A Schematic Model of Low Temperature and High Salinity Seawaters in Southern Java of the Indian Ocean during ENSO-IOD 2017

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Abstract. The semi-permanent jAVA coasTal Upwelling that is known as RATU, it was named semi-permanent because upwelling does not occur every month of the year in Southern Java has been investigated by several international researchers. However, this study focused on investigating the horizontal distribution of upwelling areas, using the indicator of low temperature (max. ~26°C) and high salinity (min. 34 PSU) seawater mass, in different depth layers. The datasets were obtained from HYCOM, with the wind daily as well as the monthly ONI, SOI ENSO, and DMI datasets obtained from ECMWF, NOAA, BoM Australia, and Jamstec, respectively. Furthermore, the horizontal propagation of the low temperature and high salinity in 2017 at depths of 0 m, 50 m, 75 m, 125 m, 150 m, and 300 m have been observed and modeled as schematics. According to the results, the probable upwelling area begins from 150/125 meters to 75/50 meters layer depth. In these layers, the horizontal propagation from the east monsoon (July) to the transition monsoon (October) dominantly begins from the east and moves westward. This shows the highest correlation between temperature/salinity and SOI occurred from August to October during La Nina, from a depth of 0 m to 100m. Similarly, for the ONI, low temperature and high salinity also occurred from the Normal phase to the La Nina phase. The correlation between temperature/salinity and IOD shows the probable upwelling season occurred during IOD (+) phase until a 100 m depth because salinity becomes more irregular with increasing ocean depth.

1. Introduction
The waters in Indonesia are influenced by a changing wind system known as the monsoon wind [7]. Furthermore, the southern Java waters are offshore and connected to the Indian Ocean, where upwelling occurs during the east season, from June to mid-October. However, this is also affected by the El Nino Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), and the Indonesian Cross Flow (ICF) [5].
Meanwhile, upwelling is the process where a water mass rises from the deeper water column to the surface due to wind movement, as well as several other factors [1], and is usually indicated by lower temperatures, compared to other areas with nutrient-rich water mass on the surface [8].

The occurrence of this phenomenon has been studied widely, including the process and consequences [3]. Several researchers have identified the location and intensity, as well as their correlation to climate variability in the southern Java waters, using satellite imagery data in the form of sea surface temperature distribution and chlorophyll-a concentration values. The upwelling intensity is determined based on the temperature average range (26°C – 28°C) and chlorophyll-a values [6]. Other studies have also reported the phenomenon’s spatial and temporal distribution using the same technique, such as the study that was done previously by [5] and [8], stating that the commonly range of the seawater surface temperature (SST) at upwelling area are about 26–28°C. This is also observed from the water mass movement with low temperature and high salinity as an indicator of upwelling. Which however, the salinity distribution is influenced by various factors such as water circulation patterns [11].

Currently, studies of vertical upwelling dynamics in Indonesian waters are limited, especially regarding monsoons, ENSO, IOD, and seabed morphology. This study, therefore, identifies areas and upwelling movements from deep layers to the surface, based on the spatial distribution of mass movements of low temperature and high salinity water. Vertical information is important for a detailed observation of the dynamics and events in waters.

2. Research Methods

This study used a quantitative descriptive method involving schematic model formulations and analysis, to discover areas in the waters of Southern Java where upwelling occurred in 2017 and the movement at a certain depth. Subsequently, supporting data, including wind data, as well as ENSO and IOD index were processed to support the discussion.

2.1. Location Determination

The study area covers the Indian Ocean in southern Java at coordinates 105.4375°E to 114.7125°E Longitude, and -6.75°S to -14.9°S Latitude. This location was determined by considering the phenomenon that exist in the area and also the data availability. Furthermore, the Indian Ocean reaches an 8,047 m depth, therefore, transects were carried to determine the mass movement of low temperature and high salinity water as an upwelling indicator at 0 m (surface), 50 m, 75 m, 125 m, 150m, 300m depths. The selected depths are representative of the ocean's three layers, with 0 m, 50 m, 75 m representing the Mixed Layer Depth, 125 m, and 150 m representing the thermocline/halocline layer, while 300 m represents the fixed layer.

2.2. Data Collection

2.2.1. HYCOM Temperature and Salinity Data. The temperature and salinity data used are models downloaded from hycom.org in Net Common Data File (NetCDF) format, in the form of daily data for 12 months in 2017 in 33 depth layers with a resolution of 1/12°. Subsequently, the downloaded data was processed spatially and temporally.

