1. Introduction
Mesoscale convective complex (MCC) is a special case of mesoscale convective systems (MCS), where MCS is portrayed as an organized ensemble of convective elements, whose lifecycle is longer than that of the individual convective elements, and the largest of the convective storms. It is formed when clouds occur in response to the convective instability amalgamate and organize upscale into a single cloud system with a huge upper cirriform cloud structure and rainfall covering large contiguous rain areas [1]. Trismidianto et al [2, 3, 4] and Trismidianto [5, 6] reported that MCC also occurred in Indonesian Maritime Continent (IMC), however, they did not yet explain about the analyses of the environmental condition during MCC events.

The analyses of the environmental condition during MCC events have been described by several previous researchers in several regions in the world [7–12]. In general, they found that the environmental conditions among some areas were very similar during MCC events, but several regions have different environmental conditions during MCC events. They show that certain thermodynamic patterns and dynamical features are usually present in large-scale environments. Velasco and Fritsch [13] used IR satellite data and surface data to study MCCs in Central and South America. They found that MCCs tended to occur over land and at night. Miller and Fritsch [14] found similar characteristics in their study.
of the western Pacific, as did Laing and Fritsch in their studies of African [15], Indian [16], and global MCCs [17]. MCCs are important because they produce a large fraction of warm-season rainfall [18] and often are associated with severe weather [19, 20]. They commonly occur over land in the lee of major mountain ranges and associated with low-level jets (LLJs), and likely make significant contributions to local and global hydrologic budgets [21]. The MCC is typically formed in association with a weak mid-tropospheric shortwave trough and a weak surface front or outflow boundary. Its environment often exhibits pronounced low-level temperature and moisture advection in association with a well-defined LLJ [7, 10, 11]. The critical importance of early explosive growth has been noted previously by Zhang and Fritsch [22] and Tollerud et al. [23]. Thus, a strong early growth may be the distinguishing factor in the longevity and size distributions of MCCs. It is not readily apparent, however, why a strong early growth is more effective at producing long-lasting systems in the summer than in the spring or fall. In general, the previous researcher found that some areas had very similar environment and exhibited many of the same dynamics and thermodynamic structure that was present with systems, but several areas shared different environmental condition during MCCs event.

Trismidianto et al [3] reported an analysis of environmental conditions during the occurrence of the continental MCC above Central Kalimantan using a composite analysis for several MCC events. They concluded that the initial and mature region were characterized by weak low-level convergence and upper-level divergence, but the low-level divergence began to appear during mature. The MCC develops largely driven by MCC-scale moisture convergence in the lower troposphere and cold core structure in the lower level. The weak surface divergence and upper-level divergence, warm advection in the lower atmosphere are dissipation characteristics. MCCs developed due to low-level cold advection and temperature, and separated when dissipating that indicate the existence of the new convective systems propagation. With the nearly similar way, but for the oceanic MCC, this study analyzed the large-scale condition during MCC that occurred on 27 - 28 October 2007 over the Indian Ocean near Sumatra Island, not occurred in land/continental. The existence of this MCC occurrence has been reported by Trismidianto et al. [2], but the environmental condition during that MCC occurred is not explained. Therefore, this study was a continuation of the research conducted by Trismidianto et al. [2].

2. Data and method

Identification of the MCC used MTSAT IR1 Infrared Channel (IR1) satellite imagery data obtained from Kochi University which can be accessed freely at the website address http://weather.is.kochi-u.ac.jp/sat/GAME/ in the form of portable gray map (.pgm) data and the calibration in the form of (.dat) format. The satellite data has a horizontal resolution of 0.05° x0.05° and a temporal resolution of hourly.

The environmental parameter data was 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. The data have a time resolution of 6-hourly, a horizontal resolution of 1° x 1° in latitude and longitude in 27 pressure level that includes 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 used in this study were 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 because they are not available. These data can be downloaded at http://www.ecmwf.int/.

