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Empirical Orthogonal Function (EOF) Analysis Based on Google Colab on Sea Surface Temperature (SST) Dataset in Indonesian Waters

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Abstract

Global Sea Surface Temperature (SST) data observed from yearly to yearly is limited in its use to determine spatial and temporal variations. The analysis was carried out on SST data in Indonesian waters for 252 months or for 21 years, starting from January 2000 to December 2020. The method used for analysis was Empirical Orthogonal Function (EOF) with the help of a statistical engine, Google Colab. The EOF method aims to reduce large data into several modes without eliminating the main information from the observed data. Analysis with this method resulted in the three largest principal components initialized with EOF1, EOF2 and EOF3 modes. The EOF1 mode explains 56.8% of the total variation and is the dominant pattern representing almost all SST data in Indonesian waters. The EOF2 mode represents 24.5% of the total variation. The EOF3 modes each account for 13.4% of the total variation. Each EOF mode contains coefficients containing variables in the form of grid data and eigenvectors. Grid data describe geographic locations and eigenvectors describe spatial dimensions. The effectiveness of the three resulting EOF modes is kept close to the original data. Mapping of SST in the Indonesian Territory for 20 years has been carried out in this research, this study describes the seasonal visualization of SST data in Indonesian waters using Google Colab. This visualization shows the comparison of the distribution of sea surface temperature in the Indonesian waters throughout the year with seasonal patterns.

Introduction

Indonesia is a maritime country with two-thirds of its territory surrounded by oceans. When viewed from its geographical position, Indonesia is on the equator and is located between two oceans, namely Pacific and Indian Ocean. Therefore, Indonesia has a tropical climate with two seasons, namely rainy and dry season. These tropical areas have a strong influence in determining the relationship between the atmosphere and the ocean. The sea has an important role in the process of climate change both regionally and globally [1]. One of the parameters that has a major influence in the process of changing the seasons in the Indonesian Territory is Sea Surface Temperature (SST). Previous research on SST analysis has been carried out by several researchers with different locations and timescales. The relationship between sea and air in the territory of Indonesia depends on the SST anomaly which has a strong seasonal relationship with the Pacific Ocean [2]. The SST anomaly in the Indian Ocean has a strong influence on rainfall in Indonesia [3]. Research that uses the EOF method in analyzing rainfall anomalies such as that carried out by Simanjuntak (2020) who has analyzed SST anomalies from satellite data using the EOF method to examine the characteristics of the 1997-1998 El-nino event and the results explain that the teleconnection of Central California and south to El-nino events [4], [5].

In statistics, EOF analysis is known as Principal Component Analysis (PCA). As such, EOF analysis is sometimes classified as a multivariate statistical technique. However, there is no a priori hypothesis based on some probability distribution and, hence, no statistical test. Further, EOF analysis is not based on physical principles. Rather, a field is partitioned into mathematically orthogonal (independent) modes which sometimes may be interpreted as atmospheric and oceanographic modes [6], [7]. This study explains that SST data in Indonesian waters for 252 months will be analyzed using the Empirical Orthogonal Function (EOF) method based on the Eigen Value Problem (EVP) using Google Colab [8][9].

This method aims to reduce a large set of SST data into several EOF modes without losing information from the original data [7], [10], [11]. This can be achieved by forming a new set of variables that are structured using the principle of uncorrelated principal components. This means that some of the EOF equations retain most of the variance in the original variables [12]. Anomalies of climate change caused by ENSO and IOD events have been analyzed by many previous researchers, as has been done by Aldrian (2003) who has mapped climate patterns in Indonesia into 3 regions using the EOF analysis method [8]. This study specifically analyzes SST data with coverage of Indonesian waters in a span of 252 months, from 2000 to 2020. The results obtained will be very useful to determine characteristics of SST as information in predicting climate for the long term and weather for the short term.

Empirical Orthogonal Function (EOF) analysis is a method for determining the dominant pattern in the data and developing in space and time [6], [8], [13]. In this study, the wavelet technique was not used in the analysis. For the territory of Indonesia, research has been carried out by Aldrian and Susanto using the EOF technique so that three types of climates are produced for the entire territory of Indonesia, currently known types are monsoon, equatorial, and local [1], [14]. In general, the EOF method works very well by producing several variances that describe the overall data [15].

