MJO Anomalies relationship with Volcanic Eruption in Indonesian Archipelago

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Abstract. Madden-Julian Oscillation (MJO) is a large-scale atmospheric phenomenon that crosses the equator with a propagation area ranging from 15° North to 15° South, and moves from west to east, precisely from the Indian Ocean to the Pacific. MJO propagation is usually characterized by the rising of Sea Surface Temperature (SST) in Indian Ocean respectively. MJO anomaly is closely related to the variability of weather in the area it passes, including the Indonesian Archipelago. The impact of MJO anomaly in Indonesian Archipelago itself is suspected to cause not only excessive rainfall, but also a very long consecutive No Rain Days (NRD), with in the end can also trigger massive crop failures. In addition to SST, there are also external events that can affect the duration of the MJO, i.e. volcanic eruptions. Therefore, the study aims to determine the effect of volcanic eruption events on MJO anomalies, through the SST variable as an MJO anomaly parameter and also the occurrence of volcanic eruptions in the same time span. Data from both variables were taken over a period of 35 years, from 1982 to 2016. The SST data is a daily average data, obtained from ESRL NOAA, which is then filtered by the Bandpass Filter method to reinforce the oscillation of data. The MJO anomaly that seen from the SST fluctuations is then matched with time data and the duration of volcanic eruption events over the same time span. It found out that there are three MJO anomalies occurred during the time span of 35 years, and it is hypothesized that they were clearly in correspondence between the duration of volcanic eruption events with the incidence of MJO anomalies in Indonesian Archipelago.

1. Introduction

Equatorial regions, especially Indonesia, are influenced by very complex atmospheric and oceanographic phenomena. This phenomenon has variations in space and time varies, 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 it’s a centre 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 [1]. One of the atmospheric phenomena that occur is Madden-Julian Oscillation (MJO). MJO was first discovered by Madden-Julian [2]. MJO is one of the dominant oscillations in equatorial region [3]. Another important aspect of the MJO is its time scale, related to the average period of each occurrence of 45 days. Seto [4] states that the MJO in the active phase has a correlation of high rainfall intensity to the area it passes. MJO controls a considerable fraction of the total precipitation over Indonesia and that the rainfall variability over the surrounding ocean is more clearly controlled by the MJO compared to over the large land masses [5].
The measurement of the Outgoing Longwave Radiation (OLR) variant in the convection region will read a larger signal than the red noise so it can show the MJO signal [6]. OLR actually 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 [7].

Volcanic eruptions can inject into the stratosphere tens of teragrams of chemically and microphysically active gases and solid aerosol particles, which affect the Earth’s radiative balance and climate, and disturb the stratospheric chemical equilibrium. The volcanic cloud forms in several weeks by SO2 conversion to sulfate aerosol and its subsequent microphysical transformations [8] [9]. The resulting cloud of sulfate aerosol particles, with an e-folding decay time of approximately 1 year [10], has important impacts on both shortwave and longwave radiation. The resulting disturbance to the Earth’s radiation balance affects surface temperatures through direct radiative effects as well as through indirect effects on the atmospheric circulation [11].

Figure 1 indicates the major radiative processes resulting from the stratospheric aerosol cloud from a major volcanic eruption. The most obvious and well-known effect is on solar radiation. Since the sulfate aerosol particles are about the same size as visible light, with a typical effective radius of 0.5 μm, but have a singlescatter albedo of 1, they strongly interact with solar radiation by scattering. Some of the light is backscattered, reflecting sunlight back to space, increasing the net planetary albedo and reducing the amount of solar energy that reaches the Earth’s surface. This backscattering is the dominant radiative effect at the surface and results in a net cooling there. Much of the solar radiation is forward scattered, resulting in enhanced downward diffuse radiation that somewhat compensates for a large reduction in the direct solar beam [11].

