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Carbon dioxide flux in the Java Sea estimated from satellite measurements

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ABSTRACT

The oceans play a pivotal role in the carbon cycle due to its dynamics to act as a carbon source or sink to the atmosphere. Previous studies showed that the Java Sea acts as a carbon dioxide (CO_2) source. However, their analysis was only based on the observation data which was limited in time and coverage. In the present study, we utilize the advantage of satellite measurements which have wide coverage and continues monitoring. Sea surface temperature, chlorophyll-a, sea surface salinity, surface wind speed, tropospheric mole fraction of CO_2 and sea level pressure were analyzed to calculate CO_2 gas transfer velocity, CO_2 solubility, CO_2 pressure in the sea water and atmosphere to estimate CO_2 flux in the Java Sea. We found that the Java Sea acts as a CO_2 source. However, during May 2015 and August 2016 small areas along the southern Borneo Island become the sink areas of CO_2. The influence of CO_2 gas transfer velocity and CO_2 solubility is stronger than the difference of CO_2 pressure between sea and atmosphere to determine CO_2 flux in the Java Sea. Therefore, wind speed and sea surface salinity play important role to determine the variability of CO_2 flux in the Java Sea. El Niño condition tends to amplify the release of CO_2 to the atmosphere since CO_2 gas transfer velocity, CO_2 solubility and the difference of CO_2 pressure between sea and atmosphere increases during El Niño.

1. Introduction

The global climate has changed relative to the pre-industrial period due to the increase in global mean surface temperature, which reached 0.87 °C in 2006–2015 relative to 1850–1900 (Hoegh-Guldberg et al., 2018). The Paris Climate Conference led to a new international climate agreement aiming to keep global warming below 2 °C (1.5 °C), in accordance with the recommendations of the Intergovernmental Panel on Climate Change (IPCC) (Rogelj et al., 2018). One of the major contributors for this surface warming is anthropogenic carbon dioxide (CO_2) that releases to the atmosphere. The emissions of anthropogenic CO_2 due to fossil fuel use, cement manufacture and land-use change have increased rapidly over the last decade (Friedlingstein et al., 2010). The accumulated anthropogenic CO_2 at the atmosphere can be also taken up by the terrestrial biosphere and oceans.

The oceans play an important role as a carbon storage. The annual global ocean uptake is estimated at 1.4 to 2.5 Pg C yr-1 (e.g. Takahashi et al., 2002; Takahashi et al., 2009; McKinley et al., 2011), with annual rates of CO_2 uptake increasing with time (Le Quéré et al., 2009). The cumulative total global ocean uptake of anthropogenic CO_2 since pre-industrial time is estimated at 120–140 Pg C (Sabine et al., 2004; Khatiwala et al., 2009). Le Quéré et al. (2010) stated that one quarter of the carbon emitted by anthropogenic sources is thought to be sequestered in the oceans, annually. Furthermore, the ocean has a vast uptake capacity. It currently contains an estimated 40,000 Gt C (billion tons of carbon), mostly in the form of dissolved inorganic ions. This is not comparable with only about 800 Gt C contained in the atmosphere and 2000 Gt C in the land biosphere (Adams and Caldiera, 2008). Thus, understanding the role of ocean in the carbon cycle may become the important key for global warming mitigation. However, oceans can act as the source or sink of atmospheric gases influenced by a number of biological and physical processes. The air-sea CO_2 flux is a function of surface mixing which is determined by wind speed and the concentration difference between CO_2 in the air and water. The concentration in the ocean depends on the partial pressure of CO_2 (pCO_2) in the atmosphere and ocean which is the function of temperature, salinity, photosynthesis, and respiration rate (Chester, 2000; Botkin and Keller, 2000).

Global air-sea flux of CO_2 has been mapped by Takahashi et al. (2009) based on 3 million measurements of pCO_2 difference between

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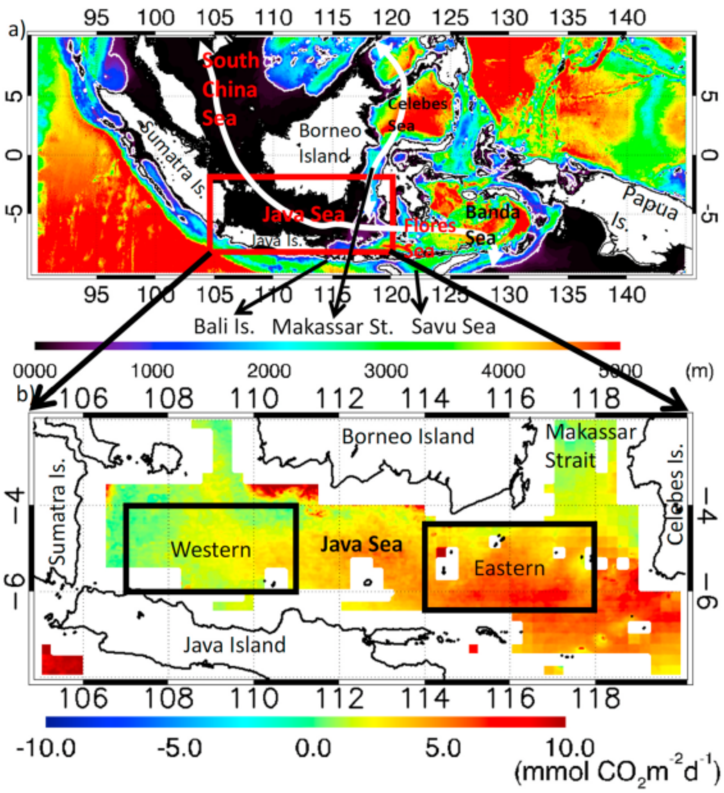

Fig. 1. a) Indonesian Seas Bathymetry. White arrows represent Asian-Australia monsoon wind system (see text for more explanation). White contour denotes 500 m depth. b) Study area. Black boxes represent the area in the western and eastern part of the Java Sea used for time series analysis shown in Figs. 10–14. The background color is the average map of CO_2 flux data from April 2015 to February 2017. Positive (negative) values denote CO_2 release from (uptaken by) the sea surface. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

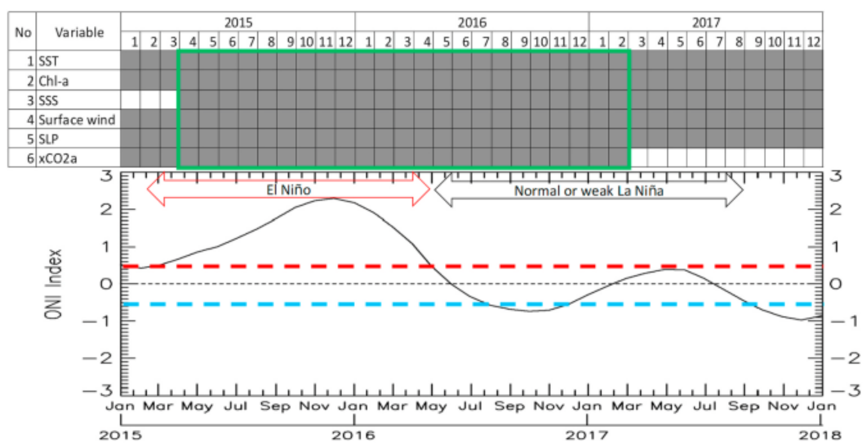

Fig. 2. Coverage of observation period provided by dataset used in the present study and the determination of El Niño and normal/weak La Niña period. Green box denotes the observation period used in the analysis of the present study. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

surface water and marine atmosphere (ΔpCO_2) from 1970s to 2005. They showed that the net global ocean uptake for CO_2 is -1.42 Pg-C/yr. Temperate and polar regions become the major sink for the atmospheric CO_2 while equatorial oceans are the major source for CO_2. The Atlantic Ocean becomes the most important region for CO_2 sink since 41% of CO_2 uptake occurs in the Atlantic Ocean. The Indian Ocean and Southern Ocean only contribute 27% of CO_2 uptake. The Pacific Ocean contributes to absorb CO_2 by 32%. However, the equatorial Pacific (14°N-14°S) becomes the major source for atmospheric CO_2, emitting about +0.48 Pg-C/yr which is about 3 times larger than the net CO_2 uptake of the global oceans.

