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ON THE VARIABILITY OF THE $Z - R$ RELATIONSHIP IN RAINFALL RELATED TO RADAR ECHO PATTERN

by

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Abstract

Based on simultaneous radar and rain gauge measurements during 16 rainstorms an attempt is made to find parameters of the radar echo distribution which could be used to specify the best possible estimate of the $Z - R$ relationship for each storm. Radar measurements were carried out by the gain stepping method. A number of parameters were calculated based on each iso-echo picture measured. Means, standard deviations and intercorrelation coefficients of various parameters for each measurement period were further correlated with the corresponding rainfall types and best mean values of coefficient a in the $Z - R$ relationship $Z = aR^{1.6}$. Evidence for significant correlations between some echo pattern describtors and the rainfall type and also the best value of coefficient a were obtained.

1. *Introduction*

Quantitative measurement of rainfall by radar is based on the fact that the average power received by radar depends on the radar parameters, on the shape, size, number and dielectric properties of raindrops in the target region and on the attenuation of microwaves between the target and the radar. If the radar parameters, the dielectric constant of water and the attenuation are known, one can calculate what is called the radar reflectivity factor Z of scatterers based on the average power received by radar.

If the raindrops are spherical and small enough compared with the wavelength used, then Z is simply the sum of the sixth powers of the diameters of the drops in a unit volume. Thus Z is a function of the drop size distribution. It has been found in many studies that the relationship between the radar reflectivity factor Z and the rainfall rate R (*sc.* $Z - R$ relation) may be approximated by the formula

$$Z = a R^b \tag{1}$$

where a and b are coefficients which depend on the size distribution and falling velocities of the drops.

If Z is measured by radar then one can solve (1) for R. Unfortunately both coefficients in (1) (and especially a) may vary widely from time to time and so far not much is known about this variability. The values reported for coefficient a are generally of the order of 100—600 and the values of coefficient b vary between 1.3 and 1.8 in most cases. The uncertainty concerning these coefficients is one of the most serious problems in the quantitative measurement of precipitation by radar today.

Several possibilities by which the difficulty mentioned above could be avoided have been studied during the last two decades. HITSCHFELD and BORDAN [3] and WILSON [8] suggest the use of a reference rain gauge. By comparing the record of the reference gauge with the corresponding values of Z measured above that gauge by radar, one can solve coefficient a (or both a and b) in equation (1) so that the radar-derived amount of precipitation equals the gauge measured amount and the $Z - R$ relationship obtained can be applied to the surrounding area of the reference gauge. This method has proved quite advantageous in many studies (see *e.g.* [1, 2, 4, 5, 8]). However, its disadvantage is that several telemetring reference rain gauges are needed in the measurement site. One gauge is not representative of a very wide area. The method does not work if there is no rain just at the reference gauge. The method also seems to overestimate the variation of the $Z - R$ relationship somehow.

Another method is to use some average Z-R relationship for each type of rainfall. It is known that in showers and in continuous rains different Z-R relations are valid on average. In most cases the values of coefficient a are in convective rains higher than in widespread rains, For instance JATILA and PUHAKKA [4] found that if b in (1) is fixed to 1.6 coefficient a has on average the value 360 in showers, 196 in continuous rains and 56 in drizzle. Nevertheless, the storm to storm variability of a was from 243 to 575 in showers and from 106 to 402 in continuous rains. Hence great errors may appear in individual measurements and again, a method for observing and telemetring the type of rainfall is needed in the measurement site. If the rainfall type classification could be made based on the information obtainable with radar then the use of the average Z-R relation for each type of rain could be a significant improvement over existing methods.

The character of PPI echoes received from convective rain and continuous rain differ. The echo pattern received from convective rain is often composed of several separated echoes whose horisontal areas are rather small but intensity rather high. Thus the boundaries of convective echoes are sharp and intensity gradients may be large. The echo pattern received from continous rain is typically much smoother than the convective echo. The horizontal area of the echo received from continous rain is often rather wide and the intensities do not vary from point to point and with time as much as in convective rains. As a consequence, the echo received from continuous rain is characterized by a relatively wide echo coverage, diffuse boundaries of separated echoes and rather small intensity gradients.

