Analysis of the Meteorological Condition of Tropical Cyclone Cempaka and Its Effect on Heavy Rainfall in Java Island

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Abstract. Indonesia, literally tropical cyclone free area, still gains some influence from the surrounding cyclones, such as high-intensity precipitation which causes flooding. Therefore, cyclones monitoring is important to observe its growth, movement and intensity. Using ECMWF ERA-Interim data, Himawari-8 channel infrared 1 (IR1), and GSMaP satellite data, this study attempts to spatially analyze the evolution of Cempaka tropical cyclones (occurred on November 2017), propagation cyclone and its effect to rainfall over Java Island based on the brightness temperature of the cloud. The results show that the Cempaka tropical cyclone has a three-day life span and moves from the southern ocean of Central Java to the northeast (East Java) and the peak occurs on November 27th, 2017 at 19:00 LT to 23:00 LT. Compared to rainfall data, the intensity of rainfall at 7 areas closed to Cempaka tropical cyclone began to increase ever since the cyclone peak and continue to rise despite the cyclone was slowly decaying. With this result, we hope in the future we can anticipate the impact of any tropical cyclones that arise near Indonesia.

Keywords : tropical cyclone, flood, ECMWF, rainfall.

1. Introduction
Tropical cyclones (TC) occur at the tropics or subtropics area in the form of winds storm. It began with the presence of tropical or low-pressure centers that are intensive over the oceans, thus triggering an intensive process of convection and cloud formation. The study of TC has been long introduced by Fasiq (1913) in his book that contains traces, the beginning and destructive action of TC. Many studies of TC are also carried out separately in various cyclone basins on this earth. However, based on historical events, generally TC is formed effectively above 10°LU and LS region. Therefore, Indonesia territory should be free from TC formation, but there is still some part of Indonesia that adjacent to the formation and trajectory of TC [1]. For example is the TC Cempaka which detected on November 27th, 2017, by the TC Warning Center (TCWC) of BMKG. The TC Cempaka grew very close to the southern coast of Java Island.

TC greatly affect the surrounding weather conditions. A number of studies have examined the contribution of TCs to precipitation at the regional scale [2, 3]. Villarini and Denniston [4] showed that there was a higher probability of TC-induced annual maximum rainfall events in Australia during La Niña. Yin et al [5] pointed out that the number of TC-heavy rain days is higher during El Niño years in eastern China, besides that the phenomenon of tropical cyclones can also be related to local, meso or...
other global phenomena [6]. TCs also not only affect the trajectory area directly but also affects/affected the surrounding weather conditions. Therefore, TCs affect the weather conditions in the Indonesian territory and can occur outside the appropriate period, the storm monitoring / tropical cyclone around Indonesia is important to do, so that information anticipates a possible impact on the form of bad weather such as floods and landslides [1]. The impact on the TC Cempaka is also expected to affect the surrounding weather patterns, but the trigger has not been clearly explained. For this reason, an in-depth study of the occurrence of this TC is needed. Based on this, this paper will explain in detail the analysis of meteorological conditions during TC Cempaka events and their effects on rainfall on the island of Java.

2. Data and Method

In this study, the three main data are brightness temperature \( T_{BB} \), rainfall estimation data, and meteorological parameter data. All data is processed using GrADS. The \( T_{BB} \) data was taken from the Himawari-8 satellite operated by the Japan Meteorological Agency (JMA) with a horizontal resolution of 0.05° x 0.05° and temporal resolution of 1 hour for infrared (IR) imagery (http://weather.is.kochiu.ac.jp/sat/GAME). Analysis of the development of TC Cempaka was carried out by visual observation method on the results of Himawari-8 data plotting on IR1 channels by looking at the \( T_{BB} \) value. Some literature states that analyzing of Convective Index (CI) can be determined by using cloud peak temperatures from \( T_{BB} \) [7, 8, 9, 10]. The threshold value of brightness temperature or black body temperature is determined to separate the surface temperature from high convective clouds. This threshold value according to Chen and Houze [11] can describe diurnal variation in convective activity. Adler and Negri [7] use a threshold value of 253 K as the hottest brightness temperature to determine clouds that are thought to produce rain. CI is equal to threshold - \( T_{BB} \) if \( T_{BB} \) is smaller than the threshold value (CI = threshold - \( T_{BB} \), for \( T_{BB} <\) threshold) and a convective index equal to zero for the \( T_{BB} \) greater than or equal to the threshold value, (CI = 0, for \( T_{BB} \geq \) threshold).

