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Development of tropical cloud clusters analyzed with satellite data

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सार — टोगा कोयरे क्षेत्र में मेघ गुच्छों के सामान्य लक्षणों का पता लगाने के लिए 10 दिनों (3-12 नवम्बर, 1992) के उपग्रह आंकड़ों का विश्लेषण किया गया। दिनांक 3-5 नवम्बर, 1992 को चार बड़े मेघ गुच्छों (एल सी सी) और एक छोटे मेघ गुच्छे (एस सी सी) का विश्लेषण किया गया। तीन एल सी सी कई एम सी सी के साथ जुड़े हुए थे। एक एल सी सी दक्षाभ ढाल वाला लम्बी रेखा के आकार का (1100 कि.मी.) था जिसमें कोई एम सी एस शामिल नहीं है। एल सी सी की क्षैतिज लम्बाई 750-1150 कि.मी. तक पाई गई जो उनकी विद्यमानता में 14-28 घंटे तक रही और इसका प्रसार लगभग 6 मि./सै. की गति से हुआ। एस सी सी की क्षैतिज लम्बाई 200 कि.मी. से अधिक थी जो लगभग 12 घंटे तक बनी रही और इसका प्रसार ~ 13 मि./सै. की गति से हुआ।

$T_{BB} \leq 230$ K की संलग्न परिधि के अनुसार मेघ की पहचान करने के पश्चात् 3-12 नवम्बर, 1992 को जी एम एस - आई आर आंकड़ों का प्रयोग करते हुए मेघों/गुच्छों की उर्ध्वाधर संरचना का विश्लेषण किया गया। अल्प अवधि वाले (<1 दिन) मेघ गुच्छों के लक्षण दीर्घावधि वाले (>1.5 दिन) मेघ गुच्छों से भिन्न पाए गए हैं।

ABSTRACT. In order to understand the general characteristics of the cloud clusters in the TOGA-COARE domain, analyses were performed on 10 days (3-12 November, 1992) of satellite data. Four large cloud clusters (LCCs) and one small cloud cluster (SCC) were analyzed on 3-5 November, 1992. Three of LCCs were composed of several MCSs. One LCC was a long line shaped (1100 km) cirrus shield that contains no MCS. The horizontal length of LCCs were found to be 750-1150 km, lasted 14-28 hours in their lifetime, and propagated with a speed of about 6 m/s. NP The SCC had a horizontal length of above 200 km, and lasted approximately 12 hours and propagated with a speed of ~13 m/s.

The vertical structure of the clouds/clusters were analyzed using GMS-IR data on 3-12 November, 1992, after defining a cloud by the enclosed boundary of $T_{BB} \leq 230$ K. The characteristics of the short-lived (<1 day) cloud clusters were found different from those of long-lived(>1.5 days) cloud clusters.

Key words- Cloud, Cloud cluster, Threshold, Black body temperature, Stratiform, Mesoscale convective system, Vertical structure.

1. Introduction

In order to understand the organization mechanism of the tropical meso-scale convective systems (MCSs), which have often been referred as "cloud clusters" (*e.g.*, Houze and Betts, 1981; Houze, 1982; Houze, 1989), we need to analyze their detailed internal structure throughout their lifetime. Houze (1982) summarized the cloud and precipitation structure of MCSs as observed in the field experiments GATE(Global Atmospheric Research Program's Atlantic Tropical Experiment) and MONEX (Monsoon Experiment). Studies in more recent field programs, COPT'81 (Convective Profonde Tropicale 1981) and EMEX (Equatorial Mesoscale Experiment), reveal several types of horizontal patterns in which the convective and staratiform precipitation are arranged within the rain areas of large cloud clusters (Houze, 1989). The large cloud clusters (maximum size of $3x10^4$ km^2 or more) are important to study because these are responsible for the bulk of the tropical rain (Houze,

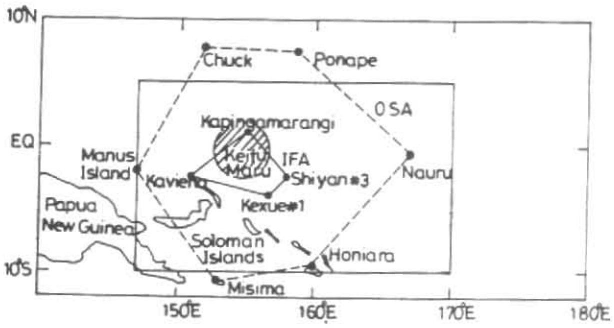

Fig. 1. The analysis area (5°N- 10°S, 147°E- 170°E) is represented by the heavy solid line in the TOGA-COARE domain. The outer sounding array (OSA) and the intensive flux array (IFA) are outlined. Keifu Maru is located (+mark) at the northern part of IFA and its coverage is represented by shade