As a part of the western equatorial Pacific, Indonesian Seas are left as blank space in Takahashi et al. (2009)'s map due to the limitation of ΔpCO_2 measurements. On the other hand, Indonesian Seas may also

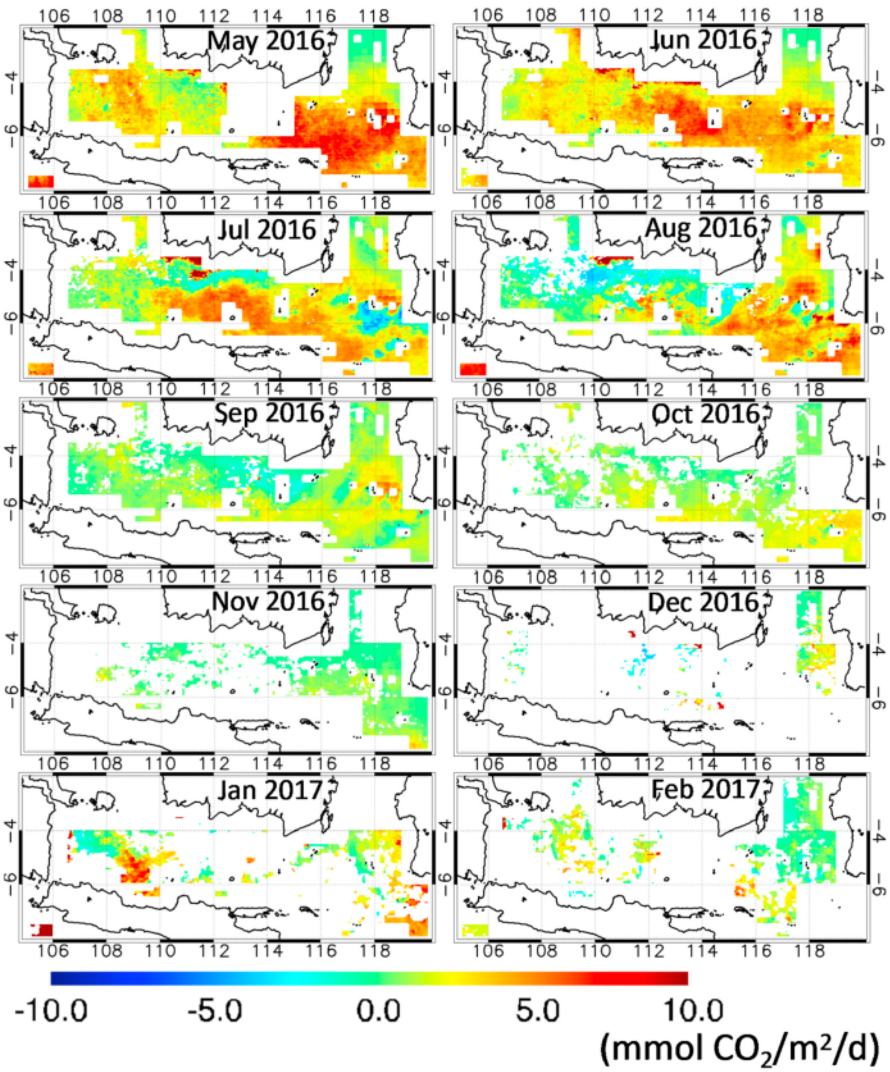

Fig. 3. Monthly CO_2 flux in the Java Sea during normal ENSO condition. Positive (negative) values denote CO_2 release from (uptaken by) the sea surface.

play an important role to the global carbon cycle. As one of the areas with the longest coastline in the world, Indonesian Seas receive huge amount of terrestrial organic matter and nutrient input (Sasai et al., 2011). Furthermore, the existence of Indonesian Throughflow which transports about 15 Sv water mass from the Pacific Ocean to the Indian Ocean (e.g. Sprintall et al., 2009; Susanto et al., 2016) may also contribute to the carbon transport between these two oceans.

To overcome this problem, Kartadikaria et al. (2015) collected and conducted the measurements of sea surface pCO_2 from 1984 to 2013 within Indonesian Seas mainly during summer monsoon. By interpolating into 30 min grid and 150 km radius, they showed that Indonesian Seas predominantly act as the carbon source spread from the Java Sea, Flores Sea, Savu Sea and the most part of the Makassar Strait. The carbon sink is observed in the Sulawesi Sea, small parts of Makassar Strait and the northern part of Bali Island. However, due to the limitation of the continuity measurement, their results cannot briefly explain the seasonal variation of pCO_2 flux within Indonesian Seas. On the other hand, Zhu et al. (2009) offered the sea surface pCO_2 calculation from satellite data. They managed to estimate pCO_2 in the South China Sea by using the algorithm derived from AVHRR Sea Surface Temperature (SST) data and SeaWiFS Chlorophyll-a (Chl_a) data with good accuracy. The root mean square error (RMSE) of the estimated pCO_2 is only 4.6 μatm. Adopting their algorithm, the present study estimates sea surface pCO_2 in the Java Sea, the area which is adjacent to the South China Sea. Both seas also have the same characteristics as the shallow seas and become the major route of the Asian-Australia Monsoon System (e.g. Wyrtki, 1961; Mohtadi et al., 2011; Pramuwardani et al., 2018; Susanto et al., 2006) which may affect the rate of air-sea gas exchange (Fig. 1). The Summer Asian monsoon is characterized by northwesterly wind blowing from Asia to Australia, which brings humid air and therefore causes the rainy season in most areas in Indonesia, while Winter Australia monsoon blows southeasterly from Australia to Asia bringing dry air mass which causes the dry season in Indonesia (Griffiths et al., 2009; Chang et al., 2005; Chang et al., 2006). Summer Asian (Winter Australia) monsoon occurs from June to August (December to February). Thus, March to May (September to November) is categorized as the first (second) transition season. For atmospheric pCO_2 we used tropospheric CO_2 mole fraction from Atmospheric Infrared Sounder (AIRS) following the

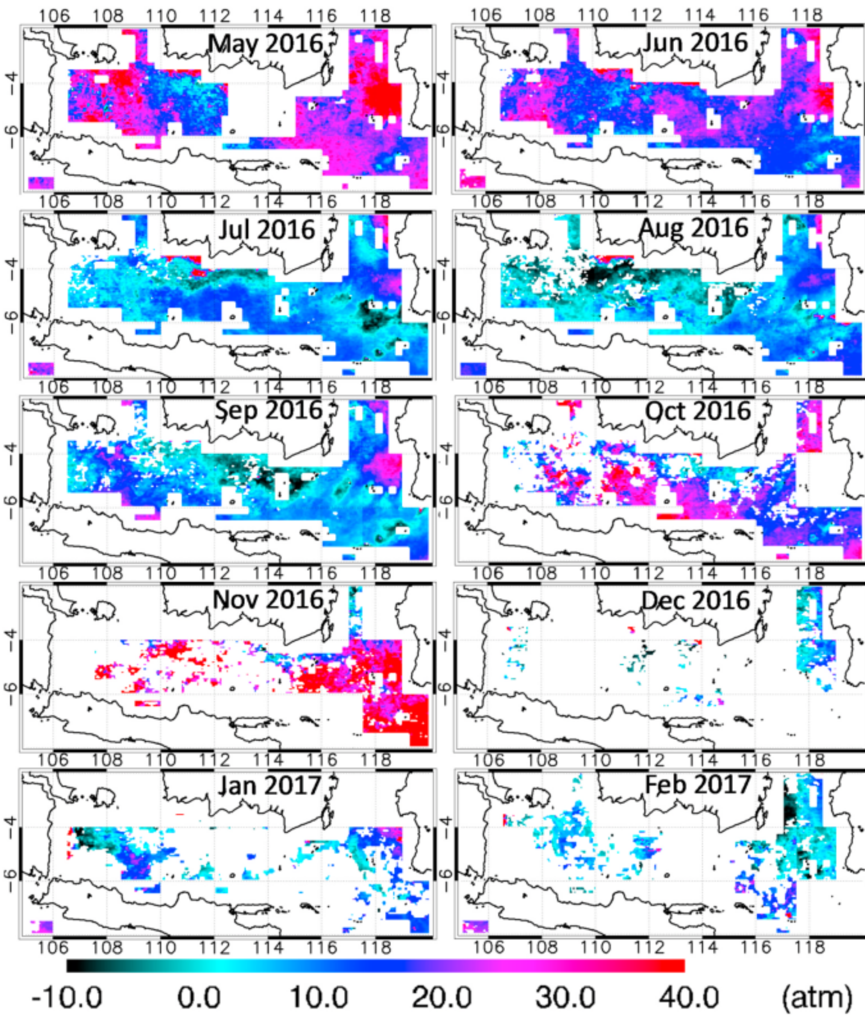

Fig. 4. Monthly ΔpCO_2 in the Java Sea during normal ENSO condition. Positive (negative) values denote pCO_{2w} is higher (lower) than pCO_{2a}.

algorithm of Dickson et al. (2007). Taking the advantage of satellite measurements which have wide coverage and continues monitoring, the present study is the first study to investigate the spatio-temporal distribution of CO_2 flux in the Java Sea. It is also the first study to examine the key parameters at the sea surface (i.e., SST, Chl_a, sea surface salinity, and surface wind) to obtain the most influencing parameter for CO_2 flux in the Java Sea. Furthermore, the effect of El Niño 2015–16 which is categorized by weaker El Niño (e.g. Chen et al., 2017) is also described in the present study.

2. Data and method

2.1. Data

For oceanic data we used SST and Chl_a derived from high spatial and temporal resolution data of the Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua Lv3, i.e., daily and 0.04 ° × 0.04 ° (Esaias et al., 1998). These datasets have been tested and calibrated against *in situ* data and ensure the best accuracy (e.g., Zhang et al., 2006; Ghanea et al., 2015; Lee et al., 2010; Qin et al., 2014). Sea surface salinity (SSS) is obtained from monthly Soil Moisture Active Passive (SMAP) mission with spatial resolution of 0.25 ° × 0.25 ° (Meissner et al., 2019).

For atmospheric parameters we used monthly tropospheric fraction mole of CO_2 obtained from AIRS measurement (AIRS Science Team/-Joao Teixeira, 2008). The spatial resolution of this dataset is 2.5 ° × 2.0 °. Surface wind speed is obtained from daily Advanced Scatterometer (ASCAT) with spatial resolution of 0.25 ° × 0.25 ° (Figa-Saldaña et al., 2002). For Sea Level Pressure (SLP), we used 6 hourly European Reanalysis (ERA) Interim with the grid interval of 0.25 ° × 0.25 ° (Dee et al., 2011). In addition, Oceanic Niño (ONI) index was used as reference for El Niño Southern Oscillation (ENSO) period. ONI index was obtained from https://www.cpc.ncep.noaa.gov/data/indices/oni.ascii.txt, described as the SST anomalies in the Niño 3.4 region (5°N-5°S, 170°W-120°W) with the basis period of 1971–2000. Bathymetry is obtained from ETOPO, a 1 arc-minute global relief model of Earth's surface that integrates land topography and ocean bathymetry (Amante and Eakins, 2009).

