The correlation between sea surface temperature and MJO incidence in Indonesian waters

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Abstract. Madden-Julian Oscillation (MJO) is a large-scale atmospheric phenomenon that crosses the equator within range of 15º North to 15º South and moves from West to East respectively. The MJO is closely related to weather anomalies (excess rainfall) that occur during the dry season in Indonesia and can make an unstable environment due to the sustainability of several staples plantation. This phenomenon is suspected to be related directly to the occurrence of sea surface temperature fluctuations in equatorial areas. This research aims to analyze the relation of sea surface temperature fluctuation in Indonesian waters with the MJO incidence, through the empirical method with statistical calculation, based on Sea Surface Temperature (SST) and Outgoing Longwave Radiation (OLR) which is representing the MJO incidence. The data of these two variables were obtained from ESRL NOAA, with a range of 35 years, from 1982 to 2016. With the hypothesis that the two data are directly correlated to each other, by using Bandpass filtering scheme, the filtering results then analyzed using simple linear regression method. It founded that the correlation between these two variables can reach up to 80.2%, and it means that the MJO incidence is directly correlated with SST in the Indonesian waters respectively.

1. Introduction

Indonesia is one area that plays an important role in the formation of weather and global climate. This is due to the condition of Indonesia as a Maritime Continent that has a wider ocean area than its mainland. This area is suspected as a storage place of heat either in the form of sensible and latent heat for the formation of rain clouds such as cumulonimbus [1].

Equatorial regions, especially Indonesia, are influenced by very complex atmospheric and oceanographic phenomena. This phenomenon has variations in space and time vary, one of which is the intra-seasonal cycle. Viewed from its geographic position, Indonesia is surrounded by two large continents (Asia and Australia) and two large oceans (the Pacific and the Indies) and is a center of mass water movement at various depths. The territory of Indonesia has a complex topography that adds to the sea-atmosphere variability in the Indonesian Ocean [2]. One of the atmospheric phenomena that occur is Madden-Julian Oscillation (MJO). MJO was first discovered by Madden-Julian [3]. MJO is one of the dominant oscillations in the equatorial region [4]. Another important aspect of the MJO is its timescale, related to the average period of each occurrence of 45 days. The MJO in the active phase has...
a correlation of high rainfall intensity to the area it passes [5]. During its journey eastwards, the MJO is influenced by the position of the sun. When the sun is at the equator MJO line moves straight eastward. Whereas when the position of the sun is to the south of the equator, then the MJO path is slightly shifted to the south of the equator known as the south-eastern propagation. When the sun's position is to the north of the equator, the MJO path shifts slightly toward the north of the equator, known as north-eastern propagation [6].

![OLR Anomalies, August-October 2014](image)

**Figure 1. OLR Anomalies, August-October 2014 [10]**

MJO is often associated with the formation of Super Cloud Cluster (SCC) clouds so it can be easily observed from satellite observations because the convective cloud tops are very cold. The measurement of the OLR variant in the convection region will read a larger signal than the red noise so it can show the MJO signal [7]. OLR is the size or value of Earth radiation that has a long wavelength detected from outer space. This detection is usually done with satellite equipment, and measured value illustrates the extent of the inhibition of the Earth's radiation; which is a negative value indicating the magnitude of the obstacle. The smaller the value of OLR on a negative scale indicates the greater the obstacles that can be visualized as the higher clouds inhibit those that are usually convective clouds. In general, the OLR pattern illustrates the pattern of potential convective areas [8].

MJO can substantially modulate the intensity of monsoons around the world. Australia (boreal winter, October-March), Asia (summer boreal, June-September), South America (boreal winter, October-March) and North America (summer boreal, May-October), and all wet seasons can be affected by MJO. The enhanced rainfall phase of MJO can affect the monsoon time and the intensity of the rainy season. Also, the initial phase of the MJO can end the season itself [9, 11, 12]. The sea has its response to MJO. When MJO is active, there is a significant increase in wind speed at the height of 1.5 km. This affects the surface wind pattern (wind 10 meters above sea level), which will modulate some parameters in the ocean [13, 14]. The dynamics occurring at sea level is closely related to sea surface temperature (SST), wave height, and sea surface current patterns.

In this research, the aspect of sea parameter that is emphasized is the fluctuation of sea surface temperature, SST, and finding out the relationship between MJO pattern and SST fluctuation, that occurred in Indonesian waters, and vice versa.
2. Research Methods

2.1. Data and Data Analysis.

The data used in this study were downloaded from the Earth System Research Laboratory of the National Oceanic and Atmospheric Administration (ESRL NOAA), including Outgoing Longwave Radiation (OLR) data with 2.5° × 2.5° spatial resolution and Sea Surface Temperature (SST) spatially 0.25° x 0.25°. Both data were taken with daily temporal resolution, taken from 1982 to 2016 (35 years). The compiled data is then filtered with Bandpass Filters using Ferret, and sensitivity analysis with simple linear regression using Microsoft Excel with Anova (Data Analysis Tools - Regression).

