Rainbands and a Weather System around a Wave Crest in Humid Season

by

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Abstract

Radar and synoptic analyses were done on the storm that occurred around the stationary front, Baiu front. Many various echo patterns that appeared were compared with the synoptic situations. Then a weather system around the wave crest of small scale was represented, in which two squall lines and quasi-stationary and perfectly stationary rainbands were involved. On the rainbands, some detailed explanations are given.

1. Introduction

At present, it is one of the most important problems in meteorology to clarify the relation between the distributions and behaviors of echoes represented in PPI scope and the synoptic situations. The solution of the problem will give a basic knowledge permitting of the effective use of PPI radar for weather prediction. It is necessary for the solution to accumulate many results obtained by comparisons of radar data with the meteorological analyses in various typical storms.

On the pre-cold-frontal squall line, analytical investigations have been made so far, Teppert (1950), Newton (1950) and Fujita (1955). In the present study, rainbands that appeared in the vicinity of a quasi-stationary front extended over Japan in the rainy season were investigated. The radar data used are photographs taken by a PPI 5.6-cm radar which has been operated with a fixed elevation angle of about 1.8 degrees, and a fixed scanning range of 200 km. The radar has a blind sector to the east of the radar site as illustrated with hatches in Fig. 1. The scanning region in the vertical section was calculated from the elevation angle, the beam width and the following formula are also shown in it by numerals beside the range marks.

Fig. 1. Detectable vertical range. Range marks are taken every 40 km. Ground echoes are shown by shadows.
where $L$, $\theta$ and $H_0$ are the range, elevation angle and height of the radar station respectively.

The radar observation was performed from the evening of the 3rd to that of the 5th of July, 1957. The meteorological data used for the synoptic analyses are mainly meteorolographs taken by the routine network of the Japan Meteorological Agency (see Fig. 21 in which the stations are shown by dots).

2. Synoptic situation

Surface — The synoptic situation of large scale will be explained referring to the surface and upper maps shown in Fig. 2 (a) and (b) respectively. It is usual, as in this case, that the polar front of the Far East comes over Japan in the season. The Okhotsk Sea high associated with a blocking high exists in the north-eastern region out of the map. The high seems to be located north of the normal position in the season. An occluded low had been developed in the northern vicinity of Hokkaido. Only the surface map at 0900 JST on the 4th was shown in the figure as the situation was very stationary. In the period that the radar observation was made, the stationary front (the Baiu front) ran past the vicinity of Hangchow, just south of Shanghai, China, and Honshu of Japan and extended to Hokkaido. To the north of the front, a weak high remained over the Japan Sea, while low pressure was developing in Manchuria.

The Baiu front had an undulating form. A low of relatively small scale generated at the wave crest and seemed to travel along the front without intensely developing over a wide area. The precipitation area was spread across the front.
From the weather information, it is found that the precipitations were showery in the region south of the front while continuous rains fell spreading widely in the region north of it. The intensities of them were more than moderate on both sides of the front. The cloudy region spread southward up to several tens of kilometers from the front, while northward as far as several hundred kilometers from it. Accordingly the weak high mentioned above was almost covered by cloud. To the south of the polar front, a well-developed Ogasawara high, which is the ligulate part of the North Pacific high, extended to the south-west of the ocean. Within the region between the ridge of the Ogasawara high and the front, high southerly wind of several to about twenty knots developed on the surface.

These are the conditions under which a potential instability will develop. From an aerological diagram made from Kagoshima’s data, it is verified that instability had been matured (see Fig. 3).

_Upper situation_—A map of 700 mb surface at 1800 JST on the 3rd of July and the trajectory of the trough of the surface are shown in Fig. 2 (b) and (c) respectively. A low is found well developed in Manchuria and a relatively deep trough extending southwards from the center of the low. From the figure (c), it is found that the trough staying till the morning of the 4th started to move southeastwards during the afternoon of the day and then it was accelerated gradually. Thereafter the speed became more than 120 km/hr. It was noticeable that as the acceleration of the trough occurred the persistent heavy precipitation over the Kyushu District came to a sudden end.

3. Changes in echo pattern

It is not always that the observed data cover the whole period of a storm be-
cause the occurrence of showers in the northern Kyushu were found before the time that the radar observation was begun. The showers had occurred over the northern Khushu intensely from the early morning of the 3rd. Radar photographs were taken for every 5 minutes throughout about 48 hours. In the beginning of the observation, a pattern containing a rainband composed of numerous small airmass echoes, spreading over the narrow sector region involving the radar site was seen (rainband I). At about 30 minutes before the time of the photograph 1800 JST (Fig. 4 (a)), the small echoes were widely scattered. They were gradually arranged in the form of a rainband during the 20 minutes from 1740 to 1800 JST. The manner of arrangement will be explained in a later section.