Because of the differences in the character of the radar echo pattern, it should be possible to derive some parameters from the echo distribution which could be used for the determination of the type of rainfall and thus for selecting the appropriate average Z-R relationship. Furthermore, it may be possible to obtain from the echo pattern even more detailed information on the variability of the Z-R relation than only that which is related to rainfall type.

This kind of work has been done earlier by WILSON [7]. The echo pattern parameters used by WILSON were average echo intensity, variance of echo intensity, average echo length, ellipticity of pattern, orientation of pattern and echo coverage. WILSON found that the average intensity, intensity variance and orientation of pattern could perhaps provide some explanation for the variability of the Z-R relationship but due to the small number of storms studied, no general conclusions could be reached.

JOSS *et al.* [6] suggest the use of a vertically pointing radar for the determination of the rainfall type. The difference of records obtained from continuous rain and convective rain with this kind of equipment is clearly demonstrated in the paper but no method for objective and mechanical determination of the type is studied. The use of a vertically pointing radar is also restricted to the vicinity of the radar set. If there is no rain at the radar site, the type of rain somewhere else cannot be determined.

2. *Data and procedures used*

The data of this paper consist of the same 16 storms which were discussed earlier in the papers of JATILA and PUHAKKA [4, 5]. Radar measurements were carried out using the simple gain-stepping method. The area of the measurement site was about 180 sq. km (Fig. 1). As a result of the measurements a set of iso-echo contours in the measurement site was obtained at a frequency of 4—12 per hour. From these pictures the areas between adjacent iso-echo lines were measured planimetrically. Each area measured thus represents that portion of the whole measurement site for which the average power received has been inside a known range of power.

Before any further calculations were made all values of power received were replaced by DBZ values ($DBZ = 10 \, \mathrm{Log}_{10} Z$ where the dimension of Z is $mm^6 \, m^{-3}$) with the aid of what is called the radar equation. From these data, referred to as A-data later in this paper, the following items were computed for each iso-echo picture:

A0: The average DBZ for the whole measurement site
A1: The echo coverage (percentage of the whole site)
A2: The average DBZ in the echo area
A3: The maximum DBZ value met in the picture
A4: Percentage of the total measurement area $DBZ >$ A0[1])
A5: Percentage of the echo area $DBZ \geq$ A2[1])
A6: That DBZ value which represents the largest area between adjacent iso-echo lines in a particular picture
A7: A3 — A0
A8: A3 — A2
A9: Percentage of the total area of measurement site $DBZ > 24.6$

Using these items, weighted by the item A0, average values, standard deviations and intercorrelation coefficients of various items were computed for each measurement period or storm in order to get some

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[1]) Items A4 and A5 were approximated only very roughly due to difficulties in interpolation between iso-echo lines.

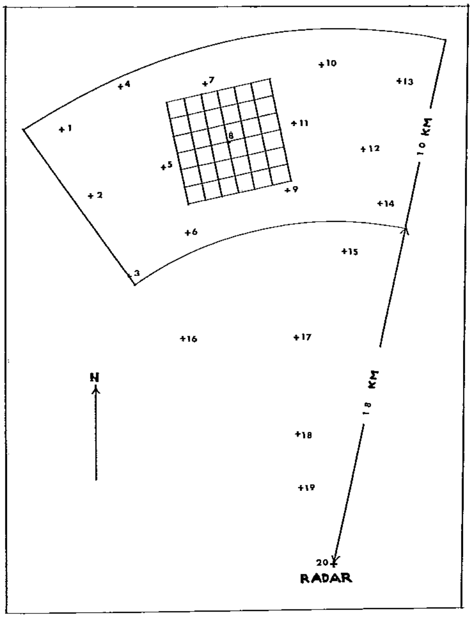

Fig. 1. The measurement site with the locations of the recording rain gauges used (nos. 1—20) and with the grid in which the iso-echo pictures were digitized.

single numbers which characterize each whole measurement period. The average of the logarithm of the radar reflectivity factor was used as weight so that those moments in the course of a particular storm, during which the average echo and thus the rainfall rate were weak, would not have too strong an effect on the result.

