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Study of Seasonal Variation of Sea Surface Salinity in Java Sea and its Surrounding Seas using SMAP Satellite

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Abstract. This research was conducted in The Java Sea and Surrounding Seas. This study uses satellite data with the period in 2015 - 2017, which composed of the main data of sea surface salinity and supporting data of rainfall, evaporation, wind, and current. The entire data processed into monthly climatology data and analyzed by using Pearson correlation. The salinity of Java Sea is generally in the range of 30.0 to 35.0 ‰. However, we found some phenomena in four areas, that is the significant decrease of salinity reach up to 30.919 ‰ in April in south waters of Borneo. Those influenced by river run off from the high precipitation reach up to 0.689 mm/hr in Borneo land. In south waters of Sulawesi, there is the highest increase of salinity in October to November reach up to 34.45 ‰ which affected by Banda Sea's water mass entering the area. Salinity fluctuation in Natuna Sea is inversely proportional to other study areas, influenced by the geographical condition in the Northern Hemisphere which was crossed east monsoon and by the minimum salinity of water mass from the Java Sea which moved by the current which has correlation around of -0.717 between salinity and current. Negative of the high value shown big inverse relation. While the phenomenon of decreasing salinity is occurring in West Sulawesi waters in June, it is influenced by mass input from Banda Sea that depresses Java Sea waters and ARLINDO (Indonesia cross flow) which had minimum salinity from the west season.

1. Introduction

The hydrology condition of the Java Sea was influenced by two monsoon seasons which alternates every year. Southeast (SE) monsoon occurs from Jun to August which is associated with easterly wind from Australia. The SE monsoon carries warm and dry air over the region. From December to February, northwest (NW) monsoon associated with westerlies from the Eurasian continent carries warm and moist air to the Indonesian region [1]. They cause fluctuation of the distribution of salinity, sea surface temperature, patterns-velocity of the Java Sea current [2]. Based on this, information on oceanographic parameters of the Java Sea and its surrounding seas is important to be investigated since these areas have the potential fishery resources.

Some parameters that have an important role in the marine life are the sea surface temperature (SST) (e.g. Hamuna et al [3], explained in his research that SST directly influence the life of sea organisms) and sea surface salinity (SSS) (e.g. SSS is indicator of water cycle alteration which affect



each other between water surface moisture (P-E) and the dynamics of mixed layer, like horizontal transport of salinity and vertical mixing [4]). However, there is a big technological gap for investigating those 2 parameters. One of the most useful technique is remote sensing approach due to its long (wide) temporal (spatial) coverage of observation. Remote sensing approaches has been widely used to investigate the SSTs phenomena due to the long record of satellite based SST measurements i.e., since 1980's. This is because the effectiveness of satellite imagery in monitoring SST periodically, so that the dynamics and symptoms of SST changes can be observed periodically-continuously and the spatial distribution patterns can be analyzed [3]. Different conditions occur in salinity studies which mainly only used insitu observation. Thus the spatial and temporal variation of SSS were not clearly revealed in the previuos studies [5].

Study of SSS which is influenced by seasonal variations is necessary to determine influence of seasonal patterns in waters, the presence of water masses and the rate of precipitation-evaporation in waters. The remote sensing approach is used in the present study by using SMAP satellite imagery launched in January 2015 [6]. The SMAP satellite is the latest satellite image with the original launcing aim is to obtain the information on soil moisture status with various roles. However, the satellite sensor is also capable for recording SSS by using an L-band radiometer with a spatial resolution of $0.25^0 \times 0.25^0$ [7]. The SSS data obtained from SMAP has been corrected and validated by Argo floats, moored buoys, and TSG vessel data on a time variation scale, with 0.2 PSU accuracy [8].

Variability of SSS occur due to several factors, including the level of precipitation - evaporation, current, wind and the input of other water masses. All of these factors will be examined in the present study to obtain the spatial and temporal variation of SSS in the Java Sea and its surroundings.

2. Research Methods

This research study was conducted in Indonesian waters especially in the Java Sea and its surrounding seas using a remote sensing approach. The main data used sea surface salinity data obtained from coverage of SMAP Mission for the 2015 to 2017 period with a spatial resolution of $0.25^0 \times 0.25^0$ in the form of monthly data [9]. NASA's Soil Moisture Active Passive (SMAP) mission is a satellite launch mission carried out in January 2015. This mission uses L-band radar and L-band radiometers simultaneously, integrated measurements at the same time as an observation system. This combination takes advantage of the relative strength of active (radar) and passive (radiometer) remote sensing microwaves to map soil moisture [10]. Supporting data used include rainfall data, evaporation data, current and wind data. Rainfall data and evaporation come from ECMWF with a resolution of $0.25^0 \times 0.25^0$ [11], the wind data was used ASCAT data $0.25^0 \times 0.25^0$ resolution [12] and $0.08^0 \times 0.08^0$ resolution of current data obtained from Hycom data. The use of supporting data is of course with the same time as the main data.

