The Analysis of tropical cyclones that occurred in the southern sea of Java during the period 2004-2019 and their effects on sea-atmospheric conditions

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Abstract. Tropical cyclones are an important part of the atmospheric circulation system, which transfers heat from the equatorial region to higher latitudes. The birth of a tropical cyclone will have an impact on increasing the intensity of heavy rain, wave height, strong winds, and the potential for lightning. The purpose of this study is to analyze tropical cyclones and their impact on ocean and atmospheric conditions that occur in the southern of Java. The data used in this study is hourly rainfall data, Madden Julian Oscillation (MJO), wind (direction and speed), significant wave height, sea surface temperature, and sea level pressure hourly from the European Centre for Medium-Range Weather Forecasts (ECMWF). The method used in this study is averaging hourly data into daily data for each sea-atmospheric parameter during the 16-years observation period (2004-2019), and representing it in the form of descriptive daily on before, being and after the occurrence of tropical cyclones. From the results of the analysis it can be concluded that there were 17 tropical cyclones which mostly occurred in April, resulting in a significant increase in intensity of sea-atmospheric parameters (rainfall, significant wave height, and wind direction & speed), but decreased for sea level pressure. As from the Riley tropical cyclone event that occurred on (24-26) January 2019, rainfall increased in intensity to 951 mm/day, significant wave heights reaching more than 4 m with wind speeds of more than 17 m/sec, sea level pressure is less than 947 hPa, and the average MJO condition is in phase 2, 3, 4, or 5, with a strong period.

1. Introduction

The tropics are areas that are more intensive in receiving solar radiation and receive two times of perpendicular solar radiation, so that sea surface temperatures in the tropics are higher than in the polar regions. When sea surface temperatures are high, low pressure centers are formed which can trigger tropical cyclones that begin with tropical disturbance and then tropical depression, tropical storms then occur tropical cyclones [1]. Tropical cyclones are an important part of the atmospheric circulation system, which transfers heat from the equatorial region to higher latitudes. The birth of a tropical cyclone will have an impact on increasing the intensity of heavy rain, wave height, strong winds, and the potential for lightning.

Tropical cyclones in general have direct and indirect impacts. The direct impact of tropical cyclones is the accompanying meteorological conditions during the cyclone. These direct impacts include an increase in rainfall [2, 3] and wind speed and the presence of high waves [4]. Indirect impacts are
secondary impacts due to an increase in meteorological activities, including floods, landslides, erosion and changes in coastal ecosystems, coastal flooding and damage to various infrastructures [5, 6].

While the impact of tropical cyclones that occur around Indonesia can affect weather conditions in various places in Indonesia such as rainfall, strong winds, high sea waves, drought and floods. Many tropical cyclones occur in the Indian Ocean region, this indirectly affects the intensity of rainfall in areas near the tropical cyclone phenomenon, such as the islands of Java, Nusa Tenggara and southern Sulawesi. Research on tropical cyclones in Indonesia has been widely carried out, including analysis of the characteristics of tropical cyclones [7, 8]. Then the study of tropical cyclones in relation to atmospheric and sea parameters [9, 10, 11, 12, 13]. Thus, the research on tropical cyclones will continue, given the importance of the phenomenon and its relation to atmospheric and oceanic parameters that affect human life.

Therefore, we need research on tropical cyclones that still occur every year, especially in the southern sea of Java or precisely in the Indian Ocean south of Java. The purpose of this study was to analyse tropical cyclones and their impacts on sea and atmospheric conditions that occur in the southern sea of Java.

2. Data and Methods

The data used in this study is hourly rainfall data from GSMaP with a resolution (0.1 x 0.1)° from ftp://rainmap: Niskur+1404@hokusai.eorc.jaxa.jp/. Then Madden Julian Oscillation (MJO) data sourced from http://www.bom.gov.au/climate/mjo/. Other data are direction and wind speed data, significant wave height (SWH), sea surface temperature (SST), and sea surface pressure (SSP) hourly from the European Centre for Medium-Range Weather Forecasts (ECMWF) with a resolution (0.125 x 0.125)°. The type of ECMWF data used is ERA-Interim which is the result of reanalysis and is available from 1979 to the present, and the boundaries of the study area are southern sea of Java with coordinates (4-18)°S, (104-128)°E, and the data source is https://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc/. The method used in this study is averaging hourly data into daily data for each ocean-atmosphere parameter during the 16-years observation period (2004-2019), and representing it in the form of descriptive daily on before, being and after the occurrence of tropical cyclones.

