Volume 2 Issue 1 (2023): 17-20 e-issn 2962-0759
Tropical Marine Environmental Sciences

The Atmospheric and Oceanic Processes on Thermal Front Variability over the Java Sea

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Article Info

Received
10 October 2023

Accepted
20 November 2023

Keywords:
Java Sea,
SST Gradient,
Thermal Front,
Volume Transport,
Wind Stress Curl.

Abstract

The Java Sea is influenced by various atmospheric and oceanographic factors such as monsoon winds and the inflow of water from adjacent seas, thus leading to the formation of thermal fronts. In this research, the atmospheric process over the thermal front was estimated by using sea surface temperature (SST) gradient and crosswind-SST gradient calculation based on the GLORYS12V1 monthly SST data from Copernicus Marine Service (CMEMS) and the ERA5 monthly surface wind data from European Centre for Medium-Range Weather Forecasts (ECMWF) for 27 years (from 1993 to 2019). Moreover, the oceanic process was determined from the volume transports of three major channels surrounding the Java Sea, which are Karimata Strait, Sunda Strait, and the eastern boundary of the Java Sea. Based on the annual variance analysis, there are four main thermal front areas, such as Northern Java Coast (NJC), Eastern Sumatra Coast (ESC), Western Borneo Coast (WBC), and Eastern Borneo Coast (EBC). The annual variation of the thermal front over the ESC, WBC, and ESC has two peaks in March and October, while the NJC thermal front area has three peaks in March, July, and November. This study results that the thermal front activities over the NJC, WBC, and EBC are significantly correlated to the wind stress curl over those areas, with a coefficient correlation of about 0.62, -0.92, and -0.73, respectively. In addition, the increase in thermal front activity over the NJC area is controlled by negative wind stress curl with no lag time, while the WBC and EBC areas are controlled by positive wind stress curl with a lag time of 1 month (wind stress leads). On the other hand, the thermal front activity over the ESC area is closely related to southward volume transport from the Karimata Strait, with a correlation coefficient of -0.74 and a lag time of 2 months (volume transport leads).

1. Introduction

Java Sea, as part of the Indonesian Fisheries Management Area 712, has abundant fisheries resources and important economic potential. Therefore, excellent and sustainable fisheries management is important to maintain the ecosystem (Hermanto et al., 2019). One of the supporting factors for optimizing fisheries management is determining fishing ground areas, which can be predicted based on oceanographic parameters, for instance, thermal fronts (Ain et al., 2015). A thermal front refers to the boundary or transition zone between two water masses of different temperatures (Bakun, 2006). The temperature difference creates a nutrient-rich transition zone and significantly impacts plankton productivity, as well as the overall marine ecosystem.

From the atmospheric perspective, the Java Sea is influenced by the Asian-Australian monsoon system. Moreover, the water circulation of the Java Sea is influenced by the confluence of water masses from the South China Sea via the Karimata Strait, the Indian Ocean via the Sunda Strait, and the Indonesian Throughflow via the Makassar Strait (see Figure 1). These atmosphere dynamics and water masses mixing have potentially formed the thermal front features. However, limited research has focused on the thermal front over the Java Sea. Thus, a research question is rising. How are the physical processes related to atmosphere and ocean interaction on these oceanographic features?

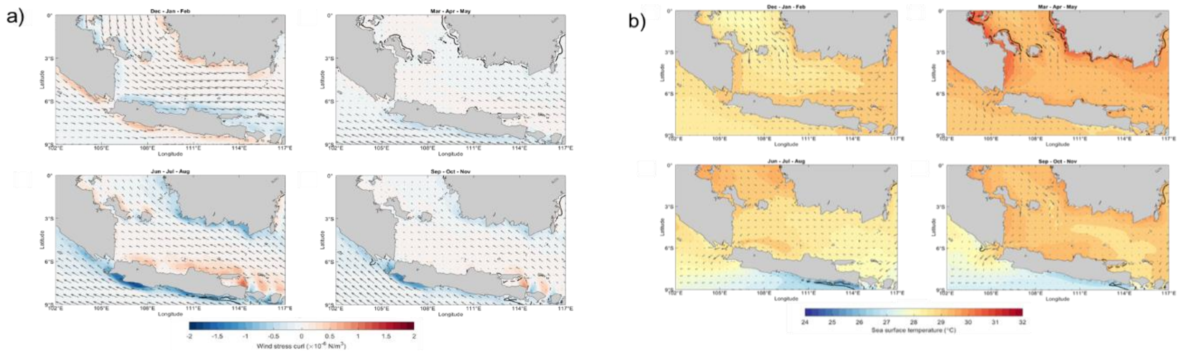

Figure 1. Seasonal Characteristics of the (a) Atmospheric and (b) Oceanic Parameters over the Java Sea

2. Methodology

In this study, we examine the monthly sea surface temperature, current, and surface wind for 27 years, from 1993 to 2019. The study is focused on the Java Sea and its surroundings limited to the black box (see Figure 2). Furthermore, the SST and current data used are the GLORYS12V1 product from Copernicus Marine Service (CMEMS) with 1/12° spatial resolution, while the wind data used is the ERA5 ECMWF reanalysis with 0.25° spatial resolution (Hersbach et al., 2020).