Rainfall estimation data used in this study comes from GSMaP (Global Satellite Mapping of Precipitation) satellite data which is Near Real Time (NRT). GSMaP near real- time (GSMaP NRT) has been implemented since October 2008. Data sets are provided in real time (about four to five hours after observation) by file transfer protocol (ftp). This GSMaP_NRT data from JAXA has been validated and calibrated with both the incisive data and radar data in Japan with validation results likely to be quite good [12]. GSMaP data can be accessed at http://sharaku.eorc.jaxa.jp/GSMaP/ (JAXA, 2014). The effect of the TC Cempaka on the surrounding rainfall is seen by visual observations of rainfall estimates from GSMaP satellite data during the TC Cempaka. The movement of the TC Cempaka can be analyzed using a hovmoller diagram or cross section during the occurrence of the TC Cempaka.

The meteorological parameter data is obtained from ECMWF ERA-Interim. ERA-interim is a reanalysis of the global atmosphere covering the data-rich period since 1979 (originally, ERA-Interim ran from 1989, but the 10-year extension for 1979-1988 produced in 2011). ERA-Interim is the latest global atmospheric reanalysis produced by the ECMWF. This data has a time resolution of 6-hourly, a horizontal resolution of 1° x 1° in latitude and longitude in 27 pressure level that include 1000, 975, 950, 925, 900, 875, 850, 825, 800, 775, 750, 700, 650, 600, 550, 500, 450, 400, 350, 300, 250, 225, 200, 175, 150, 125 and 100 hPa. The environmental parameters that used in this study are the wind, relative humidity, temperature, specific humidity, divergence, vertical velocity, vorticity and geopotential height. However, there are some parameters should be derived by using equation from some variable of ECMWF ERA-Interim data due to is not available. These data can be downloaded at http://www.ecmwf.int/. The Meteorological conditions analysis is also carried out with spatial analysis of ECMWF ERA-Interim data which is also combined with other data.

3. Result and Discussion

3.1. Analysis of Evolution of TC Cempaka Development

The evolution of the development of the TC Cempaka can be analyzed using \( T_{BB} \) from the Himawari-8 satellite data shown in Figure 1. Since morning at 0900 LT (LT=Local Time = UTC+7 hours) on
November 26, 2017 a small-scale cloud had been around the south of East Java water around 9.5°S and 111.5°E or about 75 km south of Pacitan an area which effected the TC Cempaka based on several news reports. From the small $T_{BB}$ value below 253 K it can be indicated that the cloud is a convection cloud that produces rain [7]. After several hours, the cloud underground a decay around 1100 LT but because the thermodynamic process of the decaying atmosphere of the cloud was developing again to form a fairly large convection cloud. The maximum peak of the cloud size occurs at 2300 LT at midnight. Viewed from its peak, this cloud is indicated as a cloud of Mesoscale Convective Complex (MCC) because it has a physical characteristic of cloud temperature similar with the MCC characteristic according Maddox [13] where is the cloud temperature above 221 K and has an almost circle shape, it is also in accordance with the explanation from the previous paper [14] which also states that MCC is occurring in the oceans around Indonesia are more nocturnal (maximum peak occurring at night). Trismidianto et al. [14] also stated that MCC could be a trigger for tropical cyclones.

![Figure 1. Horizontal distribution of brightness ($T_{BB}$) temperature on November 26, 2017 (top row), November 27, 2018 (middle row) and November 28, 2018 (bottom row) of Himawari-8 satellite data.](image)

Since the morning of November 27, 2017 after the MCC decays, it starts to show a high convective cloud vortex as shown in Figure 1 in the middle row. Convective clouds that have enlarged at 1100 LT. (November 26, 2017) combine with other convective clouds around them forming a vortex of clouds in the waters of the Indian Ocean (south of Java). This high convective cloud vortex was very clearly visible at 0700 LT which indicated a cyclone eye with very low $T_{BB}$ below 210 K. The vortex continued to spin and move closer to the mainland of Java Island, can be seen at 1500 LT convective clouds begin to be above the mainland of Java Island and continue to spread until convective clouds cover most of the area in Java. The peak of the TC Cempaka formation occurs at night around 1900 - 2300 LT. At 2300 LT, it was also seen that deep tropical or deep convective clouds were thought to influence the formation of the TC Cempaka. The core of the convective cloud of the TC Cempaka has also reached land at 2300 LT. Figure 1 on the bottom row shows that tropical cyclones began to decay from the morning of November 28, 2017. Several hours after decaying from 2200 LT began to notice the movement of convective clouds towards the mainland of Java which also joined with other convective clouds from the waters of the Java Sea making convective clouds over Java Island are intensified with low $T_{BB}$ values.