3. Results and discussion

From the data of the cyclone events from 2004 to 2019, there were 17 tropical cyclones that occurred in the southern waters of Java. In this paper only an image of one tropical cyclone is displayed by the name of Riley, which represents the events of another tropical cyclone, but the results of a complete analysis of other tropical cyclones are shown in the table. Figure 1 shows the MJO index on (22-30) January 2019 during the Riley tropical cyclone at the southern sea of Java.

![Figure 1. MJO phase and period on (22-30) January 2019](image_url)
From the results it can be seen that on (22-24) January 2019 MJO is in phase 5 or in the Maritime Continent with a strong period, after that on (25-30) January 2019 MJO is in phase 6 in the Western Pacific with a strong period. Thus, at the time of the tropical cyclone Riley (24-26) January 2019 MJO was in two phases (phases 5 and 6) with a strong period. Other results, such as when the Team tropical cyclone occurred on (24-25) January 2004. At the moment it appears that on January 22-27, MJO is in phase 2 and phase 3 namely in Indian Ocean, with strong period. From a total of 17 tropical cyclone events, the overall condition of MJO can be stated that, MJO is in phase 2, 3, 4, 5, or 6, with strong or weak periods, and the complete results can be seen in Table 1.

Table 1. The name of the cyclone, date of occurrence, position and phase of the MJO when the tropical cyclone occurred from 2004-2019

| No | Cyclone name | Date of occurrence | MJO position | Period |
|----|--------------|-------------------|--------------|--------|
| 1  | Tim          | (24 - 25) Jan 2004| Indian Ocean (22-27) Jan | Strong |
| 2  | Flyod        | (22 - 27) Mar 2006| Maritime Continent (22-26) Mar | Weak |
| 3  | Rosie        | (20-24) April 2008| Maritime Continent (27-29) Mar | Strong |
| 4  | Durga        | (20 - 25) April 2008| Maritime Continent (19-24) Apr | Weak |
| 5  | Anika        | (17 - 22) Nov 2008| Maritime Continent | Strong |
| 6  | Gabrielle    | (1 - 5) March 2009| Maritime Continent (1-2) Mar | Weak |
| 7  | Sean         | (21 - 25) Apr 2010| Maritime Continent (3-7) Mar | Weak |
| 8  | Narelle      | (8 - 14) Jan 2013 | Maritime Continent (19-21) Apr | Strong |
| 9  | Victoria     | (9 - 12) Apr 2013 | Western, Hem and Africa, (27-29) Apr | Weak |
| 10 | Gillian      | (22 - 26) Mar 2014| Maritime Continent (22-24) Apr | Strong |
| 11 | Bakung       | (11 - 13) Dec 2014| Maritime Continent (6-10) Jan | Weak |
| 12 | Yvette       | (21 - 23) Dec 2016| Western, Hem and Africa, (25-26) Apr | Strong |
| 13 | Ernie        | (7 - 10) Apr 2017 | Maritime Continent (7-11) Apr | Strong |
| 14 | Cempaka      | 27 Nov - 02 Dec 2017| Maritime Continent (12-16) Apr | Strong |
| 15 | Dahlia       | 30 Nov - 02 Dec 2017| Indian Ocean (20-22) Mar | Weak |
| 16 | Flamboyan    | 28 Apr - 02 May 2018| Maritime Continent (28-29) Apr | Strong |
| 17 | Riley        | (24 - 26) Jan 2019| Maritime Continent (22-24) Jan | Weak |

Furthermore, analyzing the total rainfall that occurs due to the presence of Riley's tropical cyclone, as shown in Figure 2. Based on the results it appears that on January 22, 2019 or before the peak of Riley's tropical cyclone, total rainfall with an intensity of less than 90 mm/ day occurred at South Java waters at coordinates (7-14)°S; (105-125)°E, but total rainfall with a maximum intensity of more than...
191 mm/ day occurs at coordinates (8-12)°; (110-118)°E and occurs in the southern waters of the island of Timor at coordinates (12-15)°S; (122-125)°E. Then on January 23, 2019, the intensity of rainfall was reduced compared to the previous day in the same position. At the time of the peak of the tropical cyclone Riley on (24-26) January 2019 the total intensity of rainfall increased with a maximum value of more than 951 mm/ day which occurred at the coordinate position (15-16)°S; (115-118)°E. Then, after the event of the peak of the tropical cyclone or on January 27, 2019 the peak of the tropical cyclone shifted towards the southwest, at coordinates about (15-16)°S; (109-112)°E, and the total rainfall around it is less than 96 mm/ day and occurs at coordinates (15-16)°S; (110-112)°E. This study supports previous research [14, 15] that with the occurrence of tropical cyclones, will cause an increase in rainfall intensity, especially at the time of the peak of tropical cyclones.