The rainband thus formed moved southeastwards with a considerable speed and then it was gradually reduced. In the stage of widely scattered distribution, it is very difficult to recognize from the photographs the movements as a whole. But drawing 1-hour isohyets in the period, the isohyetical maximum was found to have moved eastwards regardless of the northeastward movement of individual small echoes. This suggests that some potential pattern may govern the precipitation growth such as the rainband I in the shape of a narrow sector in the following stage. On the potential pattern, discussions will be given in Section 8.

In Fig. 4 (b) the photograph taken 2 hours after is shown. A subsequent rainband, termed II, is found appearing on the northwest sea, about 200 kilometers apart from the radar site, advancing behind the foregoing rainband I. The band II was proceeding eastwards with a speed of about 24 km/hr, and after about 0100 JST on the 4th, it disappeared in the shadow of the neighbour mountain ridge. From the inspection of photographs, it is considered that the band II was generated about 170 km WNW from the radar site. No small echo belonging to the rainband II was generated in the south region. So this band proceeded eastwards but not southeastwards as the whole. This stage is illustrated in Fig. 4 (c), photograph taken at 2400 JST. As will be mentioned later, it developed in a form cut off by some E-W line.

After the band II moved away and disappeared, the total amount of echoes in the scope decreased remarkably, while echoes were distributed all over the scope, as shown in Fig. 4 (d). It was general through the whole period of the storm that echo spaces were clarified as intense rainbands appeared. Explanations on the band II will be also given in detail in section 6. The meteorographs taken at Shimonoseki and Ezuka stations clearly reveal the passing of the two rainbands and also the micro-feature of precipitation.

It is found by a careful inspection of the two records that each rainfall consisted of many cell precipitations having durations about 10 minutes or less and successively generated. The instruments used are thynnomen rainguage which can obtain continuous records. It is shown from the records that when an airmass echo having a clear outline passes a station an almost infinitely intense precipitation occurs abruptly, then decreasing gradually and ceasing about 10 minutes later.

It took about 3 hours for the echo pattern to change from the scattered one that appeared after rainband II advanced away eastwards, such as seen in Fig. 4 (d) (0200 JST), to the comparatively systematic one, such as seen in Fig. 4 (e).
Fig. 4. PPI photographs taken at Sefuri (960 m MSL) during the Baiu storm. These selected photographs show changes in the echo pattern. Range marks are given every 40 km.
latter pattern two kinds of systematic rainbands are involved. One of them is located about 40 km apart from the radar site and extends from SSW to NNE. This band consists of innumerable fine cells which seem to have partly diffused. This rainband will be termed band III. Another one was a thin and straight band located to the southeast of the band III. This band will be termed band IV. These two bands were found emerging already at 0200 JST though only in traces as indicated with arrow heads in Fig. 4 (d). Accordingly, the developments of both rainbands were very slow and gradual. Since the completion of both, the basic arrangement of the rainbands and echoes was maintained almost invariable during a long period, though minor changes of the pattern were seen incessantly. These changes will be explained in section 6. After reaching the southmost position, band III began to advance south very slowly.

In Fig. 4 (g), the photograph taken at 1200 JST on the 4th, 6 hours after the the time of Fig. 4 (f), is shown. It is seen that the band III and IV are mixed up in the region where these two bands intersect. The echo pattern of the mixture got particular form and resulted in intense local precipitation, on which a report has been made by us (FUJIWARA and TOYA 1958). The mixing advanced gradually with the moving south of the main front. Then the pattern changed to that shown in Fig. 4 (i), at 1900 JST, temporarily showing a different pattern as illustrated in Fig. 4 (h). The pattern at 1900 JST was that of innumerable and partly diffused echoes distributed over a wide area. This type was seen in other storms (See Section 4.) and it is considered to be the most typical pattern occurring on a sub-tropical frontal surface. On this pattern, it is found that the small echoes in the southern part have sharp outlines while in the northern part, diffused outlines. Namely, this shows that the former are more convective while the latter have diffused tending toward the nature of continuous rains. From the analysis of the echo movements, it is found that the individual echoes moved northeastwards developing from southwestern airmass cells to that of diffused echoes. These crowded echoes in the wide-spread pattern became sparse for a while (see Fig. 4 (j)). But they were rearranged in a wide-spread pattern as explained above (see Fig. 4 (k)). This type remained showing some undulation incessantly, as discussed later, and seen in the figure with arrow heads.

