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Movement and Propagation of Clusters of Cumulonimbus Clouds Associated with Heavy Rainfall

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Abstract

To study the behavior of clusters of cumulonimbus clouds associated with heavy rainfalls, radar observations were carried out from 25 June to 11 July 1984 in the northwestern part of Kyushu Island. Two clusters which were formed almost at the same place and moved in different directions (case 1), and a line-shaped cluster which moved quite slowly (case 2) were observed. As a result of detailed analyses of them, it was found that the collision of outflow from convective clouds with environmental surface wind played a role as a trigger to form new updrafts which develop into convective clouds. This causes the propagation which is related to the movement of clusters. Analyses revealed the difference in relative importance of outflow and surface wind to new updraft formation in two cases. The role of outflow was greater than that of surface wind in case 1, however, the role of surface wind was greater in case 2.

1. Introduction

There are two types of heavy rainfalls in Japan, one is the orographic rainfall in which rainfall amount during a long period is great and the other is rainfall by meso-β scale clusters of cumulonimbus clouds in which rainfalls precipitate in short periods. Heavy rainfall in the Baiu frontal zone comes under the latter type.

Many studies have been made about heavy rainfall in the Baiu frontal zone and they are summarized as reports by Japan Meteorological Agency (1974) and Meteorological Society of Japan (1979). However, most of them were studied from aspects of synoptic scale or meso-α scale, and studies on meso-β scale corresponded to clusters of cumulonimbus clouds have been scarcely revealed.

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Clusters of cumulonimbus clouds are of a similar scale to severe storms such as thunderstorms in the United States, but they usually produce heavy rainfalls in Japan where the climate is generally more humid than in the United States.

It is said that the movement of convective clouds is deeply related to mean wind in cloud layer or 700 mb-wind as a steering level. However, the difference between the direction of movement of convective clouds and wind direction are often observed. Newton and Fankhauser (1964) pointed out by water-budget consideration that the movement of clouds are dominated by the spatial scale of clouds. Charba and Sasaki (1971) observed the storms separated by Mugnus effect. Yagi et al. (1976), Yagi (1979) and Bluestein and Sohl (1979) stated that the storm movement is related to the structure of precipitation clouds and convective activity.

Some observations show that the movement of clusters which are the complex of cumulonimbus clouds does not always coincide with the movement of individual clouds within the clusters. The discrepancy between them is caused by the new cloud formation which is called the effect of propagation (Newton and Fankhauser, 1975). The movement of clusters depends on the propagation in addition to the movement of individual clouds. There is no valid theory to explain the mechanism of propagation. As the rainfall area is formed along the path of clusters of cumulonimbus clouds, the movement of clusters is more important than that of individual clouds in the case of heavy rainfall events. If the direction of movement of individual clouds opposes the direction of propagation, the movement of clusters becomes slow or stationary, and it leads to localized heavy rainfall.

Therefore, it is quite important for the understanding of the heavy rainfall events to observe the behavior of clusters of cumulonimbus clouds using high resolutional radars. In this paper, the results of radar observations which were carried out to observe the clusters of cumulonimbus clouds associated with heavy rainfall during the Baiu season are described. Discussion is focused on the relation between the behavior of individual clouds and the movement of clusters.

2. Observation area and method

The observation was carried out from 25 June to 11 July 1984 in the northwestern part of Kyushu Island where disastrous heavy rainfall events often occur during the Baiu season. This was the co-operative observation with Nagoya University and Kyushu University.

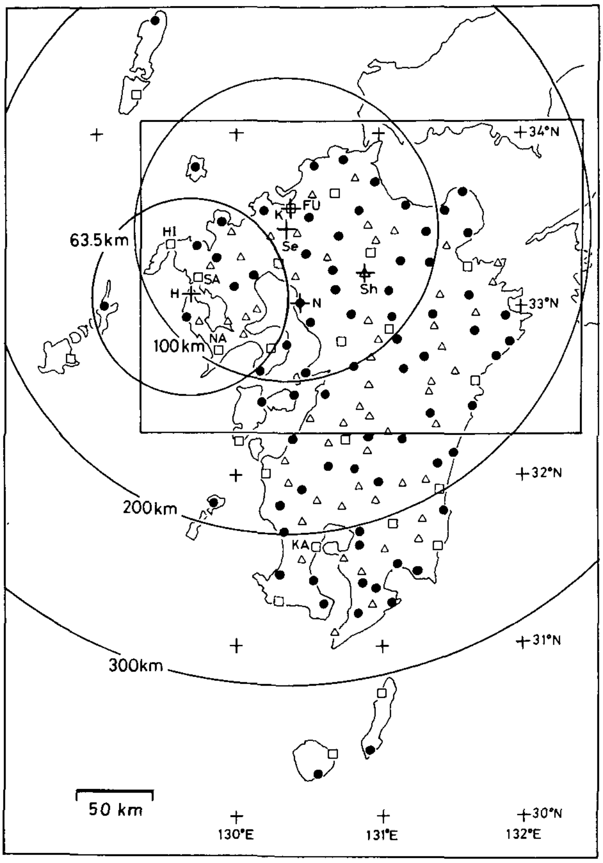

Fig. 1 Map of observation area. + represents the radar sites, circle and rectangle represent radar coverage areas, respectively. □, ● and △ represent the observation points by J.M.A.. NA, SA, HI, FU and KA represent the observation points at Nagasaki, Sasebo, Hirado, Fukuoka and Kagoshima which appear in later discussions.

Figure 1 shows the observation area. An X-band radar of Hokkaido University (hereinafter H.U. radar) was set up at Mt. Kokuzo (h=307 m) in Saikai-cho, Nagasaki prefecture (H in Fig. 1). Its coverage area was 90 km in radius (digital data recording area was 63.5 km in radius). Data forms are three dimensional digital data obtained by changing the elevation angle from 0 to 20 degree (maximum 35 degree) at intervals of 10 or 20 minutes and PPI photographs at 1.0 elevation angle at intervals of 10 minutes. The original digital data have a resolution of 250 m in radius-vector direction and 1.2 degree in azimuthal direction, and it is converted to x-y coodinate data of 1×1 km mesh in a horizontal direction and 500 m mesh in a vertical direction for analyzing. Processing for removing ground clutters (M.T.I.) and range correction are done.