Figure 2 to strong the analyzed of Figure 1 that convective activity has been seen since morning at 0900 LT. on November 26, 2017 which continued to strengthen until the formation of MCC and continued to become a TC Cempaka. Figure 3 shows that the growth potential of TC Cempaka seedlings has been detected since November 23, this can be seen in the presence of low-pressure centers on the south coast of Java Island. Geopotential height approximates the actual height of surface pressure (1000 hPa) above mean sea-level. Therefore, a geopotential height observation represents the height of the surface pressure on which the observation was taken. So that a low geopotential height value can also represent low pressure. The low geopotential height is followed by the presence of shortwave trough. A trough is a region with relatively lower heights tend to bring in cooler weather. Shortwaves may be
contained within or found ahead of long waves and range from the mesoscale to the synoptic scale. Shortwaves are most frequently caused by either a cold pool or an upper-level front. So, this also strengthens the discussion before that TC is triggered more by the presence of meso-scale convective clouds that are thought to be MCC.

**Figure 2.** Convective index on November 26, 2017 (top row), November 27, 2018 (middle row) and November 28, 2018 (bottom row) of Himawari-8 satellite data.

**Figure 3.** 850-hPa divergence ($10^{-5}$ s$^{-1}$, shaded), 850-hPa geopotential height (m, contour) and 1000-hPa wind vector (ms$^{-1}$, vector) from 23 November 2017 to 28 November 2017. The data from ECMWF ERA-Interim.

Since November 23, the low-pressure area was also followed by cyclone winds, although still weak, wind convergence began to appear with small values. This cyclone seeds continue to be on the south coast of Java Island and move northward on November 24 and November 25. The cyclone wind began to increase and the center of convergence began to look quite strong on the south coast of Java. On November 26, the cyclone seeds moved southwest and strengthened into a meso-scale convective in the form of the tropical depression. On November 27, tropical depression became the TC Cempaka and moved northeast towards the southern coast of Java. On November 28, TC Cempaka experienced landfall on the southern coast of Java. Figure 3 also shows that the formation of tropical cyclones formed due to the Low-Level Jet (LLJ) moving from the west coast of Sumatra and the Indian Ocean to the southern coast of Java since November 23, 2017, this is also strengthened by the conversion of the convergence center from the Indian Ocean to the coast south of Java Island.

Figure 4 shows that since November 25, there has been a strong low-level convergence movement and a strong upper-level divergence from the Indian Ocean towards the southern coast of Java Island.
Figure 4. 850-hPa and 200 hPa divergence ($10^{-5}$ s$^{-1}$, shaded) and vertical velocity ($10^{-2}$ Pa s$^{-1}$, contour) from 25 November 2017 to 28 November 2017. The data from ECMWF ERA-Interim.

Figure 5 strengthens the analysis of figure 4, almost the same as the analysis of Figure 4, but in this picture, it focuses on the condition of the level, low level (850 hPa), middle level (500 hPa), upper level (200 hPa). The conditions are if there is convergence in the lower level, then in the upper-layer, there will be a strong divergence. Focus on the location of the occurrence of TC Cempaka, between 110 - 111°E.

Figure 5. Pressure Longitude Cross Section of divergence ($10^{-5}$ s$^{-1}$, shaded) and vertical velocity ($10^{-2}$ Pa s$^{-1}$, contour) from 25 November 2017 to 28 November 2017. The data from ECMWF ERA-Interim.

Figure 6. Horizontal distribution in 850 hPa for Mean Sea Level Pressure (m, shaded) and vorticity ($10^{-6}$ s$^{-1}$, contour) on 27 November 2017. The data from ECMWF ERA-Interim.
Figure 6 shows that the surface pressure at the peak of cyclones is very low compared to others. And the vortices are also negative which indicates the presence of tropical cyclones which normally carry a mass of moisture around it.

![Image](image_url)

**Figure 7.** Horizontal distribution in 850 hPa for MFC (moisture flux convergence in $10^{-3}$ g kg$^{-1}$ s$^{-1}$, shaded), and wind vector (ms$^{-1}$, vector) on 27 November 2017. The data from ECMWF ERA-Interim.