2.2. Method

Before commencing the calculation for estimating carbon flux, all

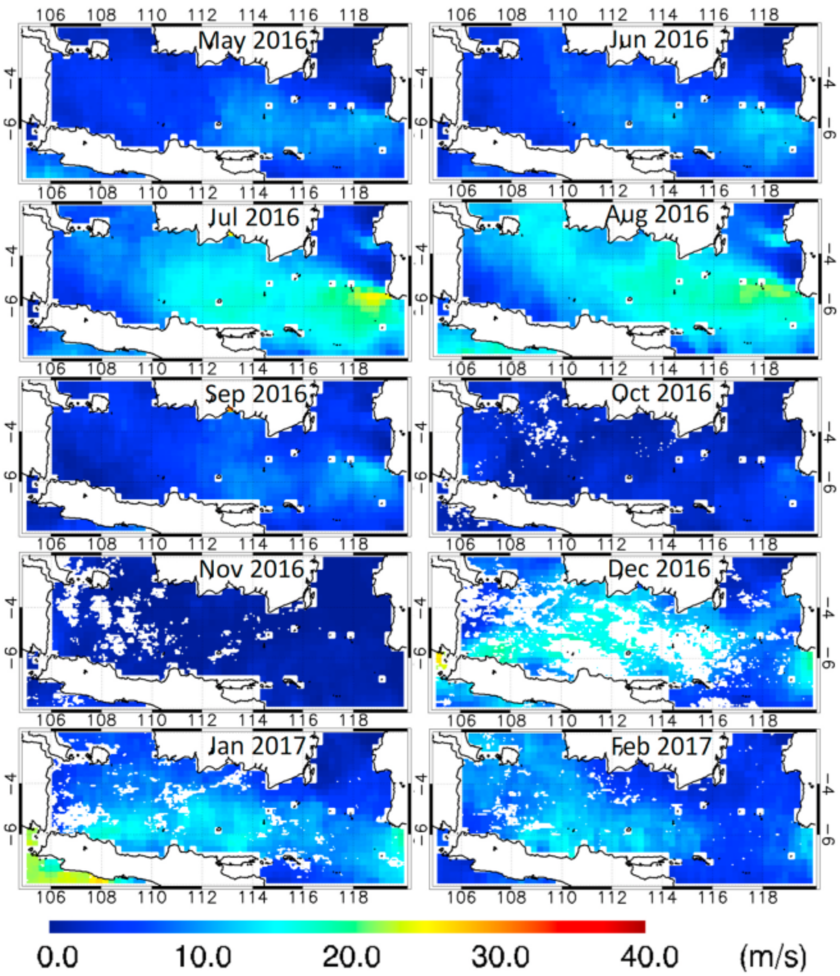

Fig. 5. Monthly k_{wa} in the Java Sea during normal ENSO condition.

parameters were interpolated into 0.04 ° × 0.04 ° with nearest neighbour method to follow the spatial resolution of MODIS SST and Chl_a data. Since our analysis is based on monthly data, the daily and semi daily data of SST, Chl_a, and SLP data were averaged into monthly data following Wirasatriya et al. (2017)'s equation:

$$\overline{X}(x,y) = \frac{1}{n}\sum_{i=1}^{n} xi(x,y,t) \quad (1)$$

where $\overline{X}(x,y)$ is monthly mean value at location (x,y), $xi(x,y,t)$ is ith value of the data at (x,y) location and time t. Furthermore, n is number of data in 1 month for monthly calculation. If xi is a hollow pixel, that pixel is excluded in the calculation.

Furthermore, due to the limitation of the observation period of each dataset, the present study can only estimate the carbon flux in the Java Sea from April 2015 to February 2017 (Fig. 2). This period of observation covers El Niño condition from April 2015 to April 2016 as denoted by the ONI index for more than 0.5 °C. The period from May 2016 to February 2017 is categorized as a normal year and therefore this period was used to obtain the seasonal variation of carbon flux in the Java Sea.

To calculate CO_2 flux in the Java Sea, we used an equation that has been used by many researchers to estimate the carbon flux for the marginal seas (e.g., Zhu et al., 2009) and global oceans (e.g., Feely et al., 2001; Tsai and Liu, 2003; Takahashi et al., 2002) summarized in Robbins et al. (2010). The equation is:

$$F = k_{wa} \times K_H \times (\Delta_p CO_2)_{\text{sea-atmosphere}} \quad (2)$$

where F and $\Delta_p CO_2$ are the net ocean-atmosphere CO_2 flux (mmol/m^2/day) and the partial pressure difference of CO_2 in the sea surface and the atmosphere, respectively. k_{wa} is the CO_2 gas transfer velocity in m/s which is calculated from SST and wind speed following Wanninkhof (1992) as:

$$k_{wa} = 0.31 \times u_{10}^2 \times (Sc/660)^{-0.5} \quad (3)$$

where u_{10} is wind speed (m/s) at 10 m above sea level. Sc is Schmidt number, calculated from SST as follows:

$$Sc = 2073.1 - (125{,}62 \times t) + (3.6276 \times t^2) - (0.043219 \times t^3) \quad (4)$$

where t is SST in °C. Furthermore, Weiss (1974) provides the formula to estimate K_H which is CO_2 solubility in mol/l/atm in sea water derived from SST and SSS.

$$K_H = -58.0931 + 90.5069/(T/100) + 22.2940 \times \ln(T/100)) + \ldots$$
$$S \times (0.02776\text{-}0.02588 \times (T/100) + 0.0050578 \times (T/100)^2) \quad (5)$$

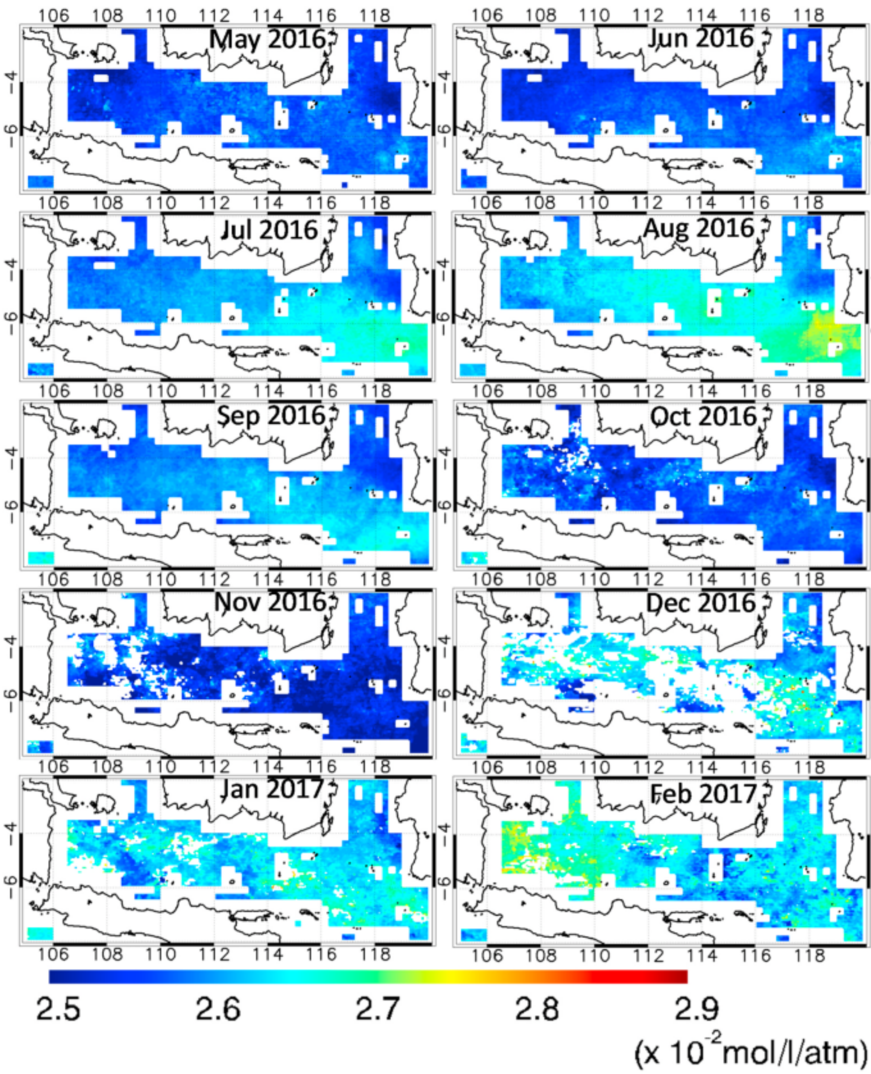

Fig. 6. Monthly K_H in the Java Sea during normal ENSO condition.

where T and S are SST in Kelvin and SSS in PSU, respectively.