This research data consists of daily and monthly data. Daily data are ASCAT wind data and Hycom current data. Monthly data consists of SMAP SSS data and precipitation – evaporation ECMWF data. These data need to be extracted and compiled in daily averages to monthly averages and compiled monthly climatology data. The following is the formula according to Wirasatriya, et al [13], for composite daily average data:

$$\bar{X}_b(x, y) = \frac{1}{mh} \sum_{j=1}^{mh} x_i(x, y, t) \quad (1)$$

Description :

$\bar{X}_b(x, y)$ = Daily average

$x_i(x, y, t)$ = i-daily data at longitude (x), latitude (y), time (t)

mh = Number of hours in 1 day

j=1 = day i

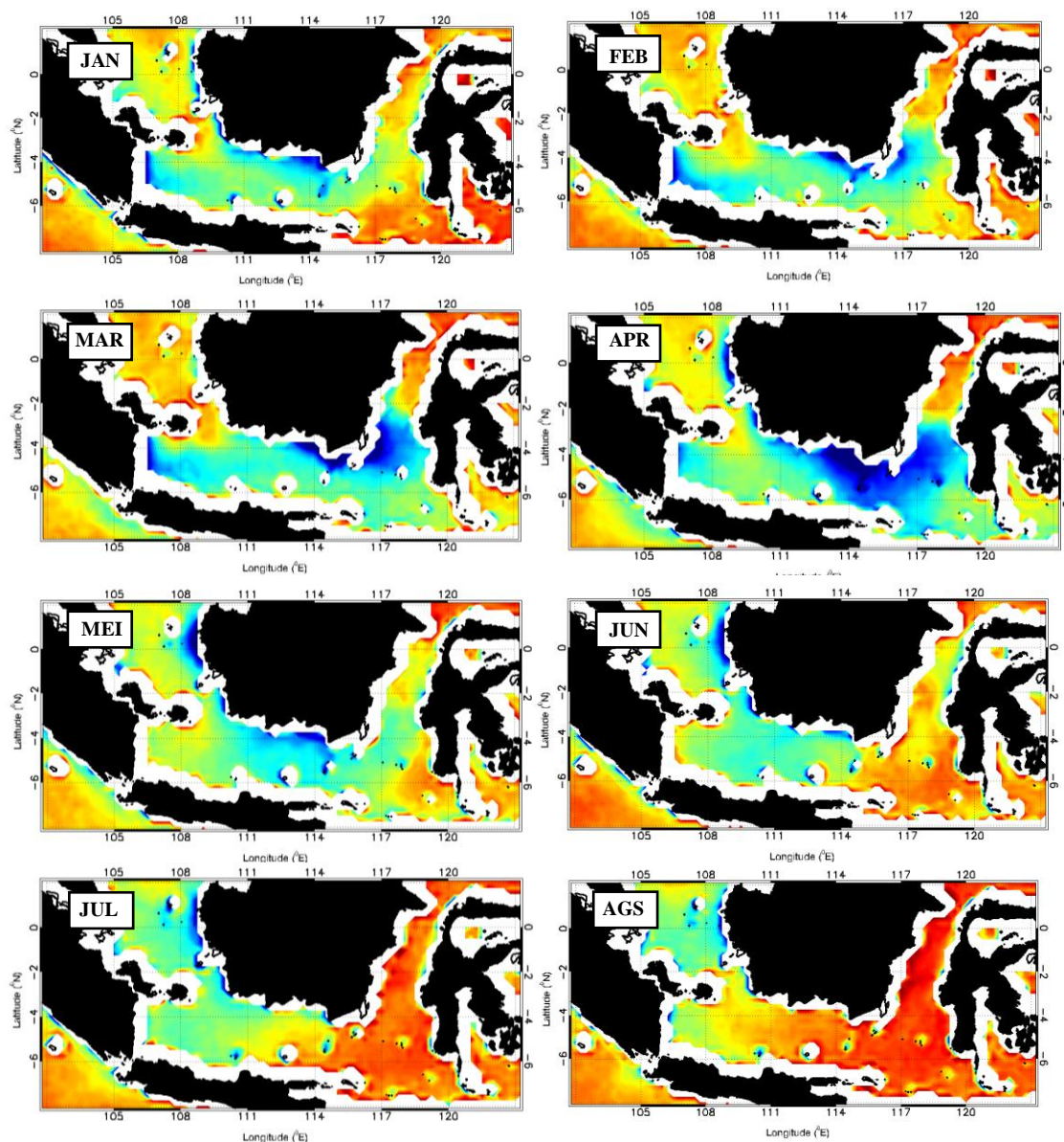
x_j = Nan in processing data shows data that has no value (empty value) and is not included in the calculation of daily averages.

After obtaining monthly climatological data with the .sav format, the data will be displayed in the form of images and further analyzed spatially and temporally. Results of sea surface salinity distribution analysis obtained areas with specific salinity distribution including, south waters of Borneo, south of Sulawesi, west of Sulawesi or the Makassar Strait and Natuna Sea which has the following geographic location, south of Borneo (longitude: 112E – 116E, latitude : 6S - 4S), south of Sulawesi (longitude: 117E – 120E, latitude: 8S –6S), west of Sulawesi (longitude: 117E – 120E, latitude: 2S - 0) and Natuna Sea (longitude: 106E – 109E, latitude: 2S - 0).

3. Result and Discussion

3.1. Distribution of Sea Surface Salinity in the Java Sea and Surrounding Seas

Sea surface salinity in Indonesian waters changes every month and season which is influenced by Indonesia's climate, namely changes in the east and west seasons. The minimum salinity is close to 30.0 ‰ and the higher reaches 35.0 ‰. During December to May in the Java Sea and its surroundings shows a low salinity compared to other waters. While from June to November, the Java Sea and its surroundings experienced an increase in salinity. This condition is in accordance with the current season in the territory of Indonesia.



