ABSTRACT
The Empirical Orthogonal Function (EOF) method is widely used in various studies for many different disciplines, and one application of this method is for oceanography research. EOF is used to obtain the dominant mode of the data and to evolve in time and space. This method can reduce a large number of the variable from original data to a few variables without substantially reducing the original information of data. The purpose of this study is to examine the EOF method for reducing sea surface temperature (SST) data. Subsequently, by analyzing the dominant pattern of temporal and spatial of SST. The analysis of SST was conducted on The North Waters of Central Java for 180 months (January 2003 – December 2017). This analysis produced several principal components that were called EOF mode. For each EOF, there is a variable which is contained by two information the pixel data and the eigenvector. The pixel data described spatial variability and eigenvector which presented the time series variability. Basic selection of EOF mode depends on the percentage of eigenvalues. The percentage of contribution will give the selection rules of EOF mode that retains most of the information from the original data. This analysis resulted from the three dominant modes with the largest variances in several EOF. The modes explained 30.6 %, 27.1% and 18.9% of the total variance for the first, second and third mode, respectively. Therefore, the first mode represented the majority data.
1. INTRODUCTION

The northern waters of Central Java are located in the Java Sea and the length of the coastline is 540.27 km [1]. The western part is connected to the South China Sea through the Karimata Strait, the eastern part is connected to the Flores Sea. The northern part is connected to the Sulawesi Sea to the Pacific Ocean through the Makassar Strait. The southern part is connected to the Indian Ocean through the Sunda Strait [2]. The characteristics of the water mass and the climate of Java Sea are directly affected by two monsoon winds [2], [3], [4] and [5]. Northwest monsoon winds, which take place from September to February. Southeast monsoon winds, which take place from March to August, affect the distribution patterns of oceanographic parameters such as sea surface temperature (SST). Temperature is the physical parameters determining the characteristics of waters. Temperature influences the processes that occur in the oceans like beach upwelling, advection, medium-scale dynamic features such as fronts and eddies etc[6]. Temperature is also an essential component to control the sustainability of organism like development, activity and mobility, breeding, and others [7] and [4]. In Indonesian waters, temperature plays an important role in the atmospheric process, both in particular area and greater area. A slight change in temperature in Indonesia might result in a significant effect to precipitation pattern in the Indo-Pacific area [2].

The research on the variability of SST in Indonesia has been conducted by [2], [4], [5] and [8]. Low SST is recorded in May-August when dry season occurs. The trend of SST has been increased since the 1970s. Lombok Strait is identified as the coldest waters with SST lower than 26 °C. A research conducted by [9] and [10] in the Java Sea shows that low SST has been recorded during the dry season and rainy season. The monthly rise of SPL was 0.0019 °C. The water is divided into three areas, namely east, middle, and west. In the dry season, transition 1 season and transition 2seasons, SST in east areas are lower than the others, while in the rainy season, SST is remained the same in 3 areas of Java sea.

The aim of the research was to observe the spatiotemporal variability of SST in the northern waters of Central Java. Data of SST are presented in a three-dimensional matrix. Two dimensions represent spatial variables, namely longitude (x) and latitude (y), while the other represents variable of time (t). Empirical Orthogonal Function (EOF) is a method to describe the dynamics of the variability of SST in space and time (spatiotemporal).

EOF is used as a tool to investigate physical variability in the fields of geophysics, atmospheric science, oceanography, and climate. EOF is part of the statistical tool for exploratory data analysis, that is, to reduce dimensions [11]. EOF is also known as Principal Component Analysis (PCA) [12]. EOF analysis is aimed to transform p variables, which correlate to k number of components that is orthogonal and independent [11] [12].
2. MATERIAL AND ANALYSIS DATA

2.1. Data of Sea Surface Temperature (SST)

The research was based on data of SST and data of surface current at 5m depth located at the coordinate 108.8 to 111.7 East Longitude and -5.5 to -7.0 South Latitude. Data of SST are the imagery data of Aqua MODIS Level-3 Satellite having spatial resolution measured at 0.05° x 0.05° and temporal resolution at the 8-day period. The data period was 180 months, from January 2003 to December 2017. Data were obtained from the Pacific Islands Fisheries Science Center (PIFSC) National Oceanic and Atmospheric Administration (NOAA) - the USA through the website (http://oceanocolor.gsfc.nasa.gov). Analysis of temporal variations of SST was performed using descriptive statistics and time series statistical analysis [15]. Analysis of spatial variations of SST was performed using GIS [9]. Analysis of SST dynamics based on spatiotemporal analysis was performed using EOF [11] and [16].