1989). To study the feasibility of modelling and to know the principal processes that organize convection in the warm-pool, we have to understand the life cycle of the individual small cloud clusters, large cloud clusters, short-lived cloud clusters and long-lived cloud clusters during the TOGA-COARE (Tropical Ocean Global-Atmosphere Coupled Ocean- Atmosphere Response Experiment, Webster and Lukas 1992) IOP (Intensive Observation Period). Moreover, we have to know how the cloud clusters are formed, *i.e.*, the internal structure and interactions within and between the MCSs, because a cloud cluster is composed of several MCSs. The large cumulonimbus were typically grouped within a cluster into one or more MCSs.

Because of the lack of conventional cloud and precipitation observation over the ocean, the use of satellite data is obviously desirable. The present work focuses on the clouds from small-scale to large-scale by using high temporal and spatial resolutions GMS-IR data to obtain the general characteristics of the tropical cloud clusters in and around the IFA (Intensive Flux Array) region.

2. Data and methods

The Geostationary Meteorological Satellite (GMS-4) data (1° mesh on CD-ROM) were used in this study. The analysis domain (5°N-10°N, 147°E-170°E) of this work is shown (bold solid line) in Fig. 1. The OSA is the outer sounding array and shaded region is the coverage of Keifu Maru radar.

The modified CST (Convective Stratiform Technique) algorithm adapted for TOGA-COARE and the analytical procedure of satellite data are described in Islam *et al.*(1997). In CST, the area covered by convective precipitation was calculated using the cell-top height which is indicated by cloud-top temperature. The relative minimum cloud-top temepratute of a pixel (1°x1°) associated with a convective core was decided from the results of a one-dimensional model output. The area covered by stratiform precipitation was calculated using the startiform threshold temperature (Ts). The Ts value was decided using cloud-top temperature and reflectivity of Keifu Maru (a Japanese research vessel) radar. In addition, global analysis dataset (GANAL) was used to understand the organization mechanism of the cloud clusters. The horizontal profiles of the wind field, pressure, dewpoint depression and temperature were derived from the GANAL dataset. Keifu radar data were used to check the surface precipitation where necessary.

3. Results and discussion

3.1. *Life cycle of clusters (3-5 November, 1992)*

LCC1(1800GMT on 3 November - 2100 GMT on 4 November) —The LCC1 started to develop at around 1800 GMT on 3 November, 1992 in the confined region of about 4°S-6.5°S and 155°E-160.5°E as shown in Fig. 2(a). At this time, around 12 small clouds formed individually. The development, organization, and movement of all the clouds are shown by consecutive one hour interval T_{BB} contours. For simplicity, the contours are drawn for T_{BB} =220K at 1900GMT (solid) and 2000GMT (dashed). The contour also indicates the movement of the cold regions (centre) of the cloud. As we see, some clouds were expanding their area with time and were moving to SW with a speed of about 6 m/s. A few of them combined to form distinct MCSs which were composing to form the cloud cluster LCC1 at 2100GMT as shown in Fig. 2 (b). A few of the clouds were born in the northern and southern sides of LCC1 [Fig. 2 (c)] and merged with LCC1 to form a large cloud cluster which was in mature stage at 0600GMT on 4 November, 1992 [Fig. 2 (d)]. After 0700GMT on 4 November, LCC1 was in dissipating stage as seen by its low T_{BB} regions started to decrease with time. The horizontal length of LCC1 was about 1150 km and lasted approximately 28 hours. During this analysis period, one SCC was analyzed. The SCC (7.5°S, 157.5°E) developed at 1800GMT at 3 November, 1992 as shown in Fig. 2(a). This cluster started to develop about 1500GMT on the same day (not shown). This isolated SCC developed rapidly and moved SW with a speed of about 13 m/s. It was in mature stage at 2100GMT and after that it started to dissipate. The signature of dissipation is clearly shown in Fig. 2 (b) by contours at 2200GMT(solid) and 2300GMT (dashed). This SCC behaves as a MCS *i.e.*, this SCC contains just one MCS which developed and dissipated isolatedly. Some of non-isolated SCC have to be combined in forming large cloud clusters.