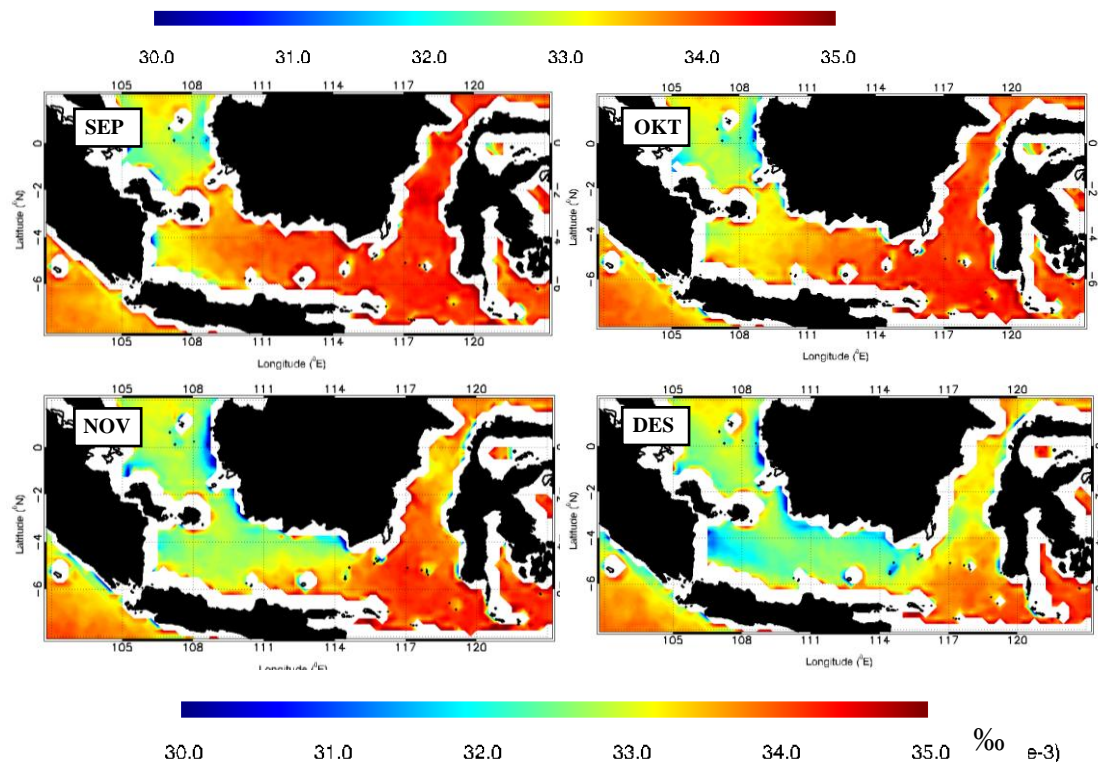


Figure 1. Spatial Distribution of Sea Surface Salinity Monthly Variation in the Java Sea for the 2015-2017 Period.

Based on the spatial interpretation of the color gradations in the image of sea surface salinity shown in Figure 1, in certain watershed areas found the phenomenon of salinity that are too low or too high that do not match the surrounding area. These conditions indicate the existence of other parameters or certain conditions that affect the occurrence of the phenomenon.

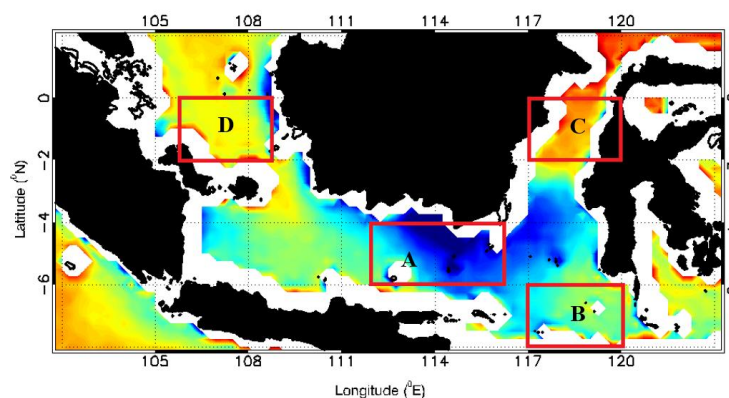


Figure 2. Water areas of the Java Sea and surrounding seas which shown existence of specific SSS distribution.

The spatial distribution of sea surface salinity throughout the year, there are four study areas that have phenomena which is shown in Figure 2. Case A is the south waters of Borneo, Case B south waters of Sulawesi, Case C is the west waters of Sulawesi or the Makassar Strait and Case D is the Natuna Sea.

Salinity phenomenon occurs because the condition of the Java Sea and its surrounding salinity is influenced by the seasons in Indonesia and Indonesia's geographical location is flanked by two Oceans, namely the Pacific Ocean and Indian Ocean which has a higher salinity of water mass. Ocean water mass input occurs alternately every season, that is in the west season, the water mass from the

South China Sea and Pacific Ocean are added more in the Java Sea and surrounding seas. Whereas in the east season, the input of water mass from the Banda Sea and Indian Ocean influence a lot of the salinity in the Java Sea and its surroundings. This makes the hydrological conditions especially complex salinity occur in the territorial waters of the Java Sea because many parameters influence it.

