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Upwelling session in Indonesia waters

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ABSTRACT

The aim of this research was to analyze monthly sea surface temperature (SST) and chlor-a satellite data for 16 years from 2003 in an area from south Java to north Papua. The results show that the temporal and spatial pattern of SST and chlor-a distribution strongly was related to the monsoonal pattern. The upwelling session starts from May and ends in the October, in the south-east monsoon season. The lowest SST (25-30 °C) and the highest chlor-a (2.23 mg/l) is found in August in the south-east monsoon season. In addition, the largest upwelling area occurs in July, and ranges within 790,221 km² of size.

Keywords: coastal area, economic exclusive zone, periodic monsoon, satellite data, upwelling

1. INTRODUCTION

Indonesia has more than 17.054 islands with a complex system of ocean basins and shape surrounding. Ocean circulation is affected by the complex system, including the atmosphere interactions [1, 2]. One of the results of the complex system is upwelling incident. Upwelling is the movement of water mass including nutrient and other properties from deeper layers to the surface. In general, the ocean upwelling refers to a complex interaction between ocean and atmosphere [3, 4]. This situation is forced by the Ekman transport along the coast [2]. Indonesia lies along the equator and due to this geographical position, upwelling phenomena could occur in different monsoon seasons. Upwelling is one of important phenomena that drives nutrients for biological systems in water column which are related to food webs [5]. Upwelling can be identified by Low Temperature and High Chlorophyll (LTHC) in the surface. SST and chlor-a

are likely to be important drivers of tuna abundance [6]. In Indonesia, the system of Asian-Australian monsoon, the eastern boundary upwelling in the Indian Ocean develops most significantly along Sumatra-Java-Nusa Tenggara coasts during the southeast monsoon period [7]. In Sumbawa waters, the coolest SST (26.58 °C) is associated with the highest chlor-a (0.6 mg/m³) which can be found in June-July-August (JJA) as a part of southeast monsoon [7, 8].

There have been many studies on upwelling in Indonesia related to temperature and chlorophyll. An early study of upwelling was done by Wrytki [1] and continue with some studies were done in Banda Seas [9, 10], in Spermonde and South Makassar [11, 12], South Java [13], Bali [14], Sumbawa [8], Bone and Flores Sea [15], Maluku Sea [16], North Papua [17], West Sumatera [18]. Recently, precise and detailed satellite data can be used to predict upwelling, both in terms of time and spatial patterns. The aim of this paper is to analyze the upwelling condition with SST and chlor-a as proxies to measure the upwelling intensity from 16 year high spatial images. The final objective is to analyze the SST and chlor-a from May to October. This research will enhance the knowledge of upwelling regions, which is useful for fishing ground forecast. The research limitation is that no El-Niño events in 2008 and 2015 were analyzed due to the focus of this research. Otherwise, the data used were provided monthly, so that the results will not show the anomaly.