4. Types of echo pattern of the storm

On the echo patterns treated of in the previous section, we have made a preliminary report (M. FUJIWARA, M. OKABE and T. NISHIHARA 1957, M. FUJIWARA and K. TOYA), in which they are divided into 6 types according to the storm. These are indicated in Fig. 6, where the patterns are named A, B, ..., F provisionally. It will be clear from the above explanation that three of them, A, B and F seem to be the most fundamental. In the following, specific features for each type will be tabulated.

Type—A: Rainbands moving eastwards with a width of tens of kilometers. (band I, II)
Type—B: Undulating rainband composed of many diffused echoes about the frontal

* It was emphasized in the report that the mixing of these rainbands is very important for the heavy rain that fell concentrated in a narrow region.
Fig. 5. PPI photographs taken at SE-FURI (960 m MSL) during the storm of the "Midget Typhoon 57-5". These photographs show the representative patterns occurred which are analogous to those of the present Baiu storm. Range marks are made every 40 km too.
wave crest (band III) and stationary rainbands composed of small air-mass cells (band IV) arranged in parallel with each other to the south-east of the former.

Type—C: A modified one of the type B, that is, the band III has collapsed.

Type—D: Isolated echoes scattered over a wide area, while the whole amount of echoes is reduced remarkably.

Type—E: A modified pattern of type F. Innumerable individual echoes in an area of broad band extended from SW to NE.

Type—F: Innumerable individual echoes diffused are crowded into a wide area whose contour is in an indeterminate form but generally has a circular outline.

These six types appeared briefly in the order of A, B, C, D, E, F. C and D appeared for very short periods. It is considered that the patterns of C, D and E were rather transitional forms. These fundamental types were also observed in the case of a tropical cyclone, midget typhoon 57-5, and the order in which the pattern appeared was the same as that of the present case. The midget typhoon had developed in the vicinity of Formosa. The surface pressure at its center was 940 mb and the diameter of outermost circle of isobars was about 400km at 0900 J.S.T. on the 26th, July, 1957. Then the typhoon traveled northeastwards toward the Baiu front which was extending from W to E. As the midget typhoon approached the front, it was transformed into a frontal cyclone as if it would be absorbed in the Baiu front. The existence of a well-developed subtropical high to the south of the quasi-stationary front was also a feature common to the present case.

From the radar photographs taken from 1800 JST on the 26th to 1100 JST on the 27th of June, 1957, some representative ones shown in Fig. 5. It is to be noticed that the photograph (a) corresponds to the pattern of type-A and the photographs (b), (c), (d) and (e) correspond to those of type-B, -C, -E, and type-F respectively. About 0100 JST on the 27th, a remarkable reduction in the whole amount of the echoes occurred. This stage may correspond to that of type-D in the present investigation.

5. Front analysis

The Baiu front in the present case was quasi-stationary as usual, and found from a large-scale map analysis
to have small wavy motion. If a more minute behavior of the wavy motion of the front is to be clarified, a more careful analysis must be performed. Owing to the sparsity of weather stations for micro-analysis all the records of meteorographs available were used. By careful inspection of them, three fronts were found in the frontal region. Here the fronts mean discontinuous lines of air density. Various kinds of fronts are known to exist. Throughout the present case the temperature shift was the most noticeable among the changes in meteorological elements that took place in passing of the fronts. And, sometimes wind shifts were striking. This nature will be common in other Baiu fronts as general subtropical fronts.

FUJITA (1955) has shown from the results of meso-scale analysis on the weather system occurring in the middle of U.S.A. that the line of pressure surges accompanies usually with that of temperature falls. In the present study, the barographs used have not enough sensitivity, so that the examination of the problem by Fujita’s procedure was given up. It was, however, considered that the temperature shift was the most systematic and essential for the analysis of the frontal weather system in the storm.

Isochrones of the temperature shifts were drawn and shown in Figs. 7~9. The front shown in Fig. 7 is regarded as the main front. The one shown in Fig. 8 is the cold micro-front accompanied by rainband I. The other one shown in Fig. 9 is the secondary cold front passing after the main front. The secondary front is regarded to be formed between the modified and the fresh and cold polar air.