2.2. Bandpass Filtering.

The MJO phenomenon has a dominant period ranging from 40 to 60 days or classified as an intra-seasonal period, so to reinforce the oscillations of data during that period it is necessary to filter them with an intra-seasonal frequency range [2]. Data filtering is expected to limit the impact of seasonal, annual, or inter-annual oscillation phenomena. Filtering data to be applied in this research is bandpass filter with a period of 20-100 days. The cut off value of the frequency used as the input of the bandpass filter function is 0.01 and 0.05. The low-frequency value (100 days) is represented by 0.01, and the high-frequency value is represented by 0.05 (20 days). The bandpass filter discards the signal oscillations with periods below 20 days and above 100 days. The input data of the Xt variable is filtered by the Lanczos equation and produces the time series data Yt. The time series equation is used as follows [15]:

\[ Y_t \sum_{k=-\infty}^{\infty} W_k X_{t-k} = \bar{W}_k \]  

\[ \bar{W}_k = \left( \frac{s \sum_{n=-\infty}^{\infty} \tilde{c}_k \sigma_n}{\pi} - \frac{s \sum_{n=-\infty}^{\infty} \tilde{c}_k \sigma_n}{\pi} \right) \sigma, k = -n, \ldots, 0, \ldots, n \]  

where:

- \( \bar{W}_k \) = signal weight at 95% confidence interval;
- \( f_{c_1} \) = cut off of 1st frequency;
- \( f_{c_2} \) = cut off of 2nd frequency which give “0” respon on Nyquist frequency;
- \( \sigma \) = sigma factor.

2.3. Simple Linear Regression.

Simple regression is based on the functional or causal relationship of one independent variable with one dependent variable. The general equation of simple linear regression [16] is:

\[ Y = a - b \]  

where:

- \( Y \) = subjects in the predicted dependent variable.
- \( a \) = value of \( Y \) when \( X = 0 \) (in constant).
- \( b \) = regression coefficient, which indicates the increase or decrease in the independent variable. If (+) the direction of the line rises, and if (-) then the direction of the line descends.
- \( X \) = subjects on independent variables that have a certain value.

If the correlation coefficient is high then the price of \( b \) is also great, otherwise, if the correlation coefficient is low, then the price of \( b \) is also low (small). Also, when the negative correlation coefficient then the price of \( b \) is also negative, and vice versa if a positive correlation coefficient then the price \( b \) is also positive [16]. Correlation value or the high degree of relationship of both variables can be analyzed from the value of the correlation coefficient (r) obtained. If the correlation coefficient value is close to positive 1, then there is a strong positive relationship, and vice versa if the correlation coefficient value close to a negative number (-) 1, then there is a close negative relationship. Whereas if the correlation
coefficient value close to 0 (zero), then the relationship between the two variables is weak or not close. The interpretation of the strong correlation of the relationship is shown in table 1 as follows [17]:

| Coefficients interval | Relationships Level |
|-----------------------|---------------------|
| 0.00 – 0.19           | Very Low            |
| 0.20 – 0.39           | Low                 |
| 0.40 – 0.59           | Medium              |
| 0.60 – 0.79           | Strong              |
| 0.80 – 1.00           | Very Strong         |

3. Results and Discussions

3.1. MJO and SST Pattern in Indonesian Waters.

The daily data of sea surface temperature (SST) and outgoing longwave radiation (OLR) for 35 years is divided into 7 period, with data length for each period of 5 years so that the analysis becomes more detailed due to the long data corresponded. The data than filtered using Bandpass Filter method. From the filtering results, a visualization then created in the form of a combined graph between OLR and SST. Propagation of MJOs in the Indonesian Ocean is indicated by a drastic reduction in the value of OLR released by the earth's surface along the equatorial region [18]. Figure 2 shows that during one of the last 5 years SST and OLR data periods, 2012 to 2016, there is a corresponding pattern that occurs when decreasing or cooling of the SST, and vice versa. When the SST value decreases, the value of OLR rises significantly, and very visible patterns of interconnection between the two variables. Similarly, when the SST value increases, the value of OLR decreases significantly. However, it appears that the dominant SST occurs when the SST decreases when compared to when the SST value rises.

![Figure 2. Fluctuations of OLR and SST, from 2012 – 2016](image-url)
It can also be seen in figure 3, the highest SST value every year occurs between April to May, while for the lowest SST value every year occurs between August to September.