2.2. Data of Surface Current

Data of surface current are the result of INDESO (Infrastructure Development of Space Oceanography) oceanography modeling having a temporal resolution at the daily period and within the time period from January 2003 – December 2017. The data of surface current were analyzed using current rose and scatter plot method by season to determine dominant directions and speed as stated in [17].

2.3. Empirical Orthogonal Function of SST

Assumed that $X$ is the matrix of time series data SST in n×p order, where n represents row/pixel and p times and rank $(X) = r$. If one conditions the data matrix $X$ by centering each column $p$, then

$$ C = \frac{X^TX}{n-1} $$

is the covariance matrix of the variables of time. Singular value decomposition (SVD) towards the covariance matrix of $C$ is factoring into form

$$ C = VS^2VT. $$

$S$ is an $p×p$ diagonal matrix. The elements of $S$ are non-negative real numbers on the diagonal and are called the singular/eigenvalues. Thus,

$$ S = \text{diag}(\lambda_1, \ldots, \lambda_p). $$

The matrix $V$ is the ortho normal matrix of $m × m$ order whose columns are the eigenvectors of the matrix $S$[18], [19],[20].

3. RESULT

3.1. Temporal Variations of SST

The average of SST for 15 years, from January 2003 to December 2017, was recorded as 29.70°C, ranging between 24.31°C and 34.88 °C. Annually, water temperature reaches two highest temperature points and two lowest temperature points. The average temperature by season is presented in Table 1. Low temperature is recorded in June, July, and August when the dry season occurs and in December, January, and February or during the rainy season. The average temperature during the dry season is 29.19°C and the average temperature during the rainy season is 29.64°C. The high temperature is recorded in March, April, and Mayor transitional 1 season and September, October, and November or transitional 2seasons. The
average temperature during the transitional 1 season is 30.14°C while in transitional 2 seasons, the average temperature is recorded at 29.81°C.

In general, SST had experienced an increase from 2003 to 2017. The monthly raise of temperature was 0.00262°C or 0.5°C annually as shown in Figure 1. From 2003 to 2017, the increase of SST was linear and can be described using the following equation:

\[ Y = 29.459 + 0.00262 \times X, \]  

where \( X = \) the \( n^{th} \) month index \((n = 1 – 180)\) and \( Y = \) SPL (°C).

**Table 1** The average of sea surface temperature (SST) by season in Northern Waters of Central Java, Indonesia

<table>
<thead>
<tr>
<th>Season</th>
<th>Month</th>
<th>Average SST (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainy</td>
<td>December, January, February</td>
<td>29.64 ± 0.66</td>
</tr>
<tr>
<td>Transition 1</td>
<td>March, April, Mei</td>
<td>30.14 ± 0.44</td>
</tr>
<tr>
<td>Dry</td>
<td>June, July, August</td>
<td>29.19 ± 0.59</td>
</tr>
<tr>
<td>Transition 2</td>
<td>September, October, November</td>
<td>29.81 ± 0.75</td>
</tr>
<tr>
<td>Yearly</td>
<td>(January 2003 to December 2017)</td>
<td>29.70 ± 0.71</td>
</tr>
</tbody>
</table>

**Figure 1** Temporal Variability of SST in Northern Waters of Central Java in 2003-2017

### 3.2. Spatial Distribution of SST

The result of the analysis of spatial variation of SST shows that the lowest temperature occurs in the dry season as presented in Figure 2c. The cold temperature comes from the eastern part of the waters which gets warm to the west. In transition 2 seasons, warm temperature occurs especially in the western parts which close to the beach (Figure 2d). In the rainy season (Figure 2a), a mixture of cold water coming from the west occurs. Water temperatures are relatively stable, especially on the high seas, but remain high on some beaches. The highest temperature occurs in the transition 1 season, especially in the area bordering the land (Figure 2b).

