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SURFACE HEAT FLUX ASPECT ON THE VARIABILITY OF SEA SURFACE TEMPERATURE AND CHLOROPHYLL-A ALONG THE SOUTHERN COAST OF JAVA

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ABSTRACT:

Indonesia as a region located in the tropics gets a greater heat distribution than the other hemisphere and has an important role in the phenomenon of atmospheric and ocean interactions in the Indo-Pacific region. The heat exchange between the ocean and the atmosphere affects the dynamics of both. The southern coast of Java is known as the upwelling area which is driven by the variability of Ekman transport and Ekman pumping. The present study aims to investigate the effect of heat flux variability on sea surface temperature variability and chlorophyll-a in surface upwelling areas along the Southern coast of Java which was less observed in the previous study. The study was conducted with a quantitative descriptive approach through climatological spatial and temporal data processing for 10 years from 2007 – 2016. The data used are Shortwave Radiation, Longwave Radiation, Latent Heat Flux, Sensible Heat Flux, Sea Surface Temperature, Chlorophyll-a, Surface Wind, and Mixed Layer Depth. The results show that the Southern coast of Java receives an average heat of 547.8 W/m2 per year. Net Heat Flux fluctuations are dominated by heat intake by Shortwave Radiation and heat release by Latent Heat Flux. Net Heat Flux has a very strong relationship with sea surface temperature with the best correlation of 0.84 and 0.83 at lag+2 and lag+3 months indicating that Net Heat Flux plays an important role in modulating changes in sea surface temperature in the next 2-3 months. A significant increase in chlorophyll-a occurred after the Net Heat Flux was positive or there was ocean heating which caused the shoaling of Mixed Layer Depth, resulting in primary productivity in the east monsoon along with nutrient rich entrainment to the surface by EMT and EPV.

Key-words: *Surface Heat Flux, SST, Chlorophyll-a, Upwelling, Southern coast of Java*

1. INTRODUCTION

The oceans play a very important role in balancing the heat energy received from the sun. It is estimated around 93% of the heat received by the earth since almost a century ago is stored in the oceans. Understanding the heat flux exchange is the key to how this balance mechanism occurs (Levitus et al., 2012). This heat exchange between the atmosphere and the ocean is known as the surface heat flux, which indicates the amount of heat absorbed or released in the ocean (Brunke et al., 2011). It is a major factor determining energy content and plays an important role in explaining air-sea interactions on a global and regional scale (Huang, 2016; Cronin et al., 2019). As a region located in the tropics, the Indonesian Seas gets a greater heat distribution than the other area on earth and has an important role in the sea-air interaction in the Indo-Pacific region. Several studies mentioned that the condition of surface heat flux in Indonesia is a key in determining the variability of ocean heat content in the Indian Ocean (Vranes et al., 2002; Lee et al., 2015; Gruenburg and Gordon., 2018). Indonesian waters also act as a region that connects the flow of heat content in the Pacific Ocean and

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the Indian Ocean. The heat received in Indonesian waters or coming from the Pacific Ocean is discharged to the Indian Ocean by the Indonesian throughflow (ITF) current.

The southern coast of Java is located in the eastern part of the Indian Ocean and is part of the outflow route for the ITF current from the Pacific Ocean. The seas along the southern coast of Java are directly opposite to the open sea so it has complex ocean characteristics that are influenced by various factors of atmospheric and oceanic dynamics. The southern coast of Java is also a fertile area with upwelling events that occur during Southeast monsoon season (Wirasatriya et al. 2021). Many studies have been conducted on the upwelling mechanism in Southern Java Sea. Susanto and Marra (2005) demonstrated the effect of 1997/98 El Niṅo to escalate the Chl-a concentration along the southern coast of Java. Wirasatriya et al. (2020) showed the role of Ekman transport and Ekman pumping to the variability of upwelling along the southern coast of Java. The impact of upwelling along the southern coast of Java for fisheries productivity has been demonstrated by Kunarso et al. (2012); Lahlali et al. (2019); and Sukresno et al. (2018). However, studies on how surface heat flux plays a role in the variability of sea surface temperature and chlorophyll-a concentration have not been widely discussed, particularly along the southern coast of Java. Therefore, this study aims to identify how the distribution of the surface heat flux and its effect on the variability of sea surface temperature and chlorophyll-a as the oceanic parameters for determining the location of upwelling in the southern coast of Java. Understanding the heat flux aspect of the upwelling along the southern coast of Java may contribute to the fisheries management in this area.

2. STUDY AREA

Our study area is located at the southern coast of Java which is part of the Fishing management Zone of Indonesia 573 (WPP RI 573). It is in the southern part of Western Indonesia Region and lies between 7°S - 12°S and between 105°E - 115°E (**Fig. 1**). WPP RI 573 is an important fishing ground for various big pelagic fish such as tuna (Wibowo et al. 2019). The southern coast of Java Sea is at the eastern part of the Indian Ocean and considered as the exit route for ITF from Bali and Lombok Straits.

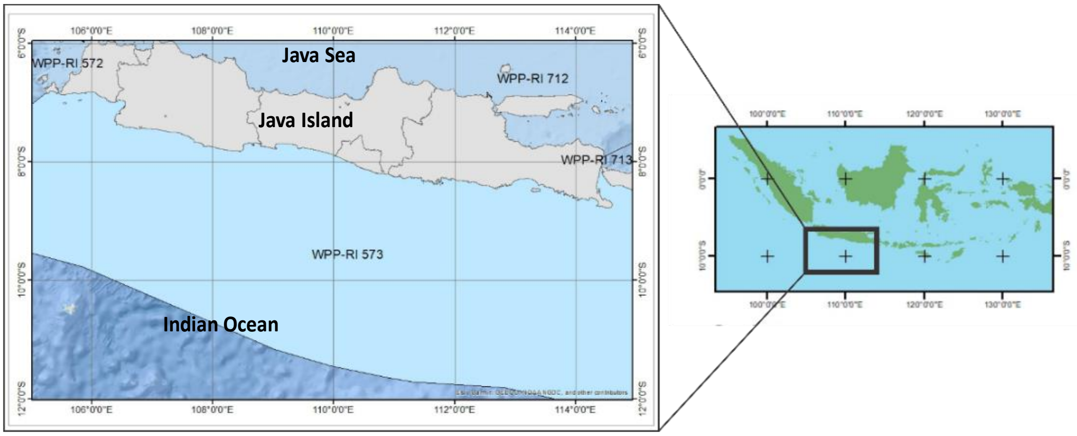

Fig. 1. Study area of the southern coast of Java. WPP-RI 573 is Fishing management Zone of Indonesia 573.

