

Formation mechanism of super cluster over the tropics

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सार — बृहत पैमाने पर मेघ परिघटना का विश्लेषण किया गया ताकि इसकी आंतरिक संरचना, संगठन और गति को समझा जा सके। इस अध्ययन वाले क्षेत्र में मेघ के पश्चिम की ओर बढ़ने वाले असामान्य महा पुंज बनते हुए दिखाई पड़े जबकि प्रत्येक मेघ पुंज/पू. द. पू. की तरफ बढ़ा। मेघ के महा पुंज के क्षैतिज की लम्बाई ~ 2000 कि. मी. थी और यह महा पुंज 2 दिनों से अधिक समय तक बना रहा, यह बहुत न्यून T_{BB} (<210 के.) मेघ क्षेत्र में -40×10^4 कि.मी.² तक रहा और -6 मि./सै. की गति से पश्चिम की ओर बढ़ा। इस महा पुंज के ये लक्षण कुछ-कुछ उन सहज महा पुंजों के सामान्य लक्षणों से भिन्न हैं जिन्हें कई कार्यों के दौरान देखा गया है। यह देखा गया है कि नये मेघ लगातार बने और आपस में मिलकर मेघ पुंजों के रूप में एकत्रित हुए। महा पुंज की संरचना के लिए मेघ के पुंज समूह पहले बने बृहत पुंज के साथ मिल गए। नए पुंज के बनने में महा पुंज के बनने जैसी प्रवर्धन गति और दिशा देखी गई है।

ABSTRACT. A large-scale cloud phenomenon was analyzed to understand its internal structure, organization and movement. A westward moving uncommon super cluster was shown to have developed in the study region while each cloud cluster moved E/ENE. The super cluster has horizontal length 2000 km, life time more than 2 days, very low T_{BB} (<210 K) cloud area -40×10^4 km² and moved westward with a speed of -6 m/s. These features are some what different from the usual properties of super cluster as reported in several works. It was found that new clouds successively formed and interacted between themselves, and organized to form cloud clusters. The cloud clusters merged with the old large cluster to take part in the maintenance of super cluster. The propagation speed and the direction of the super cluster was followed by the formation of new cluster.

Key words— Cloud, Cloud cluster, Super cluster, Organization, Merging, Black body temperature.

1. Introduction

The western pacific warm pool, where the surface temperature is exceeding 28°C, is one of the most convectively active regions of the world. Tropical warm pool covers ~20% of the earth's surface and its climatic change affects the Global climatic change by large-scale circulation. An observation and modelling program, the Tropical Ocean-Global Atmosphere (TOGA) Coupled Ocean-Atmosphere Response Experiment (COARE) has been designed to gain a clear understanding of the global climate (Webster and Lukas, 1992). Among the many objectives of TOGA-COARE, the investigation of the properties of large-scale cloud cluster in the region is an important study.

Large-scale cloud disturbances associated with equatorial waves (Takayabu, 1994) and an eastward moving super

cluster (Nakazawa, 1988, Mapes and Houze, 1993) are often observed in the tropics. Nakazawa (1988) observed a hierarchy of convective elements within the eastward moving Inter-Seasonal Oscillation (ISO): westward moving cloud clusters are organized to form an eastward moving super cluster with a horizontal extent of several thousands kilometers. Lau *et al.*, (1989) suggested that this hierarchical structure is an intrinsic feature of the Madden-Julian Oscillation (MJO) as individual convective disturbances grow and decay within the eastward propagating large-scale disturbances. Hendon and Liebmann (1994) stressed that very little synoptic variance associated with the ISO is accounted for by the super cluster in the excitation and propagation of the ISO. Takayabu (1994) analyzed the predominance of the westward moving cloud disturbance and referred to a de-