MCC was identified by inputting the temperature, latitude, and longitude values for each cloud shield pixel obtained from IR to a modified version of a computerized MCC program using MATLAB based on the characteristics of MCCs [24]. This method adapts the method from Trismidianto et al [2], based on the maximum spatial correlation tracking technique (MASCOTTE) method by Carvalho and Jones [25]. Cotton et al [10] have defined eight stages in the life cycle of an MCC: MCC-12 h, pre-MCC, initial, growth, mature, decay, dissipation, and post-MCC; however, the most important period for an MCC is from the initial to the dissipation stage. However, in this study, analyses of the environmental conditions during MCC were just analyzed during the critical stage of MCCs. i.e., initial, mature, decay
and dissipation or post-MCC stage, near similar way to Maddox [7] and Cotton et al [10], who have reported the meteorological condition during MCC in United States and Trismidianto [5], who has reported the environmental condition of MCC in Central Kalimantan using composite analysis. For the analyses, the condition of the environment during MCC event utilized several data from the ECMWF ERA-Interim analysis fields, which are available at 6-hourly intervals with 1° x 1° horizontal resolution [26].

3. Results and discussion

3.1 Overview the case study
This study was a continuation of the research conducted by Trismidianto et al [2] with similar case study. In this case study, the MCC developed from midnight on 27 October 2007 until the early morning of 28 October 2007 over the Indian Ocean near Sumatra Island. Figure 1 shows the case study of the MCC that had a cloud shield with an area of around 319,083 km², and the interior cold cloud covered an area of about 211,059 km². The center of the MCC was around 3.21°S, 97.46°E with an eccentricity of around 0.76 and life cycle duration around 16 hours. MCC, in this case, began to develop and was triggered by the cloud from the west and the coastal of the Sumatra in the average time of the initial stage around the midnight 0100 LT. The sizes of the clouds increased further, and they began merging until reaching the maximum size in the morning. After around six hours from the mature stage, the MCC decayed and then dissipated in the afternoon. When the MCC dissipated, the cloud seemed to migrate to the west and predominantly to the east toward over the Sumatra.

Figure 1. Horizontal distribution of T_{BB} for MCC criteria from the infrared data obtained by MTSAT-1R over the Indian Ocean near Sumatra on 27–28 October 2007, showing the eight stages of MCC evolution: (a) MCC-12h stage (1000 local time (LT)), 27 October 2007; (b) pre-MCC stage (2200 LT), 27 October 2007; (c) initial stage (0100 LT), 28 October 2007; (d) growth stage (0400 LT), 28 October 2007; (e) mature stage (0700 LT), 28 October 2007; (f) decay stage (1300 LT), 28 October 2007; (g) dissipation stage (1600 LT), 28 October 2007; (h) post-MCC stage (1900 LT), 28 October 2007. The color indicates T_{BB} with unit Kelvin.

3.2 Meteorological conditions in the surface and lower level
The initial region of the MCCs was characterized by low-level convergence from the surface to 700 hPa and the strong upper-level divergence as shown in figure 2 (b). At 1000 hPa, the surface condition in the initial region of the MCCs showed the depressed of surface θ as illustrated in figure 2 (a). The θ is the temperature a parcel would have if it were to expand or compress adiabatically from its present pressure and temperature to a reference pressure level. In the troposphere, the θ typically increases with increasing height. Since colder air temperatures on an isobaric surface correspond to colder θ and
warmer air temperatures on an isobaric surface, correspond to warmer $\theta$, the isentropic surfaces slope upward over a horizontal distance toward colder air. The colder temperatures typically associated with upper-level troughs are due to the southward transport of colder air in the lower troposphere. Conversely, warmer temperatures linked to upper-level ridges result from the northward transport of warmer air in the lower troposphere.

The depressed $\theta$ with value $<298$ K coincided with the area of heaviest stratiform precipitation. MCC, in this case study that occurred at midnight (around 0100 LT) over the sea, saw there were two regions of lower surface $\theta$ in the western coast of the Sumatra and the Indian Ocean near Sumatra. The initial region is not the same as the mature region, but the system due to the clouds system is not merged. Hence, the decreased surface $\theta$ due to the cold pool from the deep convective system and cloud system which will merge becomes the MCC system. The appearance of the cold pool is also supported by the high surface relative humidity. The large surface relative humidity was also seen clearly in the initial region (figure 2(b)) which reached more than 90%. The larger the relative humidity, the moister the air, which is vital for the development of clouds and precipitation. Sometimes can trigger mechanisms such as a front, outflow boundary or sea breeze moves in if the air will not have to rise much to reach saturation.