For the thermal front detection, we calculated the SST gradient by using Eq. 1 as follows (Wang & Castelao, 2016):

$$\nabla SST = \frac{\partial SST}{\partial x}\boldsymbol{i} + \frac{\partial SST}{\partial y}\boldsymbol{j} \qquad \text{(Eq. 1)}$$

Where the strong front is indicated by $\nabla SST > 0.02°C/km$. This method is more convenient to work with gridded data. Compared to the popular methods for thermal front determination by using Single Image Edge Detection, this calculation shows similar results. Thus, it can be applied for further analysis.

Next, the atmospheric processes analysis was conducted by calculating the wind stress, wind stress curl, and the crosswind-SST gradient by using Eq. 2 to Eq. 4, respectively, as follows (Castelao, 2012):

$$\vec{\tau} = \rho_a \cdot Cd \cdot |\vec{V}| \cdot \vec{V} \qquad \text{(Eq. 2)}$$

$$\nabla \times \vec{\tau} = \frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y} \qquad \text{(Eq. 3)}$$

$$\nabla SST \times \vec{\tau} = \frac{\partial SST}{\partial x} \cdot \tau_y - \frac{\partial SST}{\partial y}\tau_x \qquad \text{(Eq. 4)}$$

Where, $\vec{\tau}$ is the wind stress vector, with τ_x and τ_y as the respective eastward and northward components, ρ_a is the density of air, Cd is the drag coefficient, and $\vec{V}$ is the wind component vector that consists of a zonal component (u) and a meridional component (v). The crosswind-SST gradient calculation is used to quantify the atmosphere and ocean coupling.

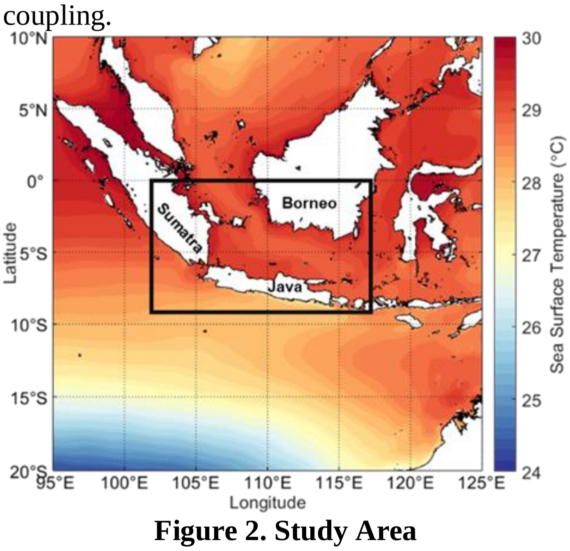

Figure 2. Study Area

3. Result and Discussion

Based on the annual variance analysis, there are four main thermal front areas, Northern Java Coast (NJC) which has three peaks in March, July, and November; Eastern Sumatra Coast (ESC) which has two peaks in March and October, Western Borneo Coast (WBC), and Eastern Borneo Coast (EBC) that also has two peaks in April and October (Figure 3).

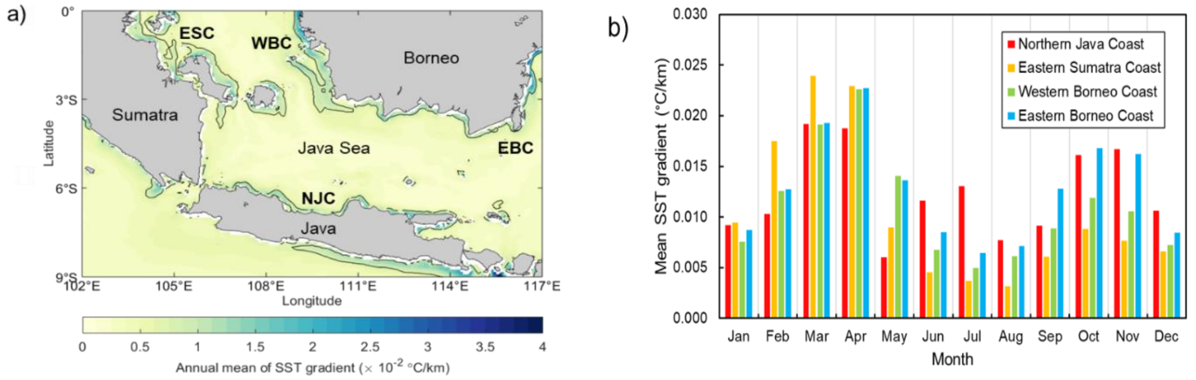

Figure 3. The annual variation of thermal fronts area over the Java Sea, (a) spatially and (b) temporally