Figure 7 explains that the source of moisture in the vapor mass that causes cyclones is from the Indian Ocean near the coast of western Sumatra.

![Image](image_url)

**Figure 8.** Pressure-longitude cross section of Equivalent Potential Temperature ($\theta_E$, contour; K) and relative humidity (shaded; %) and horizontal wind (vector; ms$^{-1}$; upward represents northward) on 27 November 2017. The data from ECMWF ERA-Interim.

Figure 8 shows relative humidity and equivalent potential temperature, the high relative humidity values indicate that there is a process of precipitation or convective clouds. Whereas $\theta_E$, equivalent potential temperature, is the temperature that results after all, the heat is released in a parcel of water and then brought to the 1000 hPa level. The increases $\theta_E$ as dewpoint and temperature increases. A region with a relatively high $\theta_E$ is often the region with the most instability. Low-level temperature and higher low-level dewpoints increase instability. The low level jet from values and thus increased instability. $\theta_E$ ridge is regions with higher $\theta_E$. They are often the bursting point for convective activity.

3.2. *Propagation Cyclone and Its effect on rainfall over Java Island*

One way to show the movement of a convective cloud or tropical cyclone is to create and analyze a hovmoller diagram. In this study, a hovmoller diagram was carried out by averaging the longitude of the area of the TC Cempaka from 102° - 116°E. The hovmoller diagramming is carried out evenly averaged because the cyclone movement is estimated from top to bottom with time changes. Figure 4.9 shows that the formation of the TC Cempaka was triggered by the incorporation of several convective clouds from the Indian Ocean at a latitude of around 7.5° - 9°S with the presence of convective clouds from the waters of the Java Sea around latitude 3° - 4°S on November 26 around 2400 LT with high rainfall intensity. The convective cloud combination triggers the occurrence of the TC Cempaka with
extreme rainfall intensity at its center at latitude 7.5°LS on November 27, 2017 at around 2100 LT. This high rainfall occurs after the peak of the TC Cempaka. The extreme rainfall then spreads in various directions, namely to latitude 8°S (Indian Ocean) and to latitude 5.5° - 6.2°S (around the mainland of Java Island) at around 1100 LT, November 28, 2017 shows the occurrence of extreme rainfall in most areas on the mainland of Java Island.

As previously explained that the influence of TC Cempaka on the surrounding rainfall can be seen by visual observation of rainfall estimates from GSMaP satellite data during the TC Cempaka. Strong convection activity is closely related to the high intensity of rainfall in the area, and vice versa. As with Himawari-8 satellite data visualized by colors that represent T_{BB} values, GSMaP satellite data is also visualized by colors representing the value of precipitation in mm / day. Figure 9 shows that throughout the day on November 26, 2017 in the Indian Ocean waters (south of Java Island) there was significant rainfall with rainfall intensity of around 0.5 - 10 mm / day, even at 1600 LT rainfall ranges from 20 mm/hr (extreme) which means there is heavy rainfall in the area, and at 2300 LT the area with rainfall reaching 10 mm/day is increasingly widespread. This is in accordance with the Figure 9 which shows the distribution of convection clouds in the waters of the Indian Ocean (south of Java Island), even seen a large cloud of convection indicated as MCC at 2300 LT (cloud convection causes rain with high rainfall).

Figure 10 shows the distribution of rainfall on November 27, 2017, when the process formed until the peak of the tropical cyclone in the Indian Ocean (south of Java). From Figure 10, it is known that the cloud vortex in the Indian Ocean waters began to appear, at that time there was moderate to heavy rain in the area, even during the process of forming a tropical cyclone cyclone some areas in Java Island near the Indian Ocean waters had experienced rain with intensity extreme rainfall above 20 mm / day. Until the time of the peak of the cyclone, which is around 1900 - 2300 LT, the rain does not only occur in the waters of the Indian Ocean, but also rain in most areas of Java, starting at 1400 LT with rainfall intensity ranging from 1 - 10 mm / day up to 2300 LT. Rainfall in some areas exceeds 20 mm / day. Most likely the extreme rainfall occurred due to the movement of cloud swirls from the waters of the
Indian Ocean towards the mainland of Java which resulted in the spread of convective clouds in most areas in Java (Figure 10 at 1100 LT).

Figure 10. Horizontal distribution of rainfall on November 26, 2017 (above), November 27, 2017 (middle) and November 28, 2017 (bottom) of GSMaP satellite data.