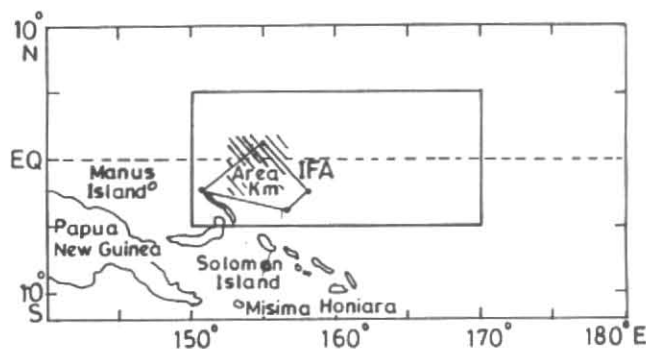


Fig.1. Analytical area to analyze large-scale event

tailed analysis of a typical westward-spreading cloud disturbance on January 1992 during the TOGA-COARE IOP (Intensive Observation period). Mapes (1993) observed the vertical profiles of the heat source from tropical MCSs (Mesoscale convective systems) and claimed that this heat caused the initiation of gravity waves and that lower level is favourable for the development of additional convection nearby. He also reported that over the oceanic warm pool, positive feedback exists between tropical deep convection and the environmental flow, which leads to self-organizing super clusters.

Recently, Nakazawa (1995) further confirmed that there is a hierarchic structure of the tropical convection: planetary-scale ISOs, eastward-moving synoptic-scale super clusters, and westward-moving meso-scale cloud clusters. The essential question is thus raised as to the organization from small-scale convection to large-scale cloud features. And since eastward propagating cloud disturbances produce westward-moving cloud clusters and eastward-moving super cluster; so westward propagating cloud disturbance may produce eastward-moving cloud cluster and westward-moving super cluster. Therefore, we have to investigate this ambiguous and interesting hypothesis by using the high quality data sets of TOGA-COARE IOP to disclose the real phenomena.

2. Materials and methodology

The Geostationary Meteorological Satellite (GMS-4) data collected over the TOGA-COARE domain (Fig.1) were utilized. The hourly GMS-IR data with the 0.1° mesh was processed specially for this analysis. Analysis was performed on the GMS-IR equivalent black body temperature (T_{BB}) data to distinguish cloud coverage from the clear sky. Also an overview of the large-scale cloud disturbance was derived from the hourly GMS-IR data.

The analysis procedure was similar to that described by Islam *et al.* (1998) which is modified for TOGA-COARE domain. In order to quantify the cloud coverage the convective and stratiform cloud components were detected by CST (Convective Stratiform Technique: a technique to analyze satellite data). In CST algorithm the GMS-IR T_{BB} field was examined for relative minima to identify the location of convective cores in each satellite image. The relative minimum temperature (T_{min}) of a pixel (0.1° mesh) of GMS-4 data in a grid box of $50 \text{ km} \times 50 \text{ km}$ may be a single pixel or the centroid of multi pixel minima. After identify the pixel location of T_{min} its strength was measured by calculating slope parameter (S) using the formula

$$S = 1/4(T_{i-1,j} + T_{i+1,j} + T_{i,j-1} + T_{i,j+1}) - T_{i,j}$$

or,

$$S = 0.25 (\bar{T} - 4T_{i,j})$$

where index i, j refers to the i -th and j -th cores respectively.

The pair of T_{min} and S calculated above were then compared with an empirical discrimination line to divide T_{min} 's associated with convective cores and without convective cores. The relationship between T_{min} and S is given by:

$$S \geq \exp [0.826 T_{min} - 207]$$

Then it was decided whether the core is convective or not using the criteria (Islam *et al.*, 1998): (i) $S \geq 4.0$ the pixel is convective and (ii) $S < 4.0$ the pixel is mature convective or stratiform. In this way all of the points colder than their respective environment are regions of enhanced convection. With the help of Keifu Maru radar data, the stratiform threshold temperature in CST algorithm was calculated and found that 230K of T_{BB} is very close to the stratiform threshold temperature (Islam *et al.*, 1998). Thus a cloud was defined by the enclosed boundary of $T_{BB} = 230\text{K}$ to extract the precipitable portion of the cloud because T_{BB} for the convective part must be much lower than 230K of T_{BB} . The value 220K of T_{BB} was used to see the convective activities of the cloud and 210K of T_{BB} was used to see very deep convective part (Mapes, 1993) of the cloud.