2. MATERIALS AND METHODS

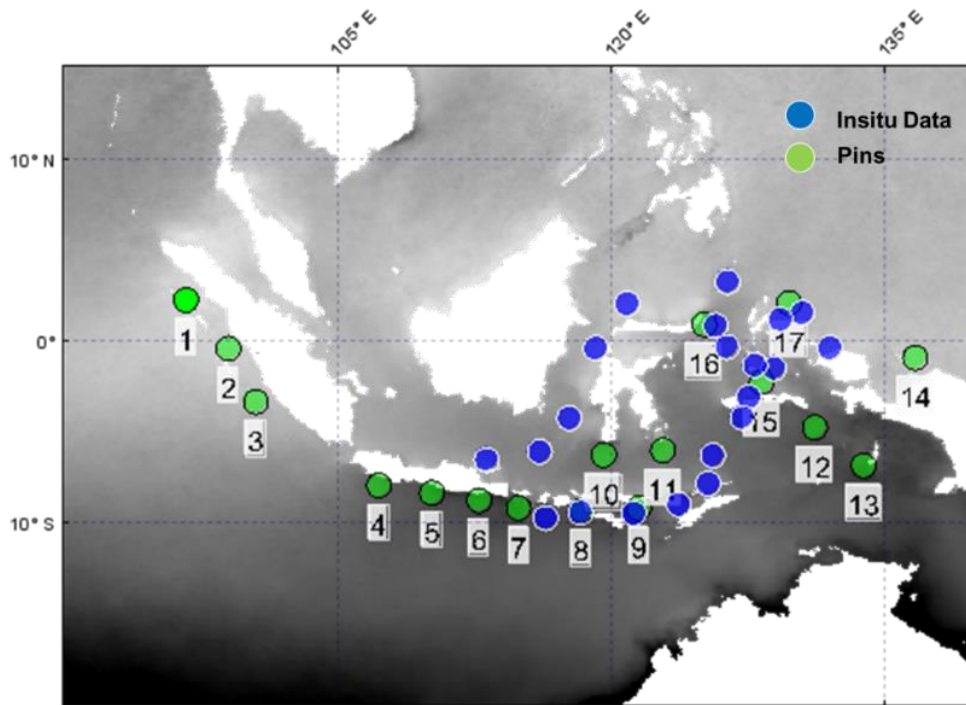


Figure 1. Area location with insitu data point (bue dot) and pins (green dot). (1,2,3) represent west Sumatera, (4,5,6,7) represent South Java, (8) Nusa Tenggara, (9) Savu Seas, (10) South Sulawesi, (11) South east Sulawesi, (12,13) Arafuru and Banda Seas, (14) North Papua, (15) Seram Seas, (16) Maluku Seas, (17) Halmahera Seas

The area of research around the Indonesian seas located on 15°N – 20°S and 90° – 140°E is a unique and complex ocean circulation surrounding the archipelago. It was in the west side (Natuna Seas, Malacca Strait, Java Seas) which is relatively shallow. In the east (Makassar Strait, Banda Seas, and Halmahera), it can reach up to 6 km. Indonesia waters border the South China Seas, Indian Ocean, and Pacific Ocean. There were 17 sample points for the SST chlor-a samples and 21 in-situ data points which were mostly located in eastern Indonesia and Indian Ocean. The sample points selection was based on previous research on upwelling within the location, approximately from the 0-20m of depths (Figure 1). The material used in this study consists of main data and supporting data. The main data used are monthly SST and chlor-a data from 2003-2018 level 3 with 4 km resolution. The SST data were obtained from oceancolor website (<https://oceancolor.gsfc.nasa.gov>) [19], and chlor-a data from globcolour (<http://hermes.acri.fr>). The in-situ data from XBT, XTD, and MBT were obtained from www.nodc.noaa.gov. The data were visualized by SeaDAS (SeaWiFS Data Analysis System) software. The data were analyzed by graphic and image qualitative description.

3. RESULT

3. 1. Temporal variation

Overall, the SST and chlor-a were varied in all months. The lowest SST was found on August (25.3 °C) and the highest STT was on May (31.32 °C). On the contrary, the highest was found on August (2.34 mg/L) and the lowest was found on February (0.13 mg/l) (Table 1). The range of SST is about 25.30 °C (August) and the highest is 31.32 °C (May). For chlor-a, the highest found was also in August (2.23 mg/l) and the lowest one was in February (0.13 mg/l).

Table 1. Statistical of data.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chlor-a (mg/L)	Min	0.14	0.13	0.15	0.14	0.18	0.18	0.18	0.15	0.15	0.17	0.18	0.14
	Max	0.34	0.30	0.35	0.37	0.70	1.45	2.07	2.23	1.65	1.15	0.82	0.37
	STDEV	0.06	0.05	0.05	0.07	0.14	0.35	0.51	0.58	0.50	0.31	0.18	0.07
SST (°C)	Min	28.82	29.10	28.90	29.47	28.34	27.00	25.99	25.30	25.64	26.90	28.10	29.00
	Max	30.29	30.88	30.99	30.80	31.32	31.04	30.63	30.75	30.50	30.91	30.43	30.75
	STDEV	0.36	0.46	0.51	0.41	0.92	1.42	1.66	1.88	1.70	1.27	0.78	0.52

The standard deviation range for chlor-a is lower (0.06-0.35) than SST (0.36-1.88). Moreover, for data validation between satellite data and in situ data, the satellite data showed values similar to data from in situ observation over the stations with $R^2 = 0.61$ (Figure 2).