![Figure 1. Schematic diagram of volcanic inputs to the atmosphere and their effects [11].](image-url)
| Effect                               | Mechanism                                                                 | Begins          | Duration        |
|--------------------------------------|----------------------------------------------------------------------------|-----------------|-----------------|
| Reduction of diurnal cycle           | Blockage of shortwave & emission of longwave radiation                    | Immediately     | 1-4 days        |
| Reduce tropical precipitation        | Blockage of shortwave radiation, reduced evaporation                      | 1-3 months      | 3-6 months      |
| Summer cooling of NH continents      | Blockage of shortwave radiation                                          | 1-3 months      | 1-2 years       |
| Stratospheric warming                | Stratospheric absorption of shortwave & longwave radiation               | 1-3 months      | 1-2 years       |
| Winter warming of NH continents      | Stratospheric absorption of shortwave & longwave radiation, dynamics     | $\frac{1}{2}$ year | One or two winters |
| Global cooling                       | Blockage of shortwave radiation                                          | Immediately     | 1-3 years       |
| Global cooling from multiple eruptions| Blockage of shortwave radiation                                          | Immediately     | 10-100 years    |
| Ozone depletion, enhanced UV         | Dilution, heterogeneous chemistry on aerosols                            | 1 day           | 1-2 years       |

The study aims to determine the relationship between MJO anomalies that occurred in Indonesian Archipelago with volcanic eruption events, through the SST variable as an MJO anomaly parameter and also the occurrence of volcanic eruptions in the same time span.

2. Research Method

2.1. Data

The data used in this study were downloaded from the Earth System Research Laboratory of the National Oceanic and Atmospheric Administration (ESRL NOAA)[12] for Sea Surface Temperature (SST) data with 0.25° x 0.25° spatial resolution & daily temporal resolution taken from 1982 to 2016 (35 years), and from the National Geophysical Data Center / World Data Service (NGDC/WDS)[13] for volcano eruption data. The SST data is then filtered with Bandpass Filters using Ferret.

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 filtered them with an intra-seasonal frequency range [1]. 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 period of 20-100 days. The cutoff 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 $X_t$ variable is filtered by the Lanczos equation and produces the time series data $Y_t$. The time series equation is used as follows [14]:

$$Y_t = \sum_{k=-\infty}^{\infty} w_k X_{t-k} = \overline{w_k}$$ (1)
\[
\overline{w}_k = \left( \frac{\sin 2\pi f_c_1 k}{\pi k} - \frac{\sin 2\pi f_c_2 k}{\pi k} \right) \sigma, k = -n, ..., 0, ..., n
\]  

where:

- \( \overline{w}_k \) = 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 of Nyquist frequency;
- \( \sigma \) = sigma factor.

3. Result and Discussion

The daily data of sea surface temperatur (SST) is filtered with Bandpass Filter method, to reinforce the oscillation of data during the MJO period. The filtered data then be taken average value for each year. The annual average SST data shown in figure 2.

![Figure 2. Annual average SST in Indonesian Waters (1982 – 2016)](image)

In figure 2, there are 3 MJO anomalies occurred for 35 years (1982 – 2016), seen from the abnormal pattern of SST (circled areas).

Large volcanic eruptions inject sulfate gas into the stratosphere and produce aerosols clouds in the stratosphere, then cause the earth surface cooling but produce warming in the stratosphere\[11\]. This is occurs because the solar flux will be blocked by the aerosol cloud. Some flux will be reflected, so the flux that arrives on the surface becomes less. These occurences can be seen in figure 1. From these statements, it is possible that SST are related with volcanic eruptions, if we match the anomaly with the eruption data that occurs, there is a volcanic eruption that occurs before and at the intervals of the anomaly occurs.

In 1982 there was an eruption of El Chicón volcano in Chiapas, Mexico, with a scale of 5 VEI (Volcanic Explosivity Index), and with 800 DVI (Dust Veil Index). The eruption was often associated with the powerful El Niño incident of 1982 - 1983. Based on satellite measurements, it is estimated that the El Chicón eruption of 1982 spewed 7 metric tons of SO2 (Sulfur Dioxide) in the air \[11\]. The eruption is also suspected to have a relationship with the occurrence of SST anomalies that occurred around 1983 to 1984 (Fig 2 in the a circle).