The Japan Meteorological Agency (JMA) global analysis dataset (GANAL) with the 1.875° grid at 0000 and 1200 GMT of every day was also utilized for the comparison with cloud analysis. In order to understand the organization mechanism of cloud clusters and super clusters: horizontal profiles of the wind field, pressure and temperature were derived from the GANAL dataset.

3. Results and discussion

The analysis area for this study is shown in Fig.1. The intensive flux array (IFA) is the heart of the TOGA-

TOGA-COARE NOV.11, 1992 0700GMT Contours: 0800GMT(solid), 0900GMT(dashed)

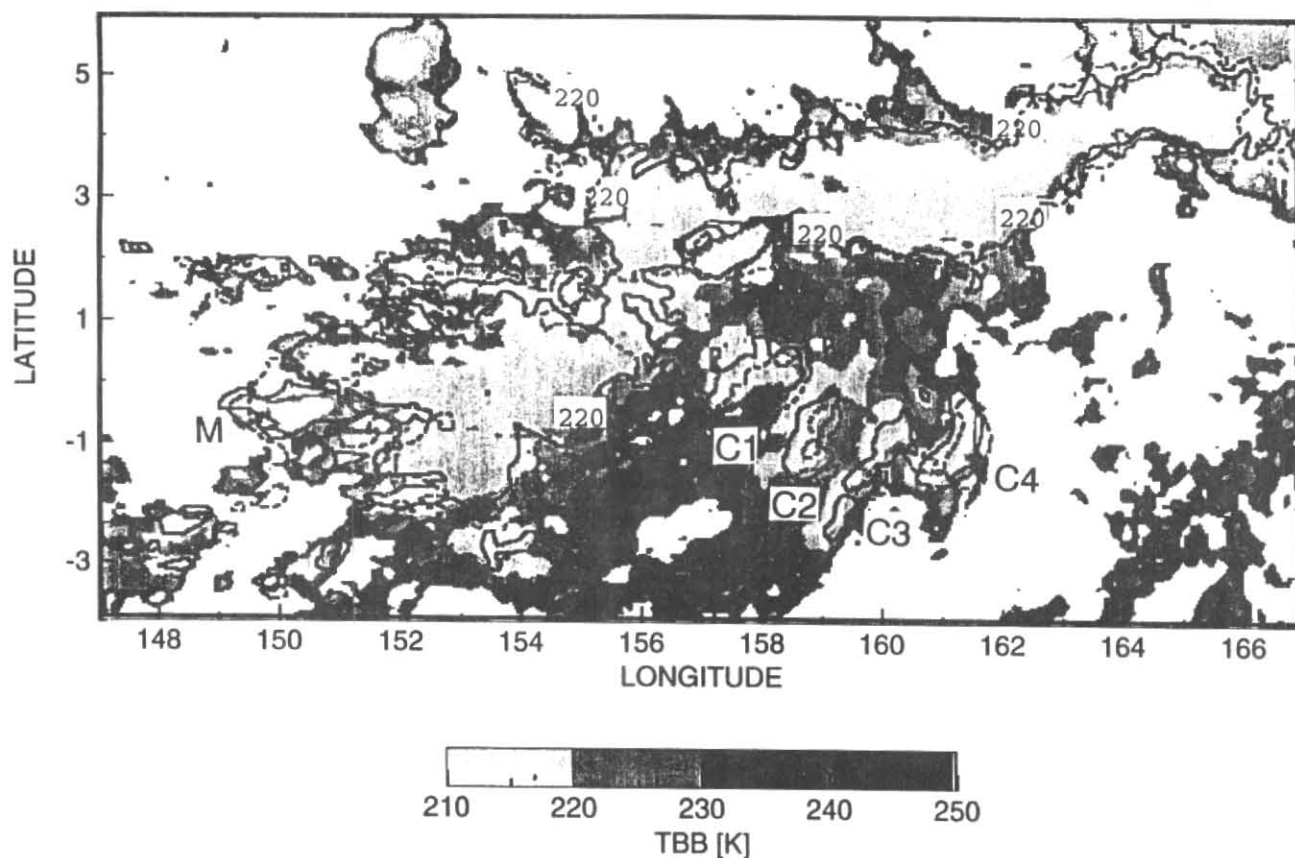


Fig.2. The shape, size and movement of the uncommon super cluster at 0700 GMT on 11 November, 1992. Successive one hour interval cloud area enclosed by $T_{BB} = 220\text{K}$ are represented by solid(0800 GMT) and dashed (0900 GMT) contours. Four cloud clusters are represented by C1, C2, C3 and C4. The letter M represents the new cluster which developed in the western side of old large cluster and merged with it

COARE, where intensive observations were performed using several Meteorological instruments. Area KM is the coverage (500 km x 500 km) of Keifu Maru radar (shaded region) that is used to observe the formation of new echo.

3.1. Structural feature of a westward super cluster

The shape, size and movement of the studied super cluster were analyzed by consecutive T_{BB} area and is shown in Fig.2. As in Fig.2, a large cloud area represented by the $T_{BB} = 220\text{K}$ was observed at 0700 GMT on 11 November, 1992. In Fig.2, successive one hour interval cloud area enclosed by $T_{BB} = 220\text{K}$ are also represented by solid (0800 GMT) and dashed (0900 GMT) contours. The value 220K of T_{BB} is