From the illustration in Fig. 7, it is found that the main front changed its sense from a warm frontal to a cold frontal one about 0400 JST on the 4th and then, several hours after the change, the speed was reduced for a while in the middle of Kyushu.

In Figs. 10~12, the temperature changes at every station which the fronts passed are illustrated. Each curve is arranged downwards from top to bottom in

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Fig. 7. Traces of the main front, which was determined from temperature shifts as mentioned in the text. Numerals show the times and dates.

Fig. 8. Traces of the cold micro-front, which was determined from temperature shifts. The magnitudes of the temperature shifts are shown by contours of broken lines.
the order of the time when the front passed the station and the time is taken at the same position on the abscissa.

The traces of temperature for the main front are shown in Fig. 10. It is seen in the figure that the transition pattern of temperature shift in passing of fronts varies with time and space. It is also found that the transition periods of the temperature after the front changed its sense from a warm frontal into a cold frontal, increased gradually till JST 1500 on the 4th. About the same time the front decreased the speed of its southward moving. Thereafter, as the speed of the front increased, the temperature fall became sharp. It is suggested that when the speed is low the temperature within the transition layer is influenced remarkably by mixing.

It is shown from Fig. 8 that the cold micro-front was formed about 1700 JST, before which, there was many air-mass echoes scattered over a wide area. The time when the band I was formed from the scattered echoes agreed with the time when the cold micro-front was formed. It is found that the cold micro-front thus formed has less dimension in vertical extent. The stations named Unzen, Aso in Fig. 10-12 have an elevation of 8,530 m and 1,143 m M.S.L. respectively. The magnitudes of the temperature shift when the micro-front

![Fig. 9. Traces of the secondary cold front. Numerals show the time. The parts of broken lines show the temperature shift is indistinct.](image)

![Fig. 10. Temperature records in passing of the main front, which are laid in the order of time when the shifts occurred. Abscissa is taken for time from that of passing of front.](image)
passed the two mountain stations are remarkably small compared with that for the other sea-level stations. It is, however, shown from Fig. 10 that in the case of the main front the differences between mountain and sea-level stations are not so remarkable. This indicates that the structure of the main front has deeper vertical extent compared with the micro-front and the secondary cold front.

It is found also from the isochrones shown in Figs. 7, 8, 9 that the times at which fronts passed these mountain weather stations, Unzen and Aso, were almost the same to those for the sea-level stations in the case of the micro-front and the secondary cold front, while, on the contrary, the time lags were reasonably large, in the case of the main front. These facts indicate the difference in structures of the fronts. That is, the frontal surface of the micro-front and of the secondary front were more sharply standing up while that of the main front
was about 1/240 inclined in the low layer.

The part of the wave crest of the main front sometimes got out to the sea. The figuration of the crest and the speed of the eastward movement were determined making use of only the information obtained at Iizuka, Shimonoseki and Bofu. Accordingly the results may retain some uncertainty. It will however be safely concluded from the results that the main front had a crest of meso-scale which traveled eastwards with a speed about 13 km/hr.

In Fig. 8, the magnitudes of the temperature shift are illustrated by contours. It is found that the cold micro-front weakened rapidly as it proceeded over the Kyushu mountain range leaving the rainband behind it.

The secondary cold front appeared in northern Kyushu about one or one-and-a-half day after the main front. Then the secondary front developed gradually and intensified as the foregoing main front was weakened. The intensity of it became maximum during its passage over Ushibuka and Hitoyoshi, becoming weak after passing Kagoshima and Aburazu, the southmost parts of Kyushu. In passing Tane-gashima and Yakushima, a distinct pattern was recorded on the meteorograph, and then the front vanished completely until it approached Nase. The southward speed in the early stage was slightly higher than that of the later stage contrary to the case of the main front. But it will be, generally, regarded as a rather constant speed. From Fig. 12 it is noticed that after fronts passed over the mountain region the temperature fall became remarkably obscured and disturbed except in the case of Hitoyoshi, which is in a valley.
6. Formation, structure and transposition of the rainband

(a) Rainband I—The locality of band I was traced for every 30 minutes and was illustrated in Fig. 13. The band moved southeastwards at a speed of about 60 km/hr from 1730 to 1900 JST. As the band approached the Kyushu mountain range its speed fell, say to about 20 km/hr. At first, the running direction of the band was more northerly than that of the mountain range. As the speed of the band I fell the two became parallel. Then the band was transformed into two parallel bands about 2000 JST as seen in Fig. 4 (b).