To obtain information of rainfall areas on a larger scale, data of Mt. Seburi radar (Se) of Fukuoka District Meteorological Observatory and Mt. Shaka radar (Sh) of Kyushu Regional Construction Bureau, Ministry of Construction were used. Data form of Mt. Seburi radar is PPI photographs at intervals of 2 minutes within a 300 km radius which is presented by intensity of 3 levels, and that of Mt. Shaka radar is 3×3 km mesh digital data at intervals of 10 minutes in the rectangle in Fig. 1 which is presented by intensity of 9 levels. To examine the reflectivity factor obtained by radar, raindrop size distribution was observed by filter paper method at radar site (H) and Sasebo (SA) which was located 15 km northeastwards of the radar site. And also two raingauges were set up at 1 km intervals from each other apart from Sasebo Weather Station in Sasebo city.

Surface meteorological data such as rainfall amount, wind direction, wind speed, temperature and pressure obtained by Japan Meteorological Agency network were used. In Fig. 1, □ represents meteorological observatories or weather stations, ● and △ represent AMeDAS stations, respectively. And the upper air data at Fukuoka (FU) and Kagoshima (KA) were used to analyses.

3. Results

3.1 Case 1 : 11 July 1984

The Baiu front moved southward and passed over Kyushu Island from 0300 to 1200 on 11 July 1984. Several radar echoes associated with the Baiu front were observed. Figure 2 shows the echo photographs by Mt. Seburi radar which illustrate the movement of such echoes. Range circles are drawn every 50 km. The gray scale indicates Weak, Moderate, Strong echoes which correspond roughly to >1 mm/h, >4 mm/h, >16 mm/h, respectively.

The ehco (A in Fig. 2) which appeared on the west coast of northwestern Kyushu Island at 0440 moved southward and developed into greater echo. After 4 hours, the echo (B), which appeared almost at the same place as A appeared, moved eastward. And the echo (C) which appeared ahead of B moved in a northeastwardly direction. Figure 3 shows the movement of echoes A, B and C, and the positions of the Baiu front and Low. As it was found by high resolutional H.U. radar that these echoes are the complex of smaller echo cells, they are called hereinafter the echo clusters in contrast to individual cells.

Detailed analyses are made on cluster A and cluster B which moved within

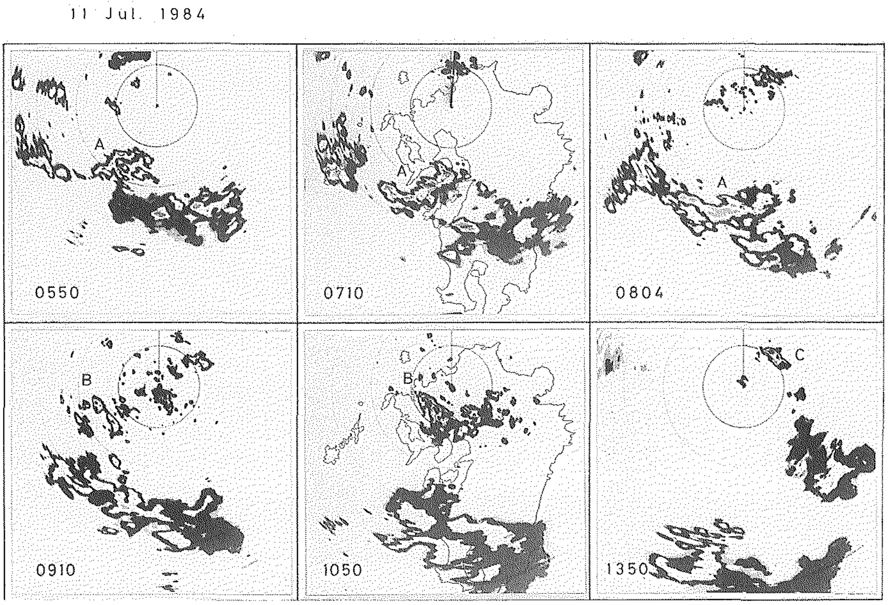

Fig. 2 Time sequence of echo photographs by Mt. Seburi radar on 11 July 1984. Range circles are drawn every 50 km.

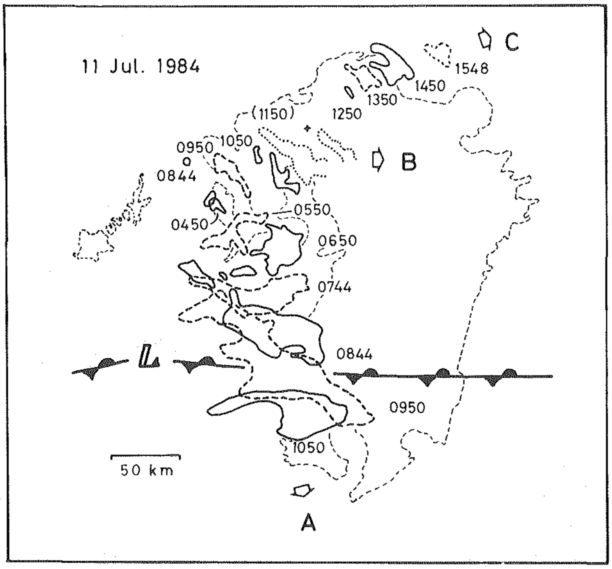

Fig. 3 Composed echo map at every 1 hour by Mt. Seburi radar. Echoes indicate greater intensity than Moderate (only 1150 and 1250 of cluster B indicate greater intensity than Weak). Low and Baiu front indicate the position at 0900.

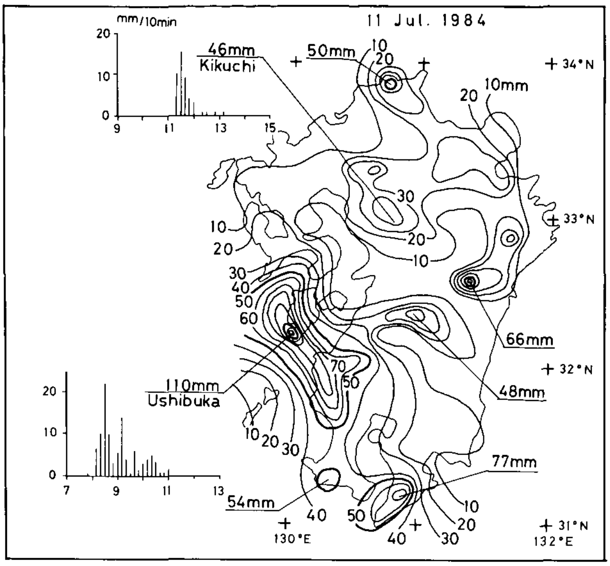

Fig. 4 Distribution of daily rainfall amount and time variations of 10 min. rainfall amount at Kikuchi and Ushibuka.

the coverage area of H.U. radar. Data of Mt. Seburi radar are used for cluster A and data of Mt. Shaka radar are used for cluster B to determine the movement of clusters. It was found that the movement of cluster A is 6.2 m/s to 160 degree, and that of cluster B is 7.2 m/s to 90 degree. As mentioned above, the two clusters A and B which were formed almost at the same place moved in different directions.