used to observe the active portions of the event. Examining the consecutive hourly T_{BB} data it was observed that a cloud burst occurred at about 1500 GMT on 10 November 1992 (not shown). A few fragments moved westward and passed over the radar observation area named Area KM. At this time there were many developing echoes observed in Area KM which were moving E/ENE (not shown). The fragments dissipated and new clouds were successively

developed and organized to form a westward moving super cluster at about 0700 GMT on 11 November 1992. The whole system disappeared after 0900 GMT on 12 November, 1992 (Fig.3). As in Fig.3, both radar and CST identified convective and stratiform regions were superimposed with $T_{BB}=220\text{K}$ (dashed-dot line). At this time radar data showed lack of the formation of new echoes that implies the ending time of the event. Nakazawa (1988) reported about the eastward-moving super cluster with a horizontal length of $\sim 10^3\text{km}$. Mapes and Houze (1993) defined a super cluster as follows: "A cloud cluster within an IR satellite image is a specially connected cold cloud area, of at least moderate size ($>5000\text{km}^2$), with T_{BB} lower than 208K". By the above definition, this large cluster was undoubtedly a super cluster because its area of very low T_{BB} ($<210\text{K}$; very close to 208K as used by Mapes and Houze, 1993) was $\sim 40 \times 10^4\text{km}^2$ and the horizontal dimension was $\sim 2000\text{km}$. This large [$\sim 80 \times 10^4\text{km}^2$ ($<230\text{K}$)] super cluster consisted of a number of gregarious convections. The E/ESE movement of each cloud cluster labelled by C1, C2, C3 and C4 is clearly shown in Fig.2. These cloud clusters (C1-C4) were ultimately