Furthermore, during time span of 1999 to 2001, while Indonesian waters experiencing SST anomalies, there were also series volcanic eruptions occurred at the same region. At least 24 eruptions recorded during that period, with the largest eruption were at Karangetang mountain in Siau, North Sulawesi in 1999, with a VEI scale of 3. Meanwhile, there was also a major eruption that occurred...
before the anomaly occurred, i.e. Soufriere Hills, in the Caribbean Islands, with a VEI scale of 4. For the anomaly occurred in 2007 - 2008, there was an eruption in form of long ash emission (from mid 2007 to early 2008, with maximum 4VEI) of Rabaul volcano in Papua New Guinea, before the anomaly occurred. Some incident data the above mentioned volcanic eruption is suspected to be associated with the occurrence of SST anomalies.

**Table 2.** Volcanic eruptions from 1982 to 2016 which are related to the SST anomaly [13]

| No | Year | Month | Day | Name | Location           | Country     | Elevation | Type       |
|----|------|-------|-----|------|--------------------|-------------|-----------|------------|
| 1. | 1982 | 3     | 29  | Chichon, El | Mexico            | Mexico      | 1150      | Tuff cone  |
| 2. | 1982 | 4     | 4   | Chichon, El | Mexico            | Mexico      | 1150      | Tuff cone  |
| 3. | 1982 | 5     | 17  | Galunggung  | Indonesia         | Indonesia   | 2168      | Stratovolcano |
| 4. | 1982 | 5     | 27  | Chichon, El | Mexico            | Mexico      | 1150      | Tuff cone  |
| 5. | 1983 | 7     | 23  | Colo [Una Una] | Sulawesi-Indonesia | Indonesia   | 507       | Stratovolcano |
| 6. | 1983 | 10    | 3   | Miyake-jima | Izu Is-Japan      | Japan       | 815       | Stratovolcano |
| 7. | 1984 | 9     | 9   | Mayon      | Luzon-Philippines  | Philippines | 2462      | Stratovolcano |
| 8. | 1984 | 10    | 16  | Etna       | Italy             | Italy       | 3350      | Stratovolcano |
| 9. | 1985 | 5     | 10  | Semeru     | Java              | Indonesia   | 3676      | Stratovolcano |
| 10.| 1985 | 11    | 13  | Ruiz       | Colombia          | Colombia    | 5321      | Stratovolcano |
| 11.| 1986 | 8     | 21  | Oku Volc Field | Africa-W         | Cameroon    | 3011      | Maar       |
| 12.| 1986 | 11    | 15  | Oshima     | Izu Is-Japan      | Japan       | 758       | Stratovolcano |
| 13.| 1987 | 1     | 25  | Pacaya     | Guatemala         | Guatemala   | 2552      | Complex volcano |
| 14.| 1999 | 1     | 20  | Soufriere Hills | W Indies         | Montserrat  | 915       | Stratovolcano |
| 15.| 1999 | 8     | 15  | Shiveluch  | Kamchatka         | Russia      | 3283      | Stratovolcano |
| 16.| 1999 | 10    | 5   | Guagua Pichincha | Ecuador     | Ecuador      | 4784      | Stratovolcano |
| 17.| 1999 | 10    | 16  | Tungurahua | Ecuador          | Ecuador      | 5023      | Stratovolcano |
| 18.| 2000 | 7     | 27  | Semeru     | Java              | Indonesia   | 3676      | Stratovolcano |
| 19.| 2000 | 8     | 23  | Arenal     | Costa Rica        | Costa Rica  | 1657      | Stratovolcano |
| 20.| 2001 | 5     | 14  | Etna       | Italy             | Italy       | 3350      | Stratovolcano |
| 21.| 2002 | 1     | 3   | Karangetang [Api Siau] | Sangihe Is-Indonesia | Indonesia   | 1784      | Stratovolcano |
| 22.| 2002 | 8     | 28  | Etna       | Italy             | Italy       | 3350      | Stratovolcano |
| 23.| 2002 | 11    | 3   | Reventador | Ecuador          | Ecuador      | 3562      | Stratovolcano |
| 24.| 2002 | 3     | 27  | Semeru     | Java              | Indonesia   | 3676      | Stratovolcano |
| 25.| 2005 | 1     | 27  | Manam     | New Guinea-NE of Papua New | United States | 1807      | Stratovolcano |
| 26.| 2005 | 10    | 1   | Santa Ana  | El Salvador       | El Salvador  | 2365      | Stratovolcano |
| 27.| 2006 | 7     | 18  | Tungurahua | Ecuador          | Ecuador      | 5023      | Stratovolcano |
| 28.| 2006 | 8     | 17  | Tungurahua | Ecuador          | Ecuador      | 5023      | Stratovolcano |
| 29.| 2007 | 3     | 27  | Manam     | New Guinea-NE of Papua New | United States | 1807      | Stratovolcano |
| 30.| 2008 | 8     | 18  | Kasatochi  | Akutian Is        | United State | 314       | Stratovolcano |
| 31.| 2008 | 8     | 22  | Tungurahua | Ecuador          | Ecuador      | 5023      | Stratovolcano |