Figure 4 shows the daily rainfall amount of 11 July 1984 and time variations of 10 minute rainfall amount at typical stations. Most of the rainfall amount of 110 mm at Ushibuka was brought about by passing of cluster A during the period from 0800 to 1100. Rainfall area around Kikuchi was brought about by clusters B and C. Thus, it can be said that the rainfall area reflects the passing (movement) of clusters.

Rainfall amount by cluster A is greater than that by clusters B and C. This was caused by the difference of the spatial scale between clusters. It is suggested that the difference of development was related to the condition of stratification. Upper air data revealed convective unstable stratification at both Fukuoka and Kagoshima and the unstable layer was higher at Kagoshima than that of Fukuoka at 0900 on 11 July 1984.

Next, the behavior of individual cells which compose clusters are examined

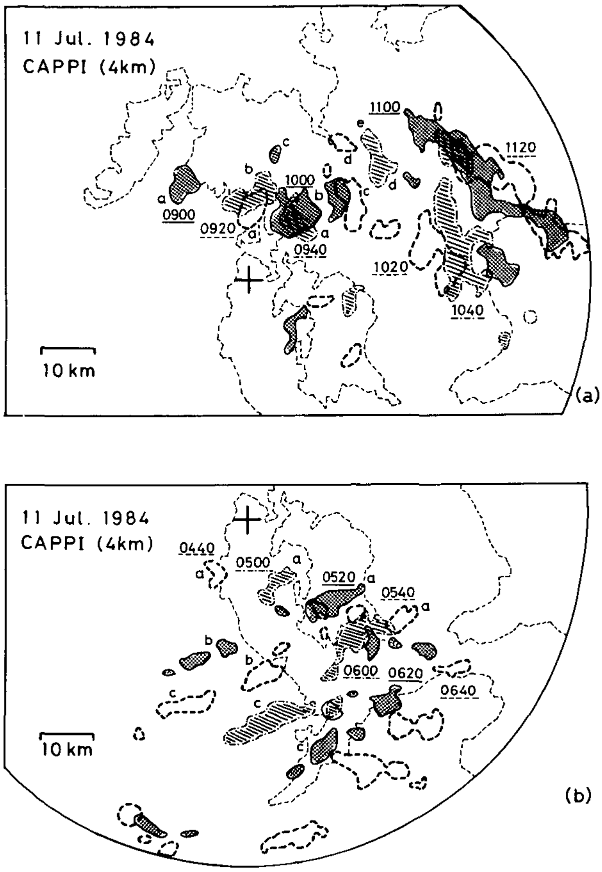

Fig. 5 Composed echo map at every 20 minutes at 4 km-level CAPPI by H.U. radar. Echoes indicate greater intensity than 30 dB(Z). (a) shows cluster B and (b) cluster A, respectively.

by using data of H.U. radar. Echoes are shown in Fig. 5a for cluster B and in Fig. 5b for cluster A, respectively. To distinguish the cells, only part of the echoes which have an intensity greater than 30dB (Z) are shown at 20 minute intervals. And each cell is indicated by an alphabet figure on the basis of cell tracing using data at 10 minute intervals.

Individual cells moved east-southeastward and new cells were formed on the southwestern flank of pre-existing cells within cluster A which moved southward. For instance, a new cell b appeared on the southwestern flank of pre-existing cell a at 0520, and cell c appeared on the southwestern flank of cell b at 0540. Thus, the movement of the cluster was more southward than the movement of individual cells because of new cell formation on the right (southwestern) flank of pre-existing cells.

Within cluster B which moved eastward, individual cells also moved east-southeastward. However, the new cells were formed on the northwestern flank of pre-existing cells. For instance, a new cell b appeared on the northwestern flank of pre-existing cell a at 0940, and cell c appeared on the northwestern flank of cell b at 1000. Thus, the movement of cluster was more northward than the

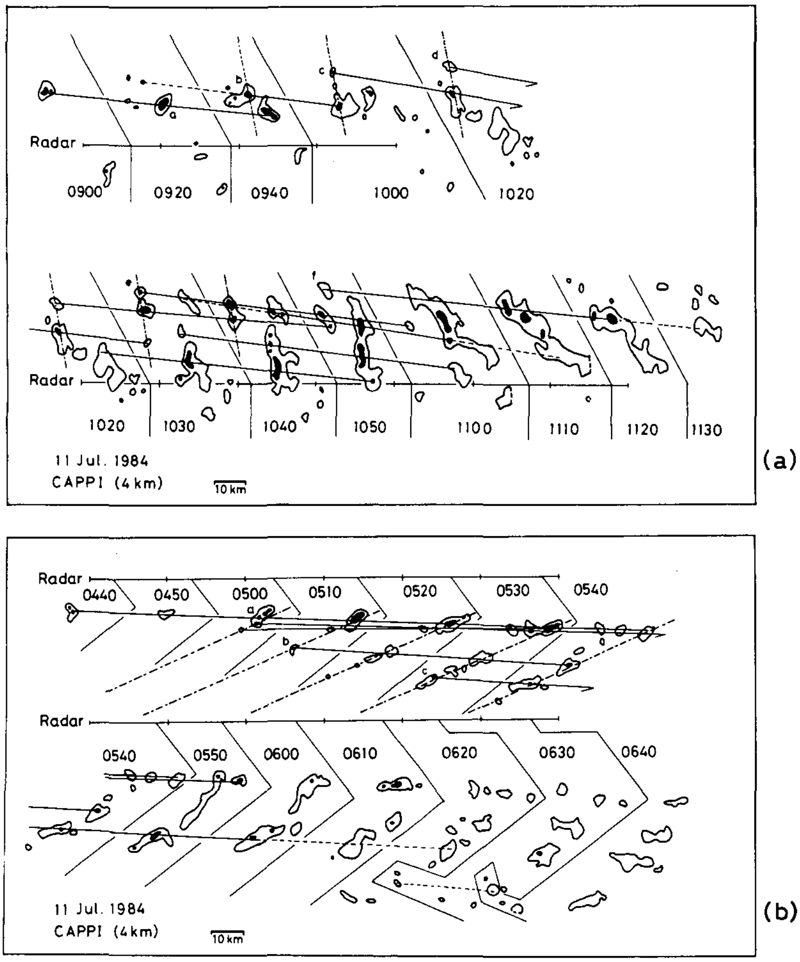

Fig. 6 Time sequence of echoes. Contours are drawn every 5 dB beginning at 30 dB(Z). Chain lines correspond to the position of vertical cross section in Fig. 7. (a) shows cluster B and (b) cluster A, respectively.

movement of individual cells.