**Figure 2.** Spatial distribution of total precipitation occurring before, being and after the occurrence of tropical cyclone Riley on (22-27) January 2019 in the southern sea of Java.

The occurrence of tropical cyclones will affect the distribution of the SSP as shown in Figure 3. At the time before the occurrence of tropical cyclone peaks (22-23 January 2019), significant low pressure’s center had not yet occurred in the southern waters of Java. But on January 23, a low pressure center with a maximum value of more than 990 hPa was seen at coordinates (15-16)°S; (117-122)°E. At the height of the tropical cyclone (24-26) in January, the center of low pressure was in the same position, but with a value of more than 995 hPa. After the peak of a tropical cyclone or on January 27, there was a shift in the center of low pressure moving towards the southwest, with SSP values ranging from (995-998) hPa, and from the results seen around coordinates (15-16)°S; (112-115)°E. From this research it can be seen that when tropical cyclones occur, together with the occurrence of low pressure’s center, this is consistent with research conducted by [16]. Other results show that there is a smaller SSP value around the waters surrounding the land compared to the SSP in the ocean, and the SSP value ranges between (980-985) hPa.
Tropical cyclones form over large oceans, which generally have warm sea surface temperatures, more than 26.5 °C, [18]. Many studies have stated that the presence of tropical cyclones is closely related to SST, including [17], as well as in this study the same thing happened, as seen in Figure 4. At the time before, and the occurrence of tropical cyclone peaks that is, on (22-26) January 2019, SST ranged between (28-31)°C. Meanwhile, after the peak of tropical cyclone on January 27, 2019, SST ranged between (27-28)°C as shown in Figure 4.

Further analysis for wind speed and direction as shown in Figure 5. Based on the results it can be seen that before the peak of the tropical cyclone on January 22, 2019, the wind speed in the southern sea of Java reached a maximum of 13 m/s, and the direction around the peak of cyclone dominant heading
west and south. When approaching the peak of a tropical cyclone on January 23-24, 2019, the wind speed increases in intensity, reaching a maximum of 13 m/s.

**Figure 5.** Same as Figure 1, but for wind direction and speed

During the peak of a tropical cyclone on January 25, 2019, the wind speed increased when approaching the cyclone's core, and its intensity ranged from (6-16) m/s, while near the cyclone core the maximum wind speed reached 19 m/s. The direction of the prevailing winds, predominantly from west to southeast and from south to east, is seen rotating around the cyclone's core. On January 27, 2019 or after the peak of the cyclone, the wind speed is reduced, and the maximum intensity reaches 11 m/s, and the wind direction is still dominant from west to southeast and rotates around the cyclone's core.

**Figure 6.** Same as Figure 1, but for significant wave height
Another important sea-atmosphere parameter to analyze when tropical cyclones occur is significant wave height. Figure 6 shows the spatial distribution of significant wave heights before, during, and after the occurrence of Riley's tropical cyclone on January 22-26, 2019. Based on the results it can be seen that on January 22, 2019 or before the peak of the tropical cyclone, tropical cyclones began to be seen next to southern sea of Java with a maximum significant wave height reaching more than 2.07 m. Then on January 23, 2019, the wave height increased to a maximum of more than 3.05 m, and was seen expanding and moving eastward or in the southern waters of West Nusa Tenggara. While on January 24, 2019, the maximum significant wave height reaching more than 3.05 m extended to the southern waters of Timor island. At the time of the tropical cyclone peak, namely on January 25, 2019, the maximum significant wave height reaching more than 4.05 m was more widespread in the Indian Ocean at coordinates (12°-15°S, 117°-120°E), and significant wave height reaching more than 2.4 m occur at coordinates (8°-17°S, 105°-110°E) up to northwestern Australian waters.

![Figure 6](image)

**Figure 6.** The spatial distribution of significant wave heights before, during, and after the occurrence of Riley's tropical cyclone on January 22-26, 2019.

During the 2004-2019 period the average number of tropical cyclones per year is shown in Figure 7 (left). The analysis shows that over a period of 16 years, on average one tropical cyclone occurred. In 2004, 2006, 2009, 2010, 2016, 2018 and 2019 there was one tropical cyclone, while in 2013 and 2014 it happened twice. Whereas in 2008 and 2017 there were three tropical cyclones. But in 2007, 2011, 2012 and 2015 no tropical cyclones occurred in the southern waters of Java or through the Indian Ocean south of Java (0°-10°S).