![Fig. 14](image)

Fig. 14. Redistribution of small echoes into rainband I. Echoes in the northwestern region to the radar site at 1740 have faded out until 1750, while in the southwestern end of the scope small echoes treating in are seen. These echoes are indicated by arrows.

In Fig. 14, two photographs at 1740 and 1745 JST are shown in which the formation of band I is revealed. Comparing the two photographs, it is found that the transformation of echo pattern was not attained by the concentrating move of individual echoes into the region of the band but through conditions favorable to the generation and development and dissipation of them. In the region to the north of the micro-front, echoes were apt to be dissipated rapidly and seemed hardly to be generated newly, while in the region forward of the front many convective cells were generated on the southwestern sea around the Koshiki islands, and moved northeastwards developing during long periods, without being dissipated. Thus the rainband I was formed gradually. For example, observe the echoes shown by arrows in the figure (a). They were considerably weakened till 5 minutes later, while at 1750, an entrance of a small echo into the scope across the 200-Km-range mark is seen. The persistency of the echo is found from the later photographs to be very notable, and it is unknown where the echo had generated.

The relation between the motion of small echoes and the structure of band I is explained by schematic illustration in Fig. 15. The directions of the echo movements differ slightly from that of the extension of the band. The northernmost end of the band moves parallel with the transposition of the generation point of elementary echoes, if all lifetimes of them are equal. So that the movement of the generation
point is the most important for that of the band. But in the other hand, in this circumstance, if the generation point moved with a constant speed, the northeastern most end would go down rapidly southwestwards along the line A-B, and so the rainband would be diminished. In the present case, rainband I was seen to continue to develop without diminishing for a while around the mountain range. This is due to the fact that the generating point was not advanced in that periods. It is therefore suggested that the mountain range may have contributed also to the generation in the backside region of the range, while to dissipation in the fore side. The influences of the mountain will further be discussed in section 8.

In some moments when echoes crossed the mountain range, a slight deflection of their moving direction occurred as shown in Fig. 15b. The phenomenon might be a temporary one, and so more examples observed are desirable. But it is suggestive to compare this with the fact that elevated cells on a frontal surface have a more W–E component of the motion than air-mass cells. (See the author’s previous paper 1958). From the scanning angle and beam width of the radar, the echoes in their developing stages, composing band I have their top levels higher than 7 km from where down to 2 km of altitudes winds were WSW.

The location of the cold micro-front which has been thus determined and that of the rainband given by tracing the outlines from the PPI photographs were illustrated in Fig. 16. Before about 1800 JST, in the initial stage of the development of both the rainband and the micro-front, the relation between them is found not very close. About 1 hour after the time, the echoes arranged in a prefrontal
squall line had proceeded the front. Then, as the speed of the squall line fell, the micro-front outstripped the rainband. About 2000 JST the rainband was above the front. In the figure it is shown that, as soon as the front outstripped the band, it appeared to be weakened. The rainband almost disappeared by 2300 JST. From rainguage records at Hitoyoshi, Miyakonojo and Miyazaki, this disappearance of the echoes is confirmed to mean true precipitation cease.

(b) Rainband II—A series of the contours of the echoes illustrating the development of rainband II is shown in Fig. 17. It is found that rainband II had been transformed into various forms during the lifetime. It was clearly generated over the northwestern sea, and its form in the initial stage was like faint spots connected in links. The difference between the forms of the two rainbands, I and II, in their initial stages was the usual one found between the regions of ocean and land. Namely echoes in the former region seem to be apt to form in a unique arrange while those in the latter region seem to be scattered.
The transformations of band II will be mentioned here. One of the initial echoes, A in the figure, had developed intensely came to have branches on its fore side about 2200 JST. As the branches developed the echo came to have the shape of brush, and then gradually became a complete broad band. In the stage of generation of the branches, individual echoes had two different motions as follows. The mother echo, A, continued to move northeastwards, and the budded echoes on the mother echo moved more easterly.

The movements in two different directions are shown in Fig. 18(b). In Fig. 18(a), the developing stage of echo A was illustrated by photographs taken every 5 minutes. In the later stage, in which band II was passing on the land in the vicinity, the broad band resulted. Small

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Fig. 17. Development rainband II. Echoes in the adjacent stages are distinguished by black and white. It is seen that a thin band as a string became like a broom and then gradually a broad band.

Fig. 18 (a). Development of echo "A" in rainband II.