In order to determine the movement of individual cells, movement of each cell within clusters A and B were averaged. It was found that the movement of individual cells within cluster A is 10.0 m/s to 104 degree, and that within cluster B is 9.7 m/s to 115 degree. These are compared with the vertical wind distribution at Kagoshima at 0300 for cluster A, at Fukuoka at 0900 for cluster B, respectively. The results show that the movement of individual cells almost coincides with wind at 600 mb height in each case. Thus, it is considered that individual cells move in the direction of the wind in cloud layer.

Next, detailed analyses are made on the process of new cell formation. Figure 6a and Figure 6b show the north-south component of movement of cluster B and cluster A, respectively. In these figures, echoes by H.U. radar are shifted to the right at every 10 minutes (every 20 minutes from 0900 to 1020). Contours are drawn every 5 dB beginning at 30 dB(Z). To identify the individual cells, the same cells are connected with each other by solid lines. While the

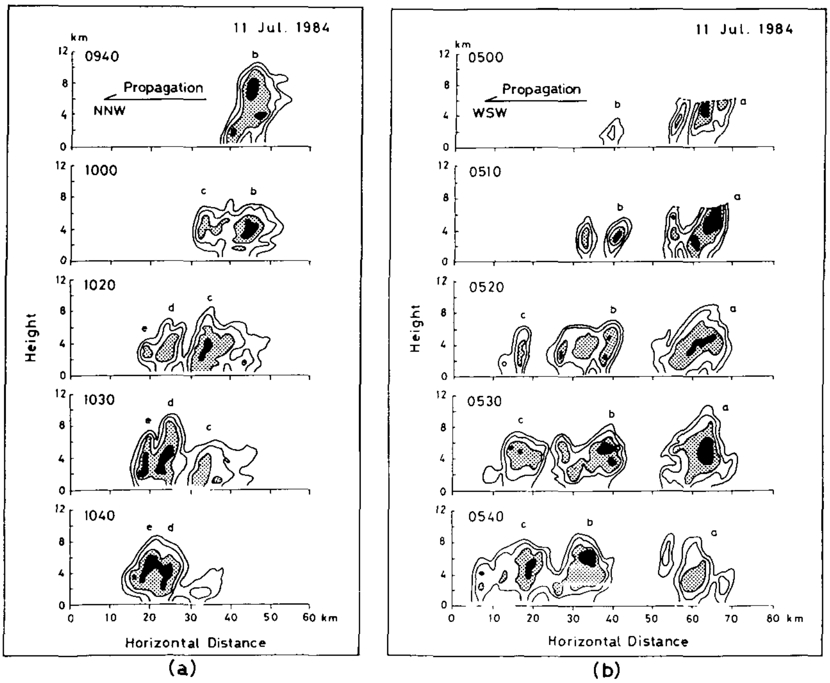

Fig. 7 Time sequence of vertical cross sections along the chain lines in Fig. 6. Contours are drawn every 5 dB beginning at 20 dB(Z). (a) shows cluster B and (b) cluster A, respectively.

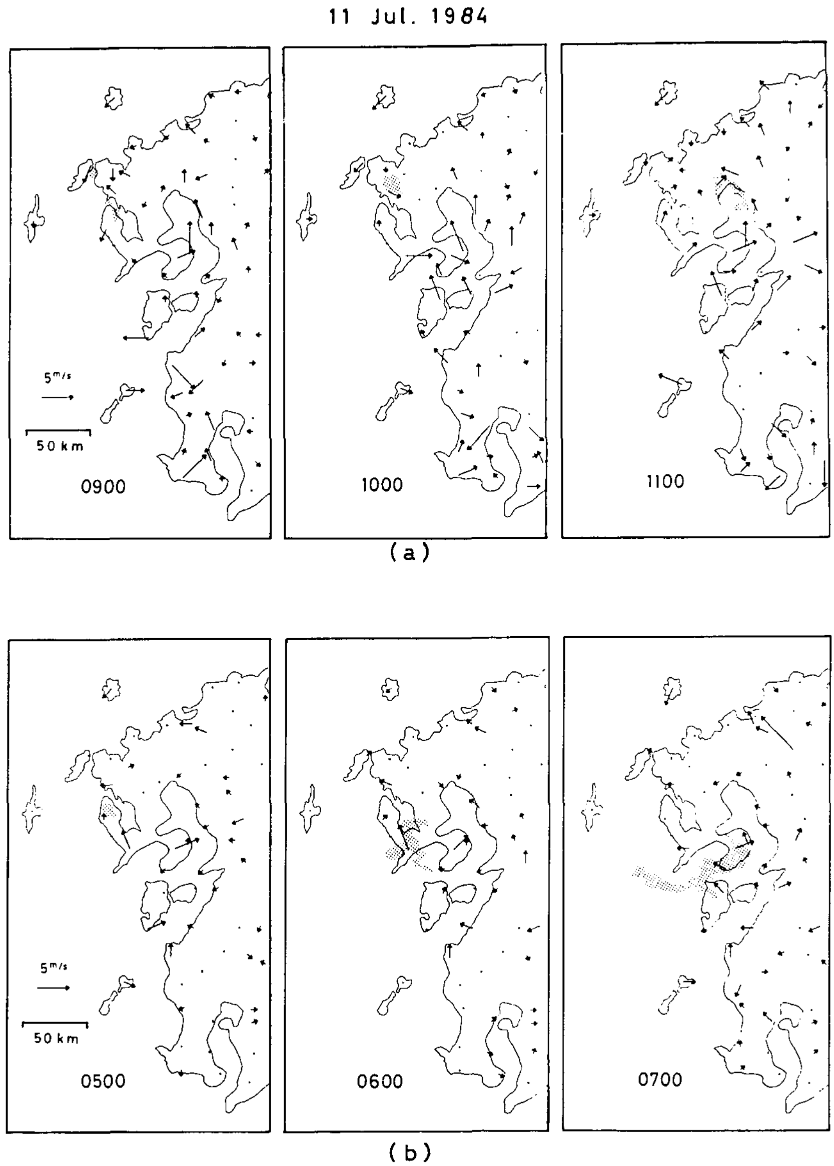

Fig. 8 Surface wind distribution and echoes with greater intensity than Moderate by Mt. Seburi radar (stippled). (a) shows cluster B and (b) cluster A, respectively.

movement of individual cells have a southward component within both clusters A and B, the directions of the new cell formation are different between clusters A and B. This causes to the discrepancy of movement of cluster between A and B.