3.2. Relation between SSS and Precipitation - Evaporation in the Java Sea and Surrounding Seas

an increase in the value of rainfall occurs in the month that approaches the western season or the rainy season. The opposite condition occurs, namely a decrease in the value of rainfall can show an increase in the evaporation process in the waters. This occurs because of the influence of the eastern monsoon from June to October. Based on the spatial distribution of evaporation, irradiation almost occurs throughout the year. This condition occurs because Indonesia is an area that is on the equator, so that it gets irradiation from the sun all year which affects the hydrology condition. The condition of increasing and decreasing the value of evaporation in Indonesian waters is inversely proportional to the conditions of its precipitation.

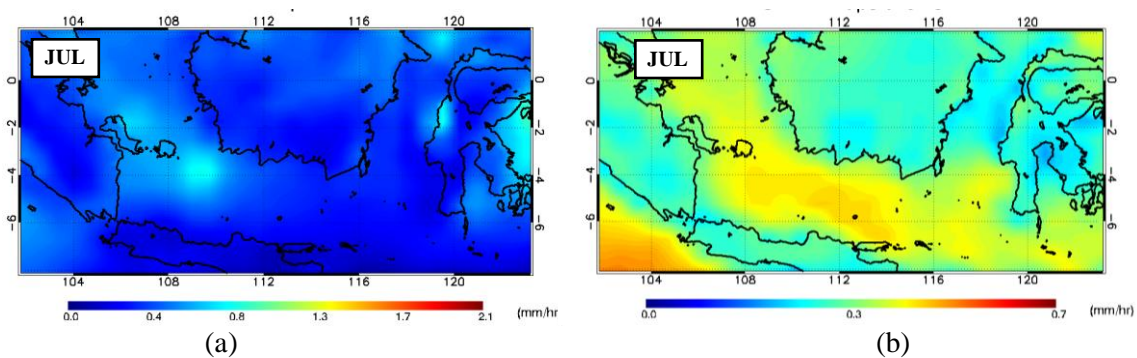


Figure 3. Conditions of (a) Precipitation and (b) Evaporation in the Java Sea and Surrounding Areas in July.

From the results of Figure 3 shown, in July the value of evaporation experienced a significant increase and vice versa in the value of precipitation. The evaporation value in the Java Sea which is indicated by the gradation of yellow to red has a value close to 0.7 mm / day, while the precipitation process in the same region approaches 0.345 to 0.0 mm / day. These conditions alternately occur based on the seasons that occur in Indonesian waters. In the dry season or the East season is affected by the presence of dry East monsoon, so the removal of the water column in the water is more than the water input. The amount of water column that enters the surface of the water throughout the year can be known by subtracted the process of entering the water column in the waters through precipitation by the process of lifting the water column in the same water through evaporation (P-E). The amount of P-E in the water shows the total number of water columns entering the water which will affect the level of salinity on the surface of the water. The higher the P-E value in the waters will dilute the salinity in these waters.

The process of precipitation, evaporation and the level of P-E that occur in a waters is one of the common causes of fluctuations in salinity values in waters, especially in the study area of the Java Sea and its surroundings. Given this, an analysis of the relationship between salinity, precipitation, evaporation and P-E in the study area that has salinity phenomena (waters of south of Borneo, southern Sulawesi, west Sulawesi / Makassar Strait and Natuna Sea) was conducted to determine the causes of phenomena in the four study areas.

3.3. Relation between SSS and Current in the Java Sea and Surroundings

Indonesia is a country flanked by two oceans, namely the Indian Ocean and the Pacific Ocean. The existence of these two oceans greatly influences the condition and direction of the currents that pass in Indonesian waters. In the western season, the visible currents in Indonesian waters are the result of the

movement of water masses from the Pacific Ocean through ARLINDO (Indonesia cross flows) and the South China Sea which have a higher salinity value. In November the movement of the South China Sea began to enter the waters of the Java Sea at a slow pace and accelerated until February. Whereas in the east season, from May to September, the waters of the Java Sea are affected by currents carrying a water mass with a higher salinity from the Banda Sea and Indian Ocean that crosses the Java Sea

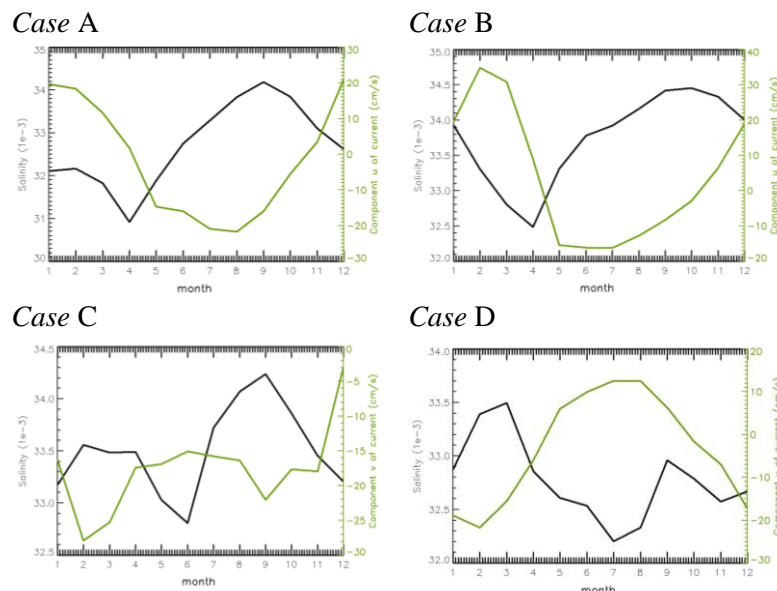


Figure 4. Relation SSS and Current in Four Study Area. Case A (South Water of Borneo) and Case B (South Water of Sulawesi) with Current movement (U Component) to Eastern or Western; Case C (Water of West of Sulawesi or Makassar Strait) and Case D (Natuna Sea) with Current Movement (V Component) to Northern or Southern.

towards the west. From the distribution of water masses throughout the year in the Indonesian landscape brought about by currents, it is known that the Java Sea and its surroundings are territorial waters that are heavily influenced, especially for fluctuations in salinity.