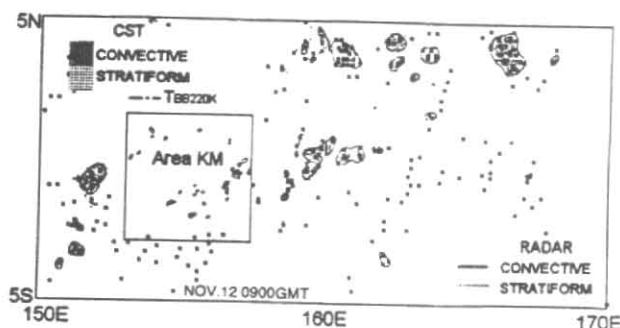


Fig.3. The radar and CST identified convective and stratiform regions superimposed with cloud of $T_{BB} = 220K$. The legends are shown in the figure

indistinguishable from each other below 230K of T_{BB} . The value of $T_{BB}=230K$ was used to cover both convective and stratiform regions of the clouds. New cloud clusters were successively developed in the western side of the system, which were moving to E/ESE and merged with the system (*i.e.*, cluster M). This reflects the westward movement of the super cluster even though it was actually stationary by the effect of the westward propagating inertial gravity wave and eastward moving ambient air.

The propagation speed and direction of the super cluster and cloud clusters on November 10-12 is shown in Fig.4. From Fig.4, the cloud clusters are divided into two groups: western side and eastern side. The western side belongs to the clusters, which were analyzed in the west side of the super cluster, and eastern side belongs to cluster, which were analyzed in the east side of the super cluster. The frequency represents the counting of the measurement. While the super cluster itself was stationary, its speed was measured when a new cluster merged with it in the western edge. Its propagation direction was westward. The cloud clusters moved E/ESE. Each group (western side and/ or eastern side) showed two peaks of propagation speed. The large peak appeared when many low-speed small clusters were analyzed. The second peak appeared when a few high-speed large clusters were analyzed. The speed of the clusters in the western side was about 2 m/s faster than the speed of the clusters in the eastern side. This revealed that the clusters were developing in the western side and were dissipating in the eastern side. The analyzed super cluster propagated westward with a speed of about 6 m/s while Nakazawa (1988) reported an eastward speed of 10-15 m/s and Hashiguchi *et al.* (1995) reported an eastward speed of 4 m/s for different super clusters. Using Fig.2, one may calculate the speed of the westward moving cloud envelope which is about 17 m/s (Mori, 1995). As previously mentioned, after careful inspection of hourly T_{BB} data, the speed in this analysis was measured when a new cluster merged with the old cluster, and the western edge expanded with time even though the large part of the old cluster was stationary.

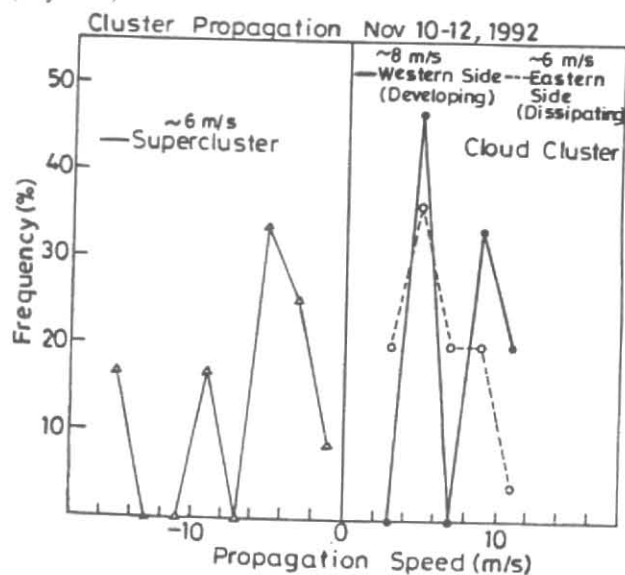


Fig.4. Propagation speed of super cluster and cloud clusters. Hourly T_{BB} data is used to this calculation. Western side and eastern side are explained in the text