Figure 7 shows the vertical cross sections along the chain lines in Fig. 6. Contours are drawn every 5 dB beginning at 20 dB(Z). In order to illustrate the process of new cell formation, the position of the oldest cells are fixed at the right end of horizontal axis, and the direction of new cell formation (propagation) are taken on the left hand side. Cyclic variation of cells which caused by new cell development and older cell dissipation is clearly seen, especially in the case of cluster B (Fig. 7a). A noticeable feature on these figures is the difference of distance between new cells and pre-existing cells. This was related to the difference of scale of propagation between clusters A and B.

As mentioned above, it is found that clusters moved in different directions because of the difference of direction of the new cell formation in spite of the same direction of movement of individual cells within clusters. That is, the movement of clusters depends on the effect of propagation.

Next, the relationship between propagation and surface wind is examined. Surface wind distribution obtained by AMeDAS network are shown in Fig. 8 in which echoes of clusters A and B by Mt. Seburi radar are superimposed at 1 hour intervals. In order to show clusters clearly, Weak echoes (<4 mm/h) are omitted. In Fig. 8b, the direction of the surface wind has a southern component at several points which are located on the southern side of cluster A. On the other hand, the direction of surface wind has a northern component at several points which are located on the northern side of cluster B (Fig. 8a). Thus, it is found that the direction of propagation coincides with the direction of the surface wind.

As compared with the location of the Baiu front, the wind distribution is not typical regarding frontal character. Surface weather charts revealed that the frontal activity tended to be weakened during this period. These facts mean that the movement of cluster A is not caused by the southward motion of the Baiu front and that the more localized wind distribution dominates the movement of clusters.

In the following section, the case study in which the distribution and strength of surface wind is different from the case in this section is demonstrated.

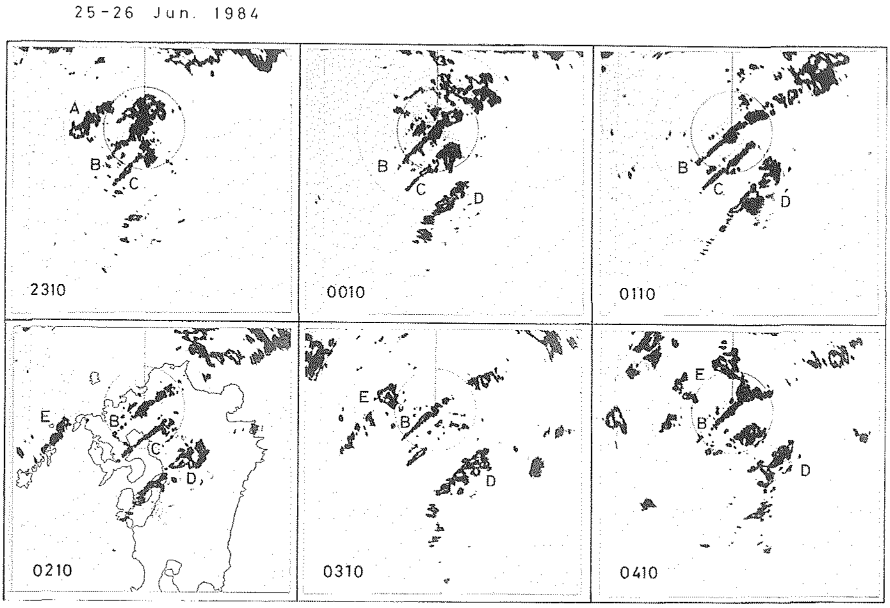

Fig. 9 Time sequence of echo photographs by Mt. Seburi radar on 25 and 26 June 1984. Range circles are drawn every 50 km.

3.2 Case 2 : 26 June 1984

The Baiu front located to the north of Kyushu Island during the period from 2100 on 25 June to 1500 on 26 June 1984. Based on both data of Fukuoka and Kagoshima, stratification was strongly convective instability. Figure 9 shows echo photographs by Mt. Seburi radar at every 1 hour. The southern edge of the echo associated with the Baiu front and several line-shaped echoes are found in these photographs. Clusters B and C remained about 4 hours from 2300 on 25 June, and cluster E moved quite slowly in a northeastwardly direction. As cluster E moved within the coverage area of H.U. radar, detailed analyses are made.

The rainfall area by these clusters reflects their line-shaped pattern as seen in Fig. 10 which is a 12 hourly rainfall amount during the period from 2000 on 25 June to 0800 on 26 June. Rainfall at Kamigoto was caused by cluster E. However, the rainfall amount is not so great and rainfall intensity is rather weak.

Figure 11 illustrates the echoes of cluster E by H.U. radar at 0200 (stippled) and 0300. Only parts of echoes which are of greater intensity than 25 dB(Z) are

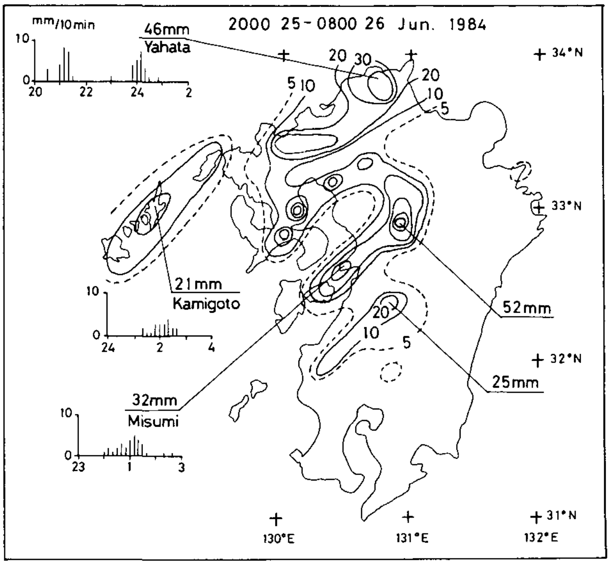

Fig. 10 Distribution of 12 hourly rainfall amount and time variations of 10 min. rainfall amount at Yahata, Kamigoto and Misumi.