The partial pressure CO_2 of sea water (pCO_{2W}) was estimated following Zhu et al. (2009) derived from SST and Chl_a data.

$$pCO_{2w} = 6.31t^2 + 61.9\ Chl\_a^2 + 365.85t - 94.41\ Chl\_a + 5715.94 \quad (6)$$

The partial pressure of CO_2 in the air (pCO_{2a}) was calculated from the formula of Dickson et al. (2007).

$$pCO_{2a} = xCO_{2a}(p_b - pH_2O) \quad (7)$$

where xCO_{2a} and p_b are the CO_2 mole fraction in the troposphere (ppm) and SLP (atm), respectively. pH_2O is saturation vapor pressure of sea water in atmosphere and it was calculated from Weiss and Price (1980)'s formula as a function of SST and SSS.

$$pH_2O = \exp(24.4543 - 67.4509 \times (100/T) - 4.8489 \times \ln(T/100) - 0.000544 \times S) \quad (8)$$

3. Results

3.1. *Spatial distribution of carbon dioxide fluxes in the Java Sea*

First, we constructed a composite map of all data period, i.e. from April 2015 to February 2017 to obtain the general feature of the spatial distribution of CO_2 flux in the Java Sea. The result is depicted in Fig. 1b. Positive CO_2 flux is observed in all grids of the Java Sea. This means that the Java Sea acts as a CO_2 source for the atmosphere. The strong (weak) CO_2 source is obtained at the eastern (western) part of the Java Sea.

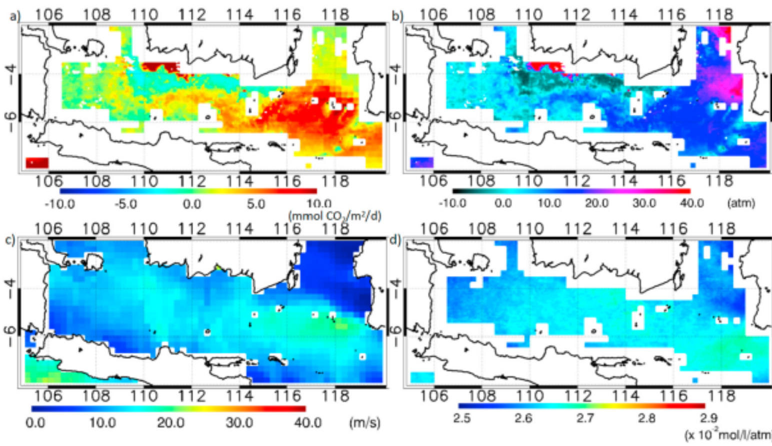

Fig. 7. Spatial distribution of a) CO_2 flux, b) ΔpCO_2, c) k_{wa}, and d) K_H in May 2015 as the representation of the first transition season during El Niño period.

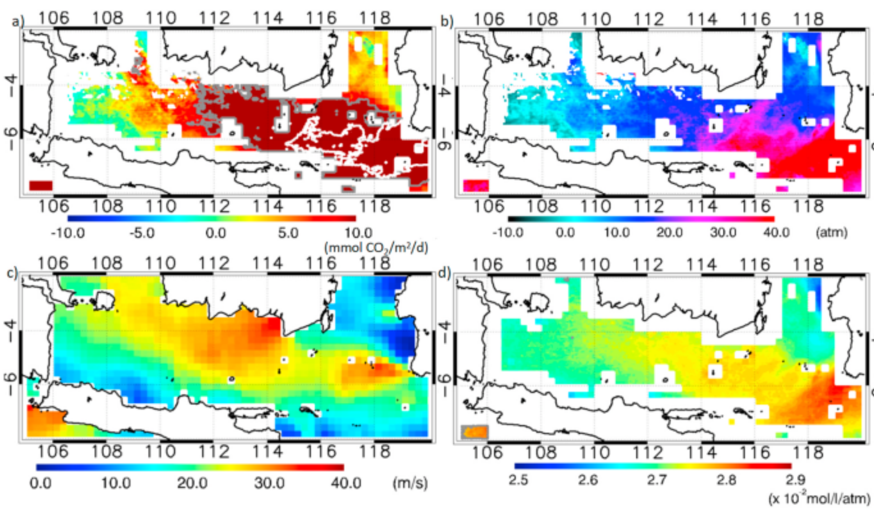

Fig. 8. Spatial distribution of a) CO_2 flux, b) ΔpCO_2, c) k_{wa}, and d) K_H in August 2015 as the representation of summer monsoon season during El Niño period. The gray and white contour in a) denotes CO_2 flux of 10 mmol/m^2/day and 20 mmol/m^2/day, respectively. Positive (negative) values in a) denote CO_2 release from (uptaken by) the sea surface.

For the second step, we analyzed the seasonal variation of CO_2 fluxes in the Java Sea which is represented by the period of observation from May 2016 to February 2017. The spatial distribution of CO_2 flux, ΔpCO_2, k_{wa} and K_H are presented in Figs. 3–6, respectively. The first transition season (represented by May 2016) has the highest values for positive CO_2 flux and positive ΔpCO_2. Large positive CO_2 flux which reaches more than 10 mmol CO_2/m^2/day is observed at the eastern part of the Java Sea. The large positive CO_2 flux corresponds to the large positive of ΔpCO_2 which reaches 30 at m. At the western part of the Java Sea, CO_2 flux and ΔpCO_2 are still positive but lower than that at the eastern part. Contrary to CO_2 flux and ΔpCO_2, the velocity of k_{wa} is low during the first transition season. Furthermore the velocity of k_{wa} at the eastern part is only slightly higher than at the western part. For the spatial distribution of K_H is almost uniform in the Java Sea and the value is only less than 2.6 × 10^{-2} mol/l/atm.

During summer monsoon (June to August 2016) distinct spatial distribution of CO_2 fluxes are observed in the Java Sea. Positive (negative) CO_2 flux are identified at the eastern (western) part of the Java Sea especially during August 2016. The positive (negative) flux is related to the positive (negative) ΔpCO_2 at the eastern (western) part of the Java Sea. It should be noted that the negative ΔpCO_2 at the western part of the Java Sea is not as large as the positive ΔpCO_2 at the eastern part of the Java Sea and the negative ΔpCO_2 is only observed partially at the western part of the Java Sea i.e., along the southern part of Borneo Island. k_{wa} and K_H attain maximum during summer monsoon. K_H (k_{wa}) shows a maximum in August (July) 2016 and the eastern part of the Java Sea reaches a magnitude about 2.75× 10^{-2} mol/l/atm (25 m/s). Since k_{wa} and K_H is high, the small negative of ΔpCO_2 at the western part still can amplify the negative flux of CO_2 at the western part of the Java Sea.

During the second transition period (September to November 2016), the CO_2 flux is positive but it is not as large as the first transition and summer monsoon. Although positive ΔpCO_2 increases in November 2016, the magnitude of k_{wa} and K_H reach the minimum in November 2016. The magnitude of k_{wa} and K_H in the Java Sea is only less than 5 m/s and less than 2.55 × 10^{-2} mol/l/atm, respectively. Thus, the weak positive of the CO_2 flux corresponds to the small value of positive k_{wa}

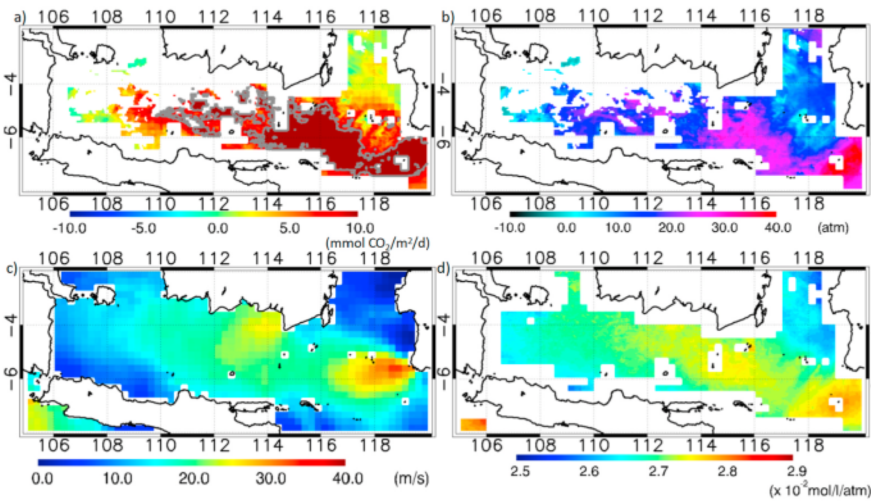

Fig. 9. Spatial distribution of a) CO_2 flux, b) ΔpCO_2, c) k_{wa}, and d) K_H in October 2015 as the representation of second transition season during El Niño period. The gray contour in a) denotes CO_2 flux of 10 mmol/m^2/day.

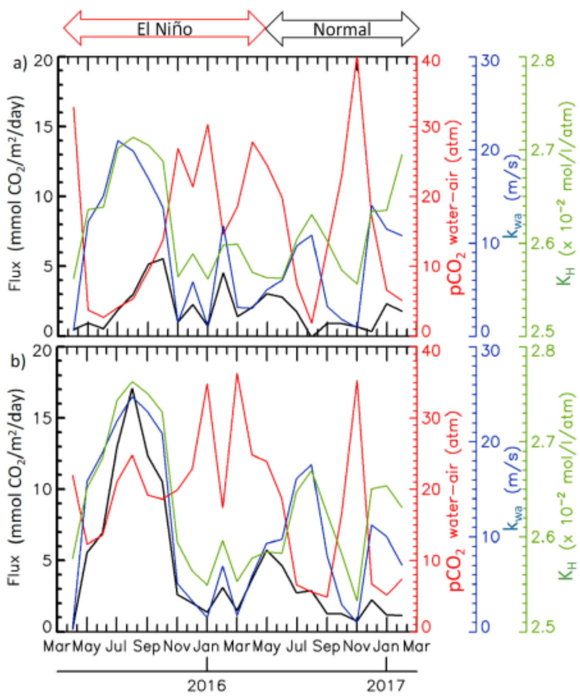

Fig. 10. Temporal variation of CO_2 flux, ΔpCO_2, k_{wa} and K_H in a) western box and b) eastern box as shown in Fig. 1b.

and K_H during the second transition season.

