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On the Confluent Phenomena of Radar Echoes

Toshio Harimaya, Seiji Kato* and Katsuhiro Kikuchi

Department of Geophysics, Faculty of Science, Hokkaido University, Sapporo 060, Japan

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Abstract

The confluent phenomena of radar echoes were observed during the period of special observations on heavy rainfall at the northwestern area of Kyushu Island. The process of the confluent phenomena of radar echoes was clarified by analyzing the data. That is to say, it was recognized that the difference in movement speeds of echoes is due to the formation of new echo cells.

As two clouds which were different in growth stage merged with each other, after the confluence the clouds became colloidal unstable and large rain drops were formed rapidly. Namely the cloud physical processes changed with the confluence.

1. Introduction

It is well noted on the radar scope that band-shaped echoes merge or intersect frequently on the occasion of heavy rainfalls (e.g. Imakado and Tsutsumi, 1966 ; Kato et al., 1977). And it was reported by Obana (1976) that the confluences of echoes corresponded to the peaks of rainfall intensity respectively during a heavy rainfall and the peaks occurred at about 10~20 minutes after the confluence of echoes.

The phenomenon was explained as follows. Obana (1976) considered that an echo joined another echo according to the different movement directions and speeds of echoes which were moved by the different wind directions and wind speeds because of the difference in each echo height. On the other hand, Kato et al. (1977) proposed the idea that the phenomenon was caused by the confluence of the air flow at the same height.

As the confluent phenomenon means the organizing of precipitation clouds to cluster, it is important on the formation of clouds which result in heavy rainfalls. Nevertheless no analytical results which describe detailed three dimensional structures of radar echoes at the time of confluence are available.

* Present affiliation : Sapporo Building and Land Readjustment Bureau, Sapporo 060.

Thus it has not been clarified whether the height of each echo is actually different each other or whether the movement of the echo is equal to that of cells composing each echo at the time of confluence.

The confluent phenomenon results in the interaction between two types of clouds, but it is not clear how the confluent phenomenon essentially affects the formation of rainfall. And it is observed frequently during heavy rainfalls, thus it may be considered that it is one of the important phenomena on the formation of heavy rainfalls. Therefore, the purpose of this paper is as follows. Based on the details of the horizontal and vertical sections of radar echoes, the real image of confluent phenomenon including the three dimensional structures and movements of both echoes at the time of confluence will be clarified. In addition, based on the time changes of cloud physical variables before and after the confluence, the essential effect on the rainfall formation of the confluent phenomenon will also be clarified.

2. Observation

Cooperative observations on heavy rainfall were carried out by Hokkaido University, Nagoya University and Kyushu University at the northwestern area of Kyushu Island during the period of June to July 1984 where a special network was set up with radars, rawinsondes and so on, as shown in Fig. 1. The confluent phenomenon of radar echoes was observed on 25 June 1984 during the observational period by the radar of Hokkaido University which was set up temporarily at Mt. Kokuzo in Saikai Town. The output data of this radar are shown as the forms of digital values of equivalent radar reflectivity factor on the grids of 1 km × 1 km on the horizontal plane of every 0.5 km in height and on the grids of 1 km × 0.5 km on the vertical plane with arbitrary directions. The following analyses are based on these data and the PPI pictures of radar at Mt. Seburi operated by Fukuoka District Meteorological Observatory.

The meteorological situation was as follows. The Baiu front was stationary over the central to northern area of Kyushu Island on 24 to 25 June, but it was moving up in a northerly direction when the confluent phenomenon of radar echoes was observed. The confluent phenomenon described in the following sections was observed in the radar echoes associated with the Baiu front.