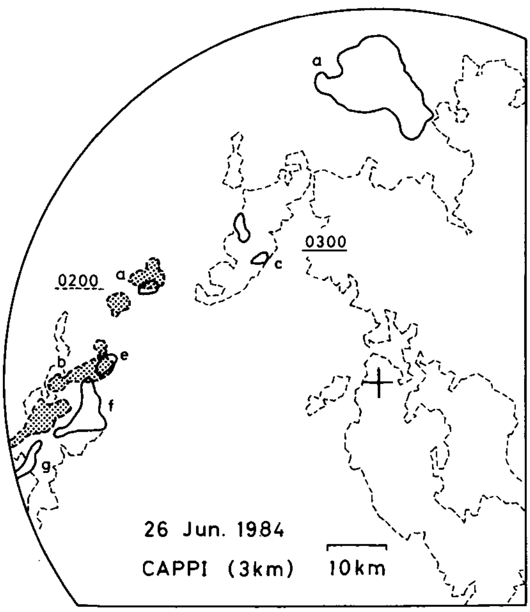

Fig. 11 Composed echo map of 0200 (stippled) and 0300 at 3 km-level CAPPI by H.U. radar. Echoes indicate greater intensity than 25 dB(Z).

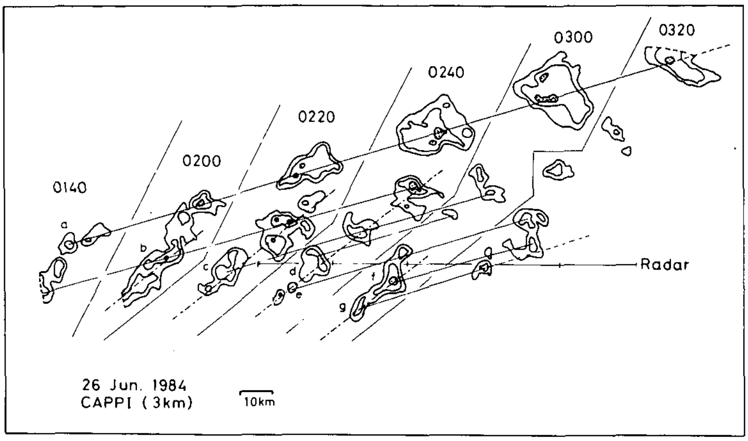

Fig. 12 Time sequence of echoes. Contours are drawn every 5 dB beginning at 20 dB(Z). Chain lines correspond to the position of vertical cross section in Fig. 13.

shown. And each cell is distinguished by an alphabet figure on the basis of cell tracing using data at 20 minute intervals. The movement of cluster E is determined to be 8.4 m/s to 54 degree as the movement of the cluster center. And the averaged movement of individual cells is determined to be 14.2 m/s to 52 degree. As compared with the vertical wind distribution at Fukuoka at 0300, the movement of individual cells almost coincides with the wind at 700 mb height. This means that the individual cells move in the direction of the wind in cloud layer.

New cells were formed on the southwestern edge of line-shaped cluster in this case. Figure 12 shows the north-south component of movement of cluster E by shifting to the right at 20 minute intervals. Contours are drawn every 5 dB beginning at 20 dB(Z). As new cells were formed near the outer edge of digital data, echo photographs by H.U. radar (90 km in radius) are used to verify the new cell formation. The same cells are connected by solid lines. A new cell c appeared on the southwestern flank of pre-existing cell b at 0220, and cell e appeared on the southwestern flank of cell d at 0240. As a result, the southwestern edge of cluster E did not move and the movement of the whole cluster became quite slow.

Figure 13 shows the vertical cross sections along the chain lines in Fig. 12. Contours are drawn in the same way as Fig. 12. The position of cell b is fixed at the right end of horizontal axis, and direction of propagation is taken on the left hand side. Broken lines represent the outer limit of digital data. It is

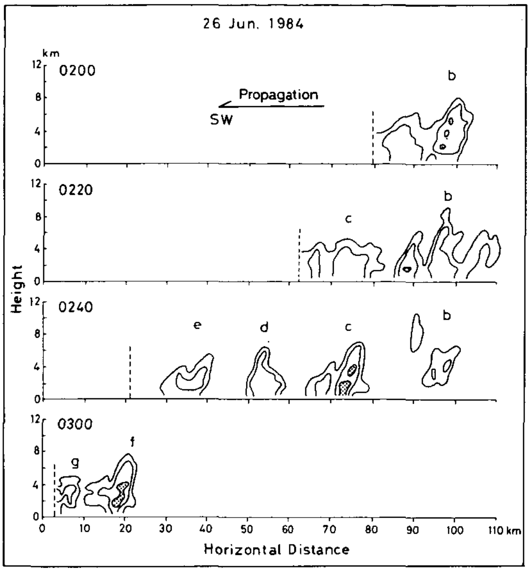

Fig. 13 Time sequence of vertical cross sections along the chain lines in Fig. 12. Contours are drawn every 5 dB beginning at 20 dB(Z).

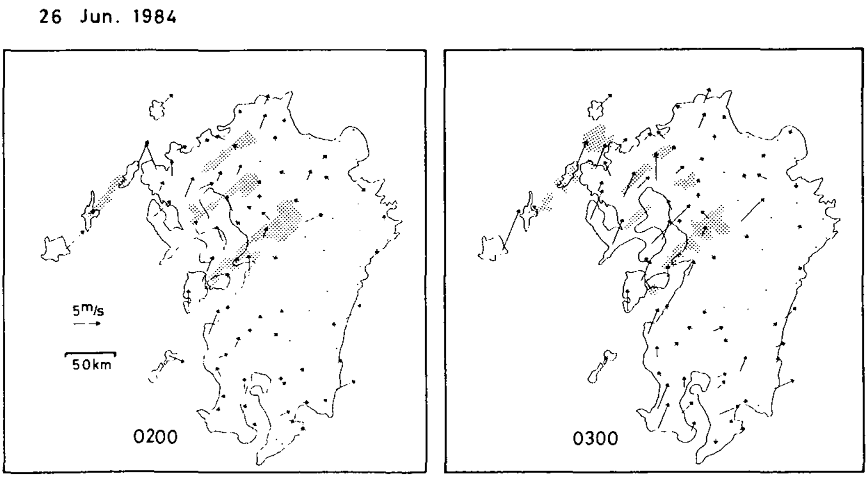

Fig. 14 Surface wind distribution and echoes greater intensity than Weak by Mt. Seburi radar (stippled).

found that new cells were formed at regular intervals. However, the radar reflectivity factor of individual cells is rather weak. This fact coincides with the weakness of rainfall intensity.