Method

The data that will be used in this research is Sea Surface Temperature (SST) data. This data is a monthly global data archive that has been reconstructed continuously. This reconstruction started from January 2000 to December 2020, so it is better known as The Extended Reconstructed Sea Surface Temperature (ERSST). Global ERSST data is open-access data that can be downloaded on the official website of the National Oceanic and Atmospheric Administration (NOAA) (http://www1.ncdc.noaa.gov/pub/data/cmb/ersst/v3b/netcdf) in

Network Common Data Form (NetCDF) digital data format. These data have a spatial resolution of 1° x 1° and a monthly temporal resolution. The SST data that will be used in this study with the domain of Indonesia 6^0 North Latitude 11^0 South Latitude and 95^0 East Longitude 141^0 East Longitude. The time span to be studied is 252 months starting from January 2000 to December 2020.

The method used in this research is to use Empirical Orthogonal Function (EOF) analysis. The EOF method is used to see the spatial and temporal patterns of the Indonesian Territory, which is expected to be able to extract information directly from rainfall data so that it can identify the period of atmospheric phenomena recorded in the data [16], [17]. Data analysis is divided into annual analysis and seasonal analysis. The data for annual analysis is monthly rainfall data for all stations for approximately 21 years, from the period range of January 1, 2000-December 31, 2020. Meanwhile, the data for seasonal analysis is divided into four periods, namely the rainy season period in December-January-February. (DJF), the dry season in June-July-August (JJA), the rainy to dry transitional season in March-April-May (MAM), and the dry to rainy transition season in September-October-November (SON).

The steps taken in the EOF analysis are [9, 19]

1. Sea Surface Temperature (SST) data is transformed in the form of a normalized $X_{m\times p}$ matrix as in equation 1

$$X_{m\times p} = \frac{Y_{m\times p} - \bar{Y}_m}{\bar{s}_m} \tag{1}$$

Equation 1 can be explained as follows the deviation matrix ($X_{m\times p}$) from the mean value at the m-th station and the p-th observation. Monthly Sea Surface Temperature (SST) data ($Y_{m\times p}$) at the m-th station and the p-th observation. Average monthly Sea Surface Temperature (SST) data data at station m ($\bar{Y}_m$). Standard deviation ($\bar{s}_m$) of monthly Sea Surface Temperature (SST) data at station m [12], [18].

2. Calculating the variance-covariance matrix X
3. Determine the eigenvalue $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_i \geq 0$ and eigenvector $a_1, a_2, \ldots. a_i$. The eigenvalue ($\lambda_{i)}$ represents the variance while the eigenvector (a_i) is the coefficient of the i-th principal component
4. Loading factor determining the correlation between the original Sea Surface Temperature (SST) data and the main component. The value of the principal component is also known as the eigenvector coefficient.

The analysis using the EOF method begins with extracting the R data matrix of size $m \times n$ into a data matrix X, then proceed with the formation of the covariance matrix ($\sum$). Determining how many modes to take in the EOF method, it is necessary to determine the corresponding eigenvalues and eigenvectors from the matrix covariance $\sum$ with characteristic equation $|\sum - \gamma I| = 0$. Mathematically determining the mode $U_m(t)$ can be done using the equation

$$U_m(t) = \sum_{x,y=1}^{N} X(x,y,t)e_m(x,y) \tag{2}$$

with $t = 1,2,\ldots,m$. The variance that can be explained by the new m-th variable in equation (2) depending on the contribution percentage P_m of each eigenvalue. Mc Kee [19] calculates the variance with the formula

$$p_m = \frac{\gamma_m}{\sum_{n=1}^{N} \gamma_n} \tag{3}$$

Equation 3 is stated to determine the proportion of variance from the obtained EOF mode, then the data is continued with spatial and temporal analysis. In general, the research flow can be explained through the diagram in Figure 1.