Fig. 18 (b). Velocities and directions of cells composing "A". The minimum division of the inserted scale shows 20 m/sec.
echoes, were generated at the southernmost end of the band and moved northeastwards. While moving on the northern part of the band, they were diffused. On this stage, descriptions were given in the previous contribution (Fujwara 1958), in which the author pointed out that the band seemed to be cut off on the southern part but by E–W line near the front. From front analysis, it was found that the cut-off was made about 20 km south of the front. Namely, small airmass echoes were generated about 20 km south of Iizuka while the front ran the city at 2400 JST on the 3rd. Echoes in the vicinity of this generation point, that is the cut-off line, were clearly to be of airmass cells.

(c) Frontal Rainband—The extending direction of the frontal band differs from the two former bands, but individual echoes composing it had almost the same moving directions as that for the two bands. The small echoes had a speed of about 25 m/s.

Band III was located most closely with the main front, and had an undulation of small scale seemingly independent of the movement of the front. The undulation form that occurred during the period from 0100 to 0400 on the 4th is shown in Fig. 19, in which the southern contours of the band at the moment shown there are given. It is found that the undulation began to appear about 0430 as the echo mass was increased. Band III advanced as a whole northwards undulating and reached the most northern position at 0620 JST on the 4th. After this time, it began to advance southward. The speed of northward movement was about 40 km/hr. The traces in the figure are given divided into the two stages: northward advance, (a), and the retreat, (b). The advance and the retreat of the band agree with that of the front in phase. The scale of undulation was as small as about 100 km in wave length and about 1 hour in the cycle.

Rainband III in the beginning of its appearance at 0200 JST was found as a trace on the south sea as shown in Fig. 4 (d). When the trace passed Tomie, a southerly wind gust, about 17.1 m/s, was observed at 0104 JST while temperature indicated only a projection of about 0.3°C on the meteorograph. In this stage of the activity of the front, no clear discontinuity of temperature as seen in the later stage seemed to be formed near the station, Tomie. No front, there was also verified by inspections of the meteorographs at other stations.

About 0400 JST, as the trace of Band III emerged more clearly, the trace increased
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the speed of northward advance (see Fig. 19 (a)), while the front was most stationary in the north to the trace. It was noticed that the southerly wind strengthened in western Kyushu about 9 hours before the emerging of the band. This is the circumstance that rainband III was advanced northwards by the jet and as it reached and outstripped the front it became much intense.

(d) **Stationary rainband**—In the period that the warm region of the main front developed, the stationary rainbands appeared within the region as shown in Fig. 4 (e). Band IV remained for as long as 12 hours without changing their principal features, such as straight lines, parallel to each other and the invariable localities. From airmass and surface analysis*, the periods was found to be the time that a southwesterly jet was developed and potential instability was matured in the lower layer.

7. **Weather system around the wave crest**

Some well-known weather system around a wave front has been proposed by Bergeron (See PETTERSSSEN 1956). However, it is generally of large scale. The present author concerns a model of the system in a smaller scale. FUJITA has published an analytical study of meso-system. In the present case, only the precipitation region is described as formative of the weather system.

The model obtained here by the analysis was illustrated in Fig. 20. So far, prefrontal squall lines were reported on by investigators (see PETTERSSSEN 1955). In the present case, band I clearly correspond to it. The formation of the band, as mentioned above, took place mainly within the warm region of the main frontal system. But as the band completed, a cold front was accompanied. Band II developed in the colder region and was limited almost within it. The other hand, band I, developed in the warm region though extended up to the cold region across the main front. The traveling speeds of the two bands were nearly the same. These two bands, may therefore, be regarded as the same kind of rainband. And they can be termed as "travel band" in contrast with the other two bands. Band III had diffused echo formatives in some degree. This will be a common feature to warm frontal echoes. The present one is more granular showing active convection developed over the frontal surface, than ordinary ones.

Band IV, which was stationary and of a particular form, was one of the most unique and striking features that appeared in the storm. The newly noticed features on the echo system of the present storm are listed in the following:

* On the analysis of band IV and the discussions see the author’s previous papers (FUJIWARA, M., M. OKAIE and T. NISHIMURA, 1958; FUJIWARA, M. 1958).
(1) Appearance of a secondary instability line, band II of a similar form to band I. They traveled eastwards independently regardless of behaviors of the cold front.

(2) Appearance of the stationary band IV, after the instability lines had passed.

(3) On the whole, precipitations were remarkably convective.

These may be attributed to the particular situation which consisted of a well-developed southerly jet near the surface blown from the subtropical high, persistent during long periods. The polar frontal system was, consequently stationary, without moving southwards. The situation around the wave front will be specified to be subtropical.