**4. Conclusion**

This research concluded clearly that there is a relationship between SST anomalies and volcanic eruptions that occurred in Indonesian Archipelago; in form of ash emissions spewed in the air which can effect the solar radiation intensity. Unfortunately, the amount of ash emission produced by that volcanic eruptions, still not calculated properly in every event that occurred. Which then lead to a question, "Is it possible to predict the active period of MJO if volcanic eruptions occur on a large scale?"

**5. References**

[1] Wu, C. &. (2009). Topographic influence on the MJO in the maritime continent. *J. Climate*, 22, 5433-5448.
[2] Madden, R.A., & P. Julian. (1971). Detection of a 40-50 day oscillation in the zonal wind in the tropical Pacific. *J. Atmos Sci.*, 28, 702-708.

[3] Madden R.A., & P. Julian. (1994). Observations of the 40-50 day tropical oscillation. *Month Weather Rev.*, 122, 814-837.

[4] Seto, T. (2004). Effect of Madden-Julian Oscillation on Variability of Tropical Rainfall (in Bahasa Indonesia: Pengaruh Osilasi Madden-Julian terhadap Variabilitas Curah Hujan Tropis), *Jurnal Sains & Teknologi Modifikasi Cuaca I(V)*, 55-58.

[5] Hidayat, R., & S. Kizu. (2010). Influence of the Madden–Julian Oscillation on Indonesian rainfall variability in austral summer. *Int. J. Climatol.*, 30, 1816-1825.

[6] Geerts, B., & M. Wheeler. (1998). The Madden-Julian Oscillation. Retrieved October 24, 2018, from http://www.das.uwyo.edu/~geerts/cwx/notes/chap12/mjo.html

[7] Aldrian, E. (2000). Monthly average rainfall pattern in Indonesia, review of the results of the contour data with ECHAM T-42 resolution (in Bahasa Indonesia: Pola hujan rata-rata bulanan wilayah Indonesia, tinjauan hasil kontur data penakar dengan resolusi ECHAM T-42), *Jurnal Sains & Teknologi Modifikasi Cuaca. 1(2)*, 112-123.

[8] Pinto, J.P., R.P. Turco, & O.B. Toon. (1989). Self-limiting physical and chemical effects in volcanic eruption clouds. *J. Geophys. Res.*, 94, 11,165-11,174.

[9] Zhao, J., R.P. Turco, O.B. Toon. (1995). A model simulation of Pinatubo volcanic aerosols in the stratosphere. *J. Geophys. Res.*, 100, 7315-7328.

[10] Barnes, J. E., & D. J. Hoffman. (1997). Lidar Measurement of stratospheric aerosol over Mauna Loa Observatory. *Geophys. Res. Lett.*, 24, 1923-1926.

[11] Robock, A. (2000). Volcanic Eruptions and Climate. *Reviews of Geophysics*, 38, 2, 191-219.

[12] NOAA High Resolution SST data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA. (n.d.). Retrieved from Earth System Research Laboratory, Physical Sciences Data: https://www.esrl.noaa.gov/psd/

[13] National Geophysical Data Center / World Data Service (NGDC/WDS): Significant Volcanic Eruptions Database. (n.d.). Retrieved from National Geophysical Data Center, NOAA: https://www.ngdc.noaa.gov/

[14] Duchon, C. E. (1979). Lanczos Filtering in One and Two Dimensions. *Journal of Applied Meteorology*, 18, 1016-1022.