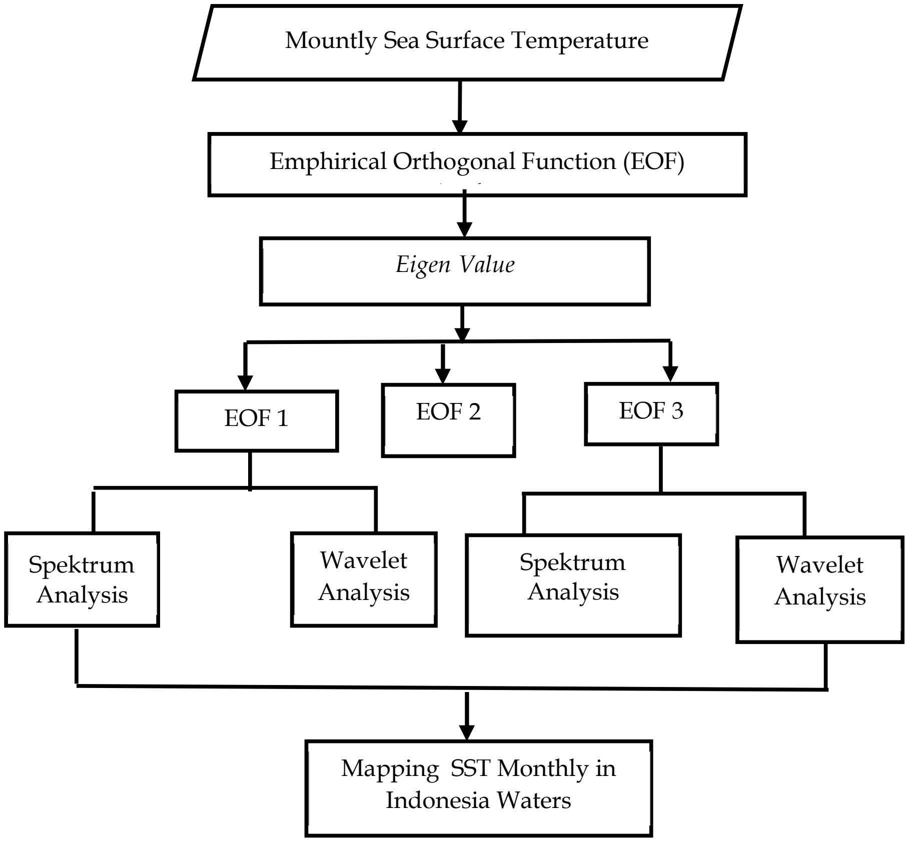


Figure 1. Research Steps

The transformation of the recording from the time domain to the frequency domain (or wavenumber) is called a spectrum or spectral. Spectral analysis is a method used to estimate the spectral density function of a given time series. Spectrum analysis can be used to identify periods that affect a time series. By definition, if X_t is a stochastic process with an autocovariance function $\gamma(k)$ with $k = \cdots, -2, -1, 0, 1, 2, \ldots$, then the spectrum $f(\omega)$ is the Fourier transform of the autocovariance function, which in its mathematical expression is as follows [10], [20].

$$f(\omega) = \frac{1}{\pi} \sum_{k=-\infty}^{\infty} \gamma(k) \exp(-i\omega\, k) \tag{4}$$

As a tool for analyzing data related to phenomena other than topography related to time, of course, a separate technique is needed to parse data information. Spectrum analysis using the Fourier transform, will be used in the solution.

According to Grinsted, a wavelet is a function with zero mean and has an allocation in frequency and time. Wavelets can be characterized by how they are allocated in time (Δt) with frequency ($\Delta\omega$) or wavelength. The Morlet wavelet is formulated as follows [6], [21]:

$$\psi_0(\eta) = \pi^{-1/4}\,\pi^{i\omega_0\eta}\pi^{-\frac{1}{2}-\eta^2} \qquad (5)$$

Where $\boldsymbol{\omega_0}$ is the dimensionless frequency and η is the dimensionless time. In this case, wavelet analysis is applied to detect the rain trend from long-term data.

Result and Discussion

Data exploration begins by presenting the available data patterns in a visual form. This pattern is presented based on a global data grid with coordinates 180^0 West 180^0 East Longitude and 90^0 North Latitude 90^0 South Latitude, so the size of the data grid with these coordinates is 190 x 80 pixels. For example, Figure 2 shows a visual illustration of seasonal SST data December-January_february 2020 and March-April-May 2020 which shows the distribution of global sea surface temperatures visualized with Google Colab.