3.2. Organization mechanism of a super cluster

Here is an interesting point concerning the common and uncommon features between a well-known super cluster (Nakazawa, 1988) and this study's super cluster. This type of gregarious convection which is connected by the enclosed boundary of $T_{BB} < 230K$, and has the large-scale westward motion seems to be a rare super cluster case as a super cluster over the tropical ocean analyzed by hourly T_{BB} data. This uncommon characteristic (westward motion) was not reported by Nakazawa (1988), Lau *et al.* (1989), Mapes and Houze (1993) and Hashiguchi *et al.* (1995). If we analyze the long time-interval data *i.e.*, 12 hours or 6 hours, or at least 3 hours it is difficult to identify the E/ESE movement of each cluster and the formation of new clusters in the western side of the large old cluster. This is why hourly T_{BB} data was used to detect them clearly and focused on the super cluster only, not on the envelope of the system. The propagation direction suggests a need to consider wave properties (Mapes, 1993); WIGW-westward propagating inertial gravity wave (Takayabu, 1994b) in the atmosphere. The possibility of the WIGW was also referred to by Mori (1995). The signature of the initiation of the gravity wave can be detected by a pressure gradient force and a relatively high temperature zone. Using GANAL dataset, possible explanations on the formation mechanism of this study's super cluster are as follows.

GANAL wind and temperature fields for 11 November, 1992 are shown in Fig.5. First, the low-level environmental wind blew from both NW and SW to converge in the west side of the large cloud cluster (Fig.5). The ambient temperature was relatively high in the east side of the large cluster and the low temperature was positioned in the convergence

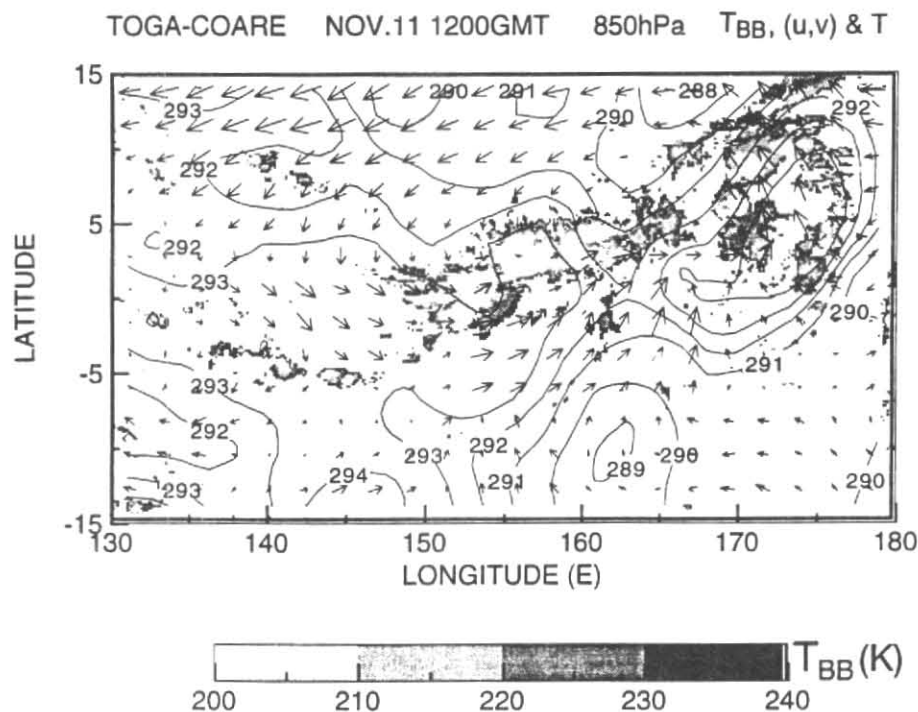


Fig.5. A large-scale cloud systems at 1200 GMT on 11 November, 1992 is superimposed with temperature (contours) and wind field (vectors) at 850 hPa. The contour drawn for temperature as levelled in the figure in unit of °K. Maximum length of the vector is 16 m/s