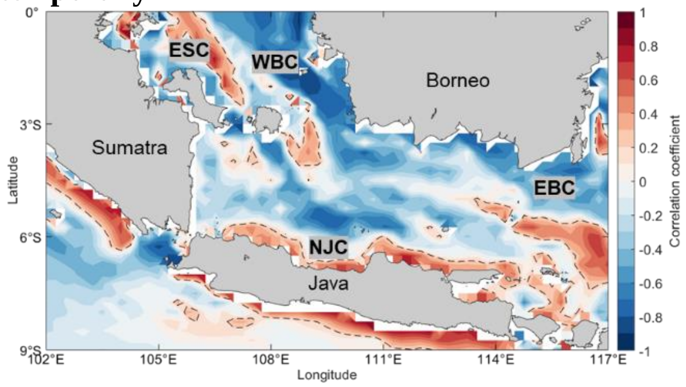

Figure 4. The Spatial Cross-Correlation between Crosswind-SST Gradient and Wind Stress Curl

Secondly, we have conducted a cross-correlation analysis, spatially and temporally, between crosswind SST gradient and wind stress curl. As can be seen in Figure 4, it is suggested that the increase in thermal front activity over the red areas is controlled by positive wind stress curl, while over the blue areas is controlled by negative wind stress curl. Specifically, to the respective thermal fronts' areas in Table 1, the thermal front activity over the NJC area is significantly correlated with positive wind stress curl with no lag time, while the others are significantly correlated with negative wind stress curl with a month lag time (wind leads).

Next, we also examined the relation of the thermal front dynamics over those four areas to the three main channel boundaries, such as Karimata Strait (KS), Sunda Strait (SS), and Eastern Java Sea boundary (EJS). It can be concluded from Table 2 that the thermal front activities ESC area has the most significant correlation with the southward transport of the Karimata Strait and northward transport of the Sunda Strait, with 2- and one-month lag time, respectively.

Table 1. The Cross-Correlation between Crosswind-SST Gradient and Wind Stress Curl on the Respective Thermal Front Areas

Thermal	Lag time (months)			
front area	0	1	2	3
NJC	0.62	0.34	0.16	-0.01
ESC	-0.67	-0.77	-0.57	-0.15
WBC	-0.82	-0.90	-0.68	-0.27
EBC	-0.55	-0.73	-0.66	0.29

Lastly, we compared the linkage or correlation analysis between the atmospheric and oceanic processes. The thermal fronts over the NJC, WBC, and EBC areas are more dominantly controlled by the wind stress curl, while over the ESC area is more dominantly controlled by the volume transport from the

South China Sea via Karimata Strait and Indian Ocean via the Sunda Strait.

Table 2. The Cross-Correlation between the SST Gradient on each Thermal Front Area and Volume Transport from Three Main Channels Bordering the Java Sea

R (lag)	KS	SS	EJS	Net
NJC	-0.30 (1)	0.33 (1)	0.35 (0)	0.35 (1)
ESC	-0.74 (2)	0.80 (1)	0.66 (0)	0.80 (2)
WBC	-0.60 (2)	0.66 (2)	0.64 (0)	0.69 (2)
EBC	-0.46 (1)	0.49 (1)	0.60 (0)	0.50 (1)

4. Conclusion

Based on the annual variance analysis, there are four main thermal front areas, such as Northern Java Coast (NJC), Eastern Sumatra Coast (ESC), Western Borneo Coast (WBC), and Eastern Borneo Coast (EBC). The annual variation of the thermal front over the ESC, WBC, and EBC has two peaks in March-April and October, while the NJC thermal front area has three peaks in March, July, and November.

The thermal front activities over the NJC, WBC, and EBC are significantly correlated to the wind stress curl over those areas. The increase in thermal front activity over the NJC area is controlled by positive wind stress curl with no lag time, while the WBC and EBC areas are controlled by negative wind stress curl with a lag time of 1 month (wind stress leads). On the other hand, the thermal front activity over the ESC area is closely related to southward and northward volume transport from the Karimata Strait and Sunda Strait, respectively

Acknowledgment

The authors gratefully acknowledge the E.U. Copernicus Marine Service Information and European Centre for Medium-Range Weather Forecasts for providing the data

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