Spatiotemporal variation of mesoscale convective system type persistent elongated convective system (PECS) in Indonesia

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Abstract. Research on Mesoscale Convective Systems (MCS) in Indonesia has been studied to identify the characteristics and distribution of MCS. Persistent Elongated Convective System (PECS) is one of the MCS types that can cause extreme weather. However, identifying the spatial and temporal variations of PECS in Indonesia has not been studied further. This study examines the Persistent Elongated Convective System (PECS) in Maritime Continent from 2010-2014. MERG Dataset with brightness temperature is used to identify PECS and input Grab 'Em Tag 'Em Graph 'Em (GTG) tracking algorithm to gain a better understanding of spatiotemporal variation in Indonesia. Flood data from BNPB in Indonesia is used to find out the correlation between flood and PECS events in Indonesia. PECS events in 2010-2014 are 5574 events, which the transitional period (MAM and SON) has the most PECS events and longest duration of life. The PECS spread in the early morning on land and sea, while on day and nighttime, it is concentrated on land for the area of Java, Papua, and Southern Kalimantan. Java and Papua have the largest concentrated PECS events. The life phase of the PECS has two peaks or semidiurnal cycles, in the morning and nighttime. There are differences in peak times for each phase of the PECS on land and sea. In Indonesia, PECS has the smallest average maximum area than in the USA and China but has the longest duration and largest eccentricity. Based on flood data from BNPB, during 2010-2014, Java has the most flood. According to flood data and PECS events in Java, there is 6.72% of flood coincided with PECS events during the period.

1. Introduction
Mesoscale Convective System (MCS) has well-known to cause bad weather such as strong winds, hail, and heavy rain [1][2]. There are two approaches to the study of MCS: the classification system and the analysis of differences for each category. Both approaches use infrared satellite imagery and radar data. Infrared satellite imagery is used to classify MCS [3][1][4]. Using satellite imagery is more objective than using radar data. The earlier studies of MCS classification used infrared satellite imagery [3][1][4]. Maddox [1] classified MCS into two types of
physical characteristic i.e., circular and linear. The linear type consists of a squall line and bow echo, and the circular type consists of a Mesoscale Convective Complex (MCC) [1]. Jirak et al. [3] developed MCS classification by dividing MCS into four types as Mesoscale Convective System (MCC), Persistent Elongated Convective System (PECS), Meso-β-Circular Convective System (MβCCS), and Meso-β-Elongated Convective System (MβECS). Research by Yang et al. [4] added two types of MCS from Jirak et al. [3] such as Small Meso-β-Circular Convective System (SMβCCS) and Small Meso-β-Elongated Convective System (SMβECS) so that there are six types of MCS. Using radar data to identify MCS was researched by Bluestein and Jain [6], Blanchard [5], and Parker and Johnson [7]. Bluestein and Jain [6] studied the formation pattern of severe squall-lines in Oklahoma, United States. They defined a squall-line as MCS, which oriented linearly. The formation pattern is divided into four i.e., broken line, back building, broken area, and embedded area [6]. Blanchard [5] identified MCS development and divided it into three types based on the mesoscale convective activity pattern i.e., linear convective systems, occluding convective systems, and chaotic convective systems [5]. Parker and Johnson [7] classified mature phase MCS into three based on the arrangement of the stratiform and convective areas: the leading-line or trailing stratiform (TS), parallel stratiform (PS), and leading stratiform (LS).

The mesoscale convective system (MCS) that occurs in Indonesia has been studied by Putri and Hayasaka [9], Trismidianto [10], and Norman and Trilaksono [8]. Putri and Hayasaka [9] examined the characteristics of MCS in Indonesia for the 2007-2008 period using the GTG method. MCS in Indonesia during this period has seasonal variations influenced by the monsoon. The concentration of MCS centers is more on land during the day and more in the sea during the night [9]. Trismidianto examined the Mesoscale Convective Complex (MCC) in the 2001-2015 period. MCC mostly occurs in inland areas, especially near mountains and areas with high elevations. MCC more often occurs in the Indian Ocean near Sumatra, the South China Sea near Kalimantan, Sulawesi, and Papua. The peak season of MCC occurs in MAM, and the fewest season MCC occurs in JJA [10]. Norman and Trilaksono [8] examined the spatial and temporal variations of six types MCS studied by Yang et al. [4] in Indonesia. There are differences in the concentration of MCS centers for six types' MCS. The six types’ MCS mostly occur in Papua. The type of elongated convective system also often occurs in Java but not as much as in Papua. MCS mostly occurs at night-early morning except for PECS, which mostly occurs during the day-evening [8].