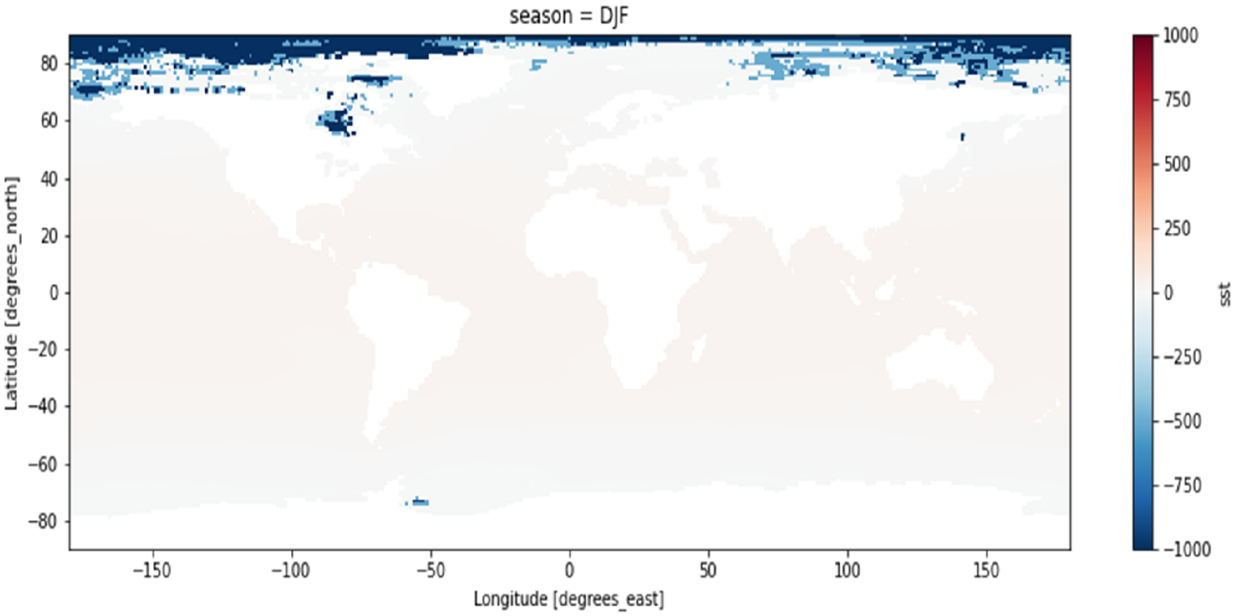


Figure 2. Data visualization Global SST

This data cut is based on the geographical location of Indonesia, which is at an area between 15 °S to 8 °N and 90 to 140 °E from the global data grid which is at coordinates 1800 West 1800 East Longitude and 900 North Latitude 900 South Latitude. This data cropping is adjusted to the original data grid so that its size becomes 26x13 pixels. Figure 2 were obtained a visual illustration of SST data from 2000-2020 for the Indonesian region with the same month and year but different seasons, namely December January and February (DJF). The following is a graph of the distribution of SST throughout 2020 which was determined using Google Colab.

