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Classification of Rainfall Processes in the Kanto Area during the Baiu Season Using 3-D Radar Reflectivity Data

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Abstract

For a quantitative assessment of rainfall and to clarify the stages of the precipitation processes, the classification of rainfall types was carried out using 3-D Akagi-san radar data. Properties of concrete rainfall events in the Baiu season of 1995 were analyzed for the Kanto area. In our work, five diagnostic parameters which represent the properties of the rainfall echoes were calculated. Using these properties, we classified rainfall into types using a practical Fuzzy Cluster method, as the resemblance among the properties of echoes have the features of a Fuzzy relationship. The classified patterns have been verified as meaningful by comparing the results of the classification with the real data recorded by AMeDAS on the ground. The rainfall types of the Baiu season are convective, mixed and stratiform patterns, with their properties showing the effects of topography and stages of rainfall period. The mixed pattern, having a large number of samples and existing at all the stations selected, is the common type of rainfall in the Baiu season. The convective pattern accompanies the largest rainrate among the rainfall patterns. There are some noticeable relationships between the properties of the classified rainfall types and the rainrates averaged on the samples in types. The rainfall processes were clarified with the aid of the diagnostic parameter and the results of the pattern recognition.

1. Introduction

Information on rainfall intensity over a large area can be obtained by radar observations: from radar reflectivity at every spot in the scanning volume, rainrates on the ground can be estimated. The distribution and the sum of the rainfall amount in a certain region within the radar scanning range can be estimated as well. In the last 50 years, radar meteorologists have been working for the purpose of accurately assessing rainfall using the reflectivity data of radar, but the development is not inspiring due to difficulties in obtaining stable data and an insufficiency of 3-D data.

There are two types of recent and noticeable research on the theme of precipitation assessment using radar data. One is attempting to get a deeper understanding of the irregularity of rainfall processes using dual-polarization techniques. The other is a statistical work for the corresponding relation between a spatial distribution of radar reflectivity and a rainfall amount on the ground. The former group of research have obtained interesting results (Ryzhkov et al., 1995a ; Ryzhkov et al., 1997 ; etc.), but naturally they demand advanced devices like polarimetric radars with high sensitivity.

The statistical works are more practical for estimating rainfall amount using radar data, although they require radar data and raingauges of high quality, and they demand data fitting the analyses (Zawadzki, 1975). Calheiros et al. (1987) matched the PDF (Probability Density Function) of non-synchronous Ze and R data sets, then a method, PMM (Probability Matching Method), was tested for utilization with a hydrological model. Rosenfeld et al. (1995b) developed the WPMM (Window Probability Matching Method) and improved the accuracy of radar estimated rainfall amount introducing the objective classification of rain types. For an accurate estimation of rainrate from reflectivity data and a deepening of the knowledge about the stages of rainfall processes, rainfall types should be clearly recognized. Using the information obtained by radar observations, it is expected that the shortage of raingauges and drop-size meters on the ground can be made up by the continuous radar observation.

The areas from Yangtse River in China to west Japan experience heavy rainfalls during the Baiu season. It is important and meaningful to make an accurate, short-range forecast of the amount of precipitation in this rainy season of eastern Asia. There has already been quite a lot of research on topics related to the rainfall processes during the Baiu season, which have focused on the life cycle of the mesoscale systems and analyzed the dynamic and thermo dynamic structures of multi-scale systems (Akiyama, 1978 ; Akiyama, 1984a, b ; Ninomiya et al., 1992 ; Takahashi et al., 1996 ; etc.). From the results of those works, we have come to understand the mode of rainfall in the Baiu season gradually. However, there are a relatively small number of works which have focused on improving the estimation of precipitation amount, and it is difficult to state whether or not the work has been very effective.

In our work, we classify the rainfall processes during the Baiu season in the Kanto area into several types as the first step, then discuss some statistical methods used to obtain a suitable Z-R relationship which can improve the accuracy of the radar-based rainfall estimation. In the first step, we calculated 5 diagnostic parameters which can represent the properties of the radar echoes, then divided rainfalls with those properties into several types using a Fuzzy Cluster method. Results show that the classification of the rainfall processes are representative and reasonable when compared to the real data recorded by AMeDAS on the ground. It is very helpful to use the results of this first step to raise the level of the precipitation estimation on the data of radar and to increase the knowledge of the evolution stages of the rainfall processes in the Baiu season.

2. Data

3-D reflectivity data from Akagi-san radar during the period of 19 June to 14 July in 1995 were used. This period was chosen because continuous rainfalls occurred in the Kanto area.

The position of the radar with an observation range of 198 km is on Mt. Akagi (Fig. 1). The radar data used has two strong points: it has a long time series (in fact, it is routine observation data) which makes statistical analysis possible; and it has 20 elevations (from $-1.8°$ to $20°$) supplying detailed information in the vertical direction. There are mountains around the position of the radar except on the Kanto Plain where the properties of rainfall echoes were analyzed. Two thirds of the radar observation area with mountains were not analyzed because of difficulty in eliminating the effect of ground clutters. The minimum reflectivity factor of the radar recorded is 12 dBZ.

AMeDAS data, as the real rainfall amount on the ground, were used to compare characteristics of rainfall obtained by the analysis of the radar data. Sounding data of Tateno Aerological Observatory were used as the average atmospheric profile in the Kanto Plain.