For the winter monsoon season (November 2016 to January 2017), we cannot observe the spatial distribution of CO_2 flux and ΔpCO_2 during this period, due to high cloud coverage that obstructed satellite measurements. Thus, we skip the analysis for CO_2 flux and ΔpCO_2 during the winter monsoon season. For k_{wa} and K_H, their magnitude increase during the winter monsoon season after reaching a minimum during the second transition season. The peak of k_{wa} (K_H) magnitude during winter monsoon occurs in December (February) 2016. However, their magnitudes are still lower than the magnitude reached in summer monsoon.

The third step is the analysis of the effect of El Niño on the distribution of CO_2 flux in the Java Sea which occurred from 2015 to mid 2016. During the first transition season (represented by May 2015), CO_2 release is still observed at the eastern part of the Java Sea (Fig. 7). CO_2 uptake is observed at the western part of the Java Sea along the southern part of Borneo Island. The magnitude of CO_2 flux during El Niño is larger than that during normal condition. This corresponds to the larger amplitude of ΔpCO_2, k_{wa} and K_H during El Niño than during normal condition.

During summer monsoon season (represented by August 2015), large CO_2 release is observed at the eastern part of the Java Sea from the southern part of Makassar Strait to the southern part of Borneo Island which is denoted by more than 10 mmol/m^2/day of CO_2 flux (Fig. 8). Furthermore, an extreme CO_2 release by more than 20 mmol/m^2/day appears at the southern part of Makassar Strait. This is caused by the maximum value of ΔpCO_2, k_{wa} and K_H at the southern part of the Makassar Strait. At the southern part of Borneo Island, only k_{wa} shows the high magnitude similar to the southern part of Makassar Strait, while positive ΔpCO_2, K_H are less than those at the southern part of Makassar Strait. Thus, the CO_2 flux at the southern part of Borneo Island is less than that of the southern part of Makassar Strait.

The magnitude of positive CO_2 flux in the Java Sea decreases during the second transition season (represented by October 2015) (Fig. 9). At the southern part of Makassar Strait, the positive CO_2 flux cannot reach 20 mmol/m^2/day. This is caused by the reduction of ΔpCO_2, k_{wa} and K_H values in the whole Java Sea area. However, the magnitude of positive CO_2 flux during the second transition season is higher than that during the first transition season. Summarizing the analysis for these three seasons, it can be concluded that El Niño tends to amplify the magnitude of CO_2 flux, ΔpCO_2, k_{wa} and K_H during all seasons.

3.2. *Temporal variation analysis*

To obtain the relationships among variables, we conducted the temporal variation analysis by extracting the mean value of all monthly variables in the western and eastern boxes as shown in Fig. 1b. This separation represents the strength of CO_2 release as described in the previous sub section. Fig. 10 shows the temporal variation of CO_2 flux, ΔpCO_2, k_{wa} and K_H. Obviously, we can see that the CO_2 source in the

Table 1

Correlation analysis among variables. Left and right column of each variable denotes western and eastern boxes as shown in Fig. 1b, respectively.

Variable	Flux		k_{wa}		K_H		pCO2w	
ΔpCO2	−0.16	0.1						
k_{wa}	0.4	0.85						
K_H	0.4	0.82						
ΔpCO2, k_{wa},K_H	0.5	0.96						
SST			−0.89	−0.95	−0.99	−0.99	0.75	0.37
Chl_a							−0.65	−0.29
SST,Chl_a							0.83	0.41
WS			0.99	0.98				
SSS					0.48	0.52		
SST, WS			0.99	0.99				
SST, SSS					0.99	0.99		

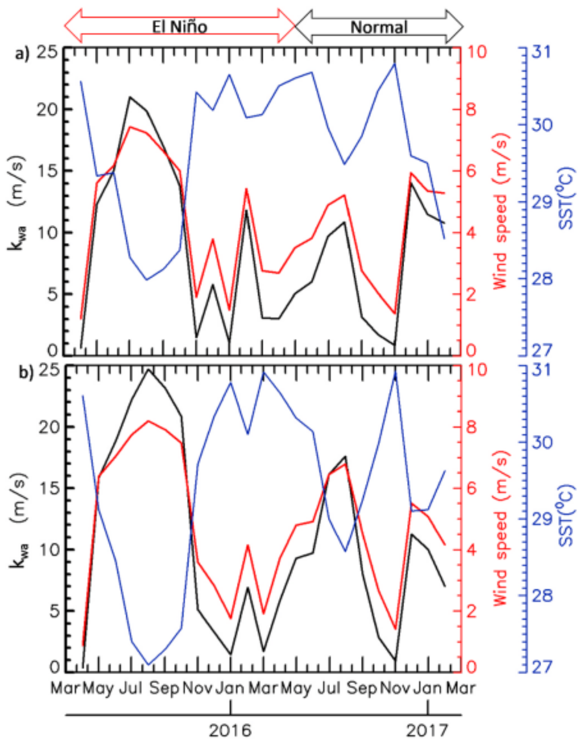

Fig. 11. Temporal variation of k_{wa}, wind speed and SST in a) western box and b) eastern box as shown in Fig. 1b.

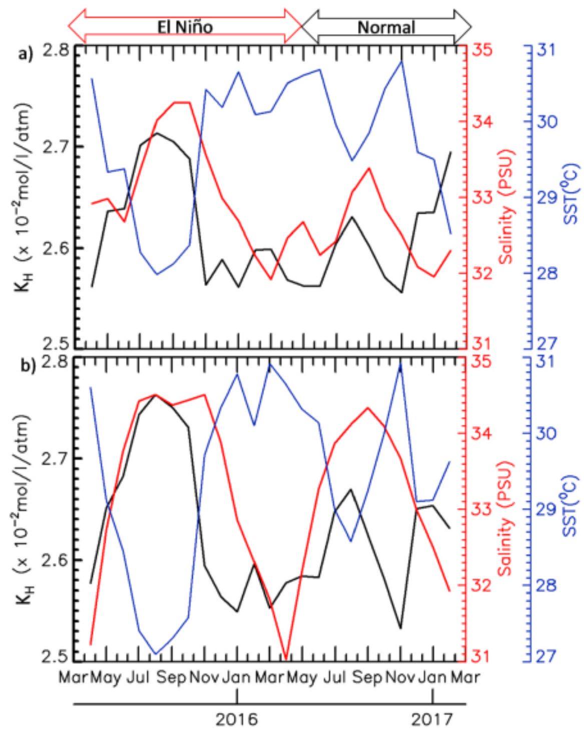

Fig. 12. Temporal variation of K_H, SSS and SST in a) western box and b) eastern box as shown in Fig. 1b.

eastern part is higher than that in the western part. In the western part, the maximum release of CO_2 is only 5 mmol/m^2/day in October 2015. In the eastern part, the maximum release of CO_2 reaches 17 mmol/m^2/day in August 2015. It also can be clearly seen in both boxes that the variation of CO_2 fluxes are much more influenced by the variation of k_{wa} and K_H. However, in the periods when ΔpCO_2 are low e.g., July 2015 in the western box, and August 2016 in both boxes, the high k_{wa} and K_H do not result in high CO_2 release. Statistical analysis depicted in Table 1 also shows that k_{wa} and K_H have stronger relationship with CO_2 flux than ΔpCO_2. However, the role of ΔpCO_2 cannot be neglected since the multivariate correlation analysis produces higher correlation value than single correlation analysis. The correlation among variables for the eastern box are stronger than the western box. This may be caused by the more frequent occurrence of low ΔpCO_2 in the western box which reduces the correlation value between CO_2 flux and k_{wa} or K_H.

The variations of k_{wa}, SST and wind speed are depicted in Fig. 11. As a function of SST and wind speed the variation of k_{wa} is parallel (reverse) with the variation of wind speed (SST). In fact, previous studies have revealed that the variability of SST depends on the variability of wind speed (Wirasatriya et al., 2018, 2019). The higher wind speed, the more latent heat releases to the atmosphere, causing SST reduction (Wirasatriya et al., 2019). This result is supported by the statistical analysis denoted by very strong positive (negative) correlation between wind speed (SST) and k_{wa}. The correlation is even higher for the multivariate analysis between wind speed; SST and k_{wa} (Table 1).