PECS (Persistent Elongated Convective System) is a type of MCS similar to MCC but has a different criterion [11]. Eccentricity PECS is smaller than MCC, which is 0.2 ≤ e ≤ 0.7. In the United States, the PECS can cause bad weather such as tornadoes, heavy rain, flash floods, and strong winds [11]. Jirak et al. also stated that PECS is associated with bad weather [3]. In Indonesia, research on PECS has not been widely researched. The event of PECS about 70% of total MCS and can cause bad weather in the United States [11]. Therefore, research on PECS in Indonesia needs to be research to determine the spatial and temporal variations of PECS related to the diurnal cycle of the PECS life phase.

2. Data and Methods
This study used the National Center for the Environmental Prediction/Climate Prediction Center (NCEP / CPC) L3 half hourly 4 km Global (60°N - 60°S) Merged IR V1 dataset (MERG dataset) [12]. MERG dataset was generated in 1999, but available starts from February 17, 2000, which combined data from geostationary satellites of Europe, Japan, and the United States (GOES-8/9/10/11/12/13/14/15/16), METEOSAT-5/7/8/9/10, and GMS-5/MTSat-1R/2/Himawari-8. MERG dataset contains the cloud top temperature (brightness temperature) with a 4 km × 4 km spatial resolution and provided twice an hour (00 and 30 minutes). The data can be downloaded at http://mirador.gsfc.nasa.gov/ (NASA Goddard Earth Sciences Data and Information Services Center -
GES DICS). Only cloud top temperature data with 00 minutes for all months from 2010 – 2014 is used in the PECS identification process. Rainfall data is obtained from the Tropical Rainfall Measuring Mission (TRMM) 3B42 version 7. TRMM is an international project from NASA and JAXA, which started operations in December 1997 and ended in April 2015. TRMM product covers an area of 50ºS-50ºN and 180ºW-180ºE with a 3 hours temporal resolution and a 0.25º × 0.25º spatial resolution. The data are downloadable freely at https://trmm.gsfc.nasa.gov. Flood data compiled by the National Disaster Management Agency (BNPB) of the Republic of Indonesia is used to examine the relationship between flood occurrence and PECS events in Indonesia. Flood data from 2010 – 2014 is used in this study. In this study, PECS identification uses the GTG method (Grab ’em, Tag’ em, Graph ’em) by Whitehall et al. [13]. The GTG algorithm employs graph theory to identify the area of the Infrared (IR) grid and find graphs that fit the MCS criteria.

In this study, there are three stages of processing: pre-processing stage, processing stage, and stage post-processing.

2.1. Pre-processing Stage

In this stage, the input data for the cloud top temperature from the MERG dataset is cut according to the area study, and the spatial resolution is roughed. MERG dataset include 0ºE - 360ºE and 60ºS - 60 ºN, which has two times (minutes) i.e. the time by 00 minutes and 30 minutes. However, this study only used MERG data at 00 minutes, and the study area is 92.5ºE - 147.5ºE and 12.5ºS - 12.5ºN. After the data is cut according to the area study, MERG data with a spatial resolution of 4 km × 4 kmi s roughed to 16 km × 16 km using the bilinear interpolation method. Roughening resolution is intended to reduce required storage and reduce running time.