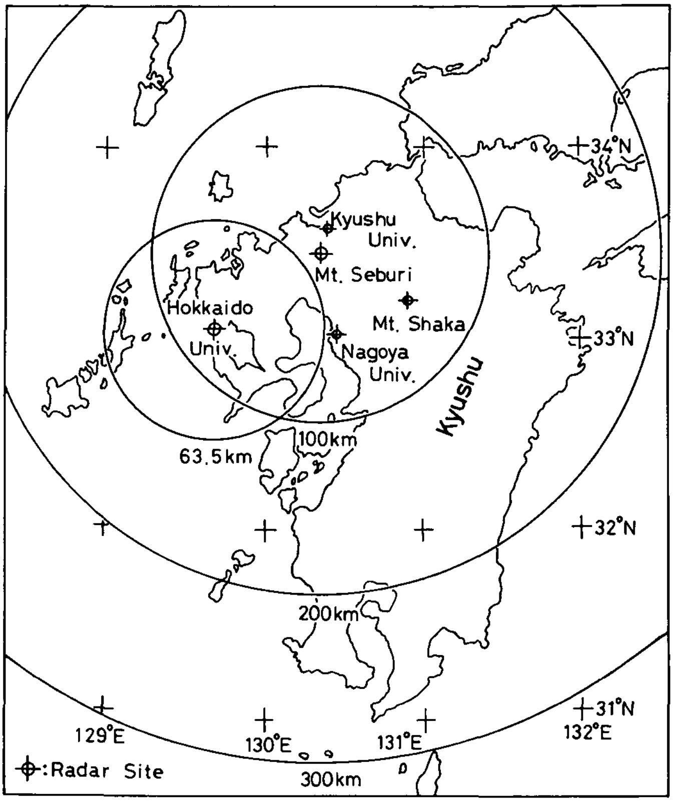

Fig. 1 Observation area and radar sites.

3. Three dimensional structures of radar echoes at the time of the confluence

At first PPI pictures of radar are analyzed in the same manner as in other studies. Fig. 2 shows the time sequence of PPI pictures obtained by the radar at Mt. Seburi. The range marks are drawn every 50 km on these pictures. It is seen from this figure that echo A moved toward the east and at about 1040 JST joined echo B which hardly showed the movement. As far as we see the time sequence of the PPI pictures, the confluent phenomenon in question seem to occur owing to the difference in movement speeds of echo A and echo B.

Next, the time sequence of high resolution CAPPI displays at 4 km in height obtained by Hokkaido University radar is shown in Fig. 3 in order to study this phenomenon in detail. So as not to overlap with each echo, the figure is

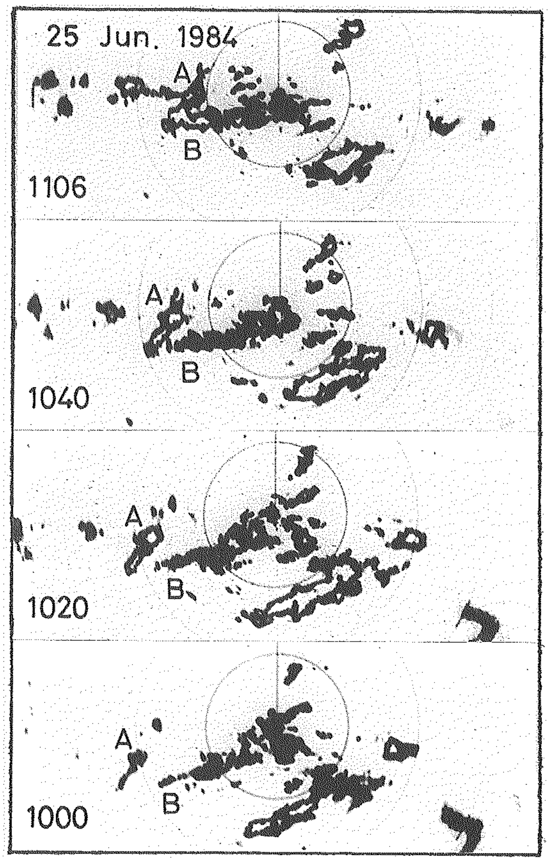

Fig. 2 PPI pictures obtained by the radar at Mt. Seburi. Range marks are drawn every 50 km.

represented in a manner in which the positions of radar site at each time are shifted vertically at equal intervals. So the mutual positions of echoes at different times are not represented correctly in a south-north direction but are represented correctly in an east-west direction. The contours of CAPPI displays are drawn at 20, 25, 30 and 35 dB(Z) in radar reflectivity factor, and PPI displays (more than 15 dB(Z)) of 1.1° in elevation angle are superimposed by dotted lines on the CAPPI displays at 1000 and 1040 JST. In the figure, the corresponding echo cells are connected by solid lines. As the vertical axis represents time and the horizontal axis indicates the distance along the east-west direction respectively, the inclinations of the solid lines represent the movement speed of the echo cells along the east-west direction. Judging from

