's transport generated by wind movements [2].

Indonesia is tropical country and located between two large oceans and two continents so that Indonesia has physical phenomena that are closely related to the monsoon system [3]. Previous research has revealed the relationship between upwelling and monsoon. Upwelling in the southern waters of the island of Java occurs when the northeast monsoon [4]. Chlorophyll-a concentrations in the northern waters of the Malacca Strait in the northeast monsoon are higher than southwest monsoons [5]. This facts also cause variation of fishing ground and fish species in Aceh waters [6, 7].

This research studies the relationship between sea surface temperature and the monsoon cycle in the western waters of Aceh. This area is influenced by Sabang waters and North Aceh waters in the north and India Ocean in the south that give variation of sea surface temperature and chlorophyll-a concentrations [8, 9, 10]. Sea surface temperature profiles and chlorophyll-a concentrations are used to identify upwelling events in these waters.

The monsoon which is related to wind has a significant influence on current circulation formation [11], although the effect of bottom friction is having a significant impact [12,13,14].
2. Materials and Methods

2.1 Materials
1. The research area is located in the eastern Indian Ocean, the western waters of Aceh Province between 5-7°N and 90-95°E. The research location is shown in the figure below.

![Research location](image)

Figure 1. Research location

Monthly data on chlorophyll-a concentration obtained from the Goddard Earth Sciences Data and Information Services Center (GES DISC) [15].

2. Sea Surface Temperature Data (SST) obtained from NOAA-AVHRR in ASCII format.
3. Wind data is obtained from NCEP (National Centers for Environmental Prediction). The data used is data from 1998 to 2010.

2.2 Methods
1. SSC and SST are used to determine upwelling in the western waters of Aceh. The data used is data from 1998 to 2010. SSC and SST data have been used to identify upwelling areas [16,17].
2. Chlorophyll-a and SST data are processed using Ocean Data View software, version 4.7 - 2015. Data processing results are displayed in 2-dimensional images.
3. SST and chlorophyll-a data are grouped according to two monsoons in Indonesia, NE monsoon and SW monsoon.
4. Wind data in this study were processed using grads software. As with SST and SSC data, wind data is also grouped according to monsoon.

3. Results and Discussion

3.1 Wind Field
Wind movement influences upwelling events. The interaction between wind and sea surface causes Ekman’s transport. Ekman’s transport that is produced by wind movements causes upwelling. Wind velocity profiles in the monsoon NE can be seen in Figure 2.
Figure 2a and b are wind velocity profiles in the NE monsoon. In the NE monsoon (December to February) the wind moves from the northeast to the southwest. This wind movement generates transport of the wind towards the right side of the wind. Ekman transport results in a vacuum of water.
on the surface so that the mass of water from below rises to the surface. Rising water masses from the bottom layer causes the temperature on the surface drops in the NE monsoon. The wind speed profile in the SW monsoon can be seen in Figure 3 below.

Figure 3. (a) Wind Field in July 1998; (b) July 2010
Figures 3a and b show that in the SW monsoon (June to September) the wind moves from southwest to northeast. This wind movement also generates transport to the right side of wind coming near to the west coast of Aceh. Ekman’s transport causes accumulation the water mass on the surface so that there is no water mass transfer from the bottom. This condition causes the sea surface temperature in the SW monsoon to be higher than the NE monsoon.

3.2 Sea Surface Temperature Variability

The profile of the average sea surface temperature in the West Aceh waters can be seen in Figure 4.

![Figure 4. SST Average Value Profile from 1998 to 2010](image)

Figure 4 shows that sea surface temperatures in the western waters of Aceh vary in each monsoon. Sea surface temperature in the NE monsoon is lower than the SW monsoon. In the SW monsoon period the average value of sea surface temperature varies in the range 29 to 30.2 °C. Meanwhile, the average of sea surface temperature in the NE monsoon is in the range 28.6 to 29 °C.

3.3 Cholorophyll-a Variability

The profile of the average sea surface temperature in the West Aceh waters can be seen in Figure 4 below.

![Figure 5. Average of Cholorophyll-a Concentration 1998 to 2010](image)
Figure 5 shows that the average value of chlorophyll-a concentration varies in each monsoon. Chlorophyll a concentration in the SW monsoon is lower than in the NE monsoon. During the NE monsoon the average value of chlorophyll-a concentration ranges 0.14 mg/m$^3$ to 0.24 mg/m$^3$. The average value of chlorophyll-a concentration in the SW monsoon ranges between 0.12 mg/m$^3$ to 0.18 mg/m$^3$.

4. Conclusions
The study of the dynamics of changes in sea surface temperature and chlorophyll-a results in the following conclusions:
1. The monsoon wind movement affects the value of sea surface temperature and chlorophyll-a concentration.
2. The average sea surface temperature in the NE monsoon is lower than the SW monsoon.
3. The average value of chlorophyll-a concentration in the NE monsoon is higher than that of SW monsoon.
4. Based on the analysis of sea surface temperature and chlorophyll-a, upwelling in the western waters of Aceh occurs in the NE monsoon.

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