The original A-data do not allow a very detailed analysis of the horizontal distribution of radar echo because one does not know anything about the locations of the iso-echo lines; only the areas between them are known. The iso-echo pictures were afterwards manually digitized in a 7×7 grid originally for some other purposes. The distance between adjacent gridpoints was about 0.9 km. Thus the digitized data covered about 29 sq. km of the total area (180 sq. km) of the measurement site. The location of the grid is illustrated in Fig. 1. The digitized data are referred to later in this paper as B-data.

Using the B-data the following additional items for the grid of each iso-echo picture were calculated:

B0: The average DBZ for the grid area
B1: The standard deviation of DBZ in the grid area
B2: The average DBZ on such a region where $DBZ > 20$
B3: The standard deviation of DBZ on such a region where $DBZ > 20$
B4: The maximum value of DBZ
B5: Percentage of gridpoints for which $DBZ \geqq 40$
B6: —»— —»— —»— $DBZ \leqq 30$
B7: —»— —»— —»— $DBZ >$ B0
B8: B4 — B0
B9: The maximum gradient of DBZ met in the grid
B10: The mean of $\nabla^2(DBZ)$
B11: The standard deviation of $\nabla^2(DBZ)$
B12: The mean of negative values of $\nabla^2(DBZ)$
B13: The standard deviation of negative values of $\nabla^2(DBZ)$
B14: The minimum value of $\nabla^2(DBZ)$
B15: Percentage of gridpoints for which $\nabla^2(DBZ) < -40$ dBZ/km^2
B16: —»— —»— —»— $|\nabla^2(DBZ)| < 5.0$ dBZ/km^2
B17: —»— —»— —»— $\nabla^2(DBZ) > 0$
B18: The maximum value of ∇^2 (DBZ)

The Laplace of DBZ at a particular gridpoint, $\nabla^2(DBZ)$, was approximated with the DBZ values at the four nearest gridpoints and the DBZ value at the point in question. Of course the Laplace could not be evaluated at the boundary of the grid.

As in the case of items A0 — A9, means, standard deviations and intercorrelation coefficients based on items B0 — B18 were calculated for each storm. Again the average DBZ (item B0) was used as a weight.

The 16 storms studied were classified into three types of rain. The classification was based on the routine observations made at Helsinki Airport (point 15 in Fig. 1). The rainfall types considered were: continuous rain, showers (or convective rain) and drizzle.

In the first part of the study the possibilities of determining the type of rainfall with the parameters derived from the radar echo pattern are examined. In the second part of the study an attempt is made to connect the variations of coefficient a in the Z-R relation (1) and the corresponding variations of the echo pattern parameters. The best possible values of coefficient a for each storm were obtained by adjusting the value of a so that the amount of rainfall measured by radar over the whole measurement site became equal to the corresponding amount

Table 1. The basic data characterizing the radar rainfall measurements around Helsinki 1969 classified into the three types of rain considered.

Type of rain	Date 1969	Duration (hours)	Number of data (iso-echo pictures)	Total amount of rain (mm)	The best a	Remarks
Continuous rain	12 July	6.75	30	6.58	256	
	18 July	4.00	51	4.31	106	
	26 Aug.	2.75	32	.75	294	
	6 Sept.	1.75	21	1.86	200	
	13 Sept.	2.00	24	.44	402	
	14 Sept.	10.25	92	11.11	204	
	15 Sept.	1.00	8	1.51	117	
	22 Sept.	4.00	33	8.35	180	
Showers	25 July	5.75	65	4.33	415	
	23 Aug.	4.50	52	2.00	480	thunder
	25 Aug.	1.50	22	5.15	243	
	30 Aug.	2.00	25	.56	515	thunder
	2 Sept.	1.50	20	.66	308	
	3 Sept.	2.00	26	.24	575	
Drizzle	27 Aug.	3.50	38	2.37	10	
	16 Sept.	2.50	21	9.19	68	rain and drizzle

measured by a network of 15 rain gauges in the measurement site. Exponent b in (1) had a constant value 1.6. (For further details see [4]) Table 1 summarizes the storms dealt with in the present study.