The negative correlation is also found between SST and K_H (Fig. 12, Table 1). The variation of SST is opposite to the variation of K_H, while the variation of SSS nearly follows the variation of K_H. This indicates that although correlation between SSS and K_H is positive, the correlation value is not as strong as SST and K_H. This means that SST plays more significant role in determining the variation of K_H. Nevertheless, the role of SSS cannot be ignored since the multivariate correlation among K_H and SST and SSS is higher than the single correlation between K_H and

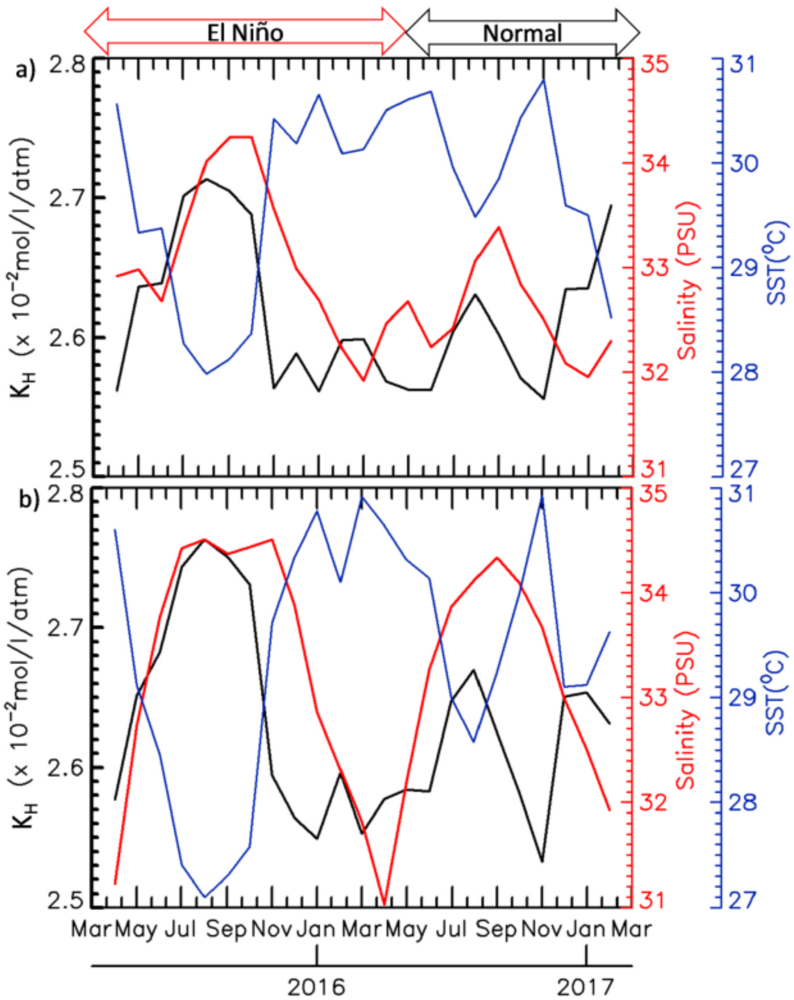

Fig. 13. Temporal variation of ΔpCO_2, pCO_{2w} (red solid line) and pCO_{2a} (red dashed line) in a) western box and b) eastern box as shown in Fig. 1b. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

SST.

The temporal variations of ΔpCO_2, pCO_{2w} and pCO_{2a} are shown in Fig. 13. The variation of ΔpCO_2 is in accordance with the pCO_{2w} variation. Since the value and the variation of pCO_{2a} is too low, the variation of ΔpCO_2 depends only on the variation of pCO_{2w}. Furthermore, Fig. 14 and Table 1 explain the relation among pCO_{2w}, SST and Chl_a. pCO_{2w} has positive (negative) correlation with SST (Chl_a). The correlation of pCO_{2w} and SST is stronger than pCO_{2w} and Chl_a. However, multivariate correlation is stronger than the single correlation. This means that both SST and Chl_an influence the variation of pCO_{2w} in the Java Sea.

Considering the correlation analysis which includes SSTs, it is important to be noted that the SST has the opposite impact to the variation of pCO_{2w} and k_{wa} or K_H. The increase of SST tends to increase pCO_{2w} but decrease k_{wa} and K_H. Since pCO_{2w}, k_{wa} and K_H determine the value of CO_2 flux, the role of SSTs on determining CO_2 flux depends on the strength of pCO_{2w}, k_{wa} and K_H in influencing CO_2 flux. In the case of Java Sea, since CO_2 flux is more correlated with k_{wa} and K_H than pCO_{2w}, the increase of SSTs tends to suppress CO_2 release. Therefore, wind speed as the function of k_{wa} and SSS as the function of K_H play important role in determining the variation of CO_2 release in the Java Sea.

4. Discussion

The results obtained in the present study is further discussed in this section by comparing them with the results obtained from Zhu et al. (2009) and Kartadikaria et al. (2015). Zhu et al. (2009) produces the map of CO_2 flux in the South China Sea during summer 2000–2005. Their results showed that South China Sea acts as CO_2 source, the same as Java Sea as obtained in the present study. The CO_2 release in the South China Sea is about 8 mmol/m^2/day, which is equivalent to the CO_2 release in the Java Sea especially in the eastern part. Thus, since both areas exhibit similar characteristics, the Java Sea and South China Sea act as the CO_2 source for the atmosphere. In addition, Zhu et al. (2009) showed that the variation of pCO_{2w} depends not only on SST variation but also Chl_a variation as also shown in the present study.

Kartadikaria et al. (2015) shows the ΔpCO_2 map created from the CO_2 observation. They found that the Java Sea mostly becomes the source of CO_2 and this is in line with the results of the present study (Fig. 15). Regarding the effect of ENSO on the variability of ΔpCO_2, fortunately Kartadikaria et al. (2015)'s observation covered La Niña period. Therefore, the result of the present study which covers El Niño period complete the analysis of the ENSO effect on the variability of CO_2

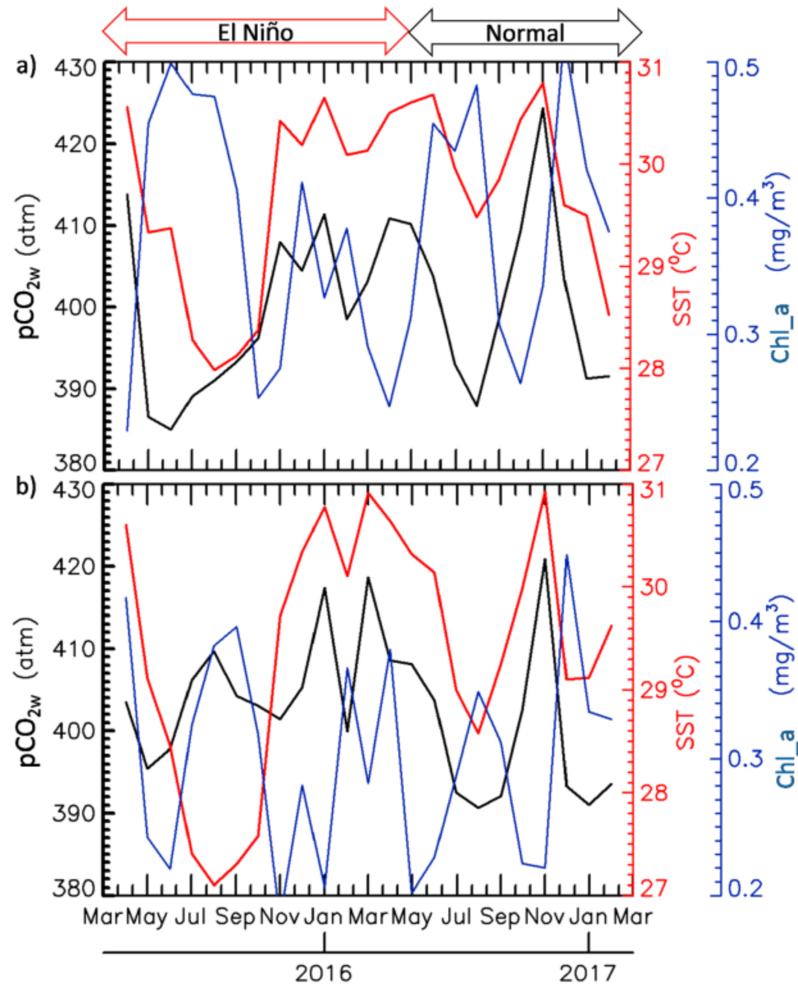

Fig. 14. Temporal variation of pCO_{2w}, SST and Chl_a in a) western box and b) eastern box as shown in Fig. 1b.

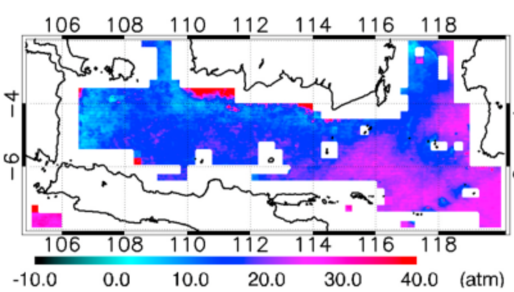

Fig. 15. The average map of ΔpCO_2 data from April 2015 to February 2017.

flux in the Java Sea. Kartadikaria et al. (2015) stated that ΔpCO_2 decreases during La Niña event, while the present study suggests that El Niño tends to increase ΔpCO_2. However, it is important to note that both study mainly focus on the summer monsoon season. During winter monsoon, the effect of ENSO on the variability of ΔpCO2 might be different since Wirasatriya et al. (2018) found that El Niño (La Niña) tends to increase (reduce) SST in the Java Sea during this season due to the reduction (increase) of northwesterly wind speed. Therefore, the analysis of CO_2 flux in the Java Sea during winter monsoon season still remains unclear and to be potentially investigated in the future study.