LCC2(0800GMT on 4 November - 1200GMT on 5 November)—The LCC2 developed in the NE flank of LCC1 when LCC1 was in dissipating stage as shown in Fig. 3(a).

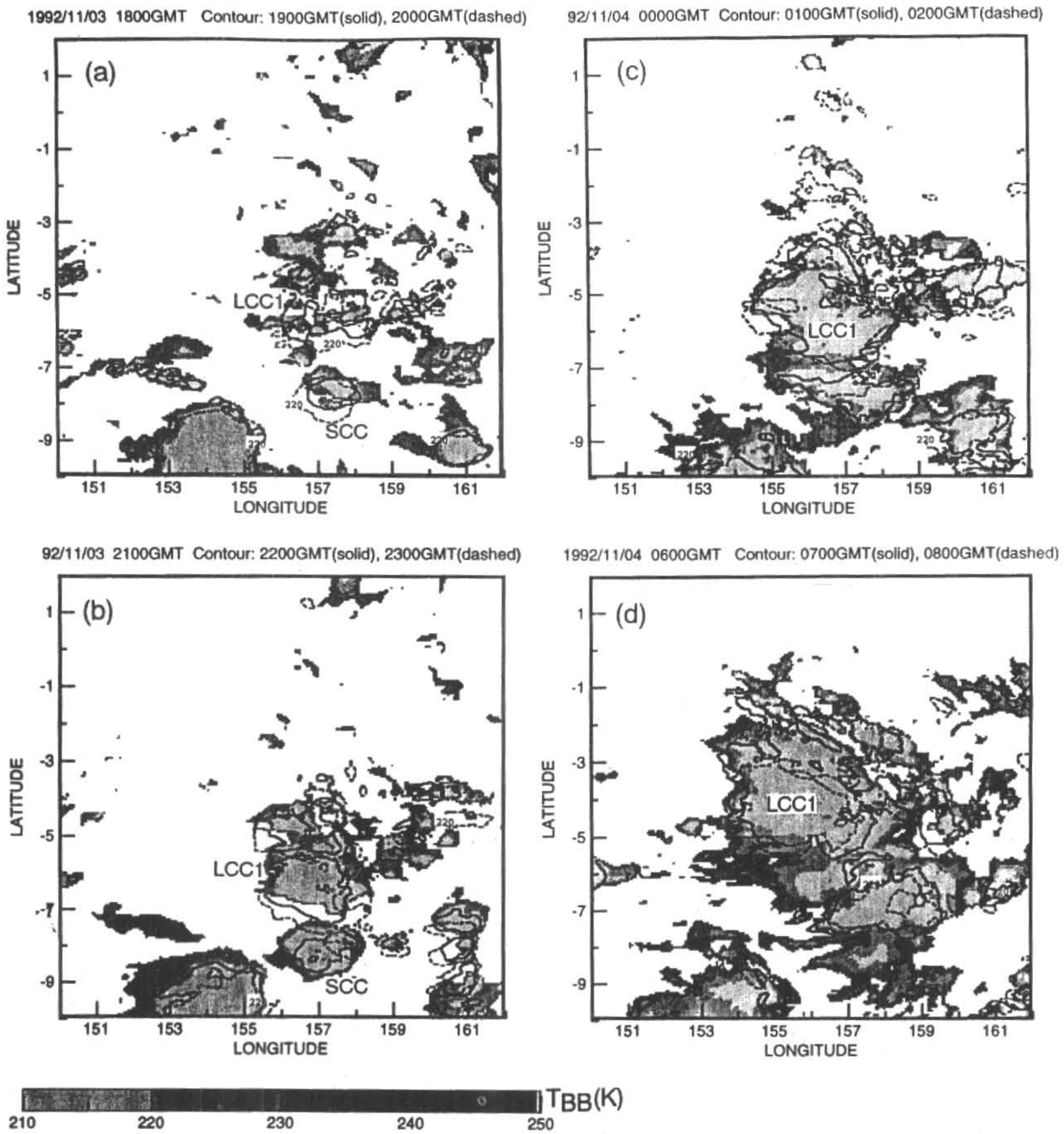

Fig.2. A sequence of T_{BB} distributions around IFA region from 1800GMT on 3 November to 0600GMT on 4 November. In each panel, consecutive 2 hours T_{BB} =220K contours are drawn showing the cloud development and movement. For latitude positive value is the north and negative value is south. For longitude positive value is east