**Figure 2.** (a), (d) and (g) 1000-hPa $\theta$ (potential temperature in K, shaded), 1000-hPa geopotential height (m, contour) and 1000-hPa wind vector (ms$^{-1}$, vector) in the initial stage, mature stage and decay stage, respectively. (b), (e) and (h) 1000-hPa divergence ($10^{-5}$ s$^{-1}$, contour), 1000-hPa relative humidity (%, shaded) and 1000-hPa wind vector (ms$^{-1}$, vector) in the initial stage, mature stage and decay stage, respectively. (c), (f) and (i) 850-hPa geopotential height (m, black contour), 850-hPa MFC (moisture flux convergence in $10^{-3}$ g kg$^{-1}$ s$^{-1}$, shaded), 850-hPa mixing ratio (g kg$^{-1}$, red dotted contour) and 850-hPa wind vector (ms$^{-1}$, vector) in the initial stage, mature stage and decay stage, respectively. Red circle in figure (a) refers to the MCC location.

Figure 2 (a) and (b) shows the convergent surface wind flows as the land breeze triggered the development of some of the clouds in the western coast of Sumatra during the initial stage. At the same time, the westerly wind and strong southerly wind in the lower atmosphere triggered the development of some of the clouds over the nearby Indian Ocean. It is also indicated by convergence pattern in the surrounding area of the initial region. Convergence means that more air is flowing into that region than flowing out. Since the air has to go somewhere, it rises, and the rising air is what induces precipitation development. Heavier rainfall is often associated with regions of stronger ($>2\times10^{-5}$ s$^{-1}$) convergence. The opposite is true for areas of divergence, where more air is flowing out of the region than flowing in. To replace the net loss of air, air sinks from above and sinking air suppresses the development of clouds and precipitation.
The 850 hPa geopotential height, MFC field, wind field and mixing ratio are shown in figure 3 (c). The geopotential height field is characterized a broad trough. The clouds system also grew over the region between the higher MFC and less MFC that could generate LLJ which was important in MCC development. The region between higher and less MFC hereafter mentioned as the border front of MFC indicates that the surface horizontal mass convergence is representative of a vertical circulation with the considerable slope. Such situations include not only warm fronts, but also subtle differences in boundary layer characteristics and depth arising from remnant outflow boundaries, differential cloud cover, or varying land surface characteristics. In these situations, localized regions of warm advection can result in sufficient lift for convective development. Furthermore, convective development may be horizontally displaced from the surface horizontal mass convergence maxima and rooted above the local boundary layer (and above a relatively cool air mass). Indeed, some forecasters look at horizontal mass convergence at levels above the surface, in search of areas where convective initiation may occur. Such scenarios may help to explain the observed displacement of storms downstream of the surface MFC maxima [27]. Severe hail and locally heavy rainfall are the most common threats from such elevated storms, with the potential for tornadoes and damaging winds which reduce owing to the stable near-surface stratification.

A shortwave trough becomes deeper at 850 hPa from the southern Sumatra and the Indian Ocean across the initial region that indicates to generate the weak LLJ as shown in figure 2 (c). Thus, the LLJ stream is a current feature of the MCCs percussion environment. It is also supported by a strong warm advection, weak MFC and moisture advection that presents ahead of the trough and into the initial region with mixing ratios around 14 g kg\(^{-1}\). It is similar to the USA MCC from the previous researcher who stated that LLJ was often present in the environments of MCCs from the United States [7, 11, 28] and of long-lived MCSs over South America [29–31]. While Velasco and Fritsch [13] showed the surface mixing ratios were between 11 and 15 g kg\(^{-1}\) for MCC events over South America. The present analysis indicates the mixing ratios at the lower end of this range for these serial MCS events. However, these lower surface mixing ratio values are typical for MCC events in the United States [7, 13].