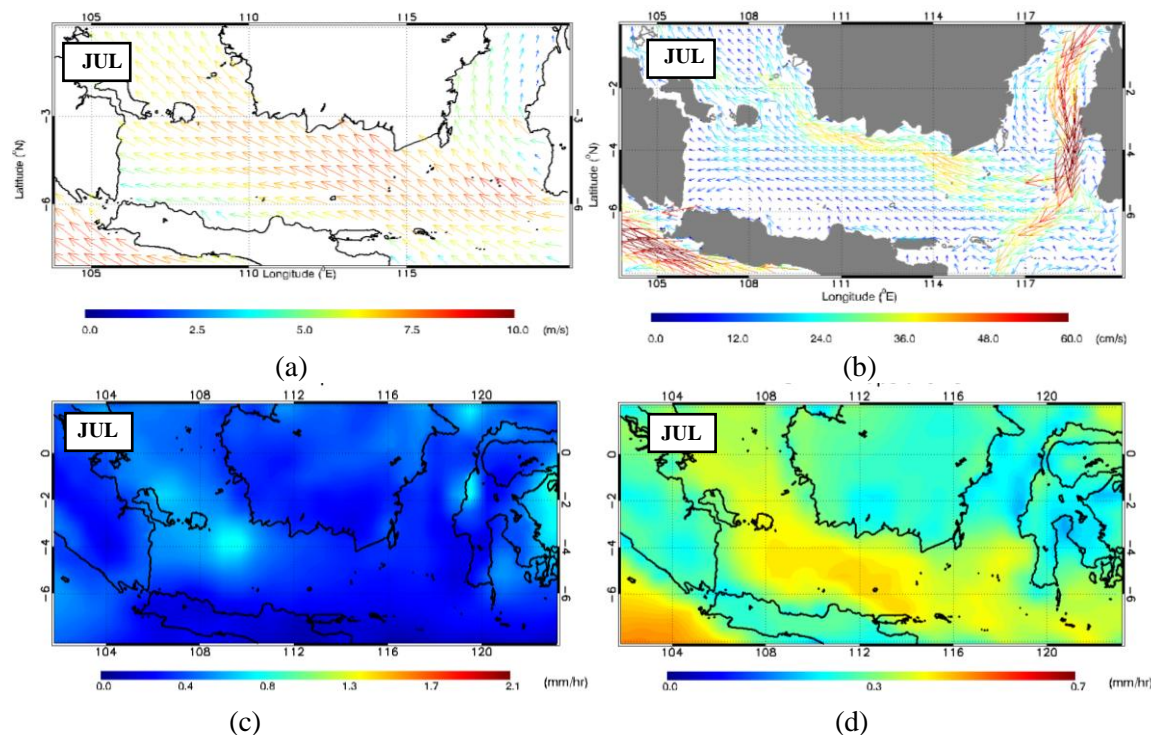
Current graphs which shown in Figure 4 are depicted based on positive and negative values. Positive values describe the current conditions that lead to the east or north and the negative values represent the current pointing west or south due to the current value. The four study areas showed that in the west season the high salinity movement of the South China Sea water mass from north to south enters the Natuna Sea at high current velocity and is deflected eastward to the south of Borneo and south of Sulawesi at an increasingly low speed. The closer the study area to the South China Sea, the greater the flow and the influence of the high salinity of the South China Sea on these waters. The weakening of the current strength will reduce the influence of the high salinity of the South China Sea in these waters. Similar to the Natuna Sea, the flow of currents that carry the water mass of the Pacific Ocean from north to south through ARLINDO throughout the year that passes west of Sulawesi or the Makassar Strait has experienced an increase in speed during the western season, causing an increase in current velocity and salinity in the southern region of Sulawesi. The opposite condition occurs in the east season, the direction of the current changes and the influencing water mass also changes, namely the mass of the Banda Sea and Indian Ocean water which has a high salinity. The study area that gained a lot of influence from the movement of high salinity of that water mass was south of Sulawesi and south of Borneo. While exceptions occur in the west of Sulawesi or the Makassar Strait which has the flow of ARLINDO. Current movement always enters Indonesian waters, but what distinguishes each season is the current velocity from ARLINDO. In the east season, a decrease in the flow velocity from ARLINDO will occur, resulting in a pressure of water mass from the Banda Sea which will continuously affect the level of water salinity as it passes ARLINDO towards the west.

3.4. The Role of Wind in Determining SSS Distribution in the Java Sea and Surrounding Seas

Wind is the movement of air masses coming from high pressure to lower pressure. In Indonesia, the wind movement is influenced by the presence of the sun's position on northern hemisphere or southern hemisphere which can change the air pressure in an area. The sun's position on the earth that is regular throughout the year causes wind patterns that are almost the same throughout the year.