The climatic system is dominated by monsoons because of the difference in seasonal air pressure variability between the Asian and the Australian continents. The characteristic of Southeast (Northwest) monsoon is denoted by southeasterly (northwesterly) wind which blows from Australia (Asia) to Asia (Auistralia), brings dry (humid) air, and causes dry (rainy) season in most areas in Indonesia (Chang et al., 2005; Chang et al., 2006; Alifdini et al., 2021). December, January and February (DJF) represent the Northwest monsoon while June, July and August (JJA) are Southeast monsoon. Transition I and II are represented by March, April, May (MAM) and September, October, November (SON), respectively.

3. DATA AND METHODS

3.1. Reanalysis Data

3.1.1. Surface Heat Flux

This research uses turbulent flux and radiative flux as a component of surface heat flux. Turbulent flux is taken through Objective Analyzed Air Sea Flux (OAFlux) images which consist of sensible heat flux and latent heat flux (Yu and Weller, 2007). For an in-depth look behind the estimation of the turbulent data, humidity and air-ocean temperature data are included. Radiative flux data was obtained through the official website of the International Satellite Cloud Climatology Project (ISCCP) with the product type H Series in the form of shortwave radiation and longwave radiation (Zhang et al., 2004). All data has a spatial resolution of 1º x 1º with the estimated error values available. Data was downloaded from January 1, 2007 to December 31, 2016 with a global coverage area which will then be cut according to the study area coverage.

3.1.2. Sea Surface Temperature (SST)

Surface temperature data used in this study is OISST (Optimally Interpolated Sea Surface Tempetarure) images provided by REMMS (Remote Sensing System). OISST is level 4 data resulting from the combination of microwave (MW) and infrared (IR) sensors so that it has high resolution and complete data (Remote Sensing System, 2017). The downloaded images are daily composite data with a spatial resolution of 0.08º x 0.08º equivalent to 8 km x 8.

3.1.3. Chlorophyll-a (Chl-a)

This study uses chlorophyll-a data obtained from Ocean Color - CCI images (Sathyendranath et al., 2019). This is daily data with a spatial resolution of 0.04º x 0.04º equivalent to 4 km x 4 km.

3.1.4. Sea Surface Wind

This study collects wind data using Cross-Calibrated Multi-Platform Wind Vector Analysis (CCMP) images version 2 provided by REMMS (Remote Sensing System) (Atlas et al., 2011). The downloaded images is daily composite data with a spatial resolution of 0.25º x 0.25º equivalent to 25 km x 25 km.

3.1.5. Mixed Layer Depth (MLD)

The Mixed Layer Depth data used in this study is Level 4 data provided by Marine Copernicus with the product code GLOBAL_MULTIYEAR_PHY_001_030. This data has a resolution of 0.08º x 0.08º and 50 level standard depth (Drévillon et al., 2021).

3.2. Net Heat Flux Balance Calculation

Net heat flux is calculated by summing up the radiative flux and turbulent flux that ocean received and released:

$$Qnet = Qsw + Qlw + Qlh + Qsh + Qadv \quad (1)$$

where Q_{Net}, Q_{SW}, Q_{LW}, Q_{SH}, and Q_{LH} are net heat flux, shortwave radiation, longwave radiation, sensible heat flux and latent heat flux, respectively.

The calculation of net heat flux in this study did not involve the *Qadv* factor due to data limitations. Positive heat flux means downward flux into the ocean while negative flux means upward flux to the atmosphere (Wirasatriya et al., 2019). The result of this formula will show the heat balance in the ocean that applied to each data grid to produce its spatial and temporal distribution.

3.3. Schematic Flowchart of Method

The method of this study is summarized in the flowchart (**Fig. 2**).