At 1100GMT on 4 November, 1992 the regions of T_{BB}=220K of LCC1 divided into three fragments, and behind of it new clouds were developing(1°S, 160°E). The new cloud successively developed and combined to form LCC2 at 1400GMT [(Fig. 3(b)] of the same day. The next two hours T_{BB} data shows the continuous development of LCC2 with time. It was in mature stage at about 1700GMT on 4 November as shown in Fig. 3(c). It had a horizontal dimension of about 1000 km and it lasted 28 hours. At this time LCC1 was a broken line inclined to NW and almost totally separated from LCC2. After 2000GMT on 4 November, 1992 LCC2 was in dissipating stage as seen by its low T_{BB} regions decreasing with time as shown in Fig. 3(d).

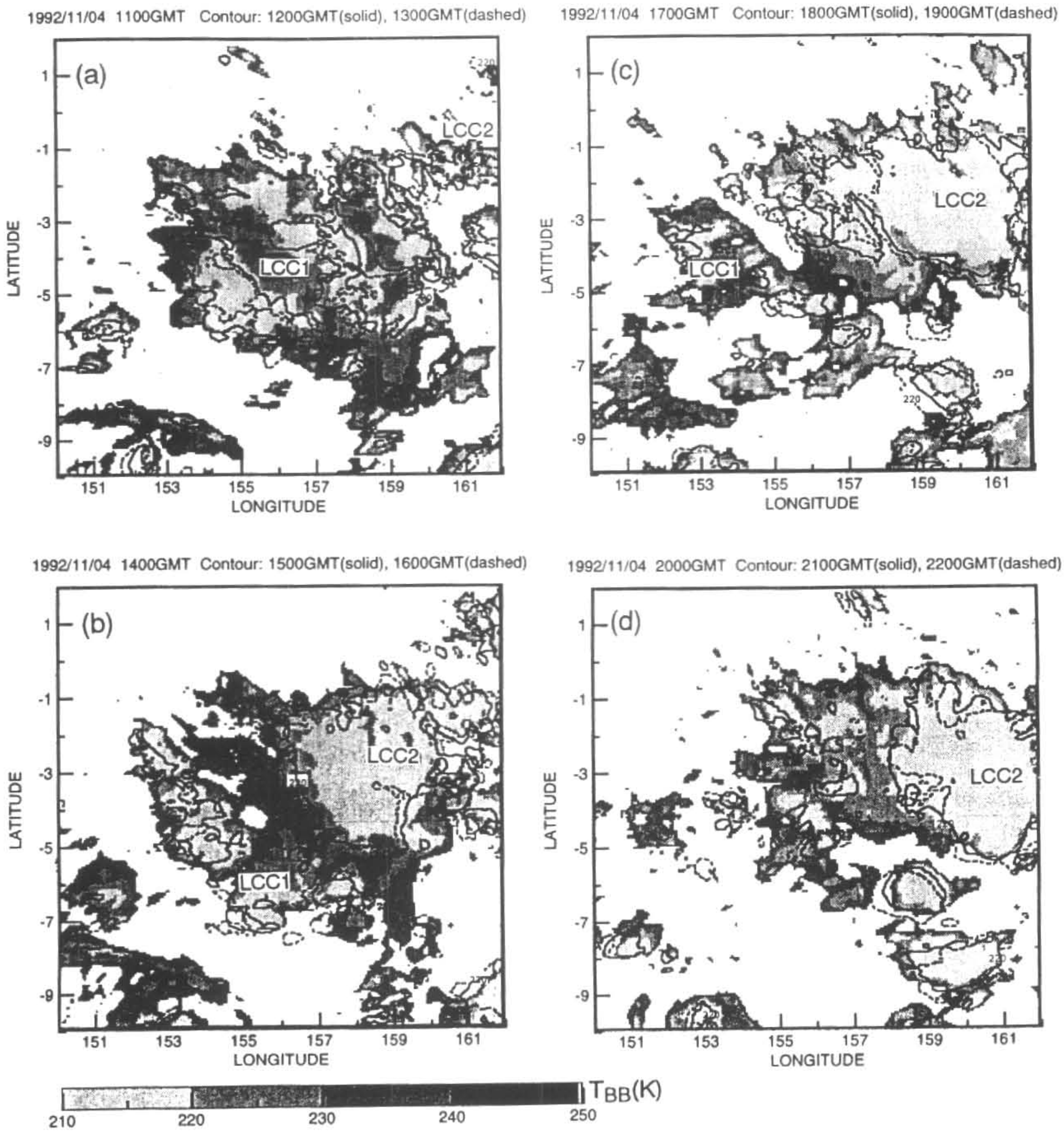

Fig.3. Same as Fig. 2 except for from 1100GMT to 2000GMT on 4 November

LCC3 and LCC4 (2000GMT on 4 November - 1600GMT on 5 November)—The LCC3 and LCC4 were developed in the dissipating stage of LCC2. As shown in Fig. 4(a), a few clouds were growing in the SW flank of LCC2, and moving towards SE at 0000GMT on 5 November, 1992. The clouds were combined to form LCC3 in the confined region of about 3°S-8°S, 151°E-159°E as shown in Fig. 4 (b). The LCC3 lasted about 21 hours and had a horizontal dimension of about 750 km. In the NW flank of LCC2, a few small regions of high TBB regions were analyzed behind the stratiform anvil of LCC2. With time of cloud cluster-like line shape (about 1100 km) named LCC4 was formed that joined with the stratiform anvil cloud LCC2 as shown in Fig. 4 (b). There were seldom low T_{BB} (<220 K) regions analyzed for LCC4. The properties of LCC4 differ from those of other LCCs.