2.2. Processing Stage

The rough's MERG data is used as input data for running GTG (Grab ’em Tag’ em Graph ’em). Data is run every five days (pentad) with 1-day increments as a correction with the next pentad. It is useful for saving time running GTG. There are two phases for identifying MCS are cloud detection and tracking cloud evolution [13]. Cloud detection uses the cloud top temperature. When running, GTG will generate a file with the netCDF4 format. The file contains the cloud top temperatures from Cloud Elements (CE). The file will be read and selected according to predetermined MCS criteria (Table 1) to produce a Cloud Cluster (CC). The information from the Cloud Cluster (CC) is summarized in a file with textfile (.txt) format. In addition, the GTG algorithm also uses precipitation data to see the precipitation generated by MCS. However, in this study, precipitation data is not used. The eccentricity generated by the GTG algorithm is different from the eccentricity in mathematical calculations. In mathematical calculations, objects with eccentricity values close to 0 will have a circular shape, while objects with eccentricity values close to 1 will have linear shapes. In the GTG algorithm, objects with eccentricity values close to 0 will have a more linear shape, while objects with eccentricity values close to 1 will have a circular shape.

| Parameter     | Criteria          |
|---------------|-------------------|
| Cloud Top Temperature | ≤ – 52°C          |
| Eccentricity  | 0.2 ≤ e ≤ 0.7     |

Table 1. Configuration of PECS Criteria adopted from Yang et al. [4]. With additional parameter denoted by (*) from Morel and Sensi [14].
Minimum Area  
≥ 50000 km²
Duration  
≥ 6 hours
Warmest Temperature for Cloud Element (*)  
− 30°C

2.3. Post-processing Stage

In the post-processing stage, textfiles from the previous stage contain information of PECS as a result of running GTG and then analyzed to identify the spatial and temporal variations of PECS. The available information from the result of running GTG is initiation start date and time (UTC), mature phase date and time (UTC), termination (dissipation) phase date and time (UTC), life duration (hours), average area (km²), maximum area at peak phase (km²), eccentricity, latitude, and longitude. Determining MERG Dataset sensitivity, a PECS case was tested on December 6, 2011, as shown in Figure 1. Persistent Elongated Convective System (PECS) case trial was selected in Java Island. In the case study, PECS has a mature phase on December 6, 2011, at 07:00 UTC, an eccentricity of 0.4236, and with a system center at 5.51ºS; 112.38ºE. The MERG Dataset (Figure 1b) with a 16 km × 16 km spatial resolution shows a similar pattern to the MERG 4 km × 4 km dataset (Figure 1a). In Figure 1c, the cloud top temperature from GTG output with MERG Dataset 16 km × 16 km is almost identical, as well as MERG Dataset 4 km × 4 km. It shows that the PECS Cloud Cluster is well filtered and can represent the cloud top temperature of MERG Dataset. The results of the MERG dataset with a 16 km × 16 km of spatial resolution are used to identify the spatial-temporal variation of PECS in Indonesia.
3. Results

3.1. Frequency and Characteristics of PECS in Indonesia
This section discusses the frequency and characteristics of PECS in Indonesia. The frequency of PECS events is divided into annual, seasonal, monthly, and characteristic frequencies. The characteristics of PECS are life’s duration, eccentricity, and maximum area.

3.1.1. Annual Frequency of PECS
The number of PECS in Indonesia during 2010-2014 is 5574 events (Table 2). The average number of PECS during this period was 1115 events per year. The year with the highest number of PECS is 2010 with 1267 events (22.73%), followed by 2014 with 1118 events (20.06%), 2012 with 1111 events
(19.93%), 2013 with 1073 events (19.25%), and the year with lowest events of PECS was in 2011 with 1005 events (18.03%). 2010 was the strongest La-Nina year compared to other years (ONI Index). During La-Nina, the potential for convective activity in Indonesia is higher than usual. It is expected that cloud growth will be even higher. It is consistent with Zolman et al. [15], which stated that when La-Nina, MCS will increase.

| Table 2. Number of PECS for 2010-2014. |
|---------------------------------------|
| Year | 2010 | 2011 | 2012 | 2013 | 2014 |
| Number of PECS | 1267 | 1005 | 1111 | 1073 | 1118 |
| Percentage (%) | 22.73 | 18.03 | 19.93 | 19.25 | 20.06 |