Next analyze the monthly pattern as shown in Figure 7 (right). By analyzing 17 tropical cyclone events in 2004-2019, based on the results of shows that tropical cyclones mostly occurred in April, it never happened in June, July, August, and September, and the results of this study are in accordance with the statement [18] which states that: Tropical cyclones that occurred in the southern region of Indonesia with a history of data for 59 years (1960-2019) found that in the south the tropical cyclone occurred in February, which was 23% of the events in a month. Followed by March (22%), January (21%), December (14%) and April (11%). However, in June, July, August and September there are known months that for 59 years there were almost no tropical cyclone events at all. Conversely, it is known that the northernmost regions of Indonesia have the most tropical cyclones in August where 20% of tropical cyclones occur this month. Followed by September (18%), July and October (15%). The maximum extreme conditions ever occurred in 1960 (13 times a tropical cyclone occurrence in a month) and the minimum extreme conditions occurred in 1980 (only 2 occurrences of a tropical cyclone in a month). And vice versa in February which experienced maximum extreme events in 1967 and 1976 with 2 times the occurrence of tropical cyclones, and in the other 57 years did not experience tropical cyclones at all.

The occurrence of tropical cyclones in May tends to be minimal when compared to the annual pattern. From the analysis of 17 tropical cyclones that occurred during the 2004-2019 period in the southern sea of Java, there are six of them occurred in April. Tropical cyclones Rosie (2008), Durga (2008) and Sean
(2010) Victoria (2013), Ernie (2017), and Flamboyan (2018) which occurred southern sea of Java in April. From the analysis it can be seen that the tropical cyclones that occur in the southern sea of Java are mostly from the east, then move towards the southwest.

From 17 tropical cyclone events, conditions of the ocean-atmosphere parameters were analyzed with minimum and maximum values of each parameter that occurred during the occurrence of tropical cyclones. For example, for tropical cyclones Riley, the minimum intensity of rainfall that occurs is 96 mm/ day, and the maximum is 951 mm/ day. For sea surface pressure parameters, the minimum is 947 hPa, and the maximum is 1013 hPa. In addition to the sea surface temperature parameters the minimum value is 22°C, and the maximum is 30°C. Another important parameter to analyze is the significant wave height, and for the Riley cyclone event, the minimum value is 0.12 m, while the maximum is 4.07 m. For wind speed, the minimum value is 0.15 and the maximum is 16.96 m.

| No | Cyclone name | Precipitation (mm/day) | Sea Surface Pressure (hPa) | Sea Surface Temperature (°C) | Significant Wave Height (m) | Wind Speed (m/s) |
|----|--------------|------------------------|---------------------------|-----------------------------|-----------------------------|-----------------|
| 1  | Tim          | 16 - 166               | 951 - 1013                | 22 - 32                     | 0.08 - 2.34                 | 0.01 - 8.47     |
| 2  | Flyod        | 70 - 760               | 947 - 1011                | 23 - 30                     | 0.08 - 3.87                 | 0.01 - 12.35    |
| 3  | Rosie        | 42 - 452               | 949 - 1014                | 22 - 30                     | 0.09 - 3.49                 | 0.01 - 12.85    |
| 4  | Durga        | 42 - 452               | 949 - 1014                | 22 - 30                     | 0.09 - 3.49                 | 0.01 - 12.85    |
| 5  | Anika        | 23 - 221               | 948 - 1012                | 22 - 32                     | 0.1 - 3.2                   | 0.01 - 11.3     |
| 6  | Gabrielle    | 57 - 561               | 950 - 1012                | 23 - 28                     | 0.07 - 3.65                 | 0.01 - 11.39    |
| 7  | Sean         | 68 - 738               | 951 - 1014                | 22 - 32                     | 0.09 - 3.11                 | 0.01 - 9.26     |
| 8  | Narelle      | 63 - 621               | 946 - 1013                | 24 - 31                     | 0.2 - 4.74                  | 0.01 - 18.69    |
| 9  | Victoria     | 26 - 251               | 951 - 1013                | 22 - 30                     | 0.08 - 3.42                 | 0.01 - 9.55     |
| 10 | Gillian      | 35 - 341               | 951 - 1012                | 23 - 31                     | 0.07 - 2.4                  | 0.01 - 8.75     |
| 11 | Bakung       | 39 - 419               | 951 - 1014                | 22 - 30                     | 0.06 - 3.1                  | 0.01 - 10.5     |
| 12 | Yvette       | 72 - 711               | 942 - 1010                | 22 - 32                     | 0.1 - 3.8                   | 0.01 - 13.95    |
| 13 | Ernie        | 38 - 408               | 950 - 1013                | 23 - 30                     | 0.07 - 3.74                 | 0.01 - 12.28    |
| 14 | Cempaka      | 47 - 507               | 948 - 1012                | 22 - 32                     | 0.07 - 3.32                 | 0.01 - 13.29    |
| 15 | Dahlia       | 47 - 507               | 948 - 1012                | 22 - 32                     | 0.07 - 3.32                 | 0.01 - 13.30    |
| 16 | Flamboyan    | 08 - 71                | 953 - 1016                | 22 - 31                     | 0.09 - 3.08                 | 0.01 - 9.54     |
| 17 | Riley        | 96 - 951               | 947 - 1013                | 22 - 30                     | 0.12 - 4.07                 | 0.15 - 16.96    |