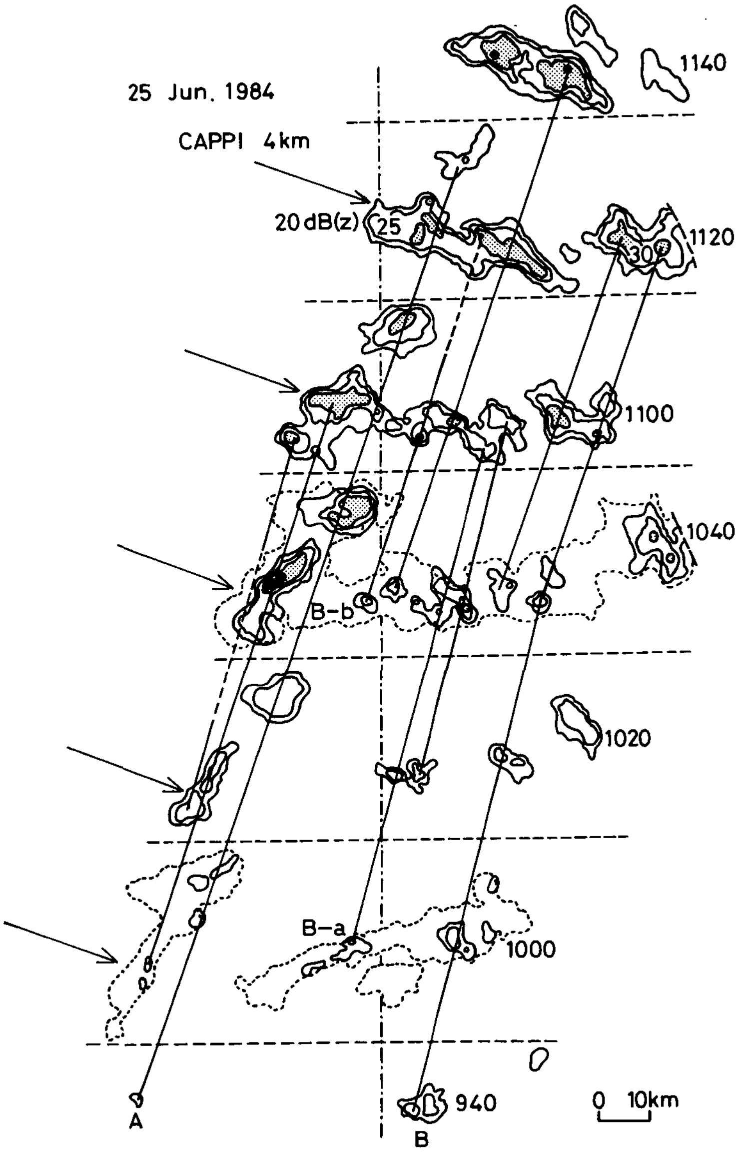

Fig. 3 Time sequence of CAPPI displays at 4 km in height obtained by Hokkaido University radar. Dotted lines describe PPI displays of 1.1° in elevation angle.