3. Diagnostic parameters

The WPMM has been verified effective for estimating precipitation using reflectivity data (Rosenfeld et al., 1994; Steiner et al., 1995). Eleven windows were chosen in the Kanto area (see also Fig. 1.) above AMeDAS station in our work. The windows are more or less evenly distributed within the same range

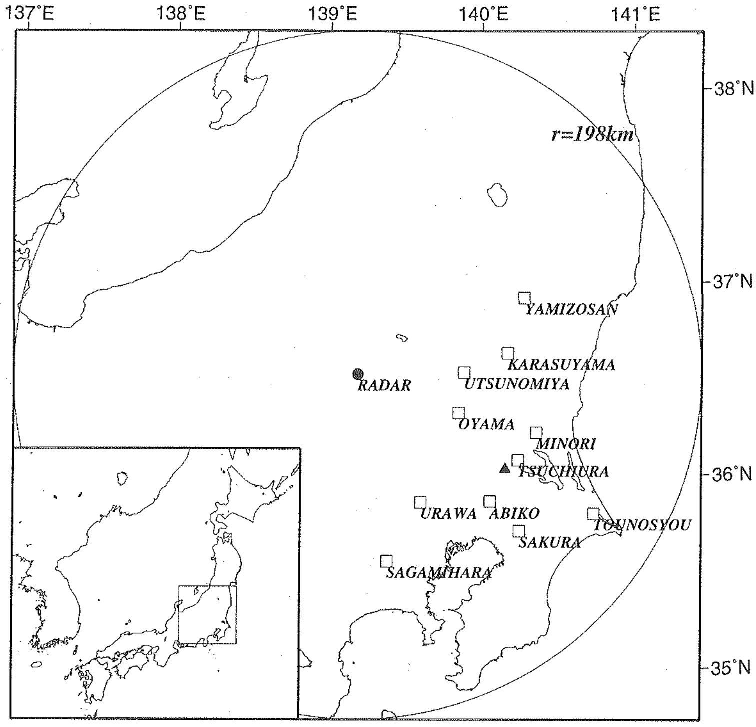

Fig. 1. Location of the radar and the selected windows. The solid triangle expresses the sounding station of Tateno.

of the radar. Each window is fan-shaped as shown in Fig. 2. The azimuthal angle is about 11° with the length of 7 km in the radial direction. The height of the air column is 20 km and the center of the window is the position of AMeDAS station.

To describe the features of rainfall echoes, several aspects of the echoes were taken into account. We used Grades 1, 2 and 3 to view the proportions of reflectivity with different intensities. The values Va and GZr were used to survey the temporal and spatial variation of reflectivity in the clouds, and Ee to express the height of cloud. The BBF (Bright Band Fraction) were used to determine the convective, mixed and stratiform rainfall.

3.1 Definition of the diagnostic parameters

(1) Grades 1, 2 and 3 are percentages of reflectivity with different threshold values within a window. The reflectivity factor is in direct proportion to the

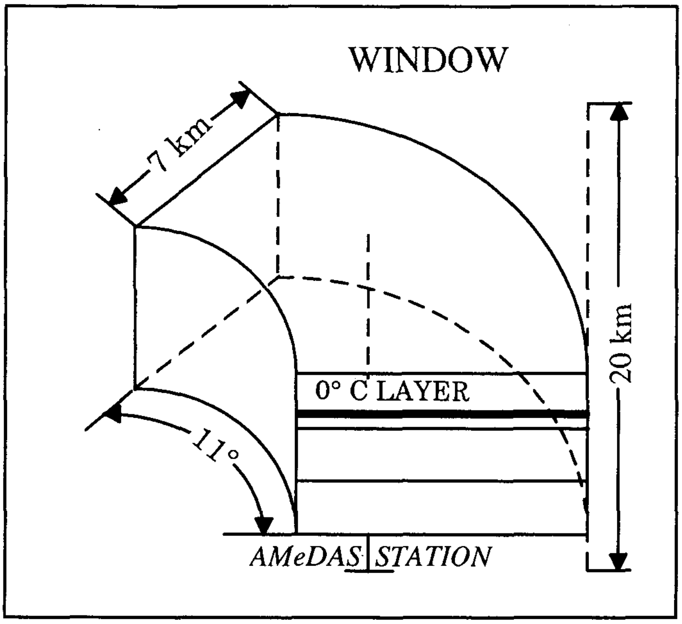

Fig. 2. The definition of a window.

sixth power of the diameter of a rain drop; the rain drops expressed by reflectivity factors with different intensities contribute quite different parts to the precipitation amount. Grade 1 with reflectivity changes from 23 to 40 dBZ represents the relative proportion of the common intensity reflectivity; Grade 2, with changes from 40 to 50 dBZ, represents the proportion of strong reflectivity; Grade 3, with changes above 50 dBZ, represents the proportion of very strong reflectivity. Because there will be serious errors if the reflectivities in the bright band are considered in the estimation of rainfall, only the reflectivities in the air column lower than the height 1.5 km below the 0° layer were used into the calculation.

(2) Va is the variation of reflectivity along time. It is a very important expression of the properties of rainfall echoes. In the processes of stratiform rainfall, air flow is steady, there is little convective portion in the cloud, and the variation of reflectivity along time is small while the existing time of the rainfall process is relatively long. In contrast, convective rainfall usually has a relatively short life cycle; temporal variation of reflectivity is large. As for the radar being used, there are 4 volume scans in an hour. Three absolute differences between reflectivities of adjacent times were calculated in an hour (except for

continuous two no echoes) and averaged to determine the value of Va within a window.