Correlative Plot

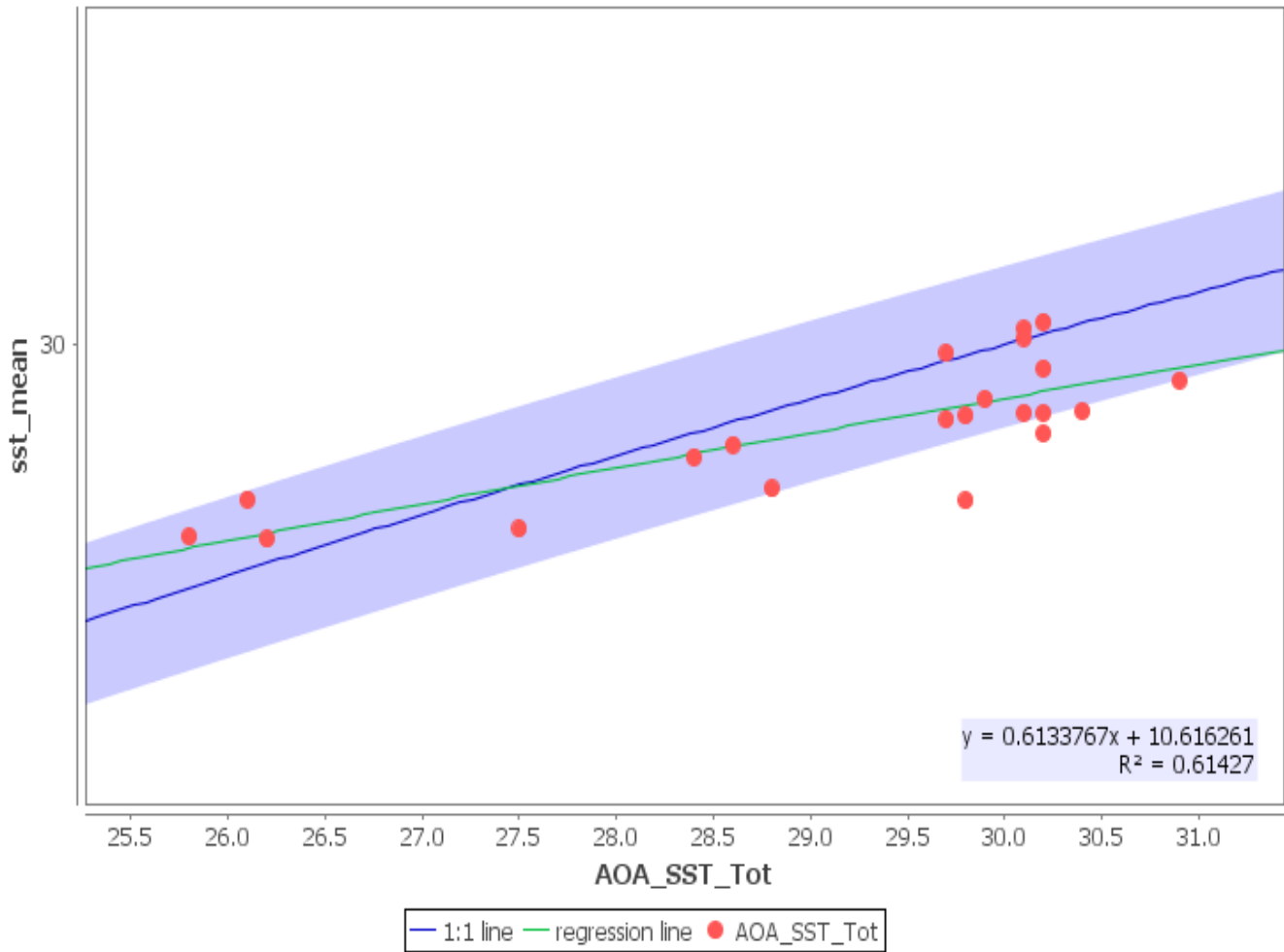


Figure 2. Insitu vs satellite data

Various SST and chlor-a were found in all pins area. Otherwise, from Jan to April and Dec, there are similar patterns. In Southern Java, Banda Sea and Aru have a similar pattern all over the months. Different from Jan-April, the SST was found to be low in Southern Java, Banda Sea and Aru (Figure 3).

For some areas in Indonesia, the SST and chlor-a experienced a significant increase especially in August. The highest chlor-a and lowest SST occurred in South Java with the minimum SST around 25.99° and chlor-a 2.23 mg/l. In western Sumatera, the chlor-a does not have a significant difference for all months.