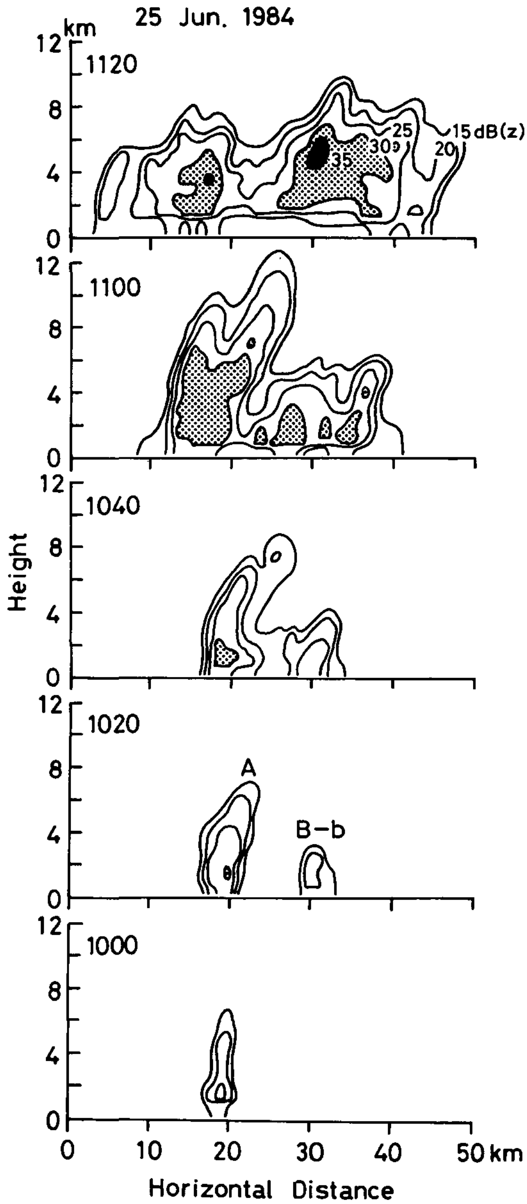

Fig. 4 Time sequence of vertical sections along the arrows in Fig. 3.

the fact that solid lines are in parallel with one another, it is recognized that each echo cell is moving with almost equal speed. Therefore, echo A should not join echo B originally, because echoes A and B are constructed from echo cells with equal movement speed. Nevertheless, echo A joined echo B. Thus the reason for the confluence is as follows. Since new echo cells are formed continuously at the western end of echo B, echo B seems to be stationary. On the other hand, echo A is moving with the same speed as the movement speed of echo cells. The result is that echo A joins echo B. Namely, it is considered that the confluent phenomenon owing to the difference of movement speed is caused by the apparent difference of movement speed of echoes in spite of the equal movement speed of echo cells.

The vertical sections along the arrows in Fig. 3 are shown in Fig. 4. Contours of 15, 20, 25, 30 and 35 dB(Z) are drawn in this figure. It is seen from this figure that echo cell B-b which appeared at about 1040 JST in CAPPI display at 4 km in height was formed in the lower layer at about 1020 JST and grew to join echo A at about 1040 JST. Though the height of each echo top is different actually at the time of confluence, it is considered that the difference in height did not cause the confluence through the difference in movement speed but the apparent difference of movement speed caused the confluence mentioned above. After the confluence, a strong portion in intensity more than 30 dB(Z) spreaded rapidly and then a new echo cell B-b grew into the larger echo instead

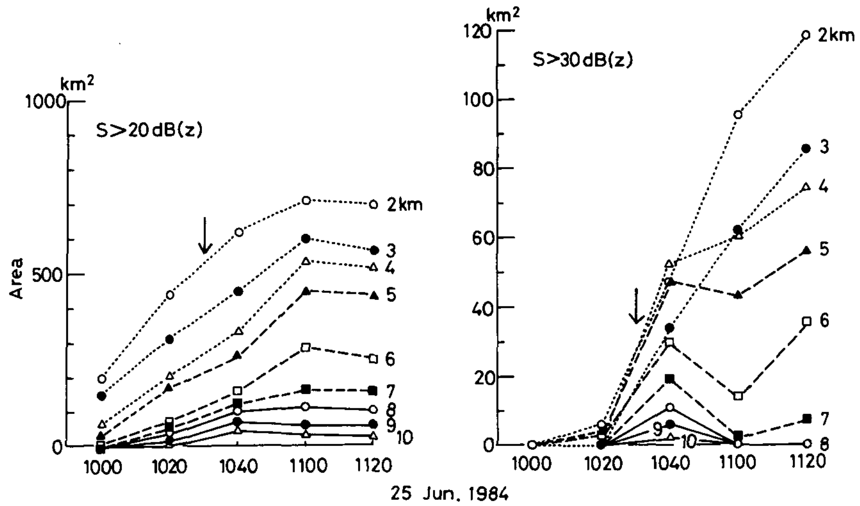

Fig. 5 Time changes of areas with more than 20 dB(Z) and 30 dB(Z) in radar reflectivity factor at each height. Arrow shows the time of confluence of echoes.

of echo A.