In order to examine the relationship between the propagation and surface wind, Fig. 14 shows surface wind distribution and echoes of clusters by Mt. Seburi radar at 0200 and 0300 on 26 June 1984. The southwestern wind were widely distributed around the northwestern part of Kyushu Island where clusters B, C, D and E existed. It is suggested that these southwestern winds are directly caused by the Baiu front which was located to the north of Kyushu Island. In this case as the same as in the previous case, the direction of propagation coincides with the direction of the surface wind.

In the previous case, the localized distribution of surface wind was related to the propagation. However, the surface wind was distributed widely, associated with the Baiu front and the wind speed was generally greater in this case. And the radar reflectivity in this case is less than that in the previous case. Therefore, it is suggested that the same mechanism as in the previous case played in a different manner to bring about new cell formation in this case. This difference is discussed in the following section.

4. Discussions

Table 1 summarizes the movement of individual cells and the clusters determined in the previous section. In this table, the clusters A and B described in section 3.1 are represented as 1A and 1B, respectively. And the cluster E described in section 3.2 are represented as 2E. Figure 15 shows the vector indication of the movements of individual cells and clusters. The vector of propagation is expressed as the remainder between the vector of movement of individual cells and of clusters.

The difference of the distance between the new cells and pre-existing cells was noted in the previous section. This fact is shown as the difference of scale

Table 1 Direction and speed of movement of individual cells and cell clusters.

Case	Date	Time	Cell Movement		Cluster Movement	
			Direction	Speed	Direction	Speed
1A	11 Jul. 1984	0440-0640	104°	10.0 m/s	160°	6.2 m/s
1B	11 Jul. 1984	0900-1130	115	9.7	90	7.2
2E	26 Jun. 1984	0140-0320	52	14.2	54	8.4

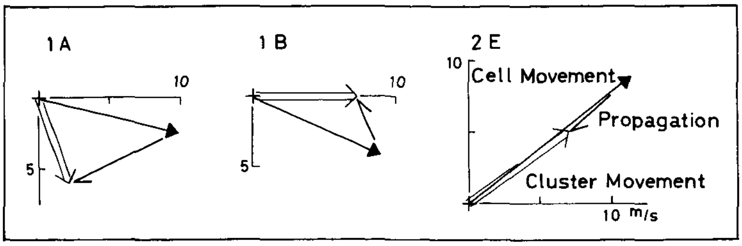

Fig. 15 Relationship among the movement vector of individual cells, of cell clusters and vector of propagation.

of propagation vector between clusters 1A and 1B in Fig. 15. It is suggested that the difference arises from the difference in surface conditions. That is, cluster 1A moved above the sea surface but cluster 1B moved above the land surface.

Next, the mechanism of propagation is described. It is well known that the collision of outflow from convective clouds with environmental air affects propagation (Weaver, 1979 ; Weaver and Nelson, 1982). Observational results in this paper revealed the coincidence of direction of propagation and direction of surface wind. The effect of collision is extremely intensified and new cells are favourably formed when the direction of the low-level wind is opposite with the direction of the outflow. It is suggested that propagation occurs toward the direction of the surface wind by the collision of outflow with the surface wind. Thus, the movement of clusters is inclined to the direction of propagation from the direction of movement of individual cells.

Figure 16 shows the time variation of maximum radar reflectivity factor near the center of each cell using data at 4 km-level CAPPI by H.U. radar. Cyclic variation of reflectivity of each cell is clearly found in the case of cluster 1B (Fig. 16b). That is, the development and dissipation of cells occur successively. And the maximum value of reflectivity decreases gradually in a whole cluster. In the case of cluster 1A (Fig. 16a), the tendency is similar to the case of cluster 1B, although the cyclic variation is less obvious. The lifetime of individual cells is longer than the case of cluster 1B. This is possibly related to the greater development of cluster 1A which causes a larger rainfall amount.

However, no cyclic variation is found in the case of cluster 2E (Fig. 16c). And the reflectivity is less than the cases of 1A and 1B. These facts suggest the possibility of difference in the mechanism of propagation.

Then, the factors which are related to the strength of outflows are described as follows. Outflows are caused through the spreading of cold downdraft

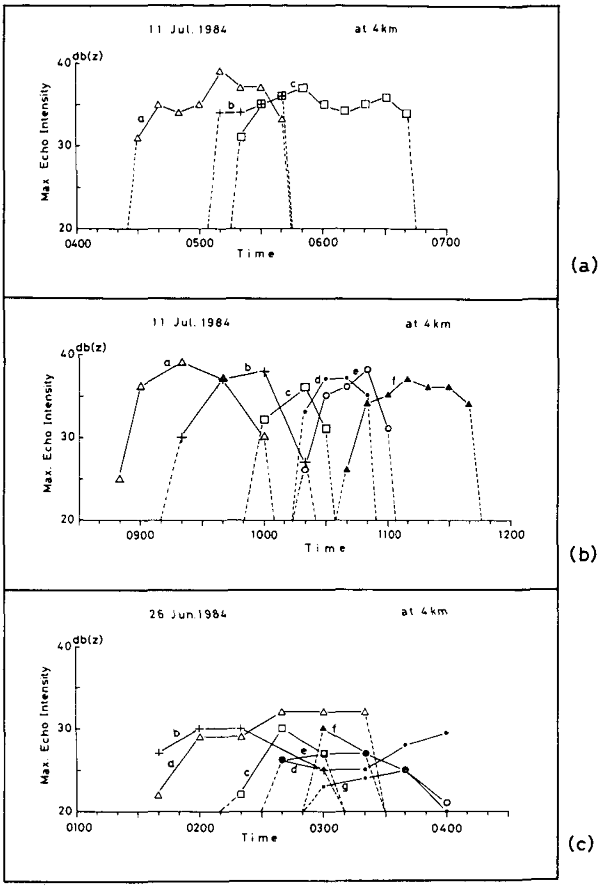

Fig. 16 Time variations of maximum value of radar reflectivity factor near the center of each cell. (a) shows cluster 1A, (b) cluster 1B and (c) cluster 2E, respectively.

induced by precipitation at the ground surface. An increase in air density resulting from evaporation cooling of raindrops and a downward drag force produced by falling raindrops produce a downdraft in precipitating clouds (Takeda, 1966). That is, the strength of downdraft depends on the effect of evaporation and the amount of raindrops. As the climate is generally humid in Japan, the effect of evaporation is rather small and the strength of downdraft is roughly corresponds to the rainfall intensity. And the strength of outflow depends on the strength of downdraft with additional effects of surface friction. Thus, it is suggested that the strength of the outflow is related to the rainfall intensity. And rainfall intensity can be seen by using radar reflectivity.