These conditions may be affected not only by monsoon periodic system, but also by South Java Currents (SJV). Otherwise, the ITF in eastern Indonesia may also influence the SST distribution in eastern Indonesia. The southeast monsoon starts from June and ends in August every year.

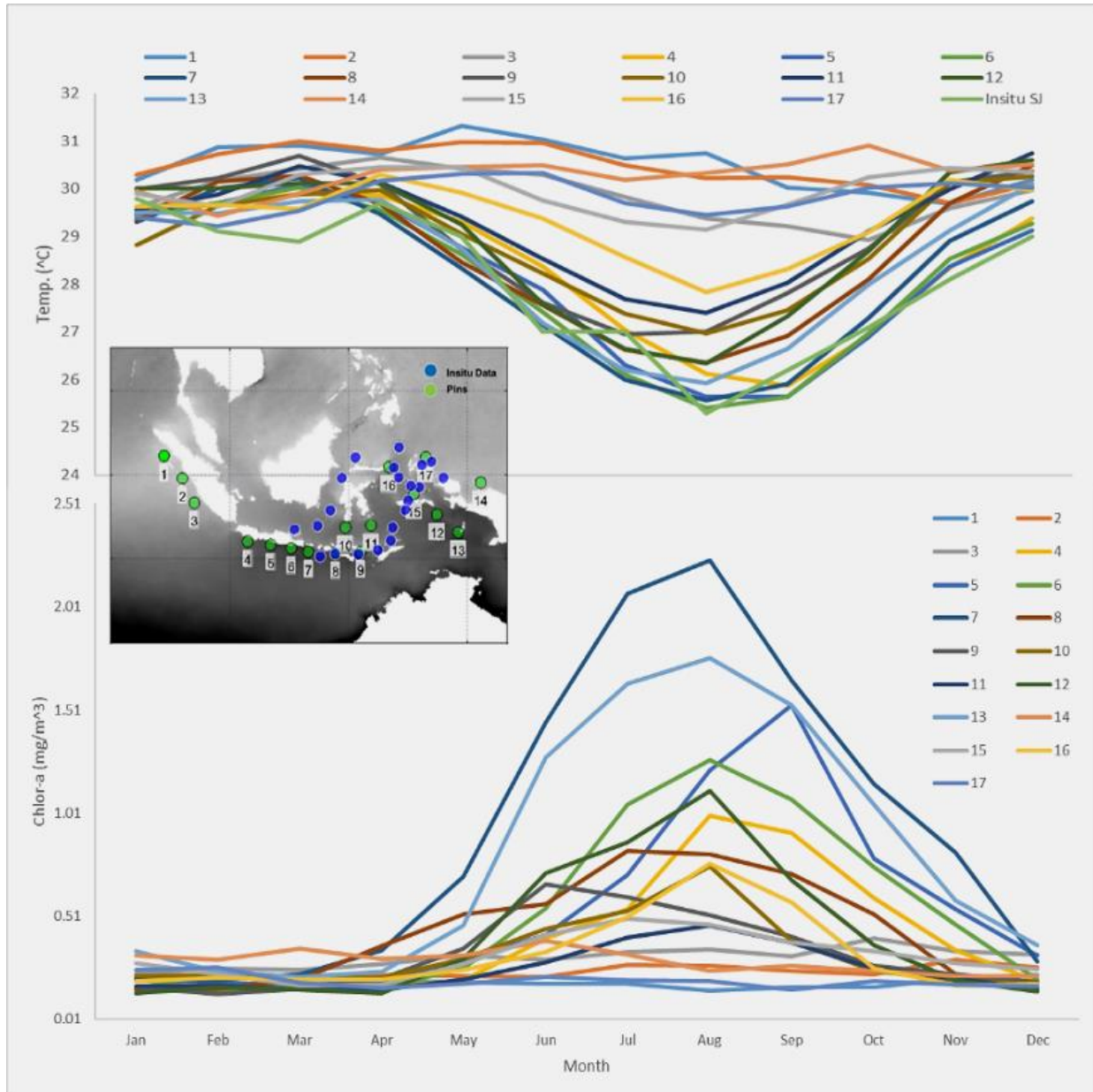


Figure 3. Temporal variation SST and Chlor-a over stations

3. 2. The Spatial Variability of SST

The spatial climatological mean of SST and chlor-a over Indonesian region clearly demonstrates the variability with complex systems. The condition of the monthly climatological of SST and chl-a in the Indonesia waters is illustrated in Fig. 2 and 3. The SST patterns in Indonesia reflect the typical equatorial warm water characteristic. During west monsoon season, warm waters in Indonesia are influenced by warm currents and winds from Asia continent. In contrariwise, during east monsoon season, cold water mass flows from east Australia influencing the eastern Indonesian waters.