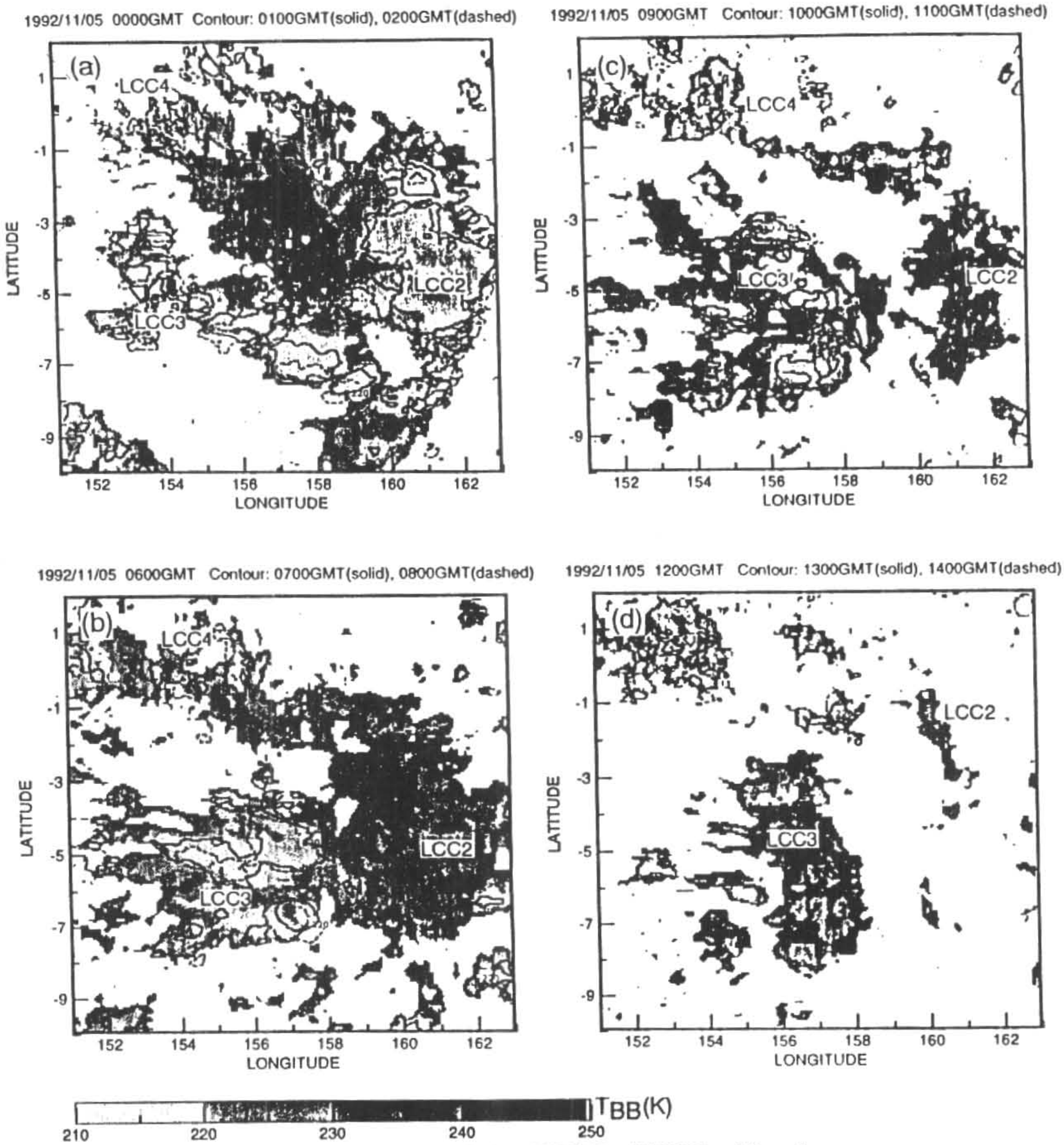

Fig. 4. Same as Fig. 2 except for from 0000GMT to 1200GMT on 5 November

The internal structure of LCC1, LCC2, LCC3 and LCC4 were analyzed by CST and are not explained here. To give a clear explanation that LCC4 is a non-precipitating cirrus shield and has no convective activity, the moisture field derived from GANAL data is documented in Fig. 5. The moisture field on surface (upper panel) is superimposed with surface pressure contours and wind field (arrows). The moisture field at 300 hPa (lower panel) is superimposed with wind field at the same level. It is seen that the moisture column was existed from bottom (lower-level) to top (upper-level) but there was no radar echo (not shown). It is also seen that the surface wind was weak and surface pressure was relatively low (Fig. 5) positioned in the location of LCC4. The