![Figure 3. Fluctuations of SST, from 2012 – 2016](image)

3.2. Correlation between SST and MJO.
Data from each filtered period then analyzed their correlation of both SST and OLR parameters using a simple linear regression method, for each period. All of SST data that has been filtered with Bandpass Filter will then be taken maximum, minimum, and average value per year. The Maximum SST is obtained from daily data in which is taken only the maximum value for every year; as also for the minimum SST that obtained from daily data in which taken only the minimum value every year. As for the average, daily SST data is then taken monthly, then from 12 monthly data per year averaged to get the average annual. For OLR data, OLR values are determined based on the maximum and minimum SST, as well as the average OLR value per year.

Correlation analysis between SST and OLR is analyzed in three conditions, i.e., maximum, mean (average), and minimum condition, to find out the value of the correlation coefficient of both variables in each condition. From this comparison, the strongest correlation then can be found at each value patterns, in rising, decreasing, or in average conditions of SST.

3.2.1. Condition on Maximum SST. At maximum SST condition, it can be seen that the data period of 1987 - 1991 has the greatest correlation value of 0.52 at the positive direction, while in other data period has correlation coefficient value less than 0.3 at positive or negative direction (table 2).

| Year | SST (Max.) | OLR | Correlation Coeff. (r) |
|------|------------|-----|-----------------------|
| 1987 | 0.550      | 9.582 |                        |
| 1988 | 0.639      | 6.982 |                        |
| 1989 | 0.527      | 5.074 | 0.52                  |
| 1990 | 0.682      | 3.644 |                        |
| 1991 | 0.368      | -0.023 |                      |
The correlation coefficient of all data periods is then averaged to obtain the overall $r$-value for the maximum SST condition, then the average $r$-value for the maximum SST is 0.11 positive. From each data period also obtained the equation of the regression line between SST and OLR variable. Regression line of all data period can be seen in the following figure 4.

![Figure 4](image-url)

**Figure 4.** Regression line Y of each period data on maximum SST

### 3.2.2. Condition on Minimum SST

At the minimum SST condition, it can be seen that from 1992 to 1996 the largest correlation value with correlation coefficient value is very significant that is 0.95 at the negative direction, while in other data period has dominant and big enough negative correlation coefficient value (table 3).

| Year | SST (Min.) | OLR  | Correlation Coeff. (r) |
|------|------------|------|------------------------|
| 1992 | -0.449     | 0.403|                        |
| 1993 | -0.688     | 5.457|                        |
| 1994 | -0.871     | 17.045| -0.95                  |
| 1995 | -0.414     | -3.592|                        |
| 1996 | -0.384     | -10.930|                      |

The correlation coefficient of all data periods is then averaged to obtain the overall $r$-value for the minimum SST condition, then the average $R$-value for the minimum SST is 0.49 in the negative direction. From each data period also obtained the equation of the line between SST and OLR variables, the regression line of the entire period of data can be seen in figure 5.

![Figure 5](image-url)

**Figure 5.** Regression line Y of each period data on minimum SST
3.2.3. **Condition on Average SST**. In the average SST condition, it can be seen that in the data period of 1987 - 1991 the largest correlation value with significant correlation coefficient value is 0.89 negative direction, while in other data period has negative dominant coefficient value (table 4).

**Table 4.** Correlation coeff. on the average value of SST, from 1987 – 1991

| Year | SST (aver.) | OLR  | Correlation coeff. (r) |
|------|-------------|------|-----------------------|
| 1987 | -0.057      | 2.335|                       |
| 1988 | 0.135       | -0.837|                      |
| 1989 | 0.213       | -1.256| -0.89                 |
| 1990 | 0.024       | 1.004|                      |
| 1991 | -0.160      | 1.526|                      |

**Figure 6.** Regression line Y of each period data on average SST

The correlation coefficient of all data periods is then averaged to obtain the overall r-value for the minimum SST condition, then the average R-value for the minimum SST is 0.37 negative. From each data period also obtained the equation of line between SST and OLR variable, regression line from all data period can be seen in figure 6.

4. **Conclusion**

Based on the regression of SST value with OLR for 35 years (1982 - 2016), the dominant negative correlation coefficient (r), with the greatest r value occurred in minimum SST condition, period 1992 - 1996 with an R-value of 0.95 at negative direction. The comparison of the correlation coefficient (r) between the maximum, minimum, and average SST conditions shows that the dominant correlation occurs in the minimum and average SST conditions, with the greatest r value occurring in the period 1987 - 1991 and 1992 - 1996. The results of this study show that there is a correlation between sea surface temperature (SST) fluctuation in Indonesian waters in the period of 1982 - 2016 with MJO incidence (OLR data as MJO parameter). From these results, it is indicated that the SST fluctuations can predict MJO events in the future, respectively.
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