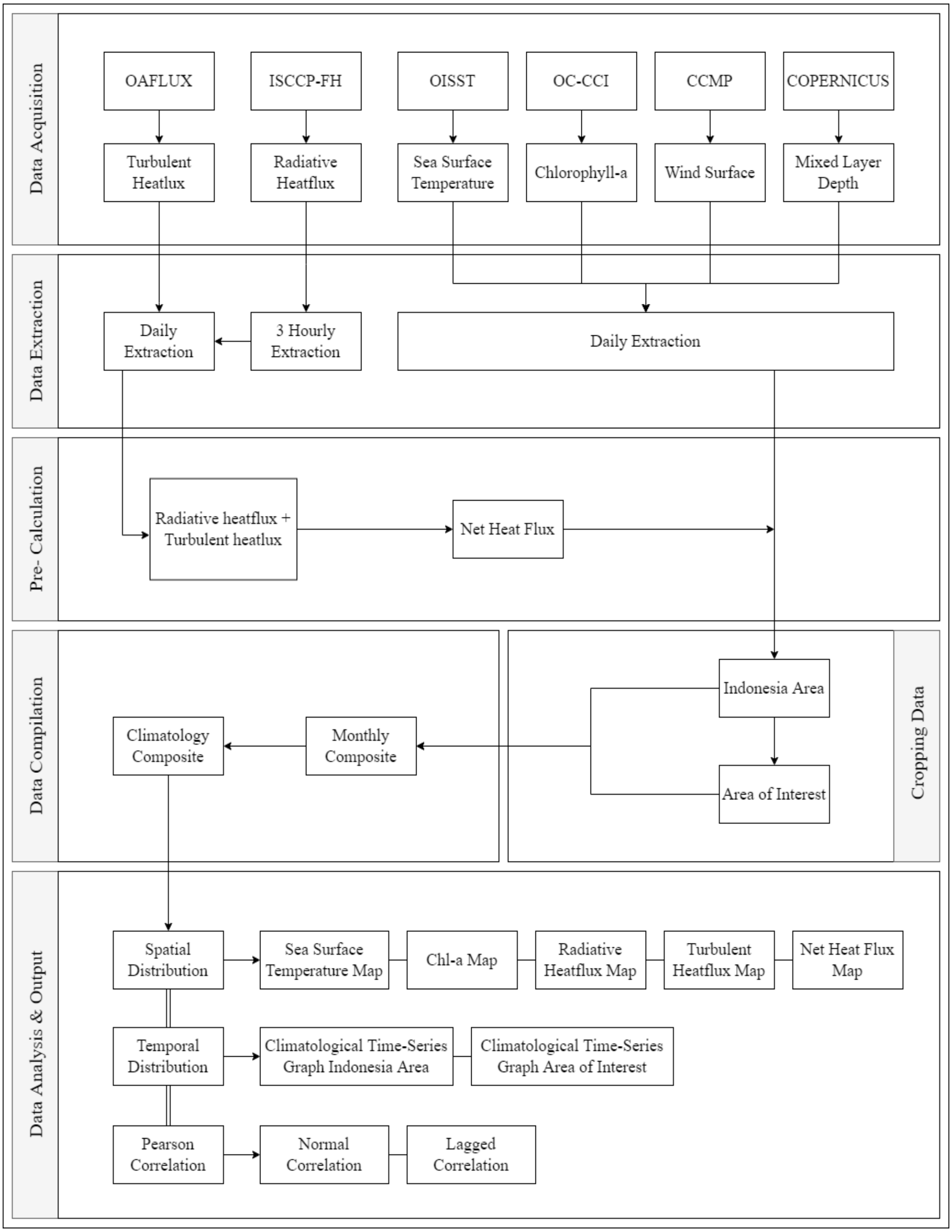

Fig. 2. Schematic flowchart of method.

3.4. Composite Data Calculation

To investigate the seasonal variation of surface heat flux and other parameters, we constructed monthly climatology data. First, all parameters were composited into monthly means and then used to derive monthly climatology by using the following formula (Wirasatriya et al. 2017):

$$\bar{x}b(x,y) = \frac{1}{mh}\sum_{i=1}^{mh} xi(x,y,t) \quad (2)$$

where *xb(x,y)* is monthly mean value or monthly climatology value at position *(x,y)*, *xi* is the value of the data at *(x,y)* position and time *t*.

Moreover, *mh* is number of data in 1 month and number of monthly data in 1 period of climatology (i.e., from 2007 to 2016 = 10 data) for monthly calculation and monthly climatology calculation respectively. Pixel *xi* is excluded in the calculation if it has a gap on data.

3.5. Pearson Correlation Analysis

Pearson correlation is used to determine the relationship between two variables, such as the linear relationship between *NHF* and *SST* or *Chl-a*, as well as other variables. The correlation calculated using the formula:

$$r = \frac{N(\sum XY)-(\sum X \sum XY)}{\sqrt{(N(\sum X^2-(\sum X)^2)-(N(\sum Y^2)-(\sum Y)^2)}} \quad (3)$$

where *r, x, y,* and N are the correlation coefficient values, the value of the first variable, the value of the second variable, and the total count of data respectively.

The output is in the form of values with a range of *0 – (±)1* indicating weak – strong relationship. We also performed lagged correlation to examine the possibility of the delaying time of the correlation among parameters.

4. RESULTS AND DISCUSSIONS

4.1. Results

4.1.1. Seasonal Variation of Sea Surface Temperature

The variation of sea surface temperature for 10 years (2007-2016) along the southern coast of Java shows that the sea surface temperature ranges from 23-30 ^{O}C as shown in **Fig. 3**. The distribution of sea surface temperature along the southern coast of Java has a seasonal pattern that has its own characteristic. In the rainy season (December, January, February), the distribution of sea surface temperature is relatively warm with an average temperature ranging from 28.7 - 28.9 ºC. In the first transitional season (March, April, May), the sea surface temperature along the southern coast of Java reached its warmest temperature in April with an average temperature of 29.2 ºC.

Entering the dry season (June, July, August), the sea surface temperature gradually drops to its lowest temperature in August with an average of 26.2 ºC. In the second transitional season (September, October, November), the sea surface temperature increased again until the average temperature ranged from 26.3 – 28.2 C.