(3) GZr, representing the spatial variation of the reflectivity, is the reflectivity gradients along the radial direction (Rosenfeld et al., 1995a). GZr is the averaged value of the absolute differences between adjacent pairs of reflectivity data bins for a window.

(4) BBF, bright band fraction, is defined as the fraction of the echo area with maximum reflectivities within the air column of a window with a height of 2.5km including the 0°C layer. Statistically, a BBF with a value larger than 0.6 represents the stratiform rainfall, less than 0.4 convective rainfall, and between 0.4 and 0.6 mixed pattern of rainfall.

(5) Ee is the effective efficiency as defined by the following equation.

$$E_e = (r_{sb} - r_{st}) / r_{sb} \tag{1}$$

here, r_{sb} and r_{st} are saturation mixing ratios at the base and the top of a cloud, respectively. Ee is the fraction of the water vapor carried up through the cloud base which is potentially available for precipitation (Rosenfeld et al., 1990). Because r_{st} is determined by the actual height of the clouds, Ee can represent the height of clouds in the value range from 0 to 1.

The height of the bottom of a cloud was determined by sounding data while the top of a cloud was observed by the radar as the average height of the grids in a window, where radar echo heights are above 2 km and reflectivities are larger than 12 dBZ. The height of the 0°C layer was determined by the sounding data also. The primary lifting height was chosen larger than 300 m to avoid the effect of the turbulence on the ground.

3.2 Relations between diagnostic parameters and rainrates

Figure 3 is the scatter diagrams of the diagnostic parameters versus rainrates. The relations between the parameters and rainfalls at the AMeDAS station, Oyama, are shown as an example. Other stations also show similar distributions in the scatter diagrams. Some relationships between diagnostic parameters and rainrates can been seen from Fig. 3 if the complexity of the mechanism of 1mm rainrate is considered. Figure 3(a) shows that clouds with weak reflectivity mainly correspond to small rainrates. Figure 3(b) shows that radar echoes with larger proportions of strong reflectivities result in large amounts of rainfall. Radar echoes with a large proportion of very strong reflectivity corresponds to a large rainrate (not shown in figure). Figure 3(c) shows that clouds with rapid temporal variation correspond to a large rainrate.

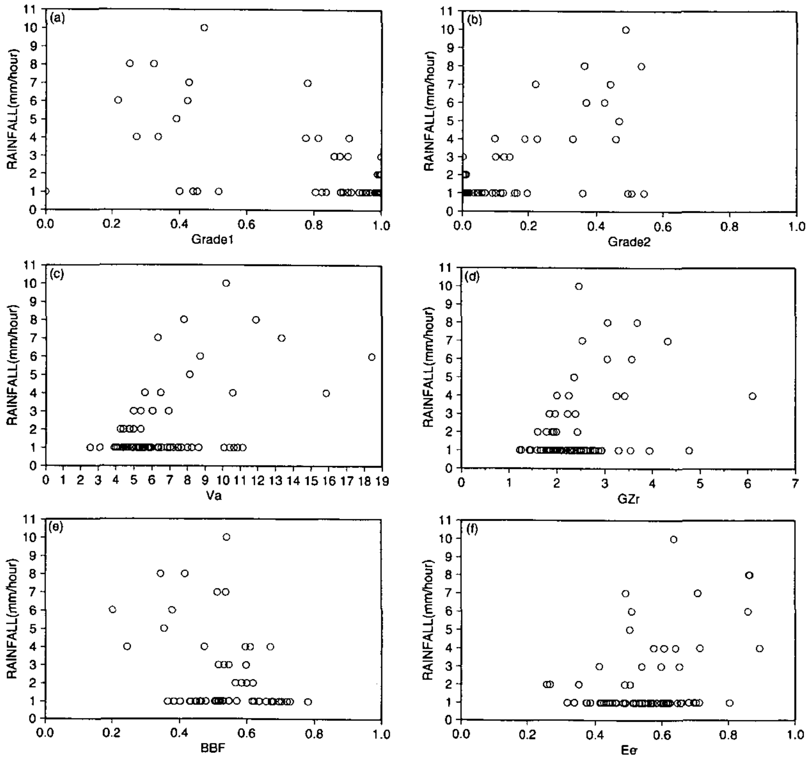

Fig. 3. Scatter diagram of the diagnostic parameter versus gauge-measured rainrate at the station Oyama. (a) Scatter diagram of Grade 1 versus rainrate; (b) The same as (a), but for Grade 2; (c) for Va; (d) for GZr; (e) for BBF; (f) for Ee.

With the increase of GZr (Fig. 3(d)), rainrate increases. That means, a larger rainrate accompanies a larger spatial variation of reflectivity over a station. We can also see that larger Ee (Fig. 3(f)) corresponds to a larger rainrate. That is, higher clouds accompany heavier rainfall. On the other hand, echoes with larger BBF correspond to smaller precipitation (Fig. 3(e)). That is, rain generally found in the stratiform pattern accompany small precipitation. Because the diagnostic parameters in the scatter diagrams have been averaged every hour, the effect of short time fluctuations or the instability of turbulence in the clouds were eliminated and the relationships are representative at the stations. These relationships lay a reliable foundation for the further analysis by the Fuzzy Cluster method.