3.1.2. Seasonal Frequency of PECS
To find the seasonal variation of PECS frequency, all data period are grouped into four categories; the DJF season for the northern hemisphere winter, the JJA season for the southern hemisphere winter, the MAM season, and the SON season. The highest season number of PECS is the MAM season, which is 1664 events or 29.85% of the total events. Meanwhile, the season with the lowest number of PECS is DJF season with 1278 incidents or 22.93% of the total events. The JJA season had 1295 PECS events or 23.23% of the total events and the SON season has a total of 1337 PECS events or 23.99% of the total events.

| Table 3. Number of PECS for the seasonal period. |
|-----------------------------------------------|
| Seasonal | DJF | MAM | JJA | SON |
| Number of PECS | 1278 | 1664 | 1295 | 1337 |
| Percentage (%) | 22.93 | 29.85 | 23.23 | 23.99 |

The MAM season has the highest number of PECS because of the monsoon circulation in Indonesia. According to Chang et al. [16], during the JJA season, the maximum convection activity occurred in the South Asia region (India and the Bay of Bengal). The maximum convection activity will move southeast through the Indian Ocean and the South China Sea, reaching southern Indonesia and north-eastern Australia during the DJF season. However, the maximum convection activity that should have turned to north is not occurring, so the convection activity is large and makes a lot of cloud growth in the MAM. This condition is due to the asymmetrical location of ITCZ during the MAM and SON seasons [16].

3.1.3. Monthly Frequency of PECS
Figure 2 shows the number of PECS events for each month. Each color represents the number of PECS events for each year. April is the highest number of PECS events with 622 events or 11.16% of the total events. Meanwhile, the month with the lowest number of PECS events in July with 379 events or 6.80% of the total events. It can be seen that April, May, and August are the months with the highest number of PECS events. The average number of PECS is 93 events per month in Indonesia.
3.1.4. Characteristics of PECS

PECS characteristics are referred to PECS life’s duration, PECS eccentricity during its mature phase, and PECS maximum area during its mature phase. Figure 3 shows the frequency graph for each of the characteristics of PECS.

Figure 2. Cumulative number of PECS for 2010-2014 period (monthly frequency).

Figure 3. Frequency of Characteristics PECS: (a) life’s duration PECS (hours), (b) the eccentricity of PECS during its mature phase, (c) the maximum area
It can be seen that the frequency of PECS events decreases as life’s duration PECS becomes longer (Figure 3a). The average life duration PECS in Indonesian is 11.7 hours with a standard deviation of 4.6 hours. Figure 3b shows that the frequency of PECS events is linearly proportional to the eccentricity. The average PECS eccentricity is 0.541 with a standard deviation of 0.122. The PECS frequency decreases exponentially with the maximum area of PECS increases, as shown in Figure 3c. The PECS average maximum area is 145145 km$^2$. The maximum area with an area < 200000 km$^2$ is more frequent than an area ≥ 200000 km$^2$. In Figure 3d, the PECS average maximum area positively correlates with the PECS life’s duration. If PECS life’s duration is longer, the size of the maximum area of PECS is greater. It is consistent with Yang et al. [4], who stated that the PECS life’s duration has a positive correlation with the size of the MCS area.

### Table 4. Statistic (mean) of PECS Characteristics.

| Season | Duration (hours) | Eccentricity | Average Maximum Area (km$^2$) |
|--------|-----------------|--------------|-------------------------------|
| DJF    | 11.5            | 0.527        | 149902                        |
| MAM    | 12.0            | 0.545        | 145577                        |
| JJA    | 11.4            | 0.551        | 142679                        |
| SON    | 11.7            | 0.541        | 142450                        |
| Total  | 11.7            | 0.541        | 145145                        |

In the MAM season, PECS has the longest average life duration compared to the other seasons with 12 hours and has a standard deviation of 4.7 hours. JJA season has the shortest mean life duration of 11.4 hours and has a standard deviation of 4.6 hours. In the MAM and SON season, the average life duration PECS was longer than that of DJF and JJA. However, it does not correspond to the average maximum area for the four seasons. MAM and SON seasons have a lower average maximum area compared to DJF and JJA. The average PECS life’s duration for the 2010-2014 period is 11.7 hours with an average eccentricity is 0.541 and has an average maximum area during the mature phase is 145145 km$^2$. 
Figure 4. Anomaly for each season for PECS characteristics: (a) life’s duration (hours), (b) eccentricity, and (c) average maximum area (km²). An anomaly is calculated by subtracting the average value of each season from the average value of total events.