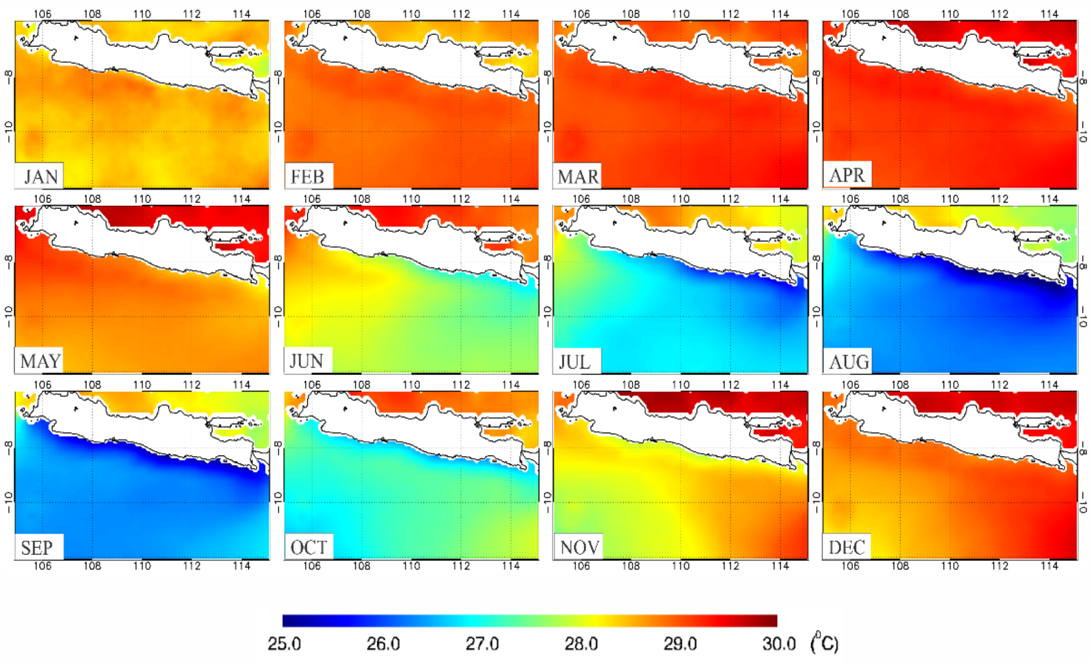

Fig. 3. Monthly climatology of SST along the southern coast of Java.

4.1.2. Seasonal Variation of Chlorophyll-a Concentration

The concentration of chlorophyll-a is the result of primary productivity that occurs in the waters. Primary productivity triggers the growth of phytoplankton as the largest biomass in the marine food chain. Each phytoplankton has a color pigment that is used to carry out photosynthesis, namely chlorophyll-a so that the more phytoplankton in the waters, the greater the concentration of chlorophyll-a. Data retrieval of chlorophyll-a on the satellite using the wavelength reflectance method. The value of chlorophyll-a concentration along the coast in **Fig. 4** could be reflectance data from suspended material in the waters. However, since the study area covers areas near the coast and the high seas, the reflectance data other than chlorophyll-a can be tolerated as an average value.

The seasonal variation of chlorophyll-a for 10 years (2007-2016) along the southern coast of Java shows the distribution of chlorophyll-a ranging from 0.1 – 2 mg/m^3. The distribution of chlorophyll-a only has one peak in one year. Chlorophyll-a concentration reached its highest peak in September with an average value of 0.55 mg/m^3. Meanwhile, the lowest average value was found in February at 0.1 mg/m^3. During the rainy season until the first transition period, the concentration of chlorophyll-a did not show a significant change while an increase began to occur during the dry season between May to September which then fell again in October. The distribution of chlorophyll-a concentrations was higher in areas near the coast, especially in the central and eastern parts of the South Java Sea. In the eastern part, chlorophyll-a concentration consistently spreads towards the offshore up to 20 km from the coastline.

This pattern may be due to the combined influence of the ITF coming out of the Bali strait, The South Equatorial Current (SEC), and The Southern Java Current (SJC) that drift away chlorophyll-a off the coast.

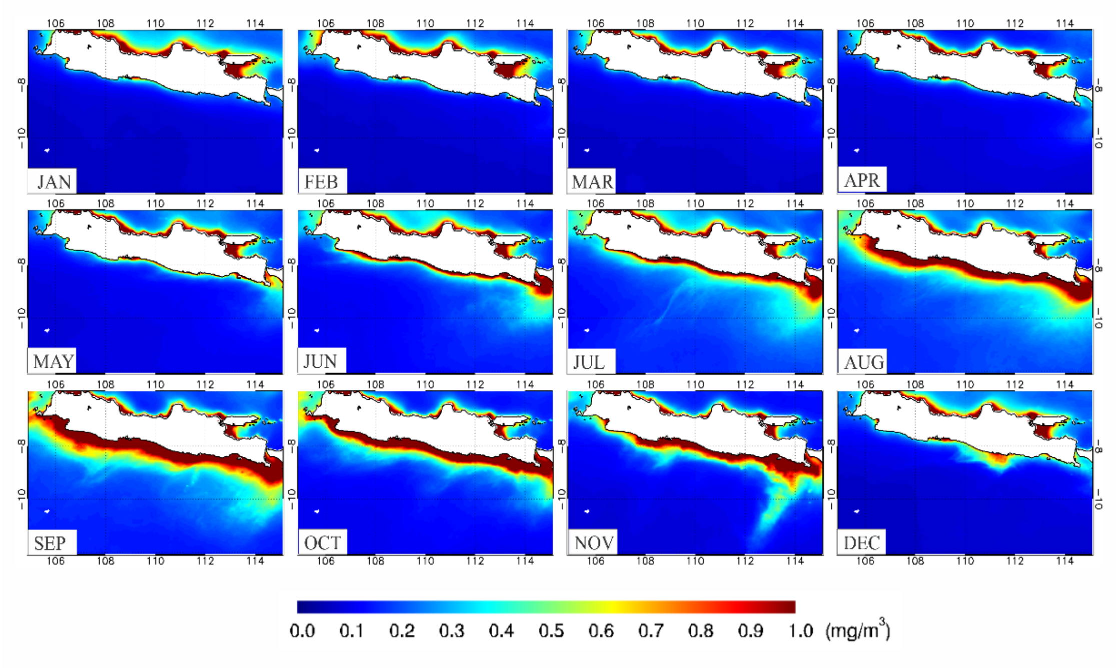

Fig. 4. Monthly climatology of chlorophyll-a along the southern coast of Java.

4.1.3. Relationship among SST, chlorophyll-a and wind speed along the southern coast of Java

Upwelling areas are generally identified using sea surface temperature parameters and chlorophyll-a concentrations in the ocean. Low sea surface temperatures can indicate that there is an water mass lifting of deep sea water to the surface which is rich in nutrients. Nutrients are then used by phytoplankton for primary productivity so that the concentration of chlorophyll-a will increase. Therefore, low sea surface temperatures followed by high chlorophyll-a concentrations indicate the area is an upwelling area. **Fig. 5** shows that along the Southern coast of Java, warm sea surface temperatures are generally found in the rainy season while it decreases during the dry season. Meanwhile, the concentration of chlorophyll-a peaked only in the dry season.