During the mature stage, the low-level convergence is still presented which interacted by the strong convergent wind flows indicated by westerly and easterly wind as shown in figure 2 (d) and (e). The low-level divergence at this stage reflects the dominant of precipitation-induced; tropopause cooling and rising reach their maximum intensity at the mature stage, reflecting the contribution of mesoscale ascent and longwave radiative cooling by the upper-level cloud shield. It is consistent with Maddox [7]. The lower surface θ is clearly presented in the initial region and seen moving from the initial region. It indicates the merging of the clouds system in the initial region toward the mature region and the cold pool began in this region.

The large surface relative humidity in 1000 hPa was also seen clearly in the initial region, on average it was higher than the initial region as shown in figure 2 (e). The cold pool began to appear which was indicated by the lower surface θ than its surrounding areas, and the relative humidity was also larger. A local maximum in absolute humidity and a local minimum instability mark the favored region for formation of the convective systems that deep convective system is formed over there. The shortwave trough of geopotential height is still presented from the westward in the initial region. The 850 hPa trough weakened at level 850 hPa that generated the weak LLJ as shown in each case study. It is also indicated by the low-level wind convergence to the mature stage which transports moisture. Weak MFC and moisture advection that was present ahead of the trough and into the mature region then became the center of the higher mixing ratios around 14.5 g kg\(^{-1}\); it was slightly increased from the initial region. It contrasted with Maddox [7]; Velasco and Fritsch [13] stated that these lower surfaces is mixing ratio values which are typical for MCC events in the United States.

The decay region is still characterized by the lower surface θ as shown in figure 2 (g). However, the lower θ seems separated or migrated southward, so that, the other lower center appears in the southern side of the system. It indicated the new convective system began to be generated by the cold pool. The center high geopotential height appears in the eastern side of the cold pool system. It indicated that the divergence field began to appear. The area with lower θ also has the high surface relative humidity. However, the center of high relative humidity is moving to Sumatra Island as shown in figure 2 (h). The decay region was also characterized by the weak surface divergence and convergence as shown in figure
2 (h). The weak convergence still exists in the eastern leading edge of decay region. It indicated that the weak upward motion still occurred in the decay region. However, the strong convergence started to leave the MCC area, which was similar to Cotton et al [10]. The central divergences appear over the system area, while the central convergences are moving to Sumatra Island. It indicated the propagation of the new convective system from the MCC system area toward the Sumatra Island was helped by the divergences outflow from the system interacting with the southerly wind in the lower atmosphere. The strong surface wind flow was dominant southerly that was predicted to help the propagation of the new convective system.

3.3 Meteorological Conditions in the Middle and Upper Level

A longwave trough of the geopotential height is also very clear from the north to south across the initial region that suggests a low-level strengthening flow over the initial region. Figure 3 (a) shows that the 700 hPa geopotential field is disturbed by the existence of shortwave in the initial region. At the same time, the wind at level 700 hPa changed the direction and became easterly flows. A 700-hPa shortwave trough is located in the southern edge of the initial region that likely generates the jet streak in the southern edge of the initial region. The atmosphere remains relatively moist, with mixing ratios above 8.5 g kg\(^{-1}\) ahead of the trough.

The 500 hPa pattern can also be used to locate where surface storms and precipitation are most likely occurring. Surface storms and precipitation are most often found over areas downstream of troughs (following the horizontal wind direction from a trough to a ridge). The reason is that the rising air motion is forced in this part of the flow pattern. Rising motion means that surface air is forced to move upward toward the tropopause. In the atmosphere, clouds and precipitation develop where air rises. The initial region was characterized by the region between two long waves mid-level and upper-level trough or near of the center lower geopotential height. The longwave mid-level trough southward but in upper-level northward. The low geopotential height (compared to other locations at the same latitude) indicates the presence of a storm or trough at mid-troposphere levels. Positive vorticity indicates counterclockwise rotation of the winds and lateral shear of the wind with the stronger flow to the right of the direction of the wind.
flow. Negative vorticity indicates clockwise rotation of the winds and lateral shear of the wind with the stronger flow to the left of the direction of flow. Positive (or negative in the Southern Hemisphere) vorticity at 500 millibars is associated with cyclones or storms at upper levels and will tend to coincide with troughs in the geopotential height field. The negative vorticity in 500 hPa is presented. Strong divergence occurred in upper-level in the initial region as shown in Figure 3 (c). The wind flows dominantly westward at the level of 500 hPa and 200 hPa across the initial region.