4. Analyses of rainfall patterns

There are some regularities in the relations between the diagnostic parameters and rainrates, but a real law can not be concluded from the scatter diagrams alone. It is difficult to take the diagnostic parameters into account simultaneously to clarify the rain types and the stages; the rainfall process is complicated and the relationships between the parameters and the rainfalls may be inharmonious. It is necessary to recognize regular patterns in the properties of the rainfall echoes in the windows and to classify rainfalls into several representative types based on the analysis of the diagnostic parameters and the relationships among the samples in the Baiu season. By combining this information with the real weather data, we hope to ascertain the physical realities of the classified types. With the help of the diagnostic parameters and the classified rainfall types, it will be possible to analyze the rainfall processes objectively and improve the accuracy of the estimation of precipitation amounts.

4.1 Usage of the Fuzzy Cluster method

A Fuzzy Cluster method was chosen to classify the rainfalls into types using those parameters as characteristics of the samples. This method is one of the "pattern recognition" methods. Fuzzy Set theory, as a mathematical theory, has been exercising influence over many subjects (Bezdek, 1981). Combined with "pattern recognition", the theory made the recognition of natural phenomena (such as earthquake, heavy rainfall processes and so on) more objectively and suitably. There are many problems with Fuzzy features in the meteorological field. For example, the resemblance of two weather processes, or two cloud charts, or the resemblance of the effects of topography on weather processes. In our work, we used the Fuzzy relationship matrix for clustering and obtained rainfall types with obvious physical meaning. The substantial steps of calculation are shown in the appendix.

There were three principles in the classification: 1) Samples with a large rainrate are allowed to be in one of the main types, 2) The types are reasonable from a meteorological point of view, 3) The value of λ is higher than a specified level. In all the windows, threshold λ was chosen as larger than 0.87.

4.2 Test of the reliability of the Fuzzy Cluster method

Several types of rainfalls were determined using the Fuzzy Cluster method in the windows. We tried to verify the reliability of the method by comparing

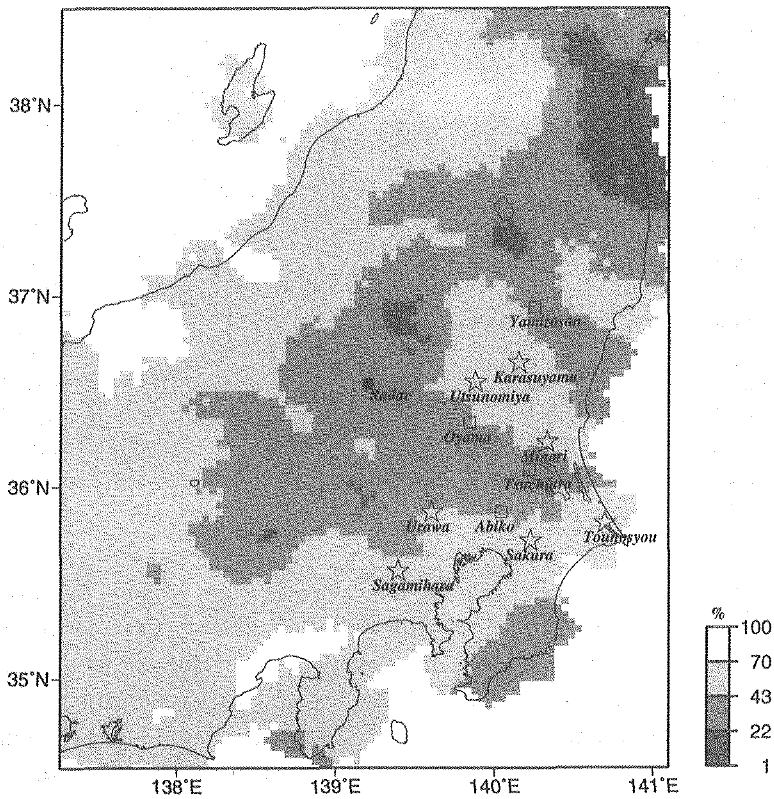

Fig. 4. Proportion of precipitation amount with rainrates larger than 5 mm/h during the Baiu period, 1995. Square expresses the place where mixed patterns' rain processes contribute the most important part to the sum of precipitation ; Star expresses the place where convective patterns' rain processes contribute the most important part to the sum of precipitation.

the results of the classification and AMeDAS data on the ground.

The percentage of rainfall with a rainrate larger than 5 mm/h in the Baiu season of 1995 at the stations surrounding the radar site were calculated as shown in Fig. 4. Above 43% of the precipitation amount at Sagamihara, Sakura, Tounosyou, Urawa, Minori, Karasuyama and Utsunomiya was formed by rainfall processes with a rainrate larger than 5 mm/h. On the other hand, precipitation at Abiko, Oyama, Tsuchiura and Yamizosan was mainly composed of rainfall processes with a smaller rainrate. The types with the largest contributions to the precipitation amount at the 11 selected stations are shown in Table 1. Convective rainfalls contributed the most important part of precipi-

Table 1. The properties and percentage of the number of samples of the type which contributes the most important part to the sum of precipitation in the selected window.