From December to April, the sun's position is on northern hemisphere which causes high-speed winds to come from the north or the Asian Continent to the south which is referred to as the western monsoon which carries many water columns from the Asian continent at an increasingly low speed when it reaches Indonesia. The condition of wind movement from southern hemisphere or Australia Continent in May to October passing through Indonesia to the north, namely the east monsoon which carries dry air which causes summer or drought in Indonesia.

Specific area of Indonesian waters, experience a lot of lifting of the water column by the wind which is referred to as evaporation and movement of the water mass due to the strong wind force from the surface of the water or surface currents. Increasing of the evaporation process will also make increasing of the water salinity. While the movement of surface currents due to wind pressure will bring water masses from other waters that can affect the salinity of the water that is passed. The study area in the west season that gets the influence of high-salinity water mass is the Natuna Sea which gets the influence of high salinity from the South China Sea, and the waters of western of Sulawesi or the Makassar Strait which get the influence of high salinity from the Pacific Ocean. Whereas the reduction of western monsoon speeds that reached the Indonesian territory caused the water column carried by the wind to experience many precipitation processes in regions that have low wind speeds. One study area that experienced a high precipitation process was south of Borneo. In addition to precipitation in the waters, the precipitation process on the mainland of Borneo also affects the water salinity, this is because the run off process of the river that carries the water mass of precipitation from the land to the sea.



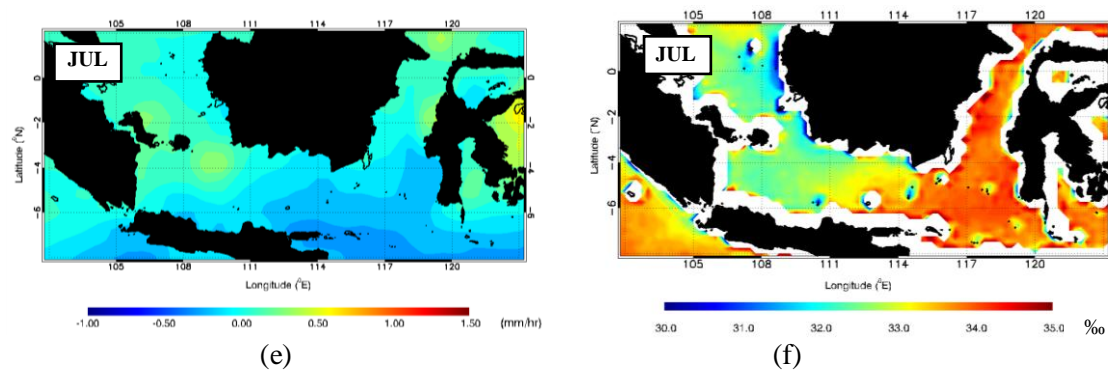


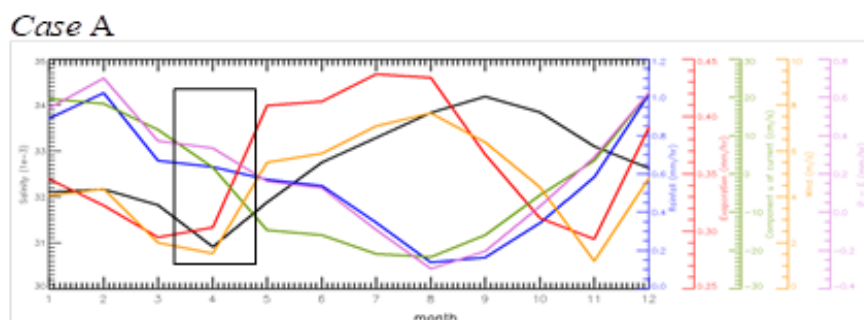
Figure 5. Conditions of (a) Wind, (b) Flow, (c) Precipitation, (d) Evaporation, (e) P-E and (f) SSS in the Java Sea and Surroundings in July.

Based on Figure 5, the east monsoon that occurs in the waters of the Java Sea and its surroundings has the same scheme as the western monsoon. East monsoon velocity causes the movement of the water mass to follow the direction of the wind towards the west, namely from the Banda Sea which has high salinity towards the Java Sea. Because of the high wind speed, it also causes high evaporation processes and low precipitation. This results in water lifting have higher levels than water input in the water, which is indicated by the P-E value which is negative. The overall condition of these parameters caused the waters of the Java Sea had a high salinity value in July. The study area that received much influence from the high salinity of the Banda Sea were the waters south of Sulawesi, west of Sulawesi and south of Borneo.

3.5. Case Study of Variability in Sea Surface Salinity in the Waters of South of Borneo, South of Sulawesi, West of Sulawesi and Natuna Sea

In the west season which occurs from December to February, the west monsoon blows from the Asian Continent to the Eurasian Continent that passes through Indonesia. The monsoon is wet because it transports moisture in the journey. When passing through the Indonesian territory in the equatorial region, the wind experienced a curve to the right, so that in the territorial waters of Indonesia the west monsoon passed through the South China Sea and turned towards the Natuna. Continued passes through the waters of the Java Sea to east of Indonesia.

West monsoon that pass through Indonesian waters affect the precipitation-evaporation conditions and the currents. The high wind speed that affects the north of the equator, causing water vapor carried by the wind or what is referred to as the evaporation process will fall or undergo a precipitation process in areas with little influence of winds, that is the southern equator or mainland. This was supported by the statement of D'addezio, M.J. [14], Salinity can help regulate ocean circulation and processes between sea-atmosphere. Conditions of sea water salinity variations also affect hydrological conditions (precipitation-evaporation (P-E)) and vice versa [5].