It has been shown in Fig. 8 that a very large positive flux by more than 20 mmol/m^2/day appears in the southern part of Makassar Strait. This outstanding positive flux is contributed by the large ΔpCO_2, k_{wa} and K_H during El Niño period. Setiawan and Kawamura (2011) found that the southern part of Makassar Strait is known for the occurrence of upwelling areas during summer monsoon season. This upwelling condition is denoted by low SST, and high Chl_a caused by strong easterly wind that generate offshore Ekman Transport. This easterly wind is enhanced during El Niño condition (Wirasatriya et al., 2018). Therefore, stronger wind speed and lower SST (higher Chl_a) during El Niño increase k_{wa} and K_H (pCO_{2w}). This trend continues until the second transition period (represented by October 2015) (Fig. 9). However, the amplitude of CO_2 flux decreases following the decrease of ΔpCO_2, k_{wa} and K_H. These results show that El Niño tends to increase the CO_2 flux as consequences of the increase of ΔpCO_2, k_{wa} and K_H.

Some important findings that need to be addressed in the present study are as follows. We found the signature of the seasonal variation of CO_2 flux in the Java Sea. The maximum CO_2 release occurs during the first transition season which is related to the highest positive value of

ΔpCO_2 in the Java Sea. In terms of interannual variation, El Niño tends to increase the magnitude of CO_2 flux in the Java Sea. We also found that among the examined oceanic and atmospheric parameters, wind speed and SSS plays more important role than SST and Chl_a to determine the variability of CO_2 flux in the Java Sea. However, it is important to be noted that since the CO_2 flux presented in this study is based on the calculation of various atmospheric and oceanic parameters derived from satellite measurements, further investigation by using continuous CO_2 measurements are needed to support the result of the present study. These tasks are left for future study.

5. Conclusion

The estimation of CO_2 flux in the Java Sea has been conducted from various parameters obtained from satellite measurements and the results are concluded as follows:

1. Generally, the Java Sea acts as a CO_2 source. However, during May 2015 and August 2016 small areas along the southern Borneo Island become the sink areas of CO_2.
2. During the normal ENSO period, the largest source of CO_2 was found in the first transition season which is related to the highest positive value of ΔpCO_2 in the Java Sea.
3. The eastern part of the Java Sea has larger CO_2 flux than the western part since ΔpCO_2, k_{wa} and K_H are stronger at the eastern part than at the western part of the Java Sea.
4. El Niño condition tends to amplify the release of CO_2 to the atmosphere since CO_2 gas transfer velocity, CO_2 solubility and the difference of CO_2 pressure between sea and atmosphere increase during El Niño.
5. The influence of CO_2 gas transfer velocity and CO_2 solubility is stronger than the difference of CO_2 pressure between sea and atmosphere to determine CO_2 flux in the Java Sea. Therefore, wind speed and SSS play an important role in determining the variability of CO_2 flux in the Java Sea.

CRediT authorship contribution statement

Anindya Wirasatriya: Conceptualization, Methodology, Software, Investigation, Visualization, Writing - review & editing. **Denny Nugroho Sugianto:** Supervision. **Lilik Maslukah:** Supervision, Investigation. **Muhammad Faqih Ahkam:** Data curation, Writing - original draft, preparation. **Sri Yulina Wulandari:** Supervision. **Muhammad Helmi:** Formal analysis, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rsase.2020.100376.

References

Adams, E.E., Caldiera, K., 2008. Ocean storage of CO_2. Elements 4, 319–324. https://doi.org/10.2113/gselements.4.5.319.

AIRS Science Team/Joao Teixeira, 2008. AIRS/Aqua L3 Monthly CO2 in the Free Troposphere (AIRS+AMSU) 2.5 Degrees X 2 Degrees V005. Goddard Earth Sciences Data and Information Services Center (GES DISC), Greenbelt, MD, USA. https://doi.org/10.5067/Aqua/AIRS/DATA339. Accessed: [September 2019]..

Amante, C., Eakins, B.W., 2009. ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. NOAA Technical Memorandum NESDIS NGDC-24. National Geophysical Data Center, NOAA; US Dept. of Commerce. https://doi.org/10.7289/V5C8276M.

Botkin, D.B., Keller, E.A., 2000. Environmental Science, Earth as a Living Planet, third ed. John Wiley & Sons, Inc. 649p.

Chang, C.-P., Wang, Z., McBride, J., Liu, C.-H., 2005. Annual cycle of Southeast asia—Maritime continent rainfall and the asymmetric monsoon transition. J. Clim. 18, 287–301. https://doi.org/10.1175/JCLI-3257.1.

Chang, C.P., Wang, Z., Hendon, H., 2006. The Asian winter monsoon. In: The Asian Monsoon. Springer Praxis Books. Springer, Berlin, Heidelberg, pp. 89–127.

Chen, L., Li, T., Wang, B., Wang, L., 2017. Formation mechanism for 2015/16 super El Niño. Sci. Rep. 7 (2975), 1–10. https://doi.org/10.1038/s41598-017-02926-3.

Chester, R., 2000. Marine Geochemistry, second ed. Blackwell Science Ltd, Osney Mead, Oxford OX2 0EL. 506p.

Dee, D.P., Uppala, S.M., Simmons, A.J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M.A., Balsamo, G., Bauer, P., Bechtold, P., Beljaars, A.C.M., van de Berg, L., Bidlot, J., Bormann, N., Delsol, C., Dragani, R., Fuentes, M., Geer, A.J., Haimberger, L., Healy, S.B., Hersbach, H., Hólm, E.V., Isaksen, L., Kållberg, P., Köhler, M., Matricardi, M., McNally, A.P., Monge-Sanz, B.M., Morcrette, J.-J., Park, B.-K., Peubey, C., de Rosnay, P., Tavolato, C., Thépaut, J.-N., Vitart, F., 2011. The ERA-Interim reanalysis: configuration and performance of the data assimilation system. Q. J. R. Meteorol. Soc. 137, 553–597. https://doi.org/10.1002/qj.828.

Dickson, A.G., Sabine, C.L., Christian, J.R., 2007. Guide to Best Practices for Ocean CO_2 Measurements, vol. 3. PICES Special Pub., pp. 1–191

Esaias, W.E., Abbott, M.R., Barton, I., Brown, O.B., Campbell, J.W., CarderK, L., Clark, D.K., Evans, R.H., Hoge, F.E., Gordon, H.R., Balch, W.M., Letelier, R., Minnett, P.J., 1998. An overview of MODIS capabilities for ocean science observations. In: IEEE Trans. Geosci. Remote Sens, vol. 36, pp. 1250–1265. https://doi.org/10.1109/36.701076, 4.

Feely, R.A., Sabine, C.L., Takahashi, T., Wanninkhof, R., 2001. Uptake and storageof carbon dioxide in the ocean: the global CO_2 survey. Oceanography 14 (4), 18–32.

Figa-Saldaña, J., Wilson, J.J.W., Attema, E., Gelsthorpe, R.V., Drinkwater, M.R., Stoffelen, A., 2002. The Advanced scatterometer (ASCAT) on the Meteorological Operational (MetOp) Platform: a follow on for European wind scatterometers. Can. J. Rem. Sens. 28 (3), 404–412.

Friedlingstein, P., Houghton, R.A., Marland, G., Hackler, J., Boden, T.A., Conway, T.J., Canadell, J.G., Raupach, M.R., Ciais, P., Le Quere, C., 2010. Update on CO2 emissions. Nat. Geosci. 3, 811–812.

Ghanea, M., Moradi, M., Kabiri, K., Mehdinia, A., 2015. Investigation and validation of MODIS SST in the northern Persian Gulf. Adv. Space Res. 57 (1) https://doi.org/10.1016/j.asr.2015.10.040.

Griffiths, M.L., Drysdale, R.N., Gagan, M.K., Zhao, J.-X., Ayliffe, L.K., Hellstrom, J.C., Hantoro, W.S., Frisia, S., Feng, Y.-X., Cartwright, I., Pierre, E.S., Fischer, M.J., Suwargadi, B.W., 2009. Increasing Australian–Indonesian monsoon rainfall linked to early Holocene sea-level rise. Nat. Geosci. 2, 636–639. https://doi.org/10.1038/ngeo605.

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., Diedhiou, A., Djalante, R., Ebi, K.L., Engelbrecht, F., Guiot, J., Hijioka, Y., Mehrotra, S., Payne, A., Seneviratne, S.I., Thomas, A., Warren, R., Zhou, G., 2018. Impacts of 1.5°C global warming on natural and human systems. In: Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M., Waterfield, T. (Eds.), Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty (in press).

Kartadikaria, A.R., Watanabe, A., Nadaoka, K., Adi, N.S., Prayitno, H.B., Soemorumekso, S., Muchtar, M., Triyulianti, I., Setiawan, A., Suratno, S., Khasanah, E.N., 2015. CO_2 sink/source characteristics in the tropical Indonesian seas. J. Geophys. Res. Oceans. 120, 7842–7856. https://doi.org/10.1002/2015JC010925.

Khatiwala, S., Primeau, F., Hall, T., 2009. Reconstruction of the history of anthropogenic CO_2 concentrations in the ocean. Nature 462, 346–349.

Lee, M.A., Tzeng, M.T., Hosoda, K., Sakaida, F., Kawamura, H., Shieh, W.J., Yang, Y., Chang, Y., 2010. Validation of JAXA/MODIS sea surface temperature in water around Taiwan using the Terra and Aqua satellites. Terr. Atmos. Ocean Sci. 21 (4), 727–736.