### 3.3. Spatio-Temporal Variations of SST

The oceanographic study is needed to analyze the pattern or variability of SPL, both spatially and temporally, to show how it changes by the time[21]. In order to do that, EOF (empirical
orthogonal function) statistical analysis is needed. EOF mathematically derived based on singular value decomposition from data of covariance matrix. Singular value decomposition results in eigenvalues and eigenvectors. Eigenvectors are orthogonal and known as EOF mode. The mode can be defined as the structure of oceanography pattern of SST.
Eigenvalues are the measures of variability percentages described by each mode. The first three modes described the variability of data as 30.6 %, 27.1 %, and 18.9 %. The 3rd mode up to the 180th mode presents negligible variability. Based on that, the first three modes were considered reliable to define the structure of the spatiotemporal pattern of SST.

The eigenvector corresponding to the eigenvalue explains the structure of the temporal pattern of SST. Each eigenvector produces a spectrum mode value during the observed period. The size and direction of the spectrum shows the correlation of each period to the mode.
Variability of Spatio-Temporal Sea Surface Temperature in Northern Waters of Central Java, Indonesia

Figure 3 Mode Spectrum (a) EOF 1, (b) EOF 2 and (c) EOF 3

The structure of the temporal pattern of the northern waters of Central Java shows that the waters have regular seasonal patterns throughout the year. As presented in Figure 3a, the high-spectrum towards positive direction occurs every year in June, July, and August, when the dry season occurs. This shows that the characteristics of SST in waters are dominantly influenced by the dry season. Mode 2 presented in Figure 3b shows that the high-spectrum with positive direction occurs in September and October when the transition 2 season occurs. Mode 3 presented in Figure 3c shows that the spectrum height is relatively similar throughout the year. The high spectrum in each year occurs during the transition 1 season and similar spectrum also occurs during rainy season with a positive direction. Influence of rainy season and transition 1 season to SST characteristics in waters is negligible.
Spatial SST pattern is obtained from the projection of the eigenvectors on the data matrix to obtain the magnitude of each grid, then the plot of the corresponding grid is then carried out. The value of projection resulted in no magnitude and shows the difference in temperatures. Spatial maps are presented in Figures 4 showing the distribution of the mixing of two water masses which have different temperatures corresponding to the mode.

EOF 1 spatial distribution pattern or the distribution of temperature differences during the dry season is presented in Figure 4a. SST during the dry season is the lowest temperature throughout the year. The mass of water having lower temperatures from the eastern waters spreads towards the west. The temperature difference in the east is negative. The smallest difference occurs along the coast starting from Pati to the eastern part of Teluk Semarang towards the Karimunjawa Islands. Moving to the west, the temperature is higher so that the difference in SST is positive. The biggest temperature difference occurs along the coast starting from Batang to Tegal.
EOF 2 distribution pattern or the difference in temperature during transition 2 seasons is presented in Figure 4b. SST during transition 2 seasons is warmer, especially around the coast, and gets colder towards the high seas to the Karimunjawa Islands. Positive temperature differences along the coast start from Pati to Batang except in Jepara towards the Karimunjawa Islands.

Mode spectrum of EOF presenting temperature differences during transitional 1 season is presented in Figure 4c. Sea surface temperature in transitional 1 season is the highest compared to other seasons in a year. During the rainy season, sea surface temperature is relatively stable so that there are no temperature differences recorded in waters.

4. DISCUSSION

Based on the analysis on SST in the northern waters of Central Java, period from 2003 to 2017, SST had a monthly increase recorded as 0.00262°C or annually increase as 0.5°C. It was higher than the record period from 1971 to 2000, the monthly increase of SST was 0.0019°C [9]. The average SST recorded in 2003-2017 was 29.70°C ± 0.71°C, higher than the recorded period from 1971 to 2000 showing the average SST recorded as 27.48°C to 29.66°C.