PECS characteristic anomalies for the life’s duration, eccentricity, and average maximum area of each season are shown in Figure 4. The DJF and JJA seasons have a shorter life’s duration than the transition seasons (MAM and SON). In the DJF season, PECS is more linear than other seasons even though the anomaly value is very small. JJA and SON seasons have smaller average maximum areas than the DJF and MAM seasons.

3.2. Spatial and Temporal Variations of PECS in Indonesia
The spatial variation of PECS is seen from the coordinate center of PECS (PECS center) during its mature phase, which is spread over land and sea. There is a difference between the PECS center in the morning and the evening. The temporal variation is seen from the number of life’s phase PECS which
is the initiation phase, maturation phase, and termination phase for each hour. It is used to see the diurnal variation in the life’s phase of the PECS.

3.2.1. Spatial Distribution of PECS

The PECS spatial variation in Indonesia for the period 2010-2014 is shown in Figure 5, which is shown by a blue mark (Figure 5a). In Figure 5a, it can be seen that the PECS center is distributed in the sea areas, i.e., Indian Ocean, South China Sea, and the Pacific Ocean. Some areas on land, such as large islands in Indonesia, have large concentrations of PECS centers. The islands of Java and Papua have the highest concentrations of PECS centers compared to other large islands, as seen in Figure 5b. The southern Philippines region also has a significant concentration of PECS. In Figure 5a, it can be seen that there is a big difference in the concentrations of PECS centers that occur on land and sea. The difference between PECS centers is seen from two different times i.e., early-morning until afternoon and evening until night. Figures 5c and 5d show the PECS center at two different times i.e. 00-12 LT (Local Time) and 12-24 LT.

In the early morning, PECS centers spread out on land and at sea, except in Papua, where PECS centers are concentrated in the center of Papua. Meanwhile, other large island areas in Indonesia are not very visible. During the evening and night, PECS centers are concentrated in land areas of the large islands such as Java, South Kalimantan, and Central Papua, as well as the south Philippines. In the early morning, the PECS center is concentrated in two regions i.e., West Papua and Central Papua, while during the day and night are concentrated in the West Papua only. There is a big difference in concentration of PECS between early morning and latenight over Java Island. The concentration of PECS centers in the early morning is not visible in Java, while during the day and night, the PECS centers are concentrated in Central Java, eastern West Java, and East Java. According to Qian [17], the sea-breeze, which blows towards the land, converges and strengthens
convection inland areas during the day, results in suitable conditions for the formation of MCS over the land.

3.2.2. Seasonal Spatial Variations of PECS

The PECS seasonal spatial variations can be seen in Figure 6. Seasonal spatial variations are divided into four, i.e. DJF (Northern Hemisphere winter), MMA (transition season), JJA (Southern Hemisphere winter), and SON (transition season). The distribution of PECS centers for four seasons is shown in Figure 6a, 6b, 6c, and 6d, respectively. Figure 6e shows the latitude distribution for DJF (red line), MAM (green line), JJA (blue line), and SON (magenta line).

Figure 6. Seasonal variation of PECS: (a) DJF, (b) MAM, (c) JJA, (d) SON, and (e) Latitude Distribution for four seasons.
During the DJF season, the PECS center in the south equator is more than in the north equator (Figure 6a). In contrast to the DJF season, the PECS center in the area north equator is more than in the south equator. In southern Java, PECS centers have a smaller number during the JJA season than the DJF season. It is because the JJA season is influenced by the dry Australian monsoon in the territory of Indonesia [14]. It is supported by Figure 6e, which shows that during the DJF season, the number of PECS in the north equator is more than the south equator. In the transitional season (MAM and SON), PECS centers are mostly in the south equator. In Figure 6e, the maximum event of PECS for each season is different. For DJF season is at 2ºS, MAM season is at 7ºS, JJA season is at 4ºS, and SON season is at 3ºS latitude. It is presumably because the latitudes between 2ºS - 7ºS have a diverse land-sea distribution and a fairly complex topography [9].