To take a closer look, the wind movement shows a different pattern in the two seasons. The wind moves to the east in the rainy season while in the dry season it moves to the northwest. These two opposing patterns are the result of the monsoon winds movement between the continents of Asia and Australia. This wind movement causes the Ekman mass transport which triggers the displacement of water masses around the coast. With reference to this mechanism, along the southern coast of Java, the downwelling occurs in the rainy season and upwelling in the dry season along the coast. Furthermore, the upwelling intensity is greater in the eastern part of the southern sea of Java than the western part as denoted by the higher chlorophyll-a concentrations and lower SST at the eastern part.

For further analysis, we plot the variation of SST, chlorophyll-a concentration and wind speed in the time series graph which shows the highest chlorophyll-a concentration and lowest SST occur during the highest wind speed during the Southeast monsoon season. High correlation between wind and SST (i.e., -0.88) or wind and Chl-a (i.e., 0.88) indicating that wind plays a major role in the variability of these two parameters.

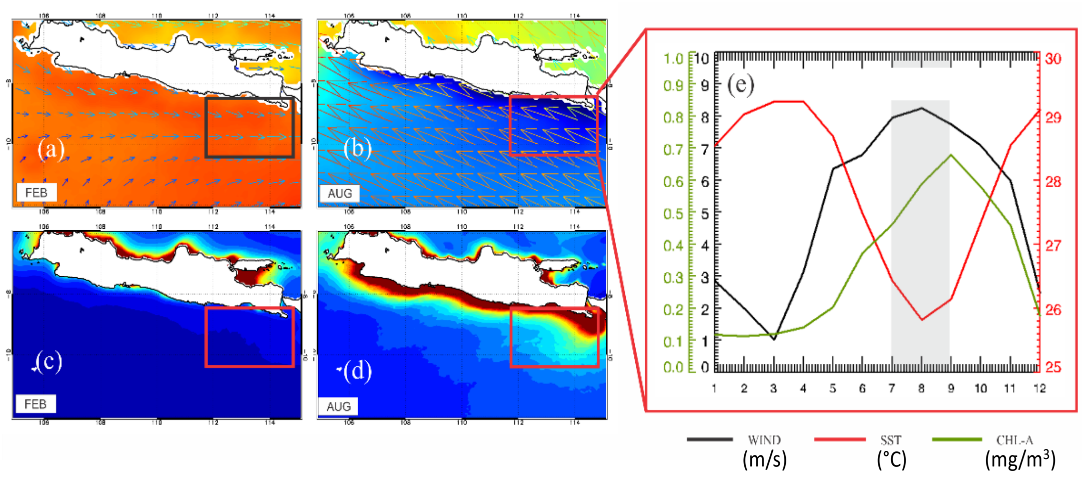

Fig. 5. The location and time of upwelling based on the spatial distribution of (a,b) wind overlaid with SST (c,d), chlorophyll-a concentration and (e) temporal distribution of SST, wind, and chlorophyll-a.

4.1.4. Seasonal Variation of Surface Heat Fluxes

The variation of shortwave radiation in 12 months of climatology shows that the flux distribution into the waters ranges from 140 - 250 W/m^2 as shown in **Fig. 6**. The distribution of shortwave radiation flux increased from December to March with an average flux ranging from 200 – 250 W/m^2 then decreased from April to June with the lowest average flux ranging from 140 – 180 W/m^2. The flux increased again in July to November with the average amount of flux peaking in November to 250 W/m^2. The variation of the heat flux of short-wave radiation is closely related to the annual position of the sun, where the closer the sun is, the greater the incoming heat flux. In the south of Java, the closest position of the sun is in January or October and the farthest one is in June. While the variation of longwave radiation in 12 months of climatology shows the distribution of flux out into the atmosphere ranging from 20 - 80 W/m^2 **Fig. 6**. The spatial distribution shows that the longwave radiation emitted into the atmosphere has increased since January with an average flux of 29.2 W/m^2 until it peaked in October at 53.8 W/m^2 and then decreased again until December to 28 W/m^2. Low radiation fluxes are scattered around the island while high radiation is generally scattered over ocean areas.

Sensible heat flux variation in 12 monthly climatology in shows the flux distribution ranging from -5 to 20 W/m^2. The negative and positive value indicates that the sensible heat flux can occur in two directions, namely receiving heat (negative) or releasing heat (positive). This can be caused by the effect of the resultant air and sea temperatures which are not always positive. The high value of sensible heat flux is generally distributed in the western part of the South Java Sea, while the low value of flux is generally distributed in the eastern part of the South Java Sea.

A significant difference in distribution contours is formed between eastern and western part, especially in June and July. The distribution of sensible heat flux has the highest average value in the rainy season (DJF) in January with an average of 11.2 W/m^2. During the first transitional season (MAM), the sensible heat flux decreased until April reached to 7.3 W/m^2 and rose again in May to 10 W/m^2. In the dry season (JJA), the distribution of sensible heat flux does not change significantly, but the difference in sensible heat flux contours value on the west and east part of the South Java Sea is getting clearer. Sensible heat decreased again in August and reached its lowest point in the second transitional season (SON) in October which reached 5.4 W/m^2 and increased again in November towards the rainy season.