A relatively high concentration and wide distribution of chlor-a was seen during May to October. During this period, high concentration can be found in some areas. In the eastern area, it tends to extend to the center and western area of the Banda Sea [20] (Figure 4). In south Java, higher concentration is located near Bali and all coasts of south Java.

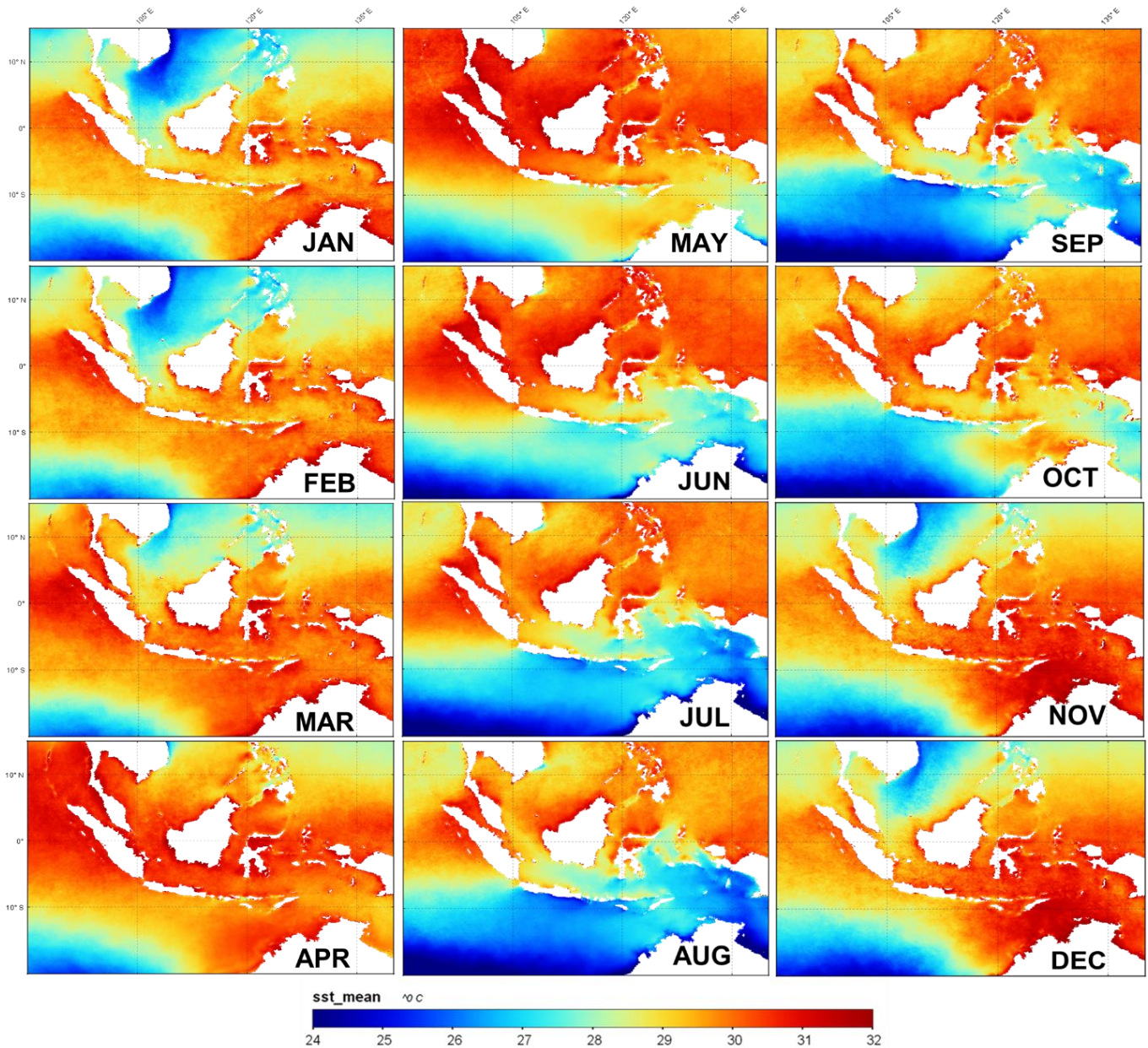
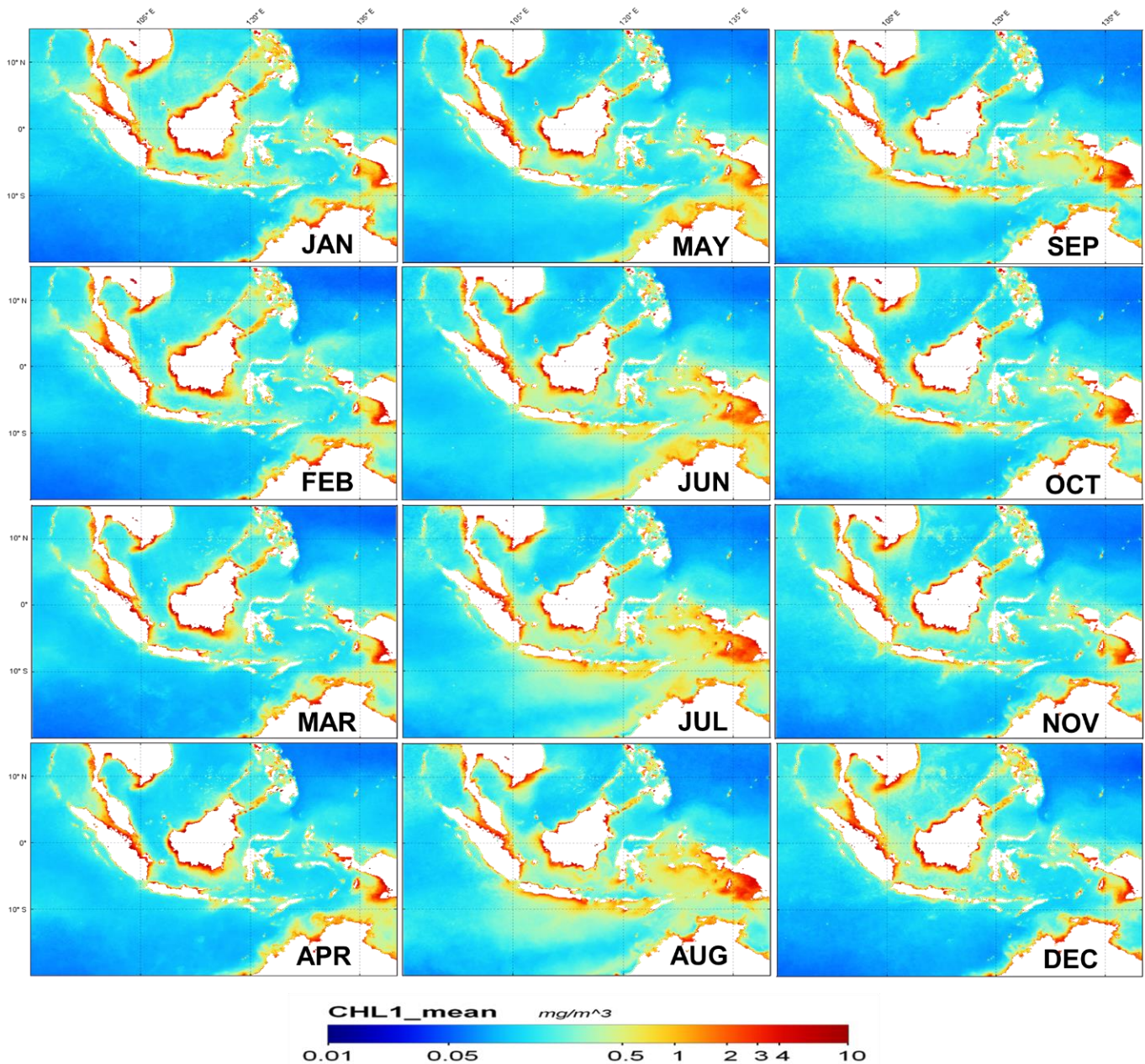


Figure 4. Monthly SST mean over Indonesia

The cool temperature as an upwelling signal first occurs from May. The following months up to October, areas such as southern Sulawesi, Aru Sea and Banda Sea began to appear noticed that there is decreasing of SST during SE Monsoon [21].