After it was discovered that the TC Cempaka affected rainfall in several areas of Java, several areas were chosen which were considered to have had a large influence from the occurrence of the TC Cempaka. These areas are Sukabumi, Cilacap, Yogyakarta, Pacitan, Wonogiri, Tulungagung, and Sidoarjo.

Figure 11 shows a graph of rainfall hourly for 3 days, which is November 26 -28, 2017. On November 26, 2017 before the occurrence of the TC Cempaka, since 1300 LT, the rainfall in the Sukabumi and Yogyakarta regions has increased (not reaching the bulk extreme rain), a significant increase in rainfall occurred in Wonogiri at 1500 LT, with rainfall reaching 8 mm/hr which was then followed by increased rainfall in Pacitan at 1600 LT. with a rainfall of 7.2 mm/hr, and during the night a significant bulk increase occurred in Cilacap at 2300 LT the rainfall reached 11 mm/hr (extreme rainfall), it continued until at 0100 LT (November 27, 2017) the rainfall in Cilacap reached 14 mm/hr.

On November 27, 2017 since 0000 LT there was rain in Cilacap (extreme rainfall) and Sukabumi (rainfall 2 mm/hr), in Yogyakarta began to rain lightly at 0100 LT with rainfall of 3 mm/hr, in Pacitan it rained lightly at 0300 LT with a rainfall of 0.3 mm/hr, in Sidoarjo it started to rain at 1200 LT with rainfall of 1.7 mm/hr, in Tulungagung it began to rain at 1400 LT with rainfall of 2.6 mm/hr, and in Wonogiri began to rain in the afternoon at 1600 LT with rainfall of 2.9 mm/hr. Throughout 27 November 2017 the highest rainfall occurred in Sukabumi at 2300 LT with rainfall reaching 14.4 mm/
hr (extreme rainfall). This corresponds to Himawari-8 satellite data which shows that on November 27, 2017 at 2300 LT the TC Cempaka has enlarged so that some areas experience heavy rains at night.

On November 28, 2017, a swirl of clouds from the waters of the Indian Ocean moved towards the mainland of Java and then its convection clouds were scattered so that several areas experienced heavy rain throughout the day. The region with the highest rainfall is Pacitan with rainfall reaching 22.9 mm/hr (extreme rainfall) at 0200 LT, then the Wonogiri area with rainfall of 19.9 mm/hr at 1700 LT. At 1700 LT, in Yogyakarta also reached the peak of extreme rainfall, namely 17.7 mm/hour, while for the Sukabumi area heavy rain only lasted until 0500 LT., after that only mild rain - moderate to the night, even during the day at 1400 - 1500 LT there is no rain. In Tulungagung all day there is light rain - moderate with the highest rainfall value of 5.7 mm/hr at 0600 LT. In Sidoarjo there was only rain at 1500 LT with rainfall of 6.2 mm/hour, medium rain only lasted until 1900 LT, after that there was no rain. Whereas in Cilacap all day there was no rain at all.

**Figure 12.** Rainfall Accumulation on November 26-28, 2017 from GSMaP satellite data

Rainfall accumulation for 3 days (November 26-28, 2017) using GSMaP satellite data was conducted to see which areas had the most influence during the occurrence of the Cempaka tropical cyclone. Figure 12 shows that Pacitan and Wonogiri are areas with extreme rainfall during the Cempaka tropical cyclone, which is in accordance with Figure 11 which shows that during the 3 rainy days with the highest rainfall occurred in Pacitan and Wonogiri with 22 rainfall each, 9 mm/hour and 19.9 mm/hour, and rainfall accumulation reaches 260 mm/3dy.

4. Conclusion
Since November 26, 2017 small-scale clouds were formed around the waters south coast of East Java that trigger convective activities in the area, then the clouds that previously formed MCC and continued to become tropical cyclones. The peak is on November 27, 2017. Based on CI, the emergence of TC Cempaka due to the low-pressure center on the south coast of Java Island which triggered the emergence of cyclone winds. In addition, the formation of the devastating tropical cyclone is also caused by the presence of LLJs moving from the west coast of Sumatra and the Indian Ocean to the southern coast of Java since November 23, 2017, this is also strengthened by the conversion of the convergence center from the Indian Ocean to the south coast of the Island Java. TC Cempaka affects the weather system in most regions of Java, which is increasing the intensity of rainfall, starting from the growth stage until
after the cyclone occurs. On November 26 - 28, 2017 rainfall in several regions in Java Island experienced a significant increase, Pacitan and Wonogiri were recorded as areas with the highest rainfall.

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