The characteristics of the front/border region between the positive of low-level MFC were still not seen in the mature region as shown in Figure 2 (f). A 700-hPa longwave trough located in the mature region is still presented in this case study as shown in Figure 4 (d). The atmosphere remains relatively moist, with mixing ratios above 6.5 g kg\(^{-1}\) ahead of the trough for all of the case studies. A 700 hPa wind flow over the mature region also indicates significant changes. A 700-hPa longwave trough is located in the mature region still presented in the case study as shown in Figure 4 (d). The atmosphere remains relatively moist, with mixing ratios above 6.5 g kg\(^{-1}\) ahead of the trough for all of the case studies. A 700 hPa wind flow over the mature region also indicates significant changes. Flows over the mature region change becomes westerly, where the flow has dramatically strengthened so that a distinct jet is present over the mature region. It indicates the moved westward of the system. Bosart and Sanders [32] noted similar characteristics to a long-lived convective system that they studied.

The longwave trough is still present in the level of 500 hPa following the pattern of the positive-negative of the vorticity advection that indicates there are process the development of the MCC in the initial region for the case study as shown in Figure 3 (e). However, the pattern does not clearly seem. The longwave trough is still located at 500 hPa from the north across the initial region. The initial region is located in the center of lower geopotential height in level 500 hPa. The longwave trough is across the mature region from the south as shown in Figure 3 (f). The divergence on the upper-level is strong from the initial region of MCC as shown in Figure 3 (f).

At 700 hPa analysis during decay, the stage is shown in Figure 3 (g). A ridge of high moisture content is moving eastward with the system transported by the wind flow at the level of 850 hPa and 700 hPa. The mixing ratio decreased during the decay since the mature stage, where the decrease around 1 g kg\(^{-1}\) for this MCC case. The shortwave trough which remains meridional of geopotential height is still found in decay region at 850 hPa and 700 hPa. It is similar to Maddox [7] stating that the shortwave trough is very pronounced in the height and temperature field. At 500 hPa, the shortwave mid-level trough is very pronounced in height, and the wind fields are well balanced with the height field as shown in figure 3 (h). At 200 hPa, the longwave trough is across from the decay region as shown in figure 3 (i) followed the strong upper-level divergence.

### 3.4 Divergence and vertical velocity field

The vertical distribution of divergence and vertical velocity during MCC life cycle of the MCC in this case study are presented in Figure 4. Low-level convergence at the initial stage is relatively strong around 25 \(\times\) 10\(^{-5}\) s\(^{-1}\). Surface convergence is confined to the lower half of the troposphere (from surface until 800 hPa), at the same time, strong divergence prevails above 800 hPa until 500 hPa around 25 \(\times\) 10\(^{-5}\) s\(^{-1}\) as shown in Figure 4 (a). The condition still continued until merging the clouds system from the west helped by the westerly and easterly wind. It was also helped by the land breeze or mountain breeze because the initial stage occurred at midnight. The development of MCC in this stage was also helped by the strong southerly wind. The upward process in the growth of the cloud was started in this stage with averaged vertical velocity around 20 \(\times\) 10\(^{-2}\) Pa s\(^{-1}\). By the mature stage, as shown in figure 4 (b), convergence has strengthened through a low level (surface - 700 hPa), and strong upper-level divergence has developed a sharp maximum at 300 hPa. The convergence zone in the MCC surrounding area at the surface that shown in the initial stage was not seen in the mature stage. It indicates that the clouds system already merged each other to reach the maximum extent of the MCC. The updraft also became stronger with the averaged vertical velocity around \(-40\) \(\times\) 10\(^{-2}\) Pa s\(^{-1}\). The surface convergent wind flows are still strong at this stage. The upward increased in the systems. The surface convergent wind flows as the westerly and southerly wind was still presented at this stage.