2.2.2. ECMWF Wind Data. Data on horizontal wind direction and speed on the surface of the European Centre for Medium-Range Weather Forecasts (ECMW) was downloaded from the website http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc/ and was used during 2017 with a resolution of 0.75 x 0.75°. This data is the direction and speed in components u and v at 10 meters above sea level.

2.2.3. ENSO and IOD Index Data. The ENSO index was divided into 2: SOI from http://www.bom.gov.au and ONI from http://www.esrl.noaa.gov. Meanwhile, IOD uses the DMI index from http://www.jamstec.go.jp.
2.3. Data Processing Method

2.3.1. Processing of Temperature and Salinity Data Per Layer. The data used were from HYCOM and monthly data in 2017, processed in Matlab by averaging per depth to obtain the spatial plot. Subsequently, the upwelling area was determined based on the criteria for temperature below 26°C and salinity above 34.

2.3.2. Wind Map Data Processing. The wind data is in the form of monthly climatological data during 2017 was obtained as wind speed and direction then processed with Excel to create a wind map in the Arc Gis.

2.3.3. Data Processing Correlation Between Temperature and Salinity with ENSO, and IOD. Primary data of temperature, salinity was obtained from HYCOM and processed in Matlab to obtain the average from all the depth layers selected as transects. This was followed by creating a graph of the relationship between temperature and salinity with the ENSO, and IOD index.

2.3.4. Data Analysis. The horizontal display of average temperature and salinity will be observed for the movement in each month from 33 depth layers. And after we get the propagation of the water mass in the Southern Java of Indian Ocean, it will be correlated with other parameters such as surface winds, ENSO, and IOD index.

3. Results and Discussion

3.1. Wind Map in the East Season (June, July, and August 2017)

Based on the results, during the east season, in June, July, and August 2017, the wind blows from the southeast to the northwest, consequently, these months are called the southeast monsoon or east monsoon. According to [10], the Asian continent is exposed to more sunlight and, therefore, has a higher temperature as well as low pressure, compared to the Australian counterpart, due to the sun’s location in the northern hemisphere. The wind moves from high to lower pressure or from Australia to Asia, and has a higher speed in June close to the offshore of about 8 m/s, compared to the coastal areas of 4 to 7 m/s. Meanwhile, in July, the maximum wind speed is along latitudes 105° to 107.25°, and ranges from 7 to 9 m/s, in some locations and from 7 to 8 m/s, in others. In August, upwelling occurred with a larger volume, compared to the previous two months in the east monsoon, while the maximum speed was more diffuse and not fixed on the coastal or offshore, with a range of 7 to 9 m/s. However, compared to July, the August wind was less strong and with a larger upwelling volume, because the assistance from July when the wind was strong helped the mixing process. This process continued until August and even
down to October, meaning July is the initial period, from where the upwelling becomes more widespread with time.

3.2. The Ocean Temperature Propagation Schematic Model

![Figure 2. The Schematic Model of Temperature Propagation at a 50m Depth](image)

![Figure 3. The Schematic Model of Temperature Propagation at a 75m Depth](image)

When the wind blows across the ocean, it moves the surface currents on a large scale in a similar pattern. The water masses’ movement on the surface is predominantly influenced by the wind’s movement, and this has a higher speed in the east season (June, July, August), compared to other seasons, moving to the west then turning to the southwest. The temperature in the oceans is located at about the same degree. Therefore the isotherm lines above the ocean are more aligned than the isotherm lines above the land. A study showed the Java southern waters to Timor during the east season to transition II are passed by southeasterly winds blowing intensively, and then peaking in July and August.
consequently, the surface temperature is lower, compared to other seasons [4]. The upwelling occurs in the coastal area during the east season until the transitional season II, causing a mixing process in the inner layer, subsequently, raising the cold temperature to fill the void of the water mass, making the surface temperature lower, compared to the month where upwelling did not occur. Consequently, the depth of the thermocline upper limit is bound to increase further and also be influenced by the month’s mixing speed. At a depth of 300 meters, including the fixed layer, the water masses’ movement is not affected by the wind but is assumed to be more influenced by the movement of the Leeuwin current, gyre, and Indonesian cross currents [9].

The water mass is pushed to the north by the Leeuwin current then deflected by the Coriolis to the west, as observed during the west monsoon, the transitional season I, east season, and transitional season II. In the transitional seasons, I and II the water mass moves closer to the coast (March-April-May) and away from the coast (September-October-November). The southeastern Indian Ocean is dominated by currents along the west coast of Australia (22°S-34°S), known as the Leeuwin current, and this moves dominantly towards the south, while the undercurrent moves to the north [2].