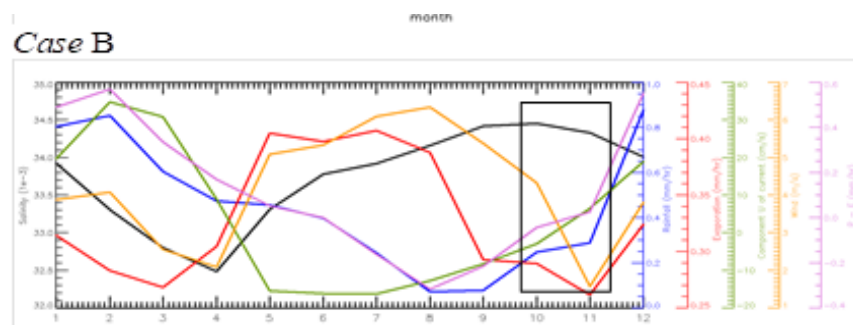


Figure6. Case A (South Water of Borneo) danCase B(South Water of Sulawesi) which Shown Existence the SpecificDistribution of Sea Surface Salinity and other Parameter.

Figure 6 shows all oceanography-climatology parameters which have relation against salinity fluctuation. Sea surface currents are one of the parameters that are heavily influenced by a monsoon. In the west monsoon conditions, the current carries a movement of water mass from the South China Sea which has a higher salinity. That condition due to the graph of Figure 6, that is positive value of current shown a movement of water mass to east or north direction. That water mass through the Natuna Sea to cause the salinity value in these waters to be worth 32.669 ‰ rising to 33.497 ‰ in April and heading towards of the Java Sea precisely in the south water of Borneo, the salinity reached 32.628 ‰ down to 31.829 ‰ with its eastward movement. The decrease in salinity in south water of Borneo continue to occur until it reached the lowest salinity in April which was mostly due to the high influence of precipitation in the southern equator which reached 1.017 mm / day in December up to 1.023 mm / day in February and precipitation in the land as a cause of run-off. These statement also described in this following graph.

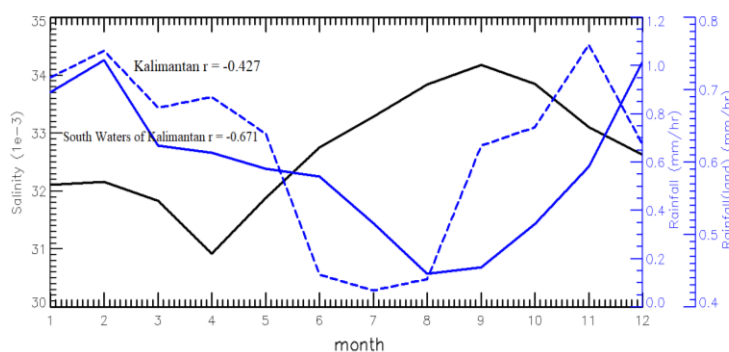


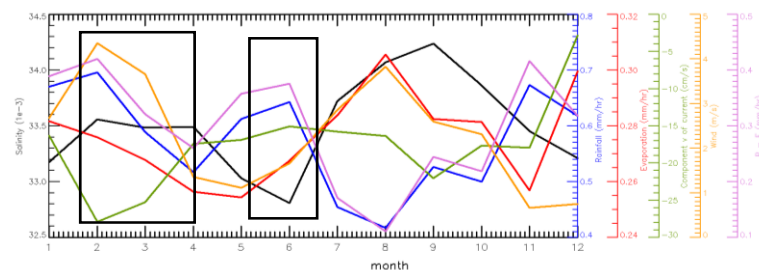
Figure 7.TheRelation graph of Sea Surface Salinity, Precipitation in southwater of Borneowith $r = -0.671$ and Precipitation in mainland of Borneo with $r = -0.427$ Monthly Average.

Figure 7 shows significant decrease of the salinity which mostly influenced by precipitation in the mainland of Borneo. This was supported also by the statement of Najid et al [5], which states that minimum salinity occurs in the west season with a peak occurring in January or February. During this season the water mass of the Natuna Sea moved through the Karimata Strait to the Java Sea with much dilution from the river flow (Sumatra, Borneo and Java) as it passed which caused the salinity to drop in which appeared in Figure 2.

The water mass moving from the South China Sea headed eastward, passing ARLINDO and affecting the waters of Sulawesi. However, because of the distant water location of Sulawesi, the movement of water masses from west to east continues to experience dilution both from run off or the precipitation process that occurs, so that the low salinity of the water mass does not affect Sulawesi waters too much. In addition to the lack of influence of the water mass of the South China Sea, salinity in Sulawesi waters is high because of the input of water masses from the Pacific Ocean throughout the year which has a higher salinity value. Salinity value in the west season in Sulawesi waters, that is 33.211 ‰ in December to reach of 33.490 ‰ in April in the water of the west of Sulawesi or the

Makasar Strait. The increase occurred because in the west season there was more water mass from the Pacific Ocean, which was evident from the wind movements that supported the movement of ARLINDO. That condition also supported by Case B of graph in Figure 6, that is negative of current value in this area shows the current which was southward movement. However, in the south waters of Sulawesi, it had a value of 34.007 ‰ in December and continued to decline to reach 32.486 ‰ in April. The decrease in value occurs because of the influence of the movement of the water mass which has a lower salinity value from the Java Sea to the east that passes through the ARLINDO track and the precipitation process reaches 0.878 mm / day in December to 0.854 mm / day in March.