Station	rainrate	Ee	BBF	Va	GZr	Grade 1	Grade 2	Grade 3	%
Sagamihara	9.40	0.66	0.20	6.17	2.01	0.276	0.682	0.042	18
Sakura	4.58	0.63	0.33	8.83	2.57	0.403	0.562	0.035	22
Urawa	4.62	0.68	0.34	6.86	2.08	0.347	0.633	0.020	12
Tounosyou	5.31	0.66	0.26	7.25	2.22	0.357	0.606	0.037	30
Abiko	3.38	0.68	0.45	6.36	2.06	0.485	0.508	0.007	22
Tsuchiura	1.39	0.56	0.51	6.21	2.01	0.973	0.027	0.000	36
Minori	5.67	0.74	0.36	6.73	2.06	0.484	0.498	0.018	16
Oyama	1.33	0.57	0.56	5.24	1.93	0.981	0.019	0.000	49
Utsunomiya	10.43	0.78	0.32	11.77	3.70	0.355	0.331	0.314	9
Karasuyma	5.08	0.68	0.36	6.42	2.27	0.428	0.553	0.019	15
Yamizosan	4.54	0.74	0.45	6.85	2.21	0.559	0.433	0.008	17

tation at Sagamihara, Sakura, Tounosyou, Urawa, Minori, Karasuyama, Utsunomiya and mixed pattern rainfalls contributed the most important part at Abiko, Oyama, Tsuchiura and Yamizosan. The regions where convective pattern rainfall processes contributed the largest part to the sum of precipitation correspond to the regions where above 43% of the precipitation amount was composed of the rainfall processes with a rainrate larger than 5 mm/h. The regions, where mixed patterns contributed the most important part to the sum of precipitation, correspond to the regions where the precipitation amount was formed by processes with a relatively smaller rainrate. With the concept that rainrate varies from large to small in the sequence of rainfall patterns, such as convective, mixed and stratiform patterns, we can conclude that the classification of the rainfall types is representative and reasonable.

4.3 Discussion of the rainfall patterns and their properties

The following regularities can be seen from the results of Fuzzy Cluster (the properties and the rainrate of the type in Table 2 were averaged on the number of samples in the type).

(1) The predominant type in the Baiu season is the mixed pattern. The mixed pattern exists in the classified types of rainfalls at all the 11 selected stations and is the type with the largest number of samples at 5 stations. The mixed pattern rainfall process in the Baiu season has the existing forms as follows. The forward position of the area is covered with echoes of a

Table 2. The patterns of rainfall processes during the Baiu season in the Kanto area in the selected windows.

Sagamihara

Type	rainrate	Ee	BBF	Va	GZr	Grade 1	Grade 2	Grade 3	%
1	9.40	0.66	0.20	6.17	2.01	0.276	0.682	0.042	18
2	1.22	0.61	0.53	7.48	2.69	0.937	0.063	0.000	16
3	2.00	0.37	0.27	8.98	3.55	0.900	0.099	0.001	15
4	1.50	0.78	0.34	5.78	2.11	0.962	0.038	0.000	7

Sakura

Type	rainrate	Ee	BBF	Va	GZr	Grade 1	Grade 2	Grade 3	%
1	4.58	0.63	0.33	8.83	2.57	0.403	0.562	0.035	22
2	1.20	0.59	0.59	6.67	2.41	0.890	0.110	0.000	18
3	1.00	0.68	0.48	5.95	1.94	0.521	0.477	0.002	7

Tsuchiura

Type	rainrate	Ee	BBF	Va	GZr	Grade 1	Grade 2	Grade 3	%
1	1.39	0.56	0.51	6.21	2.01	0.973	0.027	0.000	36
2	2.31	0.68	0.44	6.31	2.02	0.680	0.315	0.005	17
3	5.00	0.69	0.29	8.71	2.47	0.406	0.502	0.092	9

Oyama

Type	rainrate	Ee	BBF	Va	GZr	Grade 1	Grade 2	Grade 3	%
1	1.33	0.57	0.56	5.24	1.93	0.981	0.019	0.000	49
2	3.00	0.55	0.41	10.27	3.38	0.434	0.453	0.113	7
3	6.50	0.87	0.35	11.07	3.38	0.265	0.413	0.322	6

Utsunomiya

Type	rainrate	Ee	BBF	Va	GZr	Grade 1	Grade 2	Grade 3	%
1	1.59	0.60	0.62	5.81	2.05	0.986	0.014	0.000	40
2	6.70	0.62	0.36	7.40	2.76	0.547	0.427	0.026	12
3	10.43	0.78	0.32	11.77	3.70	0.355	0.331	0.314	9
4	5.50	0.52	0.46	10.32	4.02	0.753	0.218	0.029	7
5	1.40	0.36	0.45	6.66	2.79	0.998	0.002	0.000	6

Karasuyama

Type	rainrate	Ee	BBF	Va	GZr	Grade 1	Grade 2	Grade 3	%
1	1.19	0.57	0.53	6.05	2.18	0.975	0.025	0.000	36
2	5.08	0.68	0.36	6.42	2.27	0.428	0.553	0.019	15
3	11.00	0.72	0.25	10.42	3.63	0.296	0.391	0.313	4

Yamizosan

Type	rainrate	Ee	BBF	Va	GZr	Grade 1	Grade 2	Grade 3	%
1	1.48	0.66	0.60	5.27	1.92	0.983	0.017	0.000	30
2	4.54	0.74	0.45	6.85	2.21	0.559	0.433	0.008	17
3	1.57	0.45	0.65	7.44	2.68	0.899	0.101	0.000	9
4	2.20	0.51	0.41	6.39	2.25	0.970	0.030	0.000	7
5	9.25	0.78	0.28	10.06	3.29	0.517	0.310	0.173	5

convective pattern and the rear part is covered with a stratiform pattern. Mesoscale convective system comprised of convective rainfall coexist with stratiform rainfall. The transition part of the area (or the period) is what is called a mixed pattern. It should be noticed that the patterns of rainfall called mixed, convective and stratiform patterns are decided by BBF in our work. The other parameters show the properties of the echoes such as height, temporal or spatial variation of the reflectivity, and others. These are the expressions of stages of rainfall processes and the effects of some factors on the echoes, for example, the effect of topography (the distribution of the land and the ocean).