At the decay stage, as shown in figure 4 (c), the convergence grew and expanded to the level of 500 hPa. The divergence also expanded until 200 hPa. However, the weak divergence started to appear
in the western side of the system. The new convective system began to be generated in the western and eastern side of MCC system. 3 hours after MCC dissipated or post-MCC stage as shown in figure 4 (d), the surface convergence is no longer evident over the large averaging area. However, the convergence appears in a deep mid-tropospheric layer (800 - 400 hPa), while the strong divergence is presented in the low-level. The strong divergence is also present in the upper-level. This condition indicates that downdraft process already occurs in the system. Several new convective systems have been generated and migrated westward and southward, and the new convective system is shown by the propagation of the convergence zone from the system.

Figure 4. Pressure-longitude cross section (averaged for latitude 6°S - 0°N) of divergence (10^{-5} s^{-1}, shaded), vertical velocity (10^{-2} Pa s^{-1}, contour) and horizontal wind (vector; ms^{-1}; upward represents northward) for MCC using ECMWF ERA-Interim data, during (a) initiation (0100 LT), (b) mature (0700 LT), (c) decay (1300 LT) and (d) Post-MCC (1900 LT). Red arrow shaded indicates the convergence wind and blue arrow shaded illustrates the updraft motion.

In comparison with previous study, among others; Tollerud and Esbensen [33], using composite analysis of divergence in tropical clusters, reported that most of the convergence in the tropical clusters was below 800 hPa until the dissipation stage. It is different from the study result where the convergence during mature reached the level of 700 hPa, in fact, it reached until midlevel (500 hPa) during the MCC decayed. This result is also different from Maddox [7] and Cotton et al. [10] stating that deep layer of convergence is at the mature stage and persisting after that. This difference is possible due to the location of the MCC system where this MCC developed over the Indian Ocean, which is one of the heat sources interpreted as the driving force for the global circulation in the tropics [34]. This area is also one of the regions where deep cumulus convection and heavy rainfall occur most frequently in the tropics [35]. In general, the evolution of these divergence profiles is similar to that found for tropical convective systems by Reed and Recker [36], Riehl et al [37], Frank [38] and Leary [39]. However, the divergence profile at the time of the system is a little bit similar to the one presented by Williams and Gray [40].

3.5 Equivalent potential temperature and relative humidity field

Equivalent potential temperature, \( \Theta_E \), is the temperature resulted after all latent heat is released in a parcel of air, and then brought adiabatically to the 1000 hPa level. \( \Theta_E \) increases as dewpoint and temperature increase. A region with a relatively high \( \Theta_E \) is often the region with the most instability. Warmer low-level temperatures and higher low-level dewpoints increase instability. LLJ from a moisture source will often bring higher \( \Theta_E \) values and thus increase instability. \( \Theta_E \) ridge is regions with higher \( \Theta_E \). They are often the bursting point for convective activity.
The vertical distribution of $\theta_E$ and relative humidity during the life cycle of MCC are presented in figure 5. $\theta_E$ exceeded 344 K in the lower troposphere in the eastern side of the system during initial stage as shown in figure 5 (a), denoting a major source of energy driving the MCC. One can see an influx of air with high $\theta_E$ at 850 hPa, and one indicator of high flood potential. A cross-section through the layer of high $\theta_E$ air reveals other ingredients for the MCC and heavy rainfall. A deep layer of high specific humidity and rising motion. This maximum $\theta_E$ extends upward through midlevel, and with the southwesterly winds over the region, it provides low to mid-level warm advection to the MCC region. The high $\theta_E$ during initial stage reaches level 650 hPa. It indicates the jet streak or LLJ is generated in this system. The location of a low-level moisture source and associated inflow in the MCC is consistent with the composite analysis of Maddox [7] and Cotton et al. [10].