8. Conclusion and discussions

It is concluded from the explanation on the surface synoptic situations given in the previous section that the southerly jet was developed over a wide area and potential instability was matured in the low layer. The condition in the atmosphere had a close relation with the particular figuration of convective cells on the scope.

In the present case, the persistent and heavy storm finished as the deep trough of the 700 mb surface traveled southwards. This shows that the persistence of the storm for as long as 2 days was caused by the stagnation of the upper trough.

Since radar began to be used in meteorology it has frequently been reported that the precipitation patterns obtained by it are usually far from what is generally accepted on a knowledge of the weather system. This discrepancy was also true in the present observation, at least apparently. We have provisionally classified the patterns obtained into 6 patterns, in which there are fundamental and the others, transitional. The three fundamental ones consist of five principal formatives, that is, ranband I, II, III and IV and the plain echo. These formatives of the overall echo patterns were investigated in relation with the front analysis of small scale. It is found that the various echo patterns had a systematic relation with the synoptic situation as described in the last section.

From the front analysis, three fronts were found in the frontal region; one of which is the main front and the others are the cold micro-front and secondary cold front. The micro-front accompanied by rainband I seemed to be generated about the same time as the rainband was formed. This suggests clearly that the cold micro-front was generated through the accumulation of cold-air wake of the convection cells as PETTERSSON has mentioned (See Weather Forecasting II 1956).

It was found in the present case that the micro-front and the secondary front had a less extent in the vertical dimension than the main front, and, further, the frontal surfaces were vertical in the former while it was very sloped in the latter.

It is considered that the micro-front is regenerated with cold downdraft issued from convective cells successively. It is, therefore, conceivable from this that the passing of the frontal surface of the cold micro-airmass has occurred almost simultaneously at the mountain and sea-level stations. But, in the case of the secondary
cold front, the reason of such simultaneity is unknown. But it might have some relation with the fact that the front was followed by a well-developed precipitation area.

It is seen in Figs. 7, 8, 9 that the main front speeded up in southern Kyushu while both of the other fronts maintained their speeds constant. The main front, as mentioned in section 2, appeared to have much relation with the behavior of 700 mb trough. It is, therefore, concluded that the main front which had a tall structure was influenced by the upper conditions and accelerated after the evening of the 4th, while on the other hand the micro-front and the secondary front which had flat structures was not influenced by 700 mb trough.

Though the data in the mountain region and on its southeast side were very scarce, the retardation of the micro-front by the orography as mentioned by Bergeron (1949) was hardly recognized. The same holds as regards the secondary cold front. But the main front is found to show a remarkable retardation in the mountain region. These different features may be caused by the fact that the frontal surface of the former were vertical but that of the latter is not.

Band I moved southeastwards with an eastward component of about 40 km/h during the period from 1730 to 2100 JST, while the main front was moving in a warm frontal sense and the small wave crest, traveling eastwards with a speed about 10 km/hr. In the case of rainband II, a more close relation with the front was expected because it appeared mainly to the north of the main front and moved eastwards along it. However the speed was higher that of the wave crest and outstripped it on its way. In the case of the other band III, the behavior had close relation with the main front while band IV was staying as explained previously and continued to stay until the main front moved south enough to sweep them up.

On the cause and the mechanism of the traveling rainband, I and II, the results of the analysis presented in section 6 will show clearly that, it is shown that elementary echoes composing the band had a long lifetime up to one or two hours within the band’s area while the echoes existed out of the region, they were rapidly diminished and thus the rainband was formed and transported. It is, however, yet unknown clearly how a cell can maintain its life such a long period without diminishing. But the fact mentioned here concerning echo life suggests that the condition which supports the regenerations of overturnings had been constructed only in the particular region. Namely, the rainband will be formed within and by such a potentially conditioned region. And the region must be apt to be formed into band form.

Watanabe (1956) has attempted to test whether a squall line develops by the upper cold advection occurring on the line or not, and obtained a result that supports its importance for the development. It was, however, in the present case that the orography seemed to be a more determining factor than it. Two main phenomena indicated in the following are much concerned with orography.

1) Rainband I was retarded as it approached the main mountain range and disappeared in the region to the southeast of the range.
2) Generation and development of the stationary rainband in lands where an interference takes place between the potentially unstable flow and topographies. On the orographic influences on the mechanism of precipitation, two pictures are considered. One is the up-glide and the downward flow in the windward and leeward respectively. The other is the convergence forced by the orography. (See BERGERON 1955 Tellus). It is found from the upper wind data that the wind over southern Kyushu were southeasterly up to the level of about 1.5 km from the surface. This seems not to be favorable for the former picture, because the mountain range runs slightly more northerly than the wind direction.