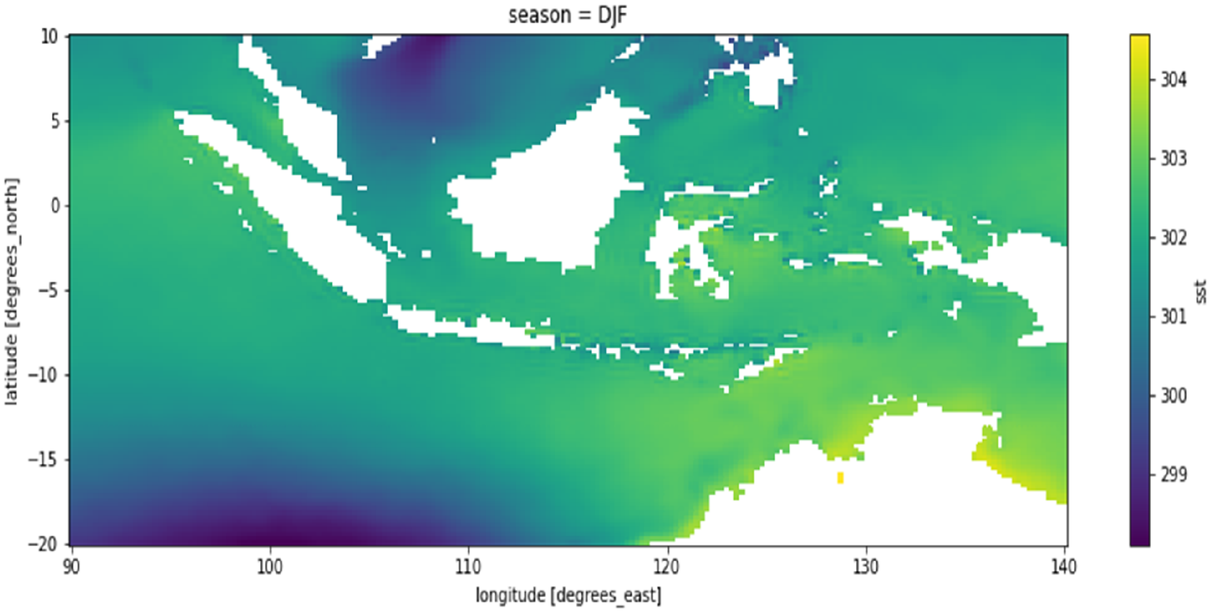


Figure 3. Data visualization after extracting global SST data to Indonesia Waters SST Data

In Figure 3 it can be seen that the sea surface temperature in Indonesian waters during the DJF season (December-January-February) is generally slightly warmer than the previous sea surface temperature, ranging from 302 K-204 K. This causes a lot of evaporation that occurs in Indonesian waters and forms rain clouds [3], [22]. Therefore, during the DJF season, parts of Indonesia will experience high rainfall due to low air pressure due to warm sea surface temperatures [10], [23]. This shows that the sea surface temperature in Indonesian waters is getting hotter which will have an impact on increasing the amount of rainfall in the Indonesian waters, especially for the northern part of Indonesia. Based on the SST analysis in Indonesian waters conducted by Lesmana [13], the increase in sea surface temperature began in March and peaked in April. During the MAM season in Indonesia, there will be an increase in high rainfall and extreme rain in the territory of Indonesia. While in June there is a decrease in sea surface temperature and it reaches its peak in August, namely in the seasonal period June, July and August (JJA). During the JJA period, the Indonesian Territory will experience a reduction in the amount of rain (the occurrence of the dry season) due to a significant decrease in sea surface temperature so that evaporation of Indonesian territorial waters is minimal. And in October there is another rise in sea surface temperature, so the rainy season will begin in the period September-October-November (SON) [24]–[26].

After visualizing the description of SST data in Indonesian waters, it is followed by mapping the description of SST for the period 2000-2020 Google Colab with the aim of seeing the dominant data variation for SST data in Indonesian waters. The first step is to determine the variance of the eigenvalues and choose the main component, namely the new EOF equation. The new equation can represent the variation of the X data matrix. The number of main components to be taken is seen from the percentage of cumulative variance. Jolliffe [3] describes several rules in determining the number of the first principal components, including those that have a cumulative variance proportion of more than 80%. Based on this, the three largest main components were selected as the result of the reduction of the 252 main components initialized with EOF1, EOF2 and EOF3. The total variance of the three EOFs is 94.7%. This figure is more than sufficient to contain information from all analyzed SST data in the territory of Indonesia. Most of the results of this study were obtained from the contribution of the SST dataset.