upper level wind was relatively strong. These imply that relatively strong wind is essential to initiate convection besides of the moisturing condition.

Here, we may conclude that the LCCs are two types: one with apparent convective activity (*e.g.*, LCC1 or LCC2) and other that appears to be without convective activity (*e.g.*, LCC4).

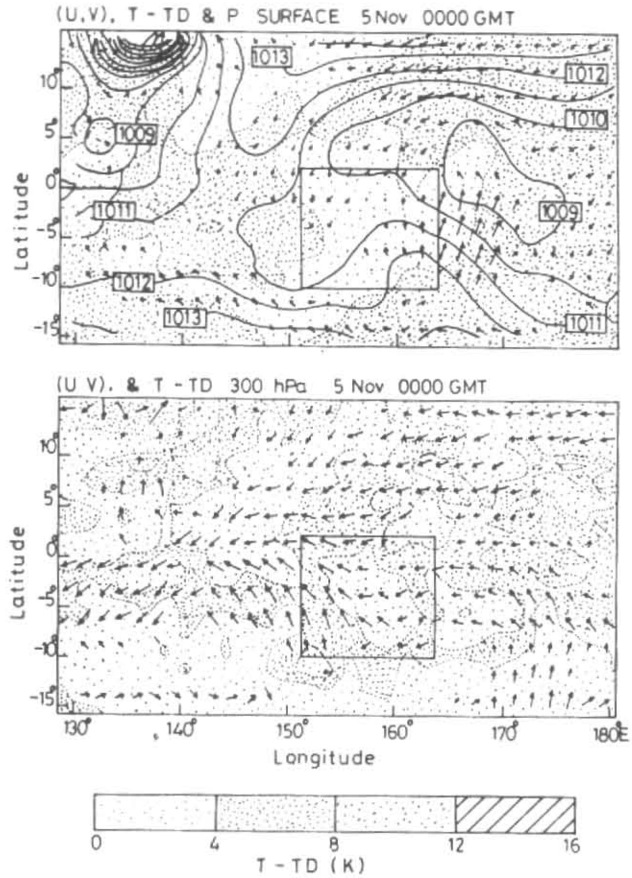

Fig. 5. GANAL data represented by the moisture field (T-TD) at the development (0000GMT on 5 November) of LCC4. The target area (2°N-10°S, 151°E-163°E)is outlined by a square box. Moisture field on surface (uer panel) is superimposed with surface pressure (contours) and wind field (arrows). Moisture field at 300 hPa (lower panel) is superimposed with wind field at the same level. The contour drawn for pressure as labelled in the figure in unit of hPa. Maximum length of the vector is 32 m/s