3. 3. The Spatial Variability of Chlor-a

High concentration and wide distribution of chlor-a were obviously seen from May and it was high during July to August. Other regions in Indonesia, for example southern Kalimantan and eastern Sumatera, have high concentrations of chlor-a due to the accumulation of nutrients that came from rivers. At Banda Sea, it was found that in JJA, the concentration of chlor-a was around 0.35-0.43 mg/m³. The concentration in south Sulawesi was also higher in JJA than DJF.



The area of chlor-a increases significantly especially in Aru seas from July to September and decreases in November. The higher chl-a concentration in the south Borneo and north of

Sumatera are generally along the coast, due to the run-off of nutrient from the rivers. In South Java, this behavior can be observed during the upwelling season (July to October) and especially in August and September when upwelling attains the highest values [13]. Upwelling pattern in southern Bali occurred from July to October and the peak of upwelling happened on August and September [22].

3. 4. Upwelling Session and Mechanism

In general, the SST and Chlor-a support the upwelling condition. The situation correlates with monsoonal situation. The extent of upwelling area occurred from May to October (Table 2). In this case, upwelling occurred in the entire waters with different coverage areas and intensity from month to month (Table 2).

Table 2. Summarize of the area of upwelling (the red indicates a limited area while the blue shows a large area).

Location	Distance (~km ²)					
	May	June	July	Aug	Sep	Oct
South Java	42.396	71.055	89.637	88.221	106.352	85.849
Nusa Tenggara	28.597	47.690	64.558	52.207	42.285	29.669
Savu Sea	14.928	33.998	54.080	37.029	19.251	14.852
Arafuru and Banda Sea	225.979	373.326	353.942	246.483	232.416	192.462
Seram Sea	19.735	49.491	69.920	110.001	54.086	22.104
Halmahera Sea	35.137	53.132	54.363	42.810	25.516	23.760
Maluku Sea	16.530	24.173	30.730	49.580	30.603	13.508
South Sulawesi	8.749	9.480	14.590	17.640	12.790	9.025
South-East Sulawesi	8.347	22.541	27.750	15.480	12.996	9.506
West Sumatera	18.389	38.241	25.230	30.689	51.971	38.270
North Papua	9.840	8.668	5.421	5.976	6.807	8.474
TOTAL	428.627	731.795	790.221	696.116	595.073	447.479

Changes in upwelling coverage area are influenced by wind-speeds generating the Ekman transport, and are also influenced by locations, as showed that on southern java, the upwelling occurred from eastern-off southern Java. Then, in the following month, it will move to the west. Previous research [16, 23] showed that mechanism regarding chlor-a blooms in Maluku Sea is

associated with increased alongshore wind fields that drag cold water from beneath mixed layer, which support phytoplankton growth in the region. Upwelling starts in the eastern area and moves to the west. Therefore, the eastern Banda Seas and Aru Sea tend to be the location of the greatest upwelling event in Indonesia.

To summarize, upwelling in Indonesia occurred in 11 areas with different intensities. The areas are located in west Sumatera, around south Java and Nusa Tenggara, Aru and Banda Seas, Sulawesi, Halmahera, and north Papua (Figure 5). These are permanent locations in which upwelling occurs every year. There is no upwelling region in shallow waters especially in Java Natuna Seas because of the depth. Moreover, in Malaka strait, the wind is not enough to force the watermass from the bottom due to the narrow strait.



Figure 5. Summarize of upwelling locations

Monsoon significantly controls the upwelling situation in the study area. Upwelling occurs during southeast monsoon from Australia to Asia passing through Indonesia. In Java Island, the wind blows parallel to the coast and due to the coriolis force, the currents is deflected away from the coast. Interactions between coriolis force, water friction and wind result in the emergence of Ekman transport (Figure 6).

Upwelling phenomenon occurred when the water mixed from the bottom moves upward to the surface. Frictions between winds and water mass on the surface cause the water to start moving. The coriolis force deflects the water to right (at BBU) and to the left (on BBS). Then,

the Ekman transport results in the movement of water mass toward offshore. Coastal upwelling can occur when surface water mass is replaced by water mass from downward.