Case C



Case D

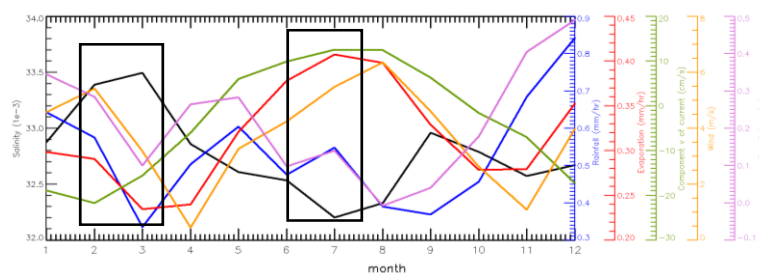


Figure8.Case C (Waters of Western Sulawesi/Makasar Strait) dan Case D (Natuna Sea) which Shown Existence the Specific Distribution of Sea Surface Salinity and other Parameter.

Figure 8 shows all oceanography-climatology parameters which have relation against salinity fluctuation. Entering the east season was occurring changes in wind direction, that is monsoon winds that move from the Eurasian Continent to the Asian Continent that passes through Indonesia. The east monsoon that passes through Indonesia is dry, which occurs in June to September [5]. The movement of the east wind through Indonesia experienced a leftward turn entering the waters of the Banda Sea through the Java Sea and towards the Natuna Sea. This was also reinforced by the statement that along the northern waters of Java-Madura was the main axis of monsoon trajectory which further influenced the hydro-oseanography, climatology and water mass circulation conditions [5].

Wind movement in the east season causes the Banda Sea water mass which has a higher salinity movement across ARLINDO towards the Java Sea to the west. In the south waters of Sulawesi, the salinity reached 33.783 ‰ in June and continued to increase to 34.454 ‰ in October. The movement of the water mass that passes through ARLINDO in the east season will suppress the previous waters in the western season which has a lower salinity, which suppresses the water mass carried by ARLINDO and the mass of the Java Sea so that the current leads east towards the Natuna Sea. That condition shown by the graph in Figure 8, maximum value of current velocity in the Natuna Sea which has positive value reached 12.53 m/s, that is current movement towards northern.

The depressed water mass in the western region of Sulawesi from the Banda Sea water mass movement showed the lowest salinity in the east season reaching 32.808 ‰ in June and then experiencing the highest increase reaching 34.237 ‰ in September. This happened because the continuous water mass movement from the Banda Sea was shown by the spatial distribution of salinity

in Figure 2. Heading south of Borneo, the Banda Sea water mass affected the maximum increase in salinity in these waters which reached 34.184 ‰ in September which was supported by minimal the precipitation process that occurs is 0.164 mm / day. In the east season of the Indonesian region, a decrease in the level of precipitation and an increase in evaporation, caused a slight of influence from land precipitation as a cause of run-off of rivers in Indonesia's marine waters. As long as the movement towards the Natuna Sea, the moving water mass from the Java Sea still has high salinity. The movement of the water mass depresses the low-salinity water mass from the previous west season, reaching the Natuna Sea. So, that caused the value of salinity in the Natuna Sea dropped to 32.202 ‰ in June, but the evaporation process remained high reaching 0.407-0.398 mm / day in July-August as a result of the high influence of the east monsoon.

From the results obtained as a whole shows the distribution of salinity in Indonesian waters is strongly influenced by the circulation of water masses that receive input from the Pacific Ocean and Indian Ocean. While the movement of the water mass is caused by the current that can occur as the influence of the monsoon movement in Indonesia every year. This is supported by Najid's statement, et al[5], that monsoon wind patterns in general are wind patterns in the Java Sea and the Java Sea water mass has a closely related to the monsoon system in Indonesia.

4. Conclusion

The study area consisting of waters of south of Borneo, southern Sulawesi, west of Sulawesi or the Makasar Strait and Natuna Sea has salinity characteristics that are strongly influenced by the climate conditions that occur in Indonesia, that is the west and east monsoons. The seasonal pattern influences the movement of water masses which have different values of salinity, thus affecting the salinity conditions of other waters.

In the western season that occurred from December to April, the movement of the water mass originated from the South China Sea which resulted in an increase in salinity in the Natuna Sea reaching 33.497 ‰ in April. The water mass that continues to move towards the Java Sea experiences a lot of water input, both from rivers run off or precipitation processes, resulting in a decrease in salinity in the south waters of Borneo reaching 30.919 ‰ in April. In other study areas, that is the west waters of Sulawesi has increased of salinity reached 33.490 ‰ in April due to the input of water mass from the Pacific Ocean. A decrease in salinity occurred in southern Sulawesi which reached 32,486 ‰ in April due to the influence of low salinity of the Java Sea.

In the east season, monsoon moving from the east cause the movement of the water mass from the Banda Sea across the Java Sea to the Natuna Sea. The high salinity water mass urged the mass of Java Sea and Arlindo water, so the increase in salinity occurred in all study areas, including reaching 34.184 ‰ in September in southern Borneo and the exception occurred in the Natuna Sea with low salinity reaching 32.962 ‰ in the same month due to the influence of the low salinity of the Java Sea mass in the west season.

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