Le Quéré, C., Raupach, M.R., Canadell, J.G., Marland, G., Bopp, L., Ciais, P., Conway, T. J., Doney, S.C., Feely, R.A., Foster, P., Friedlingstein, P., Gurney, K., Houghton, R.A., House, J.L., Huntingford, C., Levy, P.E., Lomas, M.R., Majkut, J., Metzl, N., Ometto, J.P., Peters, G.P., Prentice, I.C., Randerson, J.T., Runnning, S.W., Sarmeinto, J.L., Schuster, U., Sitch, S., Takahashi, T., Viovy, N., van der Werf, G.R., Woodward, F.I., 2009. Trends in the sources and sinks of carbon dioxide. Nat. Geosci. 2, 831–836.

Le Quéré, C., Takahashi, T., Buitenhuis, E.T., Rodenbeck, C., Sutherland, S.C., 2010. Impact of climate change and variability on the global oceanic sink of CO2. Global Biogeochem. Cycles 24, GB4007.

Meissner, T., Wentz, F.J., Manaster, A., Lindsley, R., 2019. Remote Sensing Systems SMAP Ocean Surface Salinities [Level 3 Monthly], Version 4.0 Validated Release. Remote Sensing Systems, Santa Rosa, CA, USA. https://doi.org/10.5067/SMP40-3SMCS. Available online at: www.remss.com/missions/smap.

McKinley, G.A., Fay, A.R., Takahashi, T., Metzl, N., 2011. Convergence of atmospheric and North Atlantic carbon dioxide trends on multidecadal timescales. Nat. Geosci. 4 (9), 606–610. https://doi.org/10.1038/ngeo1193.

Mohtadi, M., Oppo, D.W., Steinke, S., Stuut, J.-B.W., Holz, R.D.P., Hebbeln, D., Lückge, A., 2011. Glacial to Holocene swings of the Australian–Indonesian monsoon. Nat. Geosci. 4, 540–544. https://doi.org/10.1038/ngeo1209.

Pramuwardani, I., Hartono, Sunarto, Sopaheluwakan, A., 2018. Indonesian rainfall variability during Western North Pacific and Australian monsoon phase related to convectively coupled equatorial waves. Ar. J. Geosci. 11, 1–28. https://doi.org/10.1007/s12517-018-4003-7.

Qin, H., Chen, G., Wang, W., Wang, D., Zeng, L., 2014. Validation and application of MODIS-derived SST in the South China Sea. Int. J. Rem. Sens. 35 (11–12), 4315–4328.

Robbins, L.L., Hansen, M.E., Kleypas, J.A., Meylan, S.C., 2010. CO2calc: A User Friendly Seawater Carbon Calculator for Windows, Mac OS X, and iOS(iPhone), Florida Shelf Ecosystems Response to Climate Change Project, Open-File Report 2010-1280. U.S. Department of the Interior, U.S. Geological Survey.

Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., Ginzburg, V., Handa, C., Kheshgi, H., Kobayashi, S., Kriegler, E., Mundaca, L., Séférian, R., Vilariño, M.V., 2018. Mitigation Pathways compatible with 1.5°C in the context of sustainable development. In: Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M., Waterfield, T. (Eds.), Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty (in press).

Sabine, C.L., Feely, R.A., Gruber, N., Key, R.M., Lee, K., Bullister, J.L., Wanninkhof, R., Wong, C.S., Wallace, D.W.R., Tilbrook, B., Millero, F.J., Peng, T.-H., Kozyr, A., Ono, T., Rios, A.F., 2004. The oceanic sink for anthropogenic CO_2. Science 305, 367–371.

Sasai, Y., Kartadikaria, A.R., Miyazawa, Y., Nadaoka, K., 2011. Marine ecosystem simulation in the Indonesian seas. In: Omori, K., et al. (Eds.), Interdisciplinary Studies on Environmental Chemistry—Marine Environmental Modeling & Analysis. TERRAPUB, Tokyo, pp. 11–17.

Setiawan, R.Y., Kawamura, H., 2011. Summertime phytoplankton bloom in the South Sulawesi sea. IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens. (JSTARS) 4 (1), 241–244.

Sprintall, J., Wijffels, S.E., Molcard, R., Jaya, I., 2009. Direct estimates of the Indonesian Throughflow entering the Indian ocean: 2004-2006. J. Geophys. Res.-Oceans. 114 https://doi.org/10.1029/2008JC005257. C07001.

Susanto, R.D., Moore, T.S., Marra, J., 2006. Ocean color variability in the Indonesian Seas during the SeaWiFS era. G-cubed 7, 1–16. https://doi.org/10.1029/2005GC001009.

Susanto, R.D., Wei, Z., Adi, T.R., Zheng, Q., Fang, G., Bin, F., Supangat, A., Agustiadi, T., Li, S., Trenggono, M., Setiawan, A., 2016. Oceanography surrounding Krakatau volcano in the Sunda Strait, Indonesia. Oceanography 29 (2), 228–237. https://doi.org/10.5670/oceanog.2016.31.

Takahashi, T., Sutherland, S.G., Sweeney, C., Poisson, A.P., Metzl, N., Tilbrook, B., Bates, N.R., Wanninkhof, R.H., Feely, R.A., Sabine, C.L., Olafsson, J., 2002. Biological and temperature e ffects on seasonal changes of *p*CO2 in global ocean surface waters. Deep-Sea Res. Pt. II 49, 1601–1622.

Takahashi, T., Sutherland, S.C., Wanninkhof, R., Sweeney, C., Feely, R.A., Chipman, D. W., Hales, B., Friederich, G.E., Chavez, F.P., Watson, A.J., Bakker, D.C.E., Schuster, U., Metzl, N., Yoshikawa-Inoue, H., Olafsson, J., Arnarson, T.S., Tilbrook, B., Johannessen, T., Olsen, A., Bellerby, R.J., de Baar, H.J.W., Nojiri, Y., Wong, C.S., Delille, B., Bates, N.R., 2009. Climatological mean and decadal change in surface ocean *p*CO2, and net sea-air CO2 flux over the global oceans. Deep-Sea Res. Pt. II 56 (8–10), 554–577. https://doi.org/10.1016/j.dsr2.2008.12.009.

Tsai, W.-T., Liu, K.-K., 2003. An assessment of the effect of sea surface surfactant on global atmosphere-ocean CO_2 flux, 3127 J. Geophys. Res. 108 (C4). https://doi.org/10.1029/2000JC000740, 2003.

Wanninkhof, R., 1992. Relationship between wind speed and gas exchange over the ocean. J. Geophys. Res. 97 (C5), 7373–7382.

Weiss, R.F., 1974. Carbon dioxide in water and sea water: the solubility of a non-ideal gas. Mar. Chem. 2, 203–215.

Weiss, R., Price, B.A., 1980. Nitrous oxide solubility in water and seawater. Mar. Chem. 8, 347–359.

Wirasatriya, A., Setiawan, R.Y., Subardjo, P., 2017. The effect of ENSO on the variability of chlorophyll-a and sea surface temperature in the Maluku Sea. IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens. (JSTARS). 10 (12), 5513–5518.

Wirasatriya, A., Prasetyawan, I.B., Triyono, C.D., Muslim Maslukah, L., 2018. Effect of ENSO on the variability of SST and chlorophyll-a in Java Sea. IOP Conf. Ser. Earth Environ. Sci. 116 (2018) https://doi.org/10.1088/1755-1315/116/1/012063, 012063.

Wirasatriya, A., Sugianto, D.N., Helmi, M., Maslukah, L., Widiyandono, R.T., Herawati, V.E., Subardjo, P., Handoyo, G., Haryadi Marwoto, J., Suryoputro, A.A.D., Atmodjo, W., Setiyono, H., 2019. Heat flux aspects on the seasonal variability of sea surface temperature in the Java Sea. Ecol. Environ. Conserv. 25 (1), 434–442.

Wyrtki, K., 1961. Physical Oceanography of the Southeast Asian Waters. NAGA Report, vol. 2, 195.

Zhang, C.Y., Hu, C.M., Shang, S.L., Muller-Karger, F.E., Li, Y., Dai, M.H., Huang, B.Q., Ning, X.R., Hong, H.S., 2006. Bridging between SeaWiFS and MODIS for continuity of chlorophylla concentration assessments off Southeastern China. Remote Sens. Environ. 102, 250–263.

Zhu, Y., Shang, S., Zhai, W., Dai, M., 2009. Satellite-derived surface water pCO_2 and air–sea CO_2 fluxes in the northern South China Sea in summer. Prog. Nat. Sci. 19, 775–779. https://doi.org/10.1016/j.pnsc.2008.09.004.

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Corrigendum to 'Carbon dioxide flux in the java sea estimated from satellite measurements'. Remote sensing applications: Society and environment 20 (2020) 100376

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[b] Center for Coastal Rehabilitation and Disaster Mitigation Studies, Diponegoro University, Semarang, Indonesia

The authors regret that Fig. 13 in the original published article is incorrect and the correct Fig. 13 is included below.

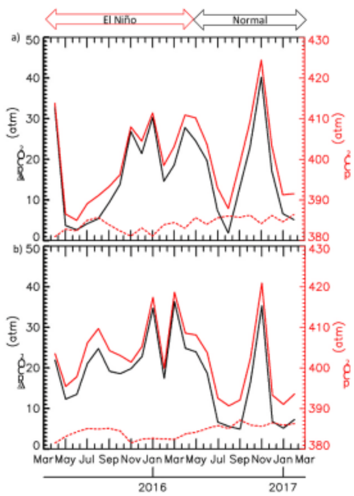

Fig. 13. Temporal variation of ΔpCO_2, pCO_{2w} (red solid line) and pCO_{2a} (red dashed line) in a) western box and b) eastern box as shown in Fig. 1b.

The authors would like to apologise for any inconvenience caused.

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