4. Time change of radar reflectivity factor before and after confluence

In this section, the phenomena occurring after confluence were studied following the process of confluence in the preceding section. First, we analyzed the time change of the areas of echoes A and B-b at each height. Fig. 5 shows the time changes of areas with more than 20 dB(Z) and 30 dB(Z) in radar reflectivity factor. In this figure the arrow indicates the time of the confluence of echoes. It is seen in left-hand figure that the areas with more than 20 dB(Z)

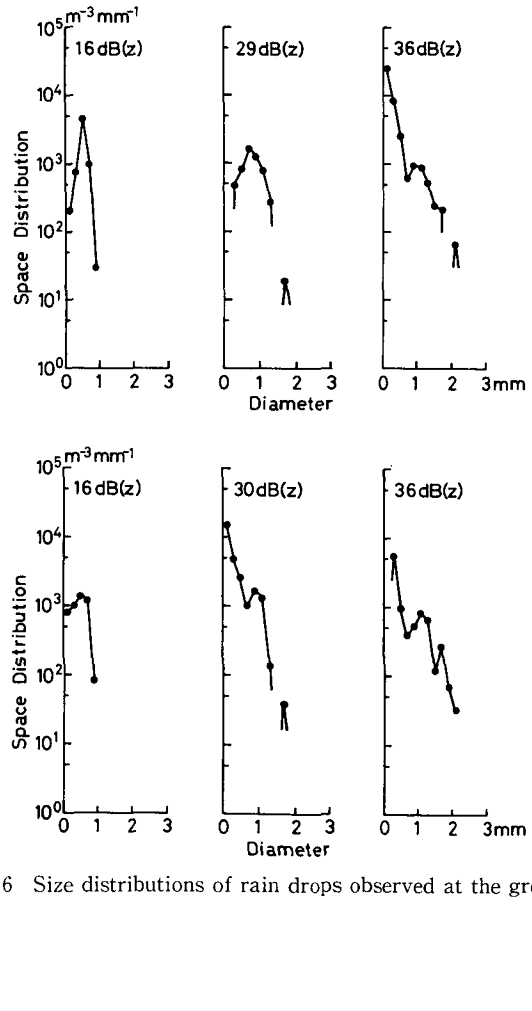

Fig. 6 Size distributions of rain drops observed at the ground.

continue to enlarge with time although the values differ at each height. And it is important that the increase rates do not change before and after the confluence.

But, it is seen in the right-hand figure of Fig. 5 that the increase rates of areas with more than 30 dB(Z) change drastically after the confluence. Then, the echo in the lower layer maintains a large increase rate although the echo in the upper layer decreases. As it is considered that the radar reflectivity factor more than 30 dB(Z) indicates the existence of larger rain drops, from a viewpoint of rain drop formation the right-hand figure may be explained as follows. In the case where two clouds that are different at the growth stage join each other, the clouds become colloidal unstable owing to the different size distribution of rain drops contained in the clouds and larger rain drops are formed rapidly. As a result, the areas with more than 30 dB(Z) spread rapidly.

Fig. 6 shows the size distributions of rain drops observed at the point which is about 20 km distance from the place of occurrence of the confluent phenomenon. The ordinate and abscissa are the space distributions and diameter of rain drops respectively. It is seen that there are rain drops of 2 mm or more than 2 mm in the case of 30 to 35 dB(Z) with regards to radar reflectivity factor whereas there are only rain drops less than 1 mm in the case of approximately 15 dB (Z). It is considered that from this degree of difference in size distribution of rain drops the clouds become colloidal unstable and larger rain drops are formed rapidly (e.g. Shiotsuki, 1974). Therefore it is appropriate to explain the rapid increase rate of area with more than 30 dB(Z) in Fig. 5 by the colloidal unstable theory.

5. Concluding remarks

The confluent phenomena of radar echoes were observed and examined in detail. It was clarified from the analysis that the confluent phenomena owing to the difference of movement speed are caused by the apparent difference of movement speed of echoes in spite of the equal movement speed of echo cells. The apparent difference of movement speed based on the fact that one echo seems to be stationary, because new echo cells are formed continuously at the western end of the echo. After the confluence, the cloud physical process changed. This can be explained as follows. Clouds become colloidal unstable owing to the different size distributions of rain drops contained in the clouds and large rain drops are formed rapidly when two clouds that are different in growth stage join each other. In order to confirm this result and clarify the other side of confluent phenomena, the confluent phenomena must be examined further in the future.

Acknowledgments

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