(2) The largest rainrates of the rainfall types at all the 11 AMeDAS stations are corresponding to the smallest BBF. This means that developed convective precipitation results in a large rainrate.

(3) The largest rainrates are corresponding to the largest Grade 3 and the smallest Grade 1. These show the different contributions to the sum of rainfall by the reflectivities with different intensities. The larger the proportion of Grade 2 and 3, the larger the rainrate. In contrast, the larger the proportion of Grade1, the smaller the rainrate.

(4) The maximum rainrate among these types usually corresponds to high Ee, but does not always correspond to the highest Ee. This means that large rainrates accompany high clouds, but there are times when the maximum rainrate occurred in the stage without the highest cloud.

(5) The type of stratiform rainfall occurring at 3 stations has the smallest GZr and Va among the classified types showing small temporal and spatial variation of reflectivity.

(6) At most of the stations, the maximum rainrates are corresponding to the maximum values of Va. This means that the clouds which bring large rainrates usually have relatively rapid variations of reflectivities. The stations at Sagamihara and Urawa are the exceptions. At Sagamihara, the largest Va is in the third type (a type of convective rainfall) but not in the first type with the largest rainrate of 9.40 mm/h. Checking all the samples in the third type, it was found that they reveal a kind of stage in convective rainfall processes with a relatively long life cycle (larger than 4 hours). At Urawa, the maximum Va is in the second type of rainfall process. Samples of this type reveal a stage with rainfall type changes from mixed pattern to stratiform pattern.

Rainfalls of each of the windows, as defined in section 3, have their own properties which can be expressed by the diagnostic parameters and the results of classification. If we have enough data for rainfalls at many points on the ground (not limited to the 11 selected stations) in the region, an improvement in the precipitation assessment for the region could be expected. Additionally, rainfall process could be described objectively in the radar data.

5. Objective view of concrete rainfall processes

Using the above parameters and the results of the classification, concrete rainfall processes were analyzed. Properties at the stations Yamizosan, Oyama and Sagamihara were considered to be representative conditions in the north, middle and south part of the Kanto area. There were continuous rainfall processes on 5 July 1995 in the Kanto area. Two whole processes were chosen for analysis. The first process started at 03 : 00JST and ended at 07 : 00JST for the Kanto area (Fig. 5(a)). Rainfall echoes moved from west to east accompanying rainfall over a large area. During this time, Yamizosan station was not affected. Sagamihara was in the passage of echoes with strong reflectivity, while Oyama was on the edge of the echoes. The second process started at 13 : 00JST and ended at 23 : 00JST (Fig. 5(b)). In that period, echoes were moving slowly (sometimes in stationary state) from northwest to southeast of the Kanto area while the intensity of reflectivity became weaker until it disappeared. In both of the processes, the rainfall patterns at Sagamihara were mainly convective patterns (Fig. 6(a)), which shows that the position of Sagamihara and the topography around the station support an easy occurrence of convective rainfalls over this area. The proportion of strong reflectivities was larger in the first process, which shows the fact that Sagamihara was in the passage of strong reflectivity in the first process but in the passage of weakening reflectivity in the second process (Fig. 6(b)). Oyama was on the fringe of the passage of radar echoes which had been stratiform rainfall in the first process. In the second process, with a larger proportion of strong reflectivity, there were mixed and stratiform pattern rainfalls, which brought us larger precipitation. In the second process, Yamizosan, with mixed or stratiform pattern rainfalls, had only common strength reflectivities. Ee had the largest value among the three stations at the station Yamizosan, the smallest value at Sagamihara (Fig. 6(c)). It expressed the fact that radar echoes were getting weaker and weaker while they moved from northwest to southeast of the Kanto area. With the aid of the diagnostic analysis and the results of classification, rainfall processes were recognized objectively.