As an example the divergence on the surface at 2100 JST was calculated, which is shown in Fig. 21. It is found from the result that the latter mechanism was probable in the present case. That is, a remarkable divergence developed on the southeast side of the mountain region, during the period that rainband I developed. It is conceivable that the pattern of the divergence reached up to 1 km level from the two mountain data and one aerological datum in the region. It was found that the echo elements of rainband I and the wind-spread echo of pattern F were neither generated newly nor continued to develop in the leeward of the mountain. Even if the echo elements were in the mature stage, they diminished rapidly as soon as they crossed over the mountain.

In the previous investigation (FUJIWARA, M. 1958), the importance of trigger action in the flow for the echo generation was pointed out in the present case. If an echo has been developed, the fluid-dynamical trigger action will become unnecessary for the successive trigger lifting of air under the convective cell. The fact mentioned above on the echo diminishing suggests, therefore, that the flow pattern (convergence or divergence) is the most decisive factor for the continuance of the development of the convection cell once generated. It is further suggested from this, that the meso-scale patterns of rainband I and II would show implicitly those of air flow. This dynamical pattern, though the verification is unable owing to scarcity of data, will occur in the case of typhoons which forms the spiral bands.

It was shown that rainband II which traveled from the west ocean to northern Kyushu was transformed on its way. In the transitional stage, it was found that a well-developed mother echo laid small echoes on the fore side and then they developed extending eastwards.

It is yet unknown how the two different movements occurred within a narrow
region. However, the mechanism will have some similarity to that of fission of developing airmass echo, on which some detailed description was given in the previous paper. (FUJIWARA, OKABE and NISHIHARA, 1958) The author considered that the more easterly component of the movement was attained influenced by the upper westerly wind as the cloud developed up to a sufficient by high level. Because similar appearances in the elevated cells were found from analysis of echoes. However, the evidence which shows clearly the development of the cloud up to a high enough level is very poor because the bud was comparatively small. Comparing the intensity of echo A on the scope with that of the others which were verified by the surface observations to have thunderstorms, it is conceivable that echo A developed sufficiently up to the level where the ice phase must be completed. If it was so, the ice seeding would occur in the direction in which the westerly was most effective.

Rainband III (frontal rainband) was quasi-stationary on the whole, though the moving of the elementary echoes was almost the same as that of the other bands. Instead of this an undulation of a small scale about several tens km which also advanced eastwards was found from the analysis on rainband III. A disturbance or undulation of such a small scale, which may be termed meso-scale, was an inevitable accompaniment of a severe storm. In the present case, some disturbances of such a secondary order were found here and there throughout the storm. And the most remarkable one caused remarkable pressure dips on the surface records that occurred in the northern Kyushu during the period from 12 to 17 JST on the 5th, on which USHIJIMA (1958) and YAMADA (1958) have reported. Whether the small-scale disturbances are stable or not is a very interesting problem for the development of local severe storm.

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References

PETTERSEN, S., 1956 : Weather Analysis and Forecasting (I).
Bergerson, T., 1949 : The problem of artificial control of rainfall on the globe. (II), Tellus, 1, No. 3. 13-32.
Fujita, T., 1955 : Results of detailed synoptic studies of squall lines. Tellus, 7, No. 4, 405-436.


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梅雨前線附近のレインバンドと天気構成

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1957年7月上旬九州における局地性豪雨を伴った梅雨のレーダー観測の結果を用い、小規模の波動を伴う梅雨前線の周囲の天気構成を計画した。地上気象観測資料を用いて前線を調べた結果、主前線とこの波動移動の域内に発生したスコールライン（不安定域）に伴われた局地的寒冷前線と主前線の通過した後に、新鮮な寒冷気団による2次前線の発生が見られた。これらの前線に伴って4種類の降雨帯（レインバンド）が発生発達し、1つの梅雨stormを形成していた。このうち、第2の移動レインバンドと暖域内に発達した気団性降雨セルより成るレインバンドはこの種のstormにおける大きな特徴点ということが出来る。これらのレインバンドの各々について運動と構造について解析した結果、レインバンドの発生に関しては、地形と上層の発散のパターンと更に大気下層の層流不安定のこれら3つの条件が重要であることを暗示している。