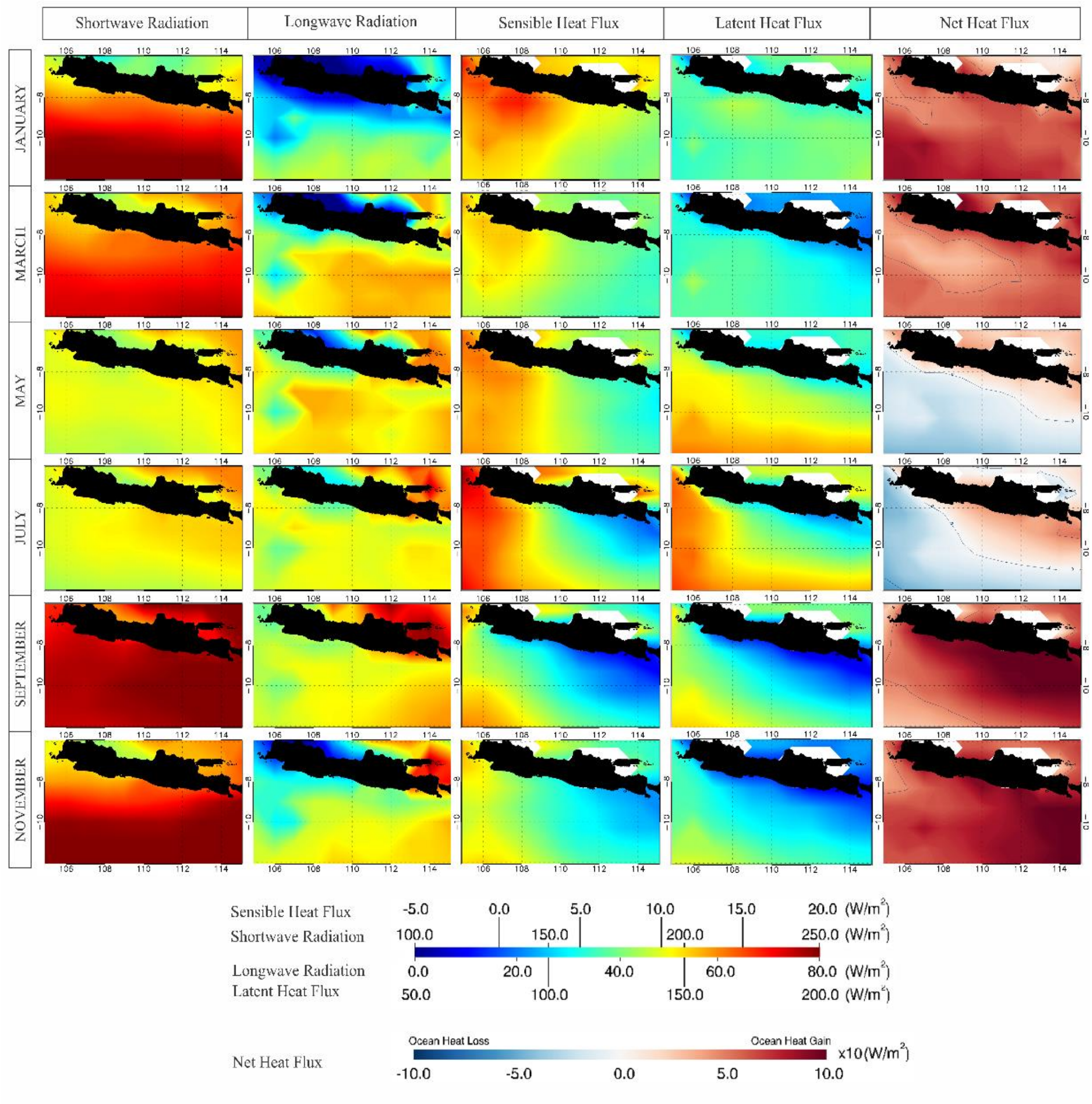

Fig. 6. Monthly climatology of surface heat flux along the southern coast of Java. Positive sign on the shortwave radiation means downward flux, while positive signs on longwave radiation, sensible heat flux, latent heat flux and net heat flux mean upward flux.

Latent heat flux variation in 12 months climatology shows the flux distribution ranging from 50 - 150 W/m^2. The positive value indicates the release of heat to the atmosphere. The average value per year of latent heat release is 120.74 W/m^2 which is relatively much larger than the sensible heat flux. The highest latent heat flux release was found in May that reached 141.45 W/m^2 and has its lowest average value in October, which is 102.78 W/m^2. In the rainy season (DJF), there is a small fluctuation in the latent heat flux around 20 W/m^2. In the first transitional season (MAM), there was a significant increase in latent heat release about 40 W/m^2 towards its highest peak in May. In the dry season (JJA), flux changes are not too significant and only change about 2 - 6 W/m^2 and there is a decrease in the coast area until the second transitional season (SON). It can also be seen that the heat release in the open seas is generally higher than the coast.

Through the calculation of the total flux coming out and entering the sea surface, the total heat flux value (Net Heat Flux) is obtained. These results indicate whether the sea surface is in a state of balance, positive, or negative. A positive state indicates that the ocean is receiving heat while on the other hand the sea is losing heat to the atmosphere. It can be seen that shortwave radiation and latent heat flux is the main flux that influence the net heat flux variation as shown in **Fig. 7**. Moreover, the South Java Sea received the highest heat in October reaching average 92.8 W/m^2. Total heat then declined since November to its lowest point in June of -14.3 W/m^2. In total, the South Java Sea gain a surplus heat of 547.8 W/m^2 per year.