zone. This environmental condition may cause a situation suitable for the formation of new clouds, which move E/ESE. New clouds successively formed and interacted between themselves, and organized to form cloud clusters. The cloud clusters merged with the old large cluster to take part in the maintenance of the super cluster. The equatorial wave forced the super cluster to move westward while ambient air pushed it eastward. So, the formation of a new cluster in the west side and its merging with the old large cluster affected the movement direction of this super cluster. In addition, the latent heat released from the large convective system (Mapes, 1993) made the cloud burst which made the system dry. Because dry air is denser than humid air, it can initiate gravity wave or a density surge of dense air. This wave can propagate well into the troposphere as well as in the stratosphere (Hauf, 1993) and enforce the hydrostatic pressure forces. If the wave is very deep, its bottom friction is insignificant hence it does not affect small developing clouds. It affects the large cluster and pushes it leeward while air motion is forward. The ambient air blew E/ESE up to 8 km level (see Fig.2, Mori, 1995) so the western side was favourable to the formation of new clouds. Also a cold air blew eastward while warm air was carried by a westward gravity wave. In the crossover zone, the favourable condition occurs to form new clouds. A simulation showed that gravity waves propagate against the shear direction (Hauf, 1993). Therefore, the large cluster was almost stationary,

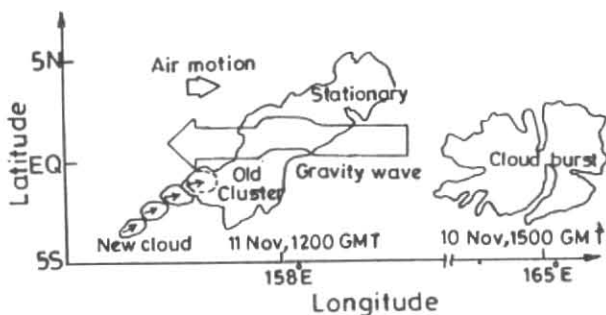


Fig.6. Schematic illustration of the organization and movement of the westward moving uncommon super cluster

and the new cloud and cloud cluster formed in the western side joined with the system (Fig.6). Then it appeared that the system was propagating westward. The schematic illustration of this mechanism is shown in Fig.6.

As schematically illustrated in Fig.6, a cloud burst occurred at about 1500 GMT on 10 November, 1992. The new cloud and cloud cluster were successively formed and merged to form a super cluster at about 1200 GMT on 11 November 1992. Because the new cloud/cluster formed in the western side of the old cluster and merged with the super cluster, so it appeared that this studied super cluster (which is a group of cloud clusters) moved westward.

There are many questions about the organization and movement of the tropical super clusters. However, the ana-

lyzed uncommon super cluster revealed some new characteristics, which are as follows. (i) studied super cluster moved westward with a speed of about 6 m/s; (ii) large part of the old cluster remained stationary with time and expanded area slowly; (iii) new cloud successively formed in the western side of the old large cluster and organized to merge with the old one; (iv) individual cluster moved E/ESE with the speed of 6 m/s (dissipating) and 8 m/s (developing); (v) interaction occurred between small-scale and large-scale cloud clusters.

Furthermore, there are some common features for all kind of super clusters, which are as follows. (i) movement of the super cluster and cloud clusters will be in opposite directions; (ii) the super cluster is composed of a number of cloud clusters; (iii) new clusters will be formed in the convergence zone of the low-level wind field; (iv) propagation speed and the direction of the super cluster will be followed by the formation of new cluster; (v) super cluster develop during a large-scale cloud disturbance.

4. Conclusions

The analysis of GMS-IR data revealed that a super cluster was composed of a number of cloud clusters. The movement of super cluster and cloud clusters were in opposite direction. For a westward moving super cluster, the new cloud system successively formed in the western side of the old cluster and organized to merge with the old one while the individual cluster moved E/ESE. And the speed and direction of the super cluster was to be followed by the formation of new cluster.

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