3.2.3. PECS Daily Variation

The life cycle of PECS events for the three phases is the initiation phase, the maturity phase, and the final phase. Yang et al. [4] used these three phases to see the life cycle of the MCS. The initiation phase is when PECS has a cold cloud area of ≥ 50,000 km² with a temperature of -52ºC. The mature phase is when the cold-cloud area (IR temperature is -52ºC) reaches its maximum size. The final phase is the time when the PECS measure criteria are no longer satisfied.

In Figure 7a, the study area is divided into three types: land, coastal, and ocean due to differences in the heating response of the sun for the three areas. On land, it has a diurnal variation with a peak at 1800 LT. In the morning at 0400 LT, PECS was quite common in land, but not as much as at 1800 LT. The coastal has a semi-diurnal variation marked by two peaks, which occur at 0700 LT and 1500 LT. It is consistent with the results of Putri and Hayasaka [9], which state that the MCS for coastal (200 km from the coastline) has a semidiurnal variations. Diurnal variations in coastal areas appear weaker than on land because of the weak diurnal warming of the earth surface [9]. Meanwhile, the ocean has diurnal variations with a peak at 1600 LT.
In these three areas, land and ocean have a mature phase during the day and night (12-24 LT), while the coastal has a mature phase in the early morning (00-12 LT) and day-night (12-24 LT). There is a lagtime for the mature phase for the three areas during the day-night (12-24 LT). Coastal areas have the earliest mature phase, followed by the ocean and then land.

The life cycle of PECS are the initiation phase, the mature phase, and the dissipation phase for the land, coastal, and ocean can be seen in Figure 7b, 7c, 7d, respectively. The initiation phase is shown as a short-dotted line, the mature phase is shown as a solid line, and the dissipation phase is shown as a long-dotted line. The land initiation phase occurs at 1100-1400 LT and has a peak at 1400 LT with 211 PECS events. After 1400 LT, PECS initiation phase events are decreasing. The mature phase increasing at 1400 LT and has a peak at 1800 LT with 212 PECS events. The peak of the initiation phase and the peak of the mature phase have a duration of 4 hours. The PECS mature phase events are decreasing after 1400 LT. Whereas in the dissipation phase, the PECS events increasing at 1800 LT and have a peak at 2300 LT with 153 PECS events. However, there is a small peak in the early morning hours (00-12 LT).

In coastal which have semidiurnal variations, the initiation phase occurs at 0100 LT and 1000 LT. After 0100 LT and 1000 LT, the PECS initiation phase events are decreasing. The PECS mature phase events are increasing at 0100 LT and 1200 LT. The mature phase of PECS in the coastal has a peak at 0700 LT and 1500 LT. The peak of the initiation phase and the peak of the mature phase have a duration of 6 hours for peak 1 and 5 hours for peak 2. The number of PECS mature phases decreases after 0700 LT and 1500 LT. Meanwhile, in the dissipation phase, the PECS events increasing at 0600 LT and 1500 LT. The PECS dissipation phase has a peak at 0900 LT and 1900 LT.

In the ocean, the initiation phase occurs at 0700-1000 WL and has a peak at 1000 LT with 92 events. After 1000 LT, the PECS initiation phase events are decreasing. The PECS mature phase events increasing at 1000 WL and have a peak at 1600 LT with 107 events. The peak of the initiation phase and the peak of the mature phase have a duration of 6 hours. The PECS mature phase events are decreasing after 1600 LT. Whereas the dissipation phase has a peak at 0900 LT by the following day with 92 events. However, there is a small peak in the early morning hours (00-12 WL).

Overall, PECS initiation occurs during the day at 1000-1400 LT, the mature phase in the afternoon is 1500-1800 LT, and the dissipation phase at night is 1900-2300 LT. According to Gray and Jacobson, convection activity is modulated by the difference in radiative heating between the convective area and the cloud-free area in the ocean [18].