The $\theta_E$ of an air parcel increases with increasing temperature and increasing moisture content. Therefore, in a region with adequate instability, $\theta_E$ ridges are often the burst points for thermodynamically induced thunderstorms and MCS. $\theta_E$ ridges can often be found in those areas experiencing the greatest warm air advection and moisture advection as shown in the Figure 5. The relative humidity also increases in region $\theta_E$ ridge. During mature stage as shown in Figure 5 (b), the $\theta_E$ ridges weakened just until the low level, but the relative humidity was widespread throughout to all the system; the compressed $\theta_E$ values coincided with the area of heaviest stratiform precipitation. During the decay and dissipation as shown in Figure 5 (c) and (d), $\theta_E$ decreased, and the $\theta_E$ ridges propagated followed by the high relative humidity. It indicates the new convective system would be generated.

4. Conclusion

The results from this study showed that, in general, the initial stage of the MCC was characterized by the strong low-level convergence and vertical convection, and largely driven by the convergence of the moisture flux in the lower troposphere. The mature stage of the MCC was characterized by weak surface convergence, strong upper-level divergence, and a shortwave ridge in the mid- and upper levels. Where there was strong surface divergence, the decay and dissipation stages were very similar, and surface convergence left the system. Movement of most MCCs was resulted from the combined contributions of advection and the propagation of surface convergence. The results of this research showed that these large convective systems tended to be formed in the vicinity of the terminus of a low-level jet.
transporting moist and warm air to the originating regions of the MCCs. Shortwave troughs and baroclinic zones were associated with MCC development.

The MCC first develops when instability is at its highest due to the latent heating. The greatest severe weather that occurs with an MCC tends to occur in the developing stages since each storm has more energy and instability. As the cluster of storms becomes more numerous, the severity of the storms will often decrease but the areal coverage of precipitation and storms increases during mature. They can remain organized and travel great distances before the storm complex dissipates. It is often after midnight before MCCs will dissipate. They can dissipate by moving into an environment where the moisture, wind shear, lift, and instability are no longer able to sustain the system. The advective component correlates strongly with the mean flow in the cloud layer. The departure from the mean cloud layer flow is strongly influenced by the speed and direction of the low-level inflow of high $\theta_e$ air feeding the deep convective overturning. New growth favors this inflow area and the systems, therefore, tend to propagate toward the source of the high $\theta_e$ air, i.e., in a direction opposite the low-level inflow. It is shown that a reasonable estimate of the speed and direction of MCCs can be obtained from the vector difference between the mean flow in the cloud layer and the low-level jet.

More studies have shown that the tendency for MCCs to propagate toward the source of the high $\theta_e$ air feeding the convection is augmented or possibly even dominated by the interaction of the MCC-generated cold pool. This leads to enhanced convergence and deeper lifting along the right (left) flank of northern (southern) hemisphere convective lines. Additional convection as a result of the enhanced forcing re-enforces the cold outflow thereby it promotes a further rightward (leftward) advancement of a northern (southern) hemisphere line. This condition is also shown in this research. There are several evidence showings that MCCs substantially alter their large-scale environment. The low-level wind accelerations that they produce provide a significant enhancement to the low-level warm advection and convergence that will normally be present as a result of an approaching short wave and/or a synoptic scale circulation. This research revealed that these large convective systems form in the vicinity of the terminus of an LLJ that supplied high-$\theta_e$ air to the MCC genesis region. Consequently, if the weak mid-level short wave is approaching the genesis area and enhances the low-level convergence associated with the LLJ. The large-scale environment itself can contribute significantly to propagate MCC. An upper short-wave trough tends to be associated with MCC development. The surface convergence wind flows in the lower atmosphere is also important in this process.

Acknowledgment
Thank you so much for the three sources data which we could get for free, and the data are beneficial for this research. This research used data from ECMWF ERA-Interim (http://www.ecmwf.int/), MTSAT IR1 satellite data (http://weather.is.kochiu.ac.jp/sat/GAME)

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