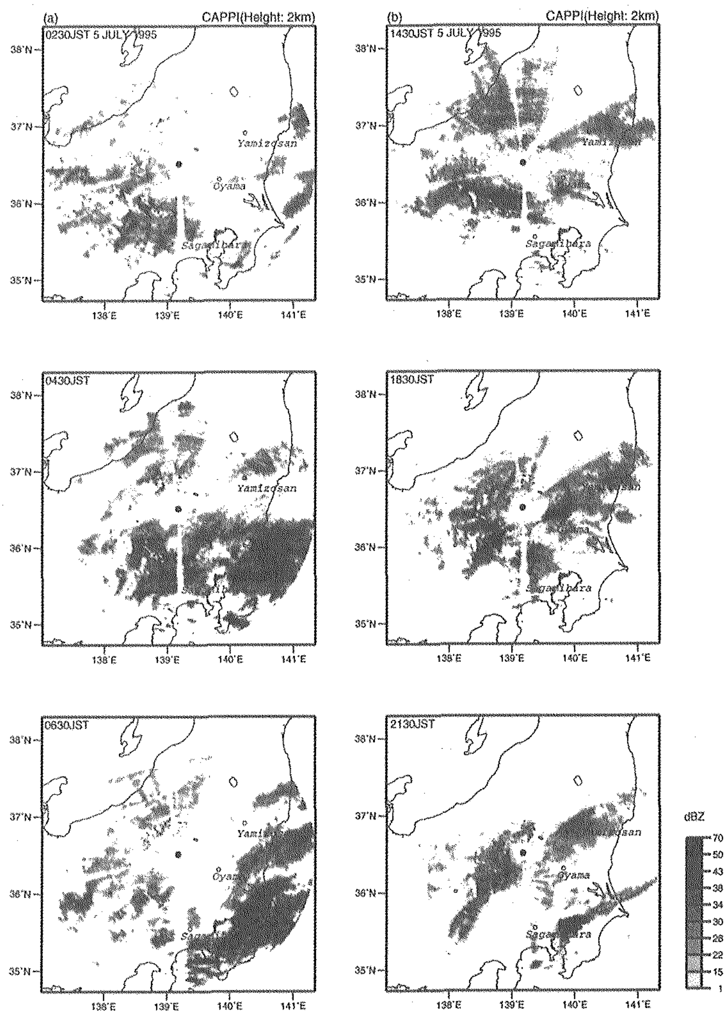

Fig. 5. The movement of radar echoes in two rainfall processes on 5 July 1995. (a) Distribution of radar echoes at 02 : 30JST, 04 : 30JST and 06 : 30JST in the first rainfall process from 03 : 00 to 07 : 00JST. (b) Distribution of radar echoes at 14 : 30JST, 18 : 30JST and 21 : 30JST in the second rainfall process from 13 : 00 to 23 : 00 JST.

6. Discussions and conclusions

Classification of the rainfall regimes using three-dimension reflectivity data is some of the most interesting work in radar meteorology. With relatively detailed information in the vertical direction we tried the algorithms of Rosen-

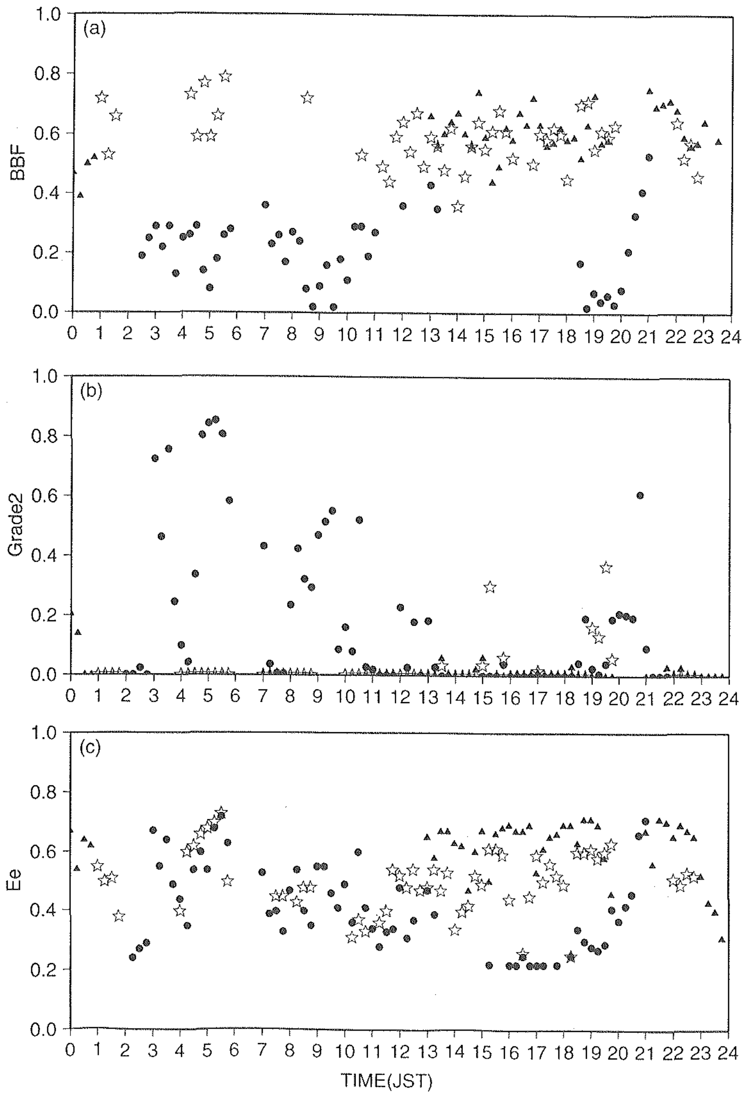

Fig. 6. (a) Time series of BBF on 5 July 1995; (b) The same as (a), but for Grade 2; (c) The same as (a), but for Ee. (Circle: Sagamihara, Star: Oyama, Triangle: Yamizosan)

feld et al. (1995a) to divide the rainfall regime as convective, mixed or stratiform. We have noticed that without detailed information in the vertical direction "bright band methods" will not be operationally useful as was pointed by Steiner et al. (1995). We have also considered that detailed information in the vertical direction is very important to precipitation estimation as was emphasized by Joss et al (1995). It is fortunate that there are 20 elevation scans in our data set. We could calculate the diagnostic parameters such as Ee and BBF which represent the properties of the rainfall echoes. The data has a continuous time series which made it possible for analyses of the typical patterns at the selected stations using a Fuzzy Cluster method.