3.2. *Assignment of T_{BB} to define the cloud boundary*

It is interesting to investigate the threshold of the stratiform cloud region *i.e.*, the enclosed boundary of the cloud. Determining the particular T_{BB} value was attempted using temperature data on 3-12 November, 1992 at different levels. This value is very close to the stratiform threshold (Ts temperature identified by the CST (Islam *et al.*, 1995). As represented in Fig. 6, it was identified that T_{BB} below 230K is very close to Ts. This finding is very essential in understanding the development of clouds in the tropics, where the vertical structures of the clouds and atmosphere are different from the other regions of the world. The active (cold) and break (warm) periods are shown for Area B(5°N-5°S, 160°E-170°E). The downward arrows represent the internal break (warm) during the active period. The average value of T_{BB} <230K is represented by the dashed line. Values are plotted with reverse axis along the ordinate, so that low temperatures are above the dashed average line. As we see, the patterns of T_{BB} <230K and Ts were very close to each other for analyzed Area B. The same was found for Area A and Area KM (not shown). At some particular moments, Ts value was lower or higher than the TBB value. These lower and higher values correspond to the contribution of the convective and stratiform cloud components.

As was found the pattern of TBB ≤ 230K is very close to Ts value. Therefore, we may presume that the boundary of the cloud will be enclosed by this identified T_{BB}.

3.3. *Vertical structure of the clouds*

The RHI (Range Height Indicator) radar reflectivity is conventionally use to see the vertical structure of clouds. In this work we tried to use the satellite data to analyze the

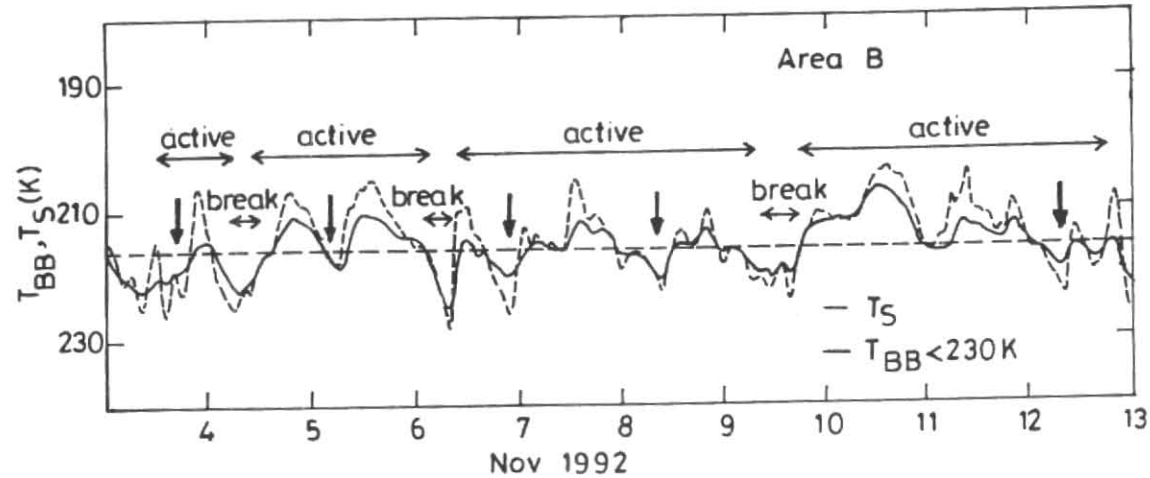

Fig. 6. Time sequence of the stratiform threshold temperature (Ts) identified by the CST and T_{BB} below 230K. Downward arrow represents the internal breaks (warm). The dashed line represents the average value of T_{BB} ≤230K

vertical structure of clouds where radar data are not available. The deviation of T_{BB} from the mean [ΔT_{BB} (K)] plays an important role in understanding the development of tropical clouds. The warm and cold regions were identified from ΔT_{BB}(K) . The amount of cloud at different level is shown in Fig. 7. The cloud amount termed as "cluster" determined from the consecutive one hour interval T_{BB} data was identified by a line (see legend of Fig. 7). The first cluster lasted 25 hours from 1000 GMT on 5 November, and the second cluster lasted 27 hours from 1100 GMT on 7 November. They seem to have been formed in the high T_{BB} regions and developed in the low T_{BB} region. After that they expanded their area and then decayed quickly. The third cluster lasted 37 hours from 1900 GMT on 9 November and showed a well developed tropical cloud cluster. It did not show any internal break *i.e.*, there was no internal break observed (Fig. 6) during the growth time of this cluster. Then it grew very smoothly and gradually from the high T_{BB} region to the low T_{BB} region and expanded its area step by step. At the first step, the cloud area increased a little but T_{BB} decreased rapidly meaning the cloud became tall. In the next step, the fact that it expanded its area even though the temperature did not vary indicates the cloud was becoming mature. After that cloud area increased, T_{BB} decreased and the cloud showed its maximum cloud top height before showing the maximum size in area. And then decayed and disappeared. This cloud system was observed one day later in Area KM (Area A), which cleared the westward movement of the cloud system.