In coastal, Oki and Musiake [19] stated that the rain that occurs in the morning is related to the local effects of land and sea wind circulation as well as the cycle of the mesoscale convective cloud system. Research Yulihastin et al. [20] mentions that in the coastal areas (coastal) northern Java, diurnal precipitation has two peaks which are in the early-morning and noon-afternoon with an early-morning is divided into two times again: early morning and morning. The peak in the early morning hours is caused by a propagating system. The coastal area (coastal), according to Kikuchi and Wang [21], is divided into two seaside coastal regimes and landside coastal regimes. The coastal regime has characteristics with diurnal peaks of rain propagating to the sea area, which occurs at night until the next day (2100-1200 LT), while the landside coastal regime has characteristics with diurnal peaks of rain propagating to land areas that occur during the day to night (1200-2100 LT).

In previous research, Norman and Trilaksono [8] stated that PECS mature phase occurs in the afternoons at 1200-1700 LT with 28% of total events. However, Anderson and Arritt [11] found that PECS develops and reaches its maximum at night-early morning, with 44% of total events, while in
the afternoon, it is 5% of total events. Table 4 compares the percentage of PECS events during the mature phase according to Norman and Trilaksono [8], Anderson and Arritt [11], and its study.

| Time  | Norman and Trilaksono | Anderson and Arritt | This study (land area) | This study (coastal area) | This study (ocean area) |
|-------|-----------------------|---------------------|------------------------|--------------------------|------------------------|
| 00 – 05 | 25.5%                  | 44.0%               | 29.4%                  | 21.8%                    | 18.4%                  |
| 06 – 11 | 21.0%                  | 14.0%               | 13.1%                  | 28.7%                    | 26.6%                  |
| 12 – 17 | 28.0%                  | 5.0%                | 15.2%                  | 30.1%                    | 36.4%                  |
| 18 – 23 | 25.5%                  | 37.0%               | 42.3%                  | 19.4%                    | 18.6%                  |

Table 5. Comparison percentages of PECS events for mature phase.

This study shows that the PECS events in land most occur between 1800-2300 LT with 42.3% of the total events. In the coastal, the most PECS events occurred at 1200-1700 LT, with 30.1% of the total events. Meanwhile, the most PECS events in ocean occur at 1200-1700 LT, with 36.4% of the total events.

3.3. Comparison of PECS in Indonesia, America, and China

This section discusses the comparison of PECS characteristics between Indonesia, America [3], and China [4]. The different characteristic location among America, China, and Indonesia is supposed to have an impact to the characteristic of PECS. Indonesia consists of many islands and sea, which contrast to those America and China which are dominated by land. The domination of the sea region in Indonesia is expected to result in intense cloud growth and more PECS development due to abundant source of convection. By comparing the PECS in the area, it can be seen the global variation of PECS. Table 6 shows a comparison of PECS characteristics between Indonesia, America, and China. The widest average maximum area of the PECS is America, followed by China and Indonesia, with an area difference is about 35000 km². However, PECS in Indonesia has an average duration that is longer than the other two countries. In Indonesia, PECS has an average duration of 11.70 hours. Meanwhile, the average duration in China is 10.94 hours and America with 10.60 hours. PECS eccentricity in Indonesia also has the highest value with 0.54, and China has the smallest eccentricity with 0.47. The differences in the characteristics of PECS in America, China, and Indonesia are due to differences in land-sea distribution, topography, and solar insolation reception, which can affect the initiation of convective processes.

| Country  | Average Maximum Area (km²) | Duration (hours) | Eccentricity |
|----------|-----------------------------|------------------|--------------|
| Indonesia | 145145                      | 11.70            | 0.54         |
| America  | 213473                      | 10.60            | 0.50         |
| China    | 180400                      | 10.94            | 0.47         |

Table 6. Comparison of PECS characteristics between Indonesia, America, and China.

PECS in America and China have same diurnal cycle. In general, the initiation phase of PECS in America and China occurs in the evening, a mature phase at night, and a dissipation phase in the early morning. Meanwhile, in Indonesia, the initiation phase is during the afternoon, the mature phase is in the evening, and the final phase is at night.
4. Discussion

PECS events in Java and Papua have a high concentration compared to other islands. Java is the densest population, and there are many cities as government and economy centers. Anderson and Arritt [11] stated that PECS can cause bad weather such as heavy rain, strong winds, and flash-flood. Figure 8 shows that western of Central Java and eastern of West Java have high PECS events.