Following the discussion above and relatively weaker radar reflectivity (<32 dB(Z)), it is considered that the outflow (downdraft) was not so strong in the case of cluster 2E. On the other hand, the surface wind speed was greater than that of cases of 1A and 1B. Thus, in the case of 2E, it is suggested that the role of surface wind is relatively greater than the role of the outflow to new

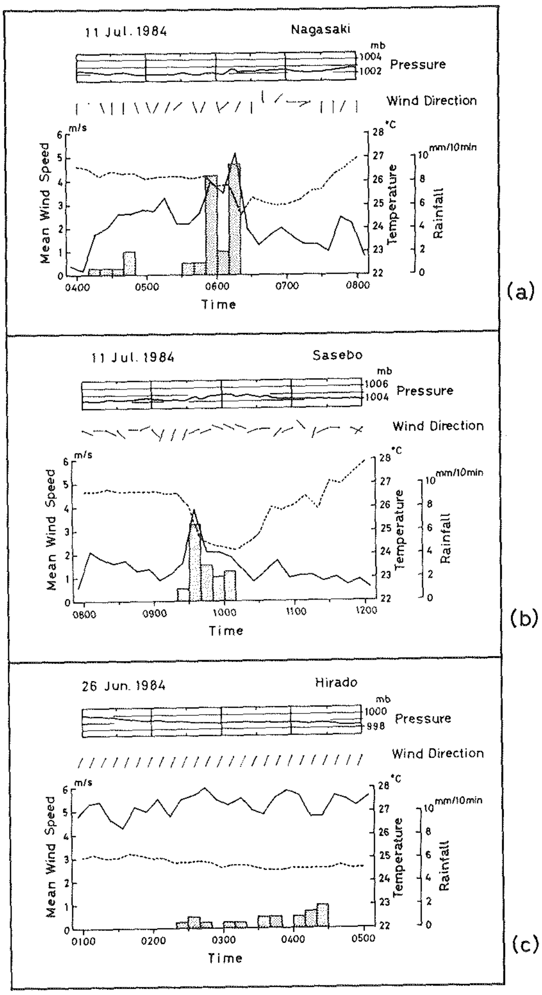

Fig. 17 Time variations of 10 min. mean wind speed (solid line), surface temperature (broken line), 10 min. rainfall amount (stippled bar), pressure and wind direction. (a) shows the records at Nagasaki for cluster 1A, (b) at Sasebo for cluster 1B and (c) at Hirado for cluster 2E, respectively.

cell formation. And obscurity of cyclic variation (Fig. 16c) can be explained by this consideration. That is, as the role of outflow is relatively smaller, no characteristic variation is shown on the radar reflectivity which is the one of the strength indices of the outflow (downdraft).

Existence of the outflow is examined on Fig. 17 which shows the time variation of surface data at three observation points. During the period from 0610 to 0620, intense rainfall (stippled bar) and the peak of wind speed (solid line) are shown in Fig. 17a which corresponds to the passing of cluster 1A. The maximum wind speed of 11.7 m/s was recorded on anemogram at Nagasaki. Temperature drop (broken line) and pressure jump are also shown. During the period from 0930 to 0940 in Fig. 17b which corresponds to cluster 1B, similar changes in rainfall amount, wind speed (maximum 9.7 m/s), temperature and pressure are shown. These data clearly reveal the existence of outflow about 10 m/s in speed akin to gust fronts. Thus, the outflow from clouds played an important role in the new cell formation in cases of 1A and 1B.

In the case of cluster 2E, rainfall beginning at 0220 was less intense (Fig. 17c). On the other hand, surface wind speed in greater, and no characteristic feature of existing of outflow is recognized. As Hirado located at the north-eastern edge of cluster 2E, the outflow may not be found because of weakening of cells. However, it is not suggested that the outflow developed sufficiently in the case of 2E.

These data coincide with the consideration regarding the difference of the mechanism of propagation. That is, there is a difference of relative importance of outflow and surface wind on the new cell formation (propagation).

As the rainfall area is formed along the path of clusters, the movement of clusters is more important than that of individual cells for understanding the rainfall area formation, in contrast with the case of hailstorms in which the movement of individual cells is more important. The movement of the clusters is affected by the propagation and the movement of individual cells as shown in Fig. 15. However, the movement of individual cells generally follows the wind in cloud layer except in the case of highly developed isolated convective clouds. Therefore, it may be said that the propagation plays an important role to the movement of clusters.

Localized heavy rainfall occurs when the movement of clusters composed of organized convective clouds is quite slow or stationary. Line-shaped clusters described in section 3.2 did not develop to cause much rainfall. However, line-shaped or band-shaped clusters are remarkable for the occurrence of localized heavy rainfall when the direction of propagation is opposite with the direction of movement of individual cells.

5. Conclusion

The relationship between the behavior of individual cells and movement of clusters was analyzed using radar data for three types of clusters. As a result, it was found that the collision of outflow from convective clouds with environmental surface wind played a role as a trigger to form new updrafts. This causes the propagation. And the difference of relative importance of outflow and surface wind to new cell formation (propagation) is found. One is the case in which the role of outflow is greater than that of surface wind, the other is the case in which the role of surface wind is greater.

The movement of clusters is inclined to the direction of propagation from the direction of movement of individual cells. As the rainfall area is formed along the path of clusters, the movement of clusters is quite important. The movement of individual cells is generally followed by the wind in cloud layer. Therefore, the direction of the propagation affects the movement of clusters. The mechanism of propagation which is important to the movement of clusters were described in this paper.

It is necessary to examine the effect of collision of outflow with surface wind quantitatively in further studies. Cloud structure which is related to the behavior of clouds and the small scale wind distribution which corresponds to the outflow or downdraft must be observed. Doppler radar is an effective means for these observations. And the result of numerical model analysis is expected. Droegemeir and Wilhelmson (1985a, b) and Shiino (1985) demonstrated that convection could be produced by outflow interaction. In comparison with observational results (Holle and Maier, 1980), these three dimensional model analyses are notable for the understanding of the role of outflows.

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