3.3. The Ocean Salinity Propagation Schematic Model

The spread of salinity is naturally influenced by several factors: glaciers, evaporation, ocean currents, mixed turbulence, and wave action [12]. In the east monsoon (June, July, August), the wind blows quite strongly compared to other months, and the mass of high salinity water from the eastern Indian Ocean ranges from 34.6 PSU moves to the north, then turns west to latitude 110-111°S. Upwelling also occurs in transitional season II (September, October, November), particularly in September and October. Upwelling lifts water mass with high salinity levels in the inner layer to water surface salinity [13]. The winds have started to weaken in this season, compared to the east monsoon, bringing water masses with salinity above 34.4 to 34.6 PSU from the south of Ujung Kulon, West Java, and receiving water mass from the Java Sea, then moving to the southeast towards a row of troughs. Meanwhile, in November, the water mass input with a salinity of 34.4 to 34.6 comes from the southern Indian Ocean and moves to the northwest in small amounts. Therefore, the movement of water mass at a 0-meter depth is quite complex because the input has high salinity compared to other areas, and is influenced significantly by the wind.

Based on the results, the high salinity concentration from June to October is due to the presence of gyre currents occurring from July to September, and consequently, affecting water mass movement [9].

Figure 4. A Schematic Model of the Salinity Propagation at a 50-meter Depth
Figure 5. A Schematic Model of the Salinity Propagation at a 75-meter Depth

3.4. The Relationship Between Temperature and ENSO, as well as IOD

Based on the relationship graph between temperature and SOI from a depth of 0 meter, August and September have lower temperatures, compared to other months. The SOI increased from June to September in line with the decreasing temperature and began to increase from September to October, followed by the SOI value. In addition, the temperature was discovered to be lower from February to April, compared to other months, therefore, in the first area case, during the month where upwelling at a greater volume compared to other months, August and September are in the Normal phase.

The DMI value shows were no IOD (-) in 2017, but in December 2016, only. At a surface depth of 100 meters, the temperature decreased from June to September, followed by a decrease in the IOD, indicating a positive correlation between temperature and IOD from July to September. In October, the temperature begins to increase while the IOD value remains constant and decreases, however, upwelling occurs from July to October during the IOD (+).

From the result of the relationship between the temperature and ENSO graph, we can also see that the temperature is not really influenced by ENSO in 2017. It maybe happens because during 2017 there is no strong El-Nino phase that usually helps the upwelling to be stronger. We can see that 2017 is dominated by normal phases, so this year can be referred as “Neutral ENSO” years so it has no major effects on the temperatures. This situation is actually might be the result of Calvin Waves that happened in 2016, but we need to do more research on this one.
3.5. The Relationship Between Salinity and ENSO, as well as IOD

Maximum salinity values occur from July to October, and this is positively correlated with the SOI index, but negatively correlated with the ONI. This is contrary to the report [9], where salinity variability is negatively correlated with the SOI, due to differences in the year under study, probably pressure differences. The SOI value from July to October has a higher value, compared to other months, however, maximum salinity from August to October occurs in the Normal phases (August and September) and La Nina (October).

Based on the relationship graph between Salinity and IOD in all areas, salinity decreases from July to October with a decrease in the IOD index. The upwelling occurs in the IOD (+) phase starting from 500 m depth to the deep layer, where the salinity variability is positively correlated to the DMI and decreases from July to October. In the coastal area, maximum salinity occurs from August to October, with decreasing IOD, therefore, the largest area of upwelling in September occurs in the La Nina-IOD (+) phase. In the offshore area, the maximum salinity at 0-10 meters depth occurs from October to November, with decreasing IOD. This is because IOD only affects the surface salinity and is calculated based on the difference between SST in the east African continent and the western Indian Ocean. As per
previous statement, since 2017 ENSO is dominated by normal phase, so there is not much difference on the intensity of salinity during the upwelling phase or not. In 2017, its intensity is more influenced by the seasonal change due to high speed of wind during June-July-August that triggered the mixing on September and October.

4. Conclusions
High upwelling, based on a minimum temperature of 26°C and a maximum salinity of 34 PSU, starting from 150 to 125 meters depth, and rising to a layer of 75-50 meters depth, occurs at latitudes of 108-109°S, 109.651°-110,072°S, and 110,877°-114,685°S.

High upwelling occurred from July to October 2017 while the southeast monsoon winds move with 8 m/s speed, therefore, the dominant growth moves from the east to the west. At this time, a coupling occurred between La Nina and IOD (+), but the expansion area tends to be influenced by IOD (+).

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