Other results show that when tropical cyclones occur, the correlation between sea-atmosphere rainfall conditions and wave heights is not always significant. Or in other words the increase in intensity of rainfall that occurs can coincide with the increase in wave height significantly or preferably. Evident from the results of the analysis, at a time of high rainfall intensity is 951 mm/day (during the tropical cyclone Riley, and significant wave height of 16.69 m). But during the Sean tropical cyclone, rainfall was 738 mm/ day while the significant wave height was only 9.26 m. For all tropical cyclones that occurred during 2004-2019, the complete sea-atmospheric conditions can be seen in Table 2.

4. Conclusions

From the analysis of 17 tropical cyclone events in 2004-2019 it can be concluded that tropical cyclone mostly occurred in April, and never occurred in June, July, August, and September. From the result it can be seen that MJO was in phases 2, 3, 4, 5, or 6 with strong or weak periods, or in other words, the biggest effect on the occurrence of tropical cyclones is the MJO phase compared to its period. Meanwhile rainfall intensity, wind speed, wave height significantly increases, on the other hand sea level pressure decreases, and sea surface temperature does not show a significant correlation. But in this
study for all events of tropical cyclones, sea surface temperatures above 26.5°C, this is consistent as stated by much literature.

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5. References
[1] Emmanuel KA 1986 J. Atmos. Sci. 43 585–605
[2] Yin Y, Gemmer M, Luo Y and Wang Y 2010 Quaternary International 226(1) 122-128
[3] Naranjo Breña JA, Pedrozo-Acuña A, Pozos-Estrada O, Jiménez-López SA and LópezLópez MR 2015 Physics and Chemistry of the Earth 83-84 111-122
[4] Sparks PR 2003 Journal of wind engineering and industrial aerodynamics 91(12) 1731-1751
[5] Farfán LM, Alfaro EJ and Cavazos T 2013 Atmosfera 26(2) 163182
[6] Raga GB, Bracamontes-Ceballos B, Farfán LM and Romero-Centeno R 2013 Atmosfera 26(2) 209- 220
[7] Asrianti P, Bey A and Ilhamsyah Y 2013 Depik 2(3) 154-161
[8] Syaifullah MD 2015 Jurnal Sains dan Teknologi Modifikasi Cuaca 16(2) 61-71
[9] Suryantoro A 2008 Majalah Sains dan Teknologi Dirgantara 3(1) 21-32
[10] Prasetya R, As’ari and Dayantolis W 2014 Jurnal Fisika dan Aplikasinya 10(1)
[11] Haryanto OD, Fadlan A, Hartoko A, Anggoro S and Zainuri M 2017 Jurnal Meteorologi dan Geofisika 18(1) 45-54
[12] Mulyana E, Prayoga MBR, Yananto A, Wirahma S, Aldrian E, Harsoyo B, Seto TH and Yaya S 2018 MATEC Web of Conferences 229 02007
[13] Gaol AL, Siadari EL, Ryan M and Kristianto A 2018 Jurnal Meteorologi Klimatologi dan Geofisika 5(3)
[14] Kim D and Ho CH 2018 Journal of Climate 31 4605-4616
[15] Lonfat M, Marks Jr FD and Chen SS 2004 Mon. Wea. Rev. 132 1645–1660
[16] Oriaku EC, Agulanna CN, Edeh CJ and Adiele ID 2014 American Journal of Engineering Research (AJER) 03(6) 120-126
[17] Lin Y, Zhao M and Zhang M 2015 Nat. Commun. 6 6591
[18] Tropical Cyclone Warning Center / TCWC Jakarta, BMKG. 2015. http://meteo.bmkg.go.id/siklon. [Downloaded September 10, 2019].