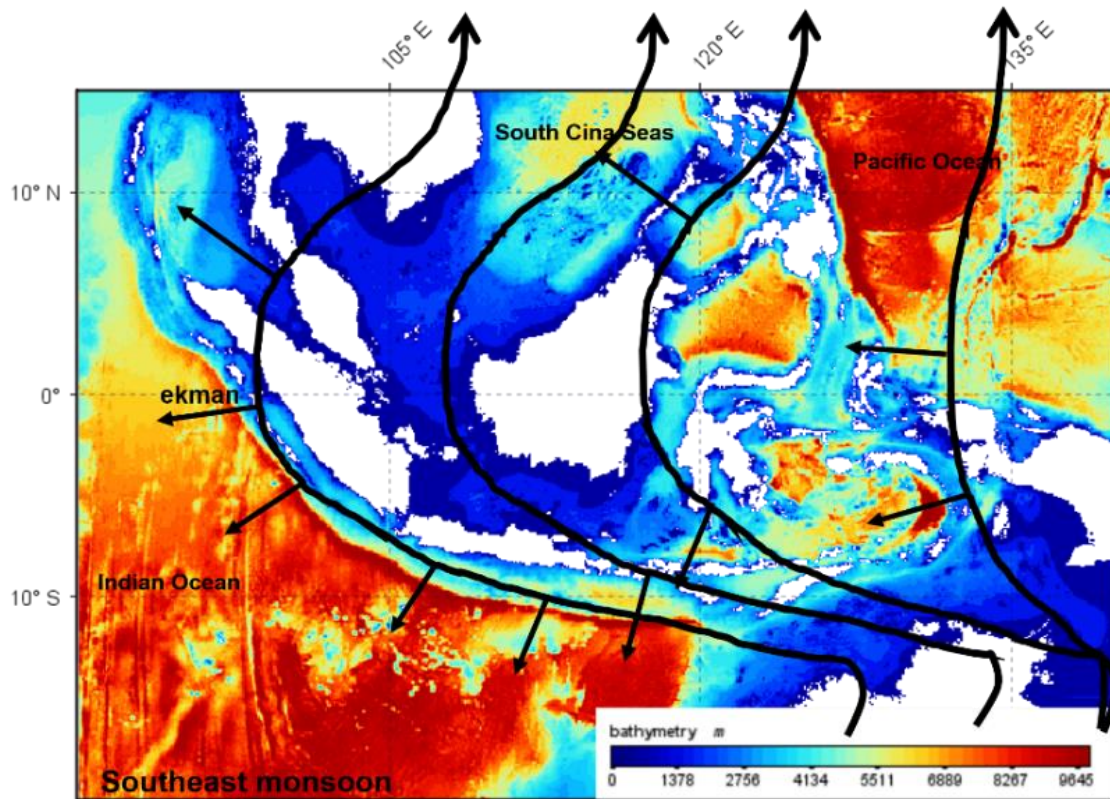


Figure 6. Monsoon pattern and Ekman direction in SE Monsoon.

Upwelling in western Sumatera does not vary clearly but the southern tip of Sumatera, Lampung indicates that upwelling may occur in limited areas. In Papua waters, the upwelling was indicated in February (west season) [17]. The absence of upwelling during west-monsoon season in the northern Indonesia is due to several reasons. First, the northern Indonesia waters, especially in Malacca Straits and Natuna Sea, are known as areas with shallow waters so that no water mass from the deep waters rises upwards. Furthermore, the northern-off east Indonesia, especially in Sulawesi and Morotai, experiences the same conditions. Since the study area is close to the equator, then the coriolis force can be neglected.

4. CONCLUSION

This article has identified the upwelling session in Indonesia area based on satellite data (temperature and chlor-a) and analyzed it is characteristic. Upwelling occurs during southeast monsoon from Australia to Asia passing through Indonesia water. The results presented here have shown the existence of the regions of upwelling in south Java, Banda and Aru Seas, south of Sulawesi, Maluku Seas, and North Papua. The characteristic of upwelling affected by

monsoon periodic. Monsoon considerably controls the upwelling condition in the study area. These area form spatially and temporally stable every year [24].

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