Temporal variation recorded by month shows that, in a year, two high temperatures, as well as two low temperatures, are observed. High temperature occurs during transitional months 1 and 2, while low temperature is observed during the rainy and dry season. The results are in line with researches conducted by [5],[9] and [10]. The cycle shows that SST variability is influenced by the changes of the season due to the monsoon pattern [2], [5] and [9]. In the rainy season, the lowest temperature is recorded in January. Sea current streams from west to east, having the direction to 84.3° in 0.15 m/sec to 0.2 m/sec. Current rise in the rainy season is presented in Figure 5a. The water mass originating from the South China Sea enters the Java Sea through Karimata Strait. Cold water mass appears to be more evenly distributed throughout the waters. This is in line with a research conducted by [9] and [10] stating that the average SST in three areas of Java Sea remains the same during the rainy season. In the rainy season, cold-water mass originating from the Pacific Ocean enters the eastern waters through Makassar Strait [9] and [25].

In the dry season, the lowest temperature is recorded in August. The current streams from east to west, directing to 299.9°, and the speed ranges from 0.15 m/sec to 0.2 m/sec. Current rise in the dry season is presented in Figure 5c. The current flows water mass from the Banda Sea and the Flores Sea entering the Java Sea. The transfer of water mass resulted in a water mass deficit in the east. To compensate for this deficit, the water mass rises from the lower layer to the upper layer or surface. The process is known as upwelling. Upwelling results in lower SST. A research conducted by [5] shows that starting from 2014 to 2016 in Makassar Straits, there was a decrease of SST from June, and the decrease was observed in the waters in August.

The research of [10] divides the waters of the Java Sea into three parts, namely the east, middle, and west. The results show that the lowest temperature occurred during the dry season and the SST was lower in the east. SST was recorded lower in the east because of upwelling in the Flores Sea and the Arafura Sea during the dry season [7] and [21]. The temperature in Lombok Strait has identified during the dry season as the lowest temperature in Indonesian waters, which was recorded at less than 26°C [4].

During transition months 1 and 2, there was no monsoon domination so that the drive to the water surface is weak in sporadic direction. In transition months 1, the current goes north with an angle of 346.5° and speed ranging between 0.05 m/sec and 0.1 m/sec. In transition
months 2, the current goes north towards 10.5° angle and having the speed between 0.05 m/sec and 0.1 m/sec. Current rose in transition 1 and transition 2 seasons are presented in Figure 5b and 5d. The flow of sea current results in a minimum input of cold-water mass from the west (South China Sea) or the east (Lombok Strait). The Java Sea becomes warm during transition months [10].

The result of spatiotemporal analysis using EOF shows that the characteristics of the northern waters of Central Java are described by SST in the dry season. According to [3] the impulse of the southeast monsoon to the water surface is stronger than the impulse of the northwest monsoon. This results in a faster distribution of cold-water masses from the east than the distribution of water masses from the west. In the dry season, the distribution of cold-water masses the Java Sea can reach the South China Sea.

The movement of water mass is seen from the spatial pattern of SST. In the dry season, the cold temperature starts from the east and gets warmer to the west (Figure 2c). This is also indicated by the distribution of temperature that is negative in the eastern region and increasingly positive to the west (Figure 4). The spatial pattern of the mixing of two water masses with different SST in the dry season (Figure 4) is more numerous and varied compared to transition 2 season and transition 1 season.

The spatial pattern indicated by the mixing of two water masses with different SST is one of the indicators showing that the area has high fertility rates. With this high fertility rate, it can be predicted that the place is a favorable aquatic environment and suitable for phytoplankton habitat or other aquatic organisms, and has the potential to be used as the area for fishing. [22],[23] and [25] observed a correlation between the supply of fish and the mixing of two water masses with different SST.

5. CONCLUSIONS

Sea surface temperature (SST) of Northern Waters of Central Java has shown a monthly temperature increase recorded as 0.00262 °C of 0.5 °C per year. Temporal variations on SST shows robust seasonal variation. SST is low during the dry and rainy season and high during transition 1 and transition 2 seasons.

Spatial distribution during dry season starts from eastern waters and continues to the west, which is strongly influenced by the speed and direction of the current. During the rainy season, SST is relatively homogeneous on the open seas.

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Variability of Spatio-Temporal Sea Surface Temperature in Northern Waters of Central Java, Indonesia

(a)

(b)

(c)
Figure 7. Current rose: speed and direction by season in Northern Waters of Central Java (a) rainy season, (b) transition 1, (c) dry season (d) transition 2

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