Here, we found that the short-lived cluster developed rapidly and decayed quickly. In contrast, the long-lived cluster developed gradually and decayed slowly. Both types of clusters showed maximum cloud top height before showing maximum cloud area.

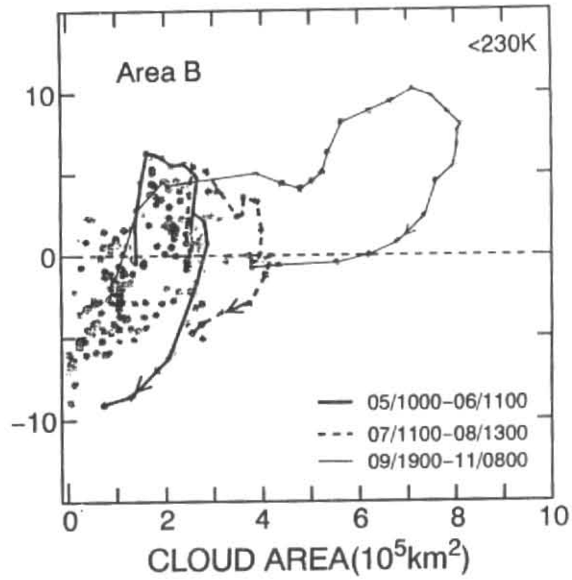

Fig.7. Distribution of cloud area for 10 days average *versus* T_{BB} in Area B. The development of three clusters is shown by three lines and their respective time. The ordinate represents the deviation of T_{BB} from the mean of T_{BB} ≤230K

4. Conclusions

It was found that large cloud clusters, having horizontal length 750-1150 km lasting 14-28 hours-period, were composed of several MCSs, and small cloud clusters having horizontal length >200 km that lasted 12 hours-period, contains just one MCS. One LCC (line shape) which developed in the high altitude contained no MCS, and was analyzed as a rare case during the study period.

A cloud was defined by the enclosed boundary of T_{BB} ≤ 230K to examine the vertical structure of the cloud clusters. Development process of the short lived (~ 1 day) and long lived (>1.5 days) cloud clusters were different even though both of them were born in the high T_{BB} region. The maximum cloud (cluster) top height was found 4-6 hours earlier than the maximum cloud (cluster) area.

Finally, it is considered that merging of clouds and cloud clusters which lasted several hours, identified by hourly T_{BB} organized to form the large cloud clusters.

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References

Houze, Jr. R.A. 1982, "Cloud cluster and large-scale vertical motion in the tropics", *J. Meteor. Soc. Japan*, **60**, 396-410.

Houze, Jr. R.A., 1989, "Observed structure of mesoscale convective systems and implications for large-scale heating", *Quart. J. Roy. Meteor. Soc.*, **115**, 425-461.

Houze, Jr. R.A. and Betts, A.K., 1981, "Convection in GATE", *Rev. Geophys. Space Phys.*, **16**, 591-576.

Islam, M.N., Uyeda H., and Kikuchi K., 1995, "Characteristics of tropical clouds and cloud clusters after defining a cloud boundary over the oceanic warm pool on November 3-12, 1992", Preprints: Annual confernce of Japan Meteorological Agency, **68**, 207.

Islam, M.N., Uyeda H. and Kikuchi K., 1997, "Characteristics of clouds and cloud clusters obtained by radar and satellite data during the TOGA-COARE IOP", *J. Fac. Sci.*, Hokkaido Univ. Ser VII.(Geophysics), **10**(2), 189-223.

Webster, P.J. and Lukas, R., 1992, "TOGA-COARE: The coupled ocean-atmosphere response experiments", *Bull. Amer. Meteor. Soc.*, **72**, 1481-1505.