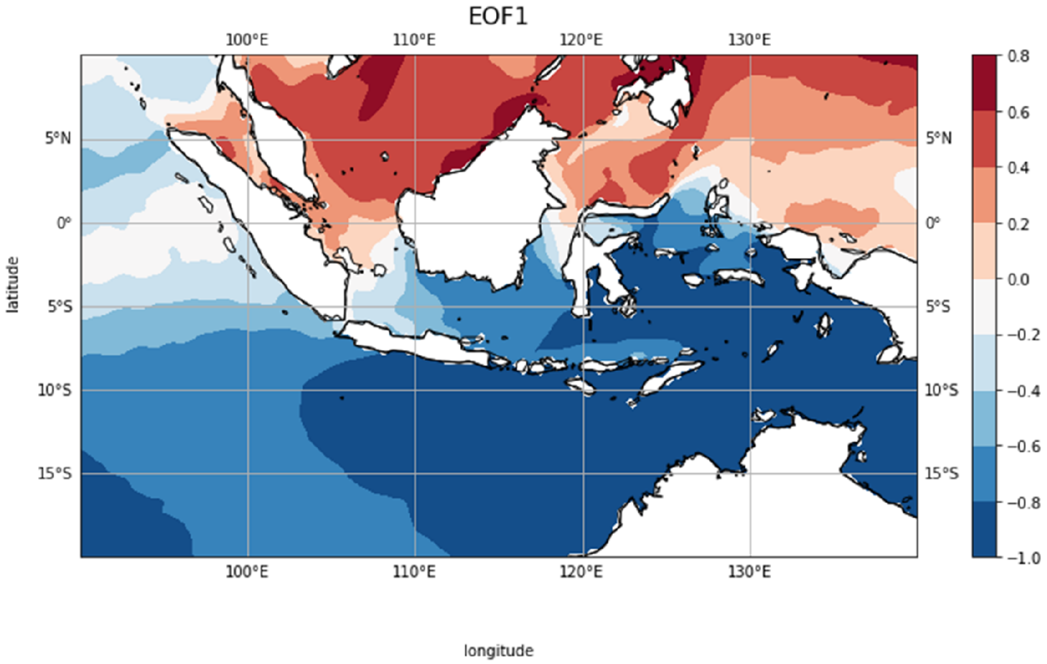


Figure 4. Visualization of SST Data with EOF Method in Mode 1 from 2000-2020

Figure 4 shows the state of Indonesian waters produced by the EOF1 mode. A negative score in this mode has SST variability which is inversely proportional to a positive SST [8], [27]. This mode also shows significant differences in SST variability in northern and southern parts of Indonesia. The northern waters of Indonesia have a variability of 0.0 to 0.8 while the southern waters of Indonesia or along the Indian Ocean have a variability of -1.0 to -0.2. Figure 4 shows that the EOF Mode 1 for the northern part of Indonesia is predominantly brown which has a positive SST value. This condition indicates that this region has a surplus of rainfall because the SST value has warmed compared to other waters. On the other hand, in the southern part of Indonesia, the dominant blue color has a negative SST value. This indicates that this region is experiencing a rainfall deficit because the SST in this region is cooler compared to other regions.

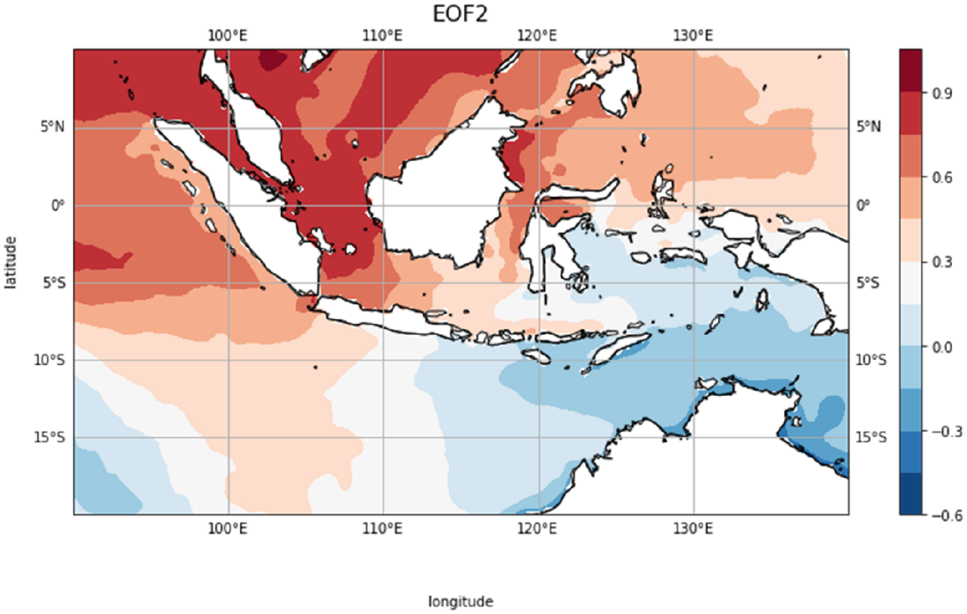


Figure 5. Visualization of SST with EOF Method in Mode 2

Figure 5 shows the EOF2 mode which explains the condition of Indonesian waters dominated by positive variability. The variability is worth 0 to 0.8 and it can be seen that the minority score is found in the Sunda strait with a score between -0.0 to -0.2. Figure 5 shows the EOF3 mode which explains that the western part of Indonesian waters has a negative score of -0.2 to 0, while the eastern part has a positive score of 0.2 to 0.6. The EOF 2 mode shows that almost all areas of Indonesia are predominantly brown, which indicates a positive SST value. This region tends to experience a surplus of rainfall due to strong evaporation in the region's atmosphere due to warm SST values. This area covers the waters of the northern part of Indonesia and the western part of the island of Sumatra. On the other hand, the southern and western parts of Papua, Nusa Tenggara, eastern Sulawesi and Maluku tend to be light blue in color. This indicates that this area has a negative SST value and this area tends to experience a rainfall deficit. A cooler SST triggers less evaporation, so convective activity in this region will decrease. As a result, rainfall in this area has decreased significantly.