Objective description of the rainfall echoes is necessary for accurate short range weather forecasting. Some aspects of the reflectivity, such as its temporal and spatial variation, its height and so on, should be expressed in a way that can be easily understood. We have chosen 5 diagnostic parameters which can express the properties of the rainfall echoes. Clouds with a large proportion of Grade 1 usually accompany small precipitation. In contrast, the larger the proportion of Grade 2 or Grade 3, the larger the precipitation. Grades 1, 2 and 3 relate to the contribution to the precipitation by the reflectivities with different intensities. The proportions of Grades 1, 2 and 3 can also show the change in the intensity of the reflectivity in a developing stage of the rainfall period. Va and GZr express the temporal and spatial variation of reflectivity in the clouds, respectively. Commonly, with larger Va and GZr, rainfall echoes accompany a larger precipitation amount, but there are exceptions which are considered as the expression of the effects of the developing stage of the rainfall processes and the effects of the topography. We will show the results of the raingauge's data with shorter time intervals in the next paper. The Ee expresses the height of the cloud. Usually, the echo with higher Ee corresponds to a larger rainrate. This parameter is also related to the stage of the rainfall processes. The BBF was used to divide the rainfall regime as convective, mixed or stratiform with statistical thresholds. The larger the value of BBF, the smaller the precipitation amount.

The typical pattern of rainfall processes was "recognized" by the Fuzzy Cluster method. The resemblance among the rainfall echo samples has Fuzzy features, which makes it suitable for the use of the Fuzzy Cluster method to deal with the classification problem. The rain processes over the selected AMeDAS stations in the Kanto area for the Baiu period were divided into several types as convective, mixed and stratiform patterns with diagnostic parameters. At different stations, the rainfall regimes we defined on the value of BBF are the same, for example, convective ($BBF \leq 0.4$ at the stations), but they have different properties as expressed by the other 4 diagnostic parameters showing the effects of the local topography and the position to the Baiu front. We verified the reliability of the classification by comparing the results of the classification and the reality expressed by the AMeDAS data. The predominant type of rain processes in the Baiu period is the mixed pattern, which is of the same view that was pointed by Du et al. (1985). Rain of the convective pattern with the largest rainrate contributes to a large part of the total rainfall amount in the Kanto area.

Using the diagnostic parameters, the concrete rainfall processes were understood objectively. The diagnostic parameters represent the main aspects of the rain echoes, they could be used as objective indexes to determine which pattern the rainfall is and what stage the rainfall process is in.

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Appendix

The Fuzzy Cluster method is usually used to classify the samples into groups objectively based on the Fuzzy Relationship. The steps of Fuzzy Cluster analysis are as follows.

(a) Take the diagnostic parameters as characteristics of the samples:

The original matrix is obtained as $X(p, q)$. Here, $p=1, 2, \ldots, P$ (P: number of samples) and $q=1, 2, \ldots, Q$ (Q: number of characteristics).

(b) Calculate the Fuzzy Resemblance matrix $R=(r_{pp})$:

In our work, we chose the correlation coefficient matrix as the Fuzzy Relationship matrix R. Element r_{ij} is the correlation coefficient of sample i and j. The characteristics were normalized to avoid the effect of different dimensions.

(c) Search for the Fuzzy Equivalent Relationship matrix:

In the matrix R, each of the elements r_{ij} expresses a subordinated degree(the extent which sample i and sample j satisfy the resemblance relationship). It is recognized as equivalent if the following conditions are satisfied.

(1) $r_{ii}=1,\ i=1,2,\ldots,P$ (*self-reversible*)

(2) $r_{ij}=r_{ji},\ i,j=1,2,\ldots,P$ (*symmetrical*)

(3) $\bigvee_{j=1}^{P}(r_{ij}\wedge r_{jk})\leq r_{ik},\ i,k=1,2,\ldots,P$ (*transitive*)

In our work, conditions (1) and (2) are clearly satisfied, but transformation should be done to satisfy condition (3) with the following theorem.

If R is a self-reversible and symmetrical Fuzzy Relationship, the limit of matrix $R(m)$ when m tends to be infinitely great will be transitive. That is, resemblance relationships between pairs of samples could be equivalent to each other if the corresponding elements in the limit of $R(m)$ are larger than a given threshold.

Here, $R(m)oR=R(m+1)$, "o" means the calculation of multiplication.

Suppose there are two Fuzzy Relationship matrix with rows and columns of n, m and m, p, respectively. Their product will be a matrix with rows of n and columns of p.

Written as $T=RoS=(t_{ik})$, here,

$$t_{ik}=\max\{\min_{1\leq j\leq m}(r_{ij},\ s_{jk})\}$$

or written as

$$t_{ik}=\bigvee_{j=1}^{m}(r_{ij}\wedge s_{jk})$$

In practice, if there has been a Fuzzy Relation matrix R, there will be a number m which can make $R(m)=R(m+1)=R(m+2)=\ldots.$ This time, $R(m)=R'=(r'_{ij})$ is already an equivalent Fuzzy Relationship.

From the point of view of the correlation relationship, define a threshold λ $(0\leq\lambda\leq1)$. If $r'_{ij}\geq\lambda$, sample i and sample j would be included in one group. Ultimately, the types could be classified.

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