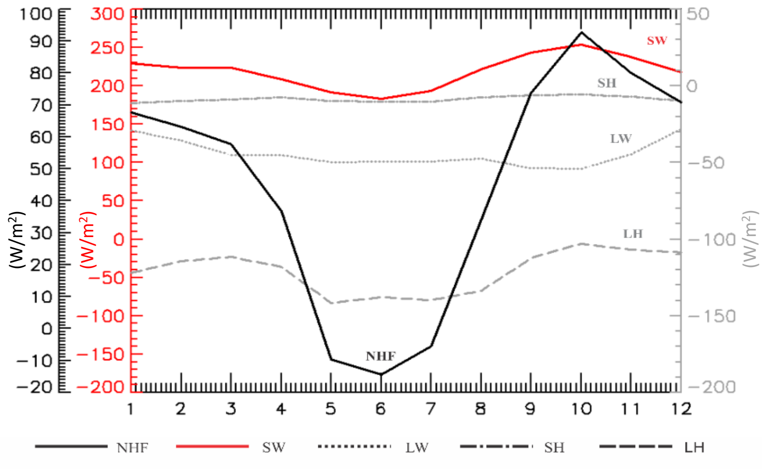

Fig. 7. Time series graph of shortwave radiation, longwave radiation, sensible heatflux, latent heatflux, and net heat flux for the whole study area as shown in Fig. 1. Positive and negative signs mean downward and upward flux, respectively.

4.1.5. Surface Heat Flux Effect on Sea Surface Temperature along the southern coast of Java

In this study, the relationship between the surface heat flux and SST was analyzed using a linear Pearson correlation which was then strengthened by descriptive analysis according to its temporal and spatial distribution. The correlation of each condition is summarized in **Table 1** using 4 months lag conditions between NHF, SST and wind. This condition is determined to see the time lag relationship that occurs between surface heat flux and sea surface temperature. A very strong correlation coefficient between NHF and SST was obtained at lag+2 and lag+3 months with the correlation value of 0.84 and 0.83, respectively. Between NHF and wind, it was obtained at lag+3 months with the correlation value of -0.81. These results indicate that there is a high possibility of delay effects between NHF, SST, and wind. In the lag conditions, the higher the surface heat flux, the higher the sea surface temperature. Meanwhile, the higher the surface wind speed, the lower the surface heat flux.

The heat received by the oceans from shortwave radiation does not necessarily make the oceans always in a hot condition. This is because the sea surface also releases a large amount of heat from the latent heat flux. The release of latent heat is influenced by wind speed and the difference in specific humidity between the sea surface and the atmosphere (ΔQ) according to the Bulk Coare 3.0 formula (Yu et al., 2007; 2008). The heat release in the latent form can be in the form of rains or displacement of water vapors to other areas. In **Fig. 8**, we can see that the variation of latent heat flux is initiated by differences in specific humidity (ΔQ) and enhanced by wind speed given the similarity of patterns between ΔQ and latent heat flux. However, it is difficult to determine which is most dominant factor since both variables are used to calculate the latent heat flux. The greater the wind speed and ΔQ, the greater the heat release that occurs.

Table 1.

Correlation of NHF, SST, wind.

Parameter		Correlation			
		Normal	Lag+1	Lag+2	Lag+3
NHF	**SST**	-0.007	0.5	0.84	0.83
	WIND	-0.007	-0.4	-0.7	-0.81

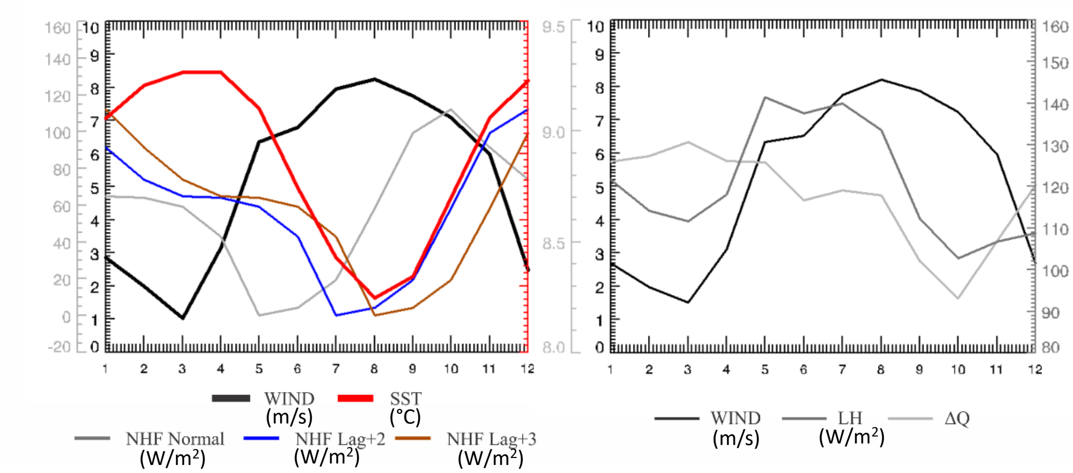

Fig. 8. Timeseries graph of wind, SST and NHF (Left)and wind, latent heat flux, and specific humifdity difference (ΔQ) at the red box shown in Fig. 4. Positive and negative signs of surface heat flux mean downward and upward flux, respectively.

4.1.6. Surface Heat Flux Effect on Chlorophyll-a along the southern coast of Java

The heat flux exchange can affect the thermodynamic processes in the sea surface and column. It can result in changes in temperature, salinity, water layers, or the growth of organisms in the ocean (Ushijima and Yoshikawa, 2019). The results in this study showed that ocean warming contributed to the increase in the chlorophyll-a concentration. The heat received by the oceans is used by autotrophic organisms for photosynthesis. In addition, ocean warming also results in shoaling of mixed layer depth so that uplifted nutrients will be trapped at critical depths (Ghisolfi et al., 2015). This shoaling of MLD causes a decrease in turbulent convection in the water column and stabilizes the mixed layer depth. The shallows MLD can stimulate the growth of phytoplankton by which nutrients is exist (Xu, Y et al., 2020).

A strong positive relationship was found between NHF and Chl-a by 0.71 in dry season as shown in **Table 2**.

Table 2.

Correlation of NHF, Chlorophyll-a, and Mixed Layer Depth.

Parameter		Correlation		
		12 Months	DJF-MAM	JJA-SON
NHF	**CHL-A**	0.35	-0.64	0.71
	MLD	-0.82	-0.51	-0.94

Meanwhile, a moderate negative relationship was found by -0.64 in the rainy season. This difference indicates that there are other factors that influence the chlorophyll-a concentration. This factor may occur in the dry season but it lacks in the rainy season. **Fig. 9.** shows that the increasing Chl-a concentration during dry season coincide with the increase of NHF.