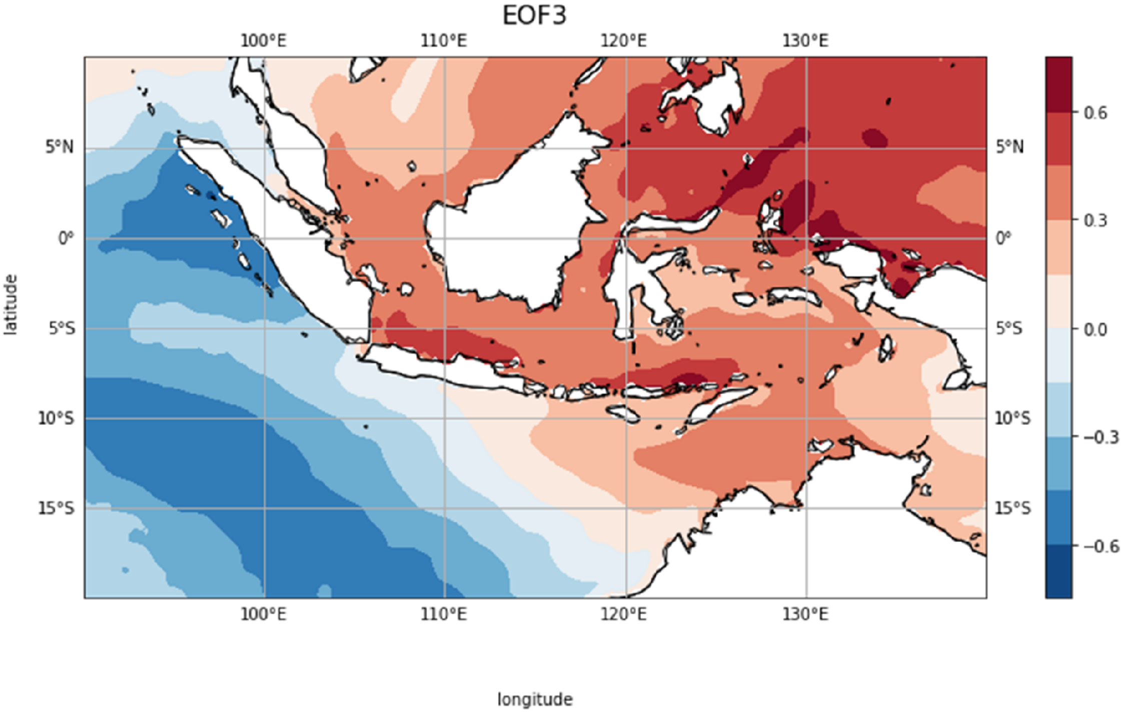
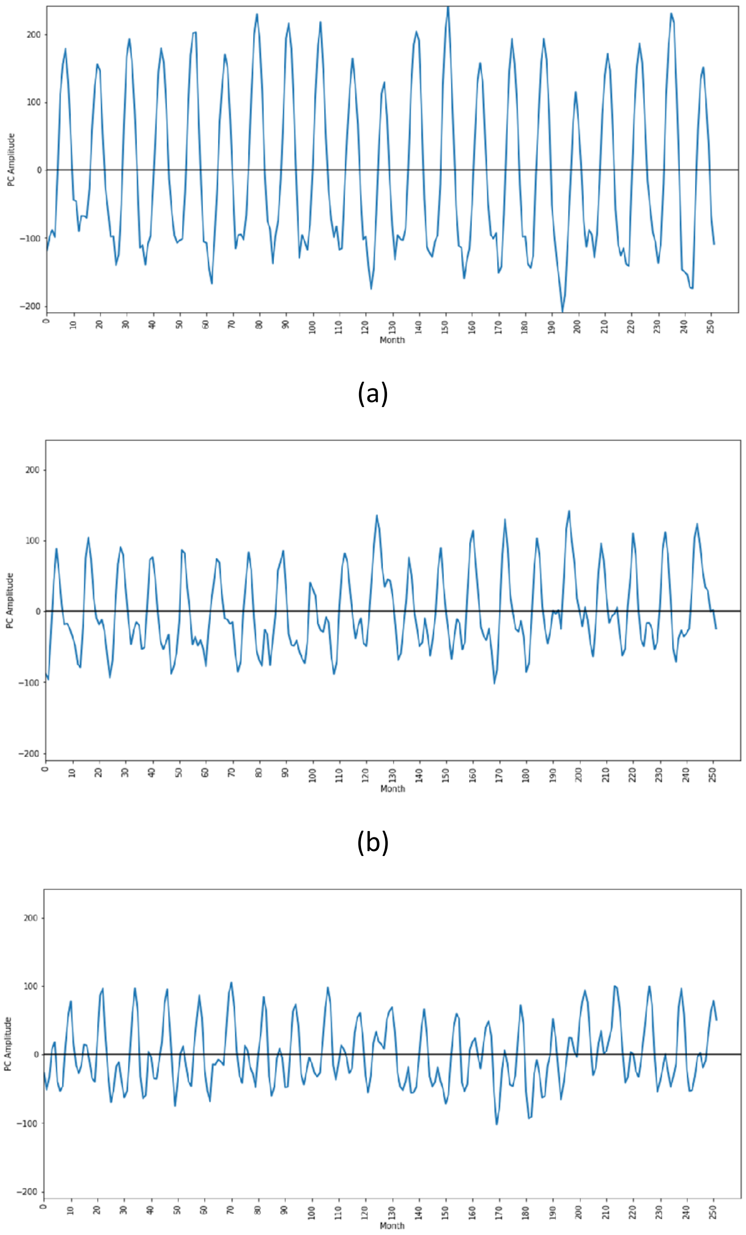