![Figure 8. PECS centers at the mature phase in Java (blue dot). The red box shows an area with a higher PECS center compare to another area.](image)

4.1. Heavy Rainfall in Jakarta (January 2013)

On January 16, 2013, PECS occurred on that date. PECS center was at 6.24°S; 106.75°E, with a maximum area of 62.005 km² and an eccentricity of 0.3214.
Figure 9. (a) Cloud top temperature at the mature phase of PECS (January 16, 2013, 21.00 UTC – January 17, 2013, 04.00 LT) with the red line is the boundary of cloud top temperature (-52ºC), (b) Rainfall accumulative at PECS event.

The initiation phase of PECS was on January 16, 2013, at 21.00 UTC (January 17, 2013, at 04.00 LT) and ended on January 17, 2013, at 10.00 UTC (January 17, 2013, at 17.00 LT). The red line is the cloud top temperature boundary of PECS, which is -52ºC. In the figure, it can be seen that the Jakarta area is in the area of the PECS event. Figure 9b is a plot of the rainfall accumulative at the time of the PECS event on January 16, 2013, at 21.00 UTC (January 17, 2013, at 04.00 LT) until January 17, 2013, at 10.00 UTC (January 17, 2013, at 17.00 LT). It can be seen that the Jakarta area has high rainfall with an accumulative rainfall of around 50 - 70 mm. However, it is necessary to study further the relationship between PECS and heavy rain events in detail.

4.2. Flood vs. PECS Events in Java

Based on previous researches, PECS can cause floods. Table 7 shows the coincidence PECS, and flood in Java. Flood data (date and location of floods) was provided by National Disaster Management Agency (BNPB) of the Republic of Indonesia, compared with dates of PECS events. For the 2010-2014 period, there are 1697 floods in Java, and there are 292 PECS events. Floods in Java have to some filtering for finding the coincidence of flood and PECS. First, floods are filtered by dates of PECS, which must have the same dates. After filtered by dates of PECS, there are 341 floods that coincide with PECS events. Second, flood location must in of the PECS area and there are 192 floods. Third, calculating the distance between PECS centers with flood locations. The distance between PECS centers and flood location must less than major or minor axes of PECS length and there are 114 flood events. There are 114 floods (6.72%) that coincide with PECS events. However, it is necessary further study to find the link between PECS and flood.

| Filtering                  | Flood (Total) | Percentage (%) |
|----------------------------|---------------|----------------|
| Before filtering           | 1697          | 100            |
| Filtering 1: by dates of PECS | 341          | 20.09          |
| Filtering 2: location floods | 192          | 11.31          |

Table 7. Coincidence PECS and flood in Java.
The distance between PECS centers and flood location from filtering 3, is shown in Figure 10. The average of distance between PECS centers and flood location is 86.67 km.

![Figure 10. Frequency of range distance PECS and floods.](image)

### 5. Conclusions
The persistent elongated convective system (PECS) in the Indonesian for the period 2010-2014 was examined in this study. The MERG dataset with the cloud top temperature parameter is used to identify PECS and input the Grab 'Em Tag' Em Graph 'Em (GTG) tracking algorithm to see the spatial and temporal variations of PECS in Indonesia. BNPB flood data in the Indonesia's territory is used to find the relationship between flood events and PECS events that occur in Indonesia.

Most PECS events and the longest duration occur during the MAM season. In the early morning, the PECS centers are spread over land and sea, except in Papua. While during the day and night, PECS centers concentrated on land for Java, Papua, and Southern Kalimantan. The life phase of PECS has a diurnal cycle for land and ocean, while for coastal has a semidiurnal variation. This research discusses the relationship between PECS-heavy rain and PECS-flood. It can be seen that in the case of January 2013, there was rain with an intensity of 50-70 mm in the Jakarta area. According to cloud top temperature as PECS identification, PECS occurs in the Jakarta area. There are 141 floods or 6.72% of total floods in Java that coincide with PECS events. However, it is necessary to further study the relationship between PECS-heavy rain and PECS-flood with more cases.

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