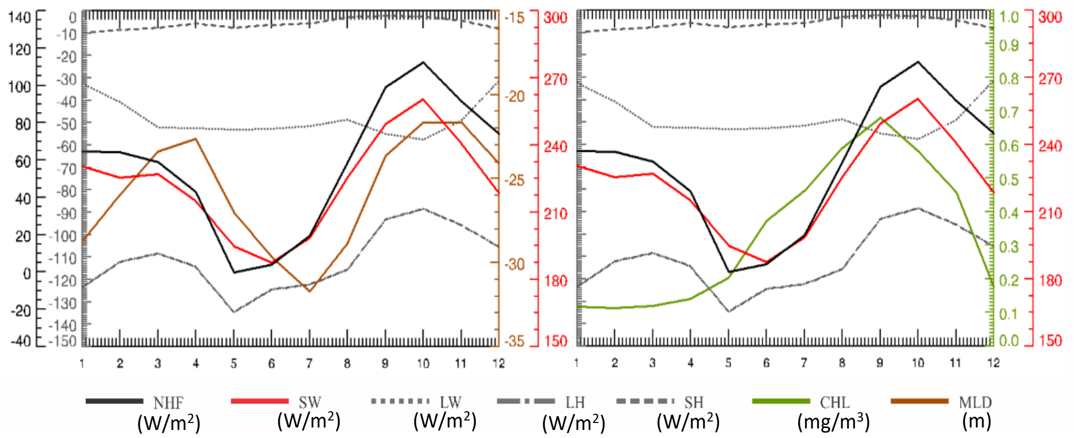

Fig. 9. Time series of surface heat flux, Chlorophyll-a and MLD at the red box shown in Fig. 4. Positive and negative signs of surface heat flux mean downward and upward flux, respectively.

4.2. Discussion

We found that there is a delay two or three month of the correlation between NHF and SST. This means that the decreasing heat gain takes two or three months to affect the decrease of SST. The delay can be caused by heat advection and convection processes that occur between the ocean and the atmosphere. This heat advection process is carried out by ocean currents and wind on the surface which takes time to be moved or released. Meanwhile, the heat convection process takes place vertically through mixing or turbulent convection. The process of heat advection (Thermal Advection) takes about 30 months according to research by Gruenburg and Gordon (2018) which examines the heat content through the Indonesian throughflow current (ITF) in the Makassar Strait to the Eastern Tropical Indian Ocean (ETIO). Given that Southern Java Sea is a small part of the ITF, the possibility of heat advection in this area has a lower time phase given the shorter distance hence the result shows 2 – 3 months delay. This result is consistent with the study conducted by Wirasatriya et al (2019) in the Northern Sea of Java which also found 2 months delay effect between surface heat flux and SST. This finding contradicts to Varela et al. (2016) which states that heat flux is not a driving factor for sea surface temperature variability along the southern coast of Java since they do not consider the delay effect of NHF to SST.

The relation between NHF and chlorophyll-a concentration along the southern coast of Java is related with The Convection Shutdown theory by Smyth et al. (2014) and Ferrari et al. (2016) who said that an increase in chlorophyll-a will occur when the cooling of the ocean by surface heat flux begins to subside and changes to ocean warming or when the NHF changes from negative to positive. This study agrees with the statement which found that significant changes in chlorophyll-a concentration start to occur when NHF switched from negative to positive in May as in **Fig. 9.** However, the concentration of chlorophyll-a is highly dependent on the presence of nutrients in the water column.

The study conducted by Wirasatriya et al. (2020) which examined Ekman transport and Ekman pumping velocity in the same area showed that in the rainy season, nutrient uptake was much lower than during the dry season. This explains why different correlations were found in the rainy and dry seasons between NHF and chlorophyll-a in this study. Although the conditions of surface heat flux and MLD support the growth of phytoplankton, if the water column does not contain nutrients, the growth of phytoplankton will not occur so that the concentration of chlorophyll-a will be low.

The application of satellite data in the present study manages to reveal the spatial and temporal distribution of surface heat flux along the southern coast of Java. However, satellite also has limitation to observe the parameters below sea surface. As explained by Dong et al. (2007), the SST variations are governed through the heat balance not only in the sea surface but also in the mixed layer of the ocean, which is influenced by surface air–sea heat fluxes, horizontal advective and diffusive processes in the mixed layer, and entrainment processes at the base of the mixed layer. Thus, for better understanding of heat budget variation along the southern coast of Java, horizontal advective and diffusive proceses and entranment should be included in the analysis. This task is left for future study.

5. CONCLUSIONS

Remote sensing data have been used to study the spatial and temporal variability of the surface heat flux and its effect on the variability of sea surface temperature and chlorophyll-a in the upwelling potential area along the Southern coast of Java. Climatologically, the seas along the southern coast of Java always gain a surplus heat with an average of 547.8 W/m^2 per year. The largest heat intake comes from shortwave radiation and the largest heat release comes from latent heat flux.

A very strong relationship occurs between surface heat flux and sea surface temperature at lag conditions of 2-3 months. This shows that surface heat flux plays an important role indirectly modulating changes in sea surface temperature which takes 2 - 3 months. The delay may be caused by heat advection and convection processes which are not fully discussed in this study.

A significant increase in chlorophyll-a concentration occurs when the ocean conditions change from cooling to warming by surface heat flux, which is indicated by a change in net heat flux from negative to positive in May. The increase in surface heat flux also affects the shoaling of mixed layer depth, resulting in stratification of the water column which in turn causes the trapping of nutrients at critical depths. If there is a lot of nutrient abundance in the water column, the combination of solar radiation and supportive water column conditions will trigger primary growth in the waters so that the concentration of chlorophyll-a will increases.

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