Figure 6. Visualization of SST data on EOF Mode 3

The spatial pattern through the three EOF modes above describes the phenomenon of the Indonesian sea for 252 months having fluctuating SST variability. This variability is indicated by positive and negative scores in each mode. When viewed from the temporal pattern, the Indonesian seas show a cycle with varying annual periods. These temporal patterns are respectively shown in Figure 6. Figure 6 shows the temporal mode of EOF1 with the largest variance. This mode shows the annual cycle shown by each peak. This means that within a period of 252 months, the Indonesian sea is clearly described by EOF1 of 56.8%. Figure 6 explains that the temporal mode of EOF2 which represents 24.5% of the total variance and finally Figure 6 also shows the temporal mode of EOF3 which represents 13.4% of the total variance. The results of the analysis using the EOF method carried out in this study are in line with previous research conducted by Aldrian 2003 which divided the climate region in Indonesia into three regions, namely Region A, Region B and Region C which have different characteristics. Region A is located in southern Indonesia from south Sumatera to Timor island, southern Kalimantan, Sulawesi and part of Irian Jaya. Region B is located in northwest Indonesia from northern Sumatra to northwestern Kalimantan. Region C encompasses Maluku and northern Sulawesi [8].



(a)

(b)

(c)

Figure 7. Temporal analysis results (a) EOF1 mode (56.8% of SST data variance) (b) EOF2 mode (24,5 % of SST data variance) (c) EOF3 mode (13,4% of SST data variance)

Thus, the first variation shows the dominant pattern that can represent the entire data. Variations that are not stored in EOF1 are stored in EOF2 and so on, so the variations will be smaller over time. In general, the temporal pattern can describe the cycle of the phenomenon described in each EOF mode and the strength of the phenomenon. The EOF mode with a strong cycle of phenomena contributes greatly to the SST data as a unit of observation and vice versa. However, to see the strength and weakness of a phenomenon, it can be seen from how much the approximate value of each mode is to the original data.

Conclusion

Analysis of Sea Surface Temperature (SST) with the EOF method for SST dataset during 252 months in Indonesian Waters resulted in three main components (EOF mode) with a total variance of 94.7%. Thus, three patterns are obtained spatially and temporally. The spatial pattern is formed based on the new equation of the eigenvector projection to the original, while the temporal pattern is obtained based on the reduced eigenvector from the original data. The acquisition of eigenvalues is used as the percentage contribution of the variance for each EOF mode. The three EOF modes represent 56.8%, 24.5%, 13.4% of the total variance, respectively. The results obtained from this technique are the norm error values that show the pattern of the relationship between the error rate and the EOF mode. In this case the error rate shows an approximate reduction to the original data.

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