3. *Results*

3.1. Determination of the type of rainfall

Means, standard deviations and intercorrelation coefficients of various items of both A- and B-data yielded about 270 indices for each storm. To find out the most effective indices in rainfall type classification is in some sense a difficult task because a great part of the indices seem to be able to separate rainfall types somehow, but the number of storms studied is too low in order to achieve some objective and statistically significant order of superiority. Thus the indices presented below were chosen to some extent subjectively. The possible physical background of each index also had some influence on the result.

3.1.1 Continuous rain and convective rain

Fig. 2 shows those indices, derived from the A-data, which seem to separate continuous rains and showers most effectively[1]). Some of the best indices based on the B-data are presented in Figs. 3 and 4.

Most of the indices in Fig. 2 are somehow related to the relative area of echoes or to the relative echo strength. This is natural because the radar echo received from continuous rains is typically wider and weaker than the echo received from showers. In Fig. 2 g an attempt is made to combine both of the properties mentioned in a single index. This is achieved by dividing the mean echo coverage (mean of A1) by the ratio of the means of items A2 and A0 (the average *DBZ* in the echo area and the average *DBZ* for the whole measurement site). This yields some kind of effective echo coverage because the ratio A2/A0 is related to both the echo coverage and the echo strength.

Based on the B-data, parameters could also be determined which are related to the horisontal variation of the echo field. Such parameters are, for instance, echo variance and horisontal gradients of echo strength. Those parameters and their time variances can be expected to be on average larger in showers than in continuous rains and the results achieved indicate just that (Fig. 3).

Other items calculated from the B-data which separate showers and continuous rains nearly as well as the items above are means of B3, B4, B11, B12, B13, B14, B15, B16 and B18 and standard deviations of B11, B12, B15, B16 and B18. These items are heavily correlated with the items in Fig. 3 and hence they probably do not give any significant additional information.

Because the digitized area consists only of about 29 sq. km, the representativeness of short measurement periods may be poor. This is clearly demonstrated in most of the cases presented in Fig. 3. If those four storms which lasted less than two hours (25. Aug., 2. Sept., 6. Sept., and 15. Sept., marked with small symbols in figures) are left out of the analysis, the separation between showers and continuous rains in almost all cases become clearer. This phenomenon is not as obvious in the A-data (Fig. 2). The reason for this may be that the larger areal extent of the

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[1]) The value of the »best *a*» as a co-ordinate is not needed in this part of the study because only the rainfall type is considered, but it is included in figures 2, 3 and 4 for use in later sections of this paper.

A-data partly compensates for the lack of data caused by the shortness of the measurement period.

As in the case of the A-data some improvement could perhaps be made by combining several items. An objective solution to a problem of this type is achieved using multivariable discriminant analysis. Unfortunately the number of storms in this particular study is too low to include some significance for the improvement possible obtained with, say, 3 or more predictors.

A little more information than in the means or standard deviations of various items alone may be included in the intercorrelation coefficients of the items because the correlation coefficient is related to both the individual variations and the co-variations of the items.

The correlation coefficient between the average *DBZ* (B0) and the standard deviation of *DBZ* (B1) is positive in showers while in most continuous rains the correlation is zero or even negative, as seen in Fig. 4a. This is obvious because in convective rains high values of B0 are related to the existence of one or more intensive echo cells and hence the echo variance $(B1)^2$ is also large. In continuous rains high values of B0 are common as the whole measurement site is occupied by a more or less intensive but rather smooth echo and hence the echo variance has a low value. In addition the correlation between maximum *DBZ* value (B4) and standard deviation of *DBZ* (B1) is strong and positive in showers while no correlation can be observed in continuous rain (Fig. 4b). In addition to these correlations, correlations between following pairs of items also seems to separate showers and continuous rains: (B2, B1), (B6, B1), (B9, B0), (B11, B0), (B11, B2), (B14, B4), (B16, B0), (B18, B0), (B18, B4) and (B18, B6). Correlations between items of the A-data did not separate rainfall types.

3.1.2 Drizzle

The present material includes only two storms classified as drizzle and only one of these is pure drizzle. Hence it is difficult to obtain from this material some certain properties by which one could decide whether some rain is drizzle or not.

An examination of Figs. 2, 3 and 4 shows that the values of various indices are in drizzle most often similar to the values in continuous rains and do not form their own group. The values of some indices, however, in pure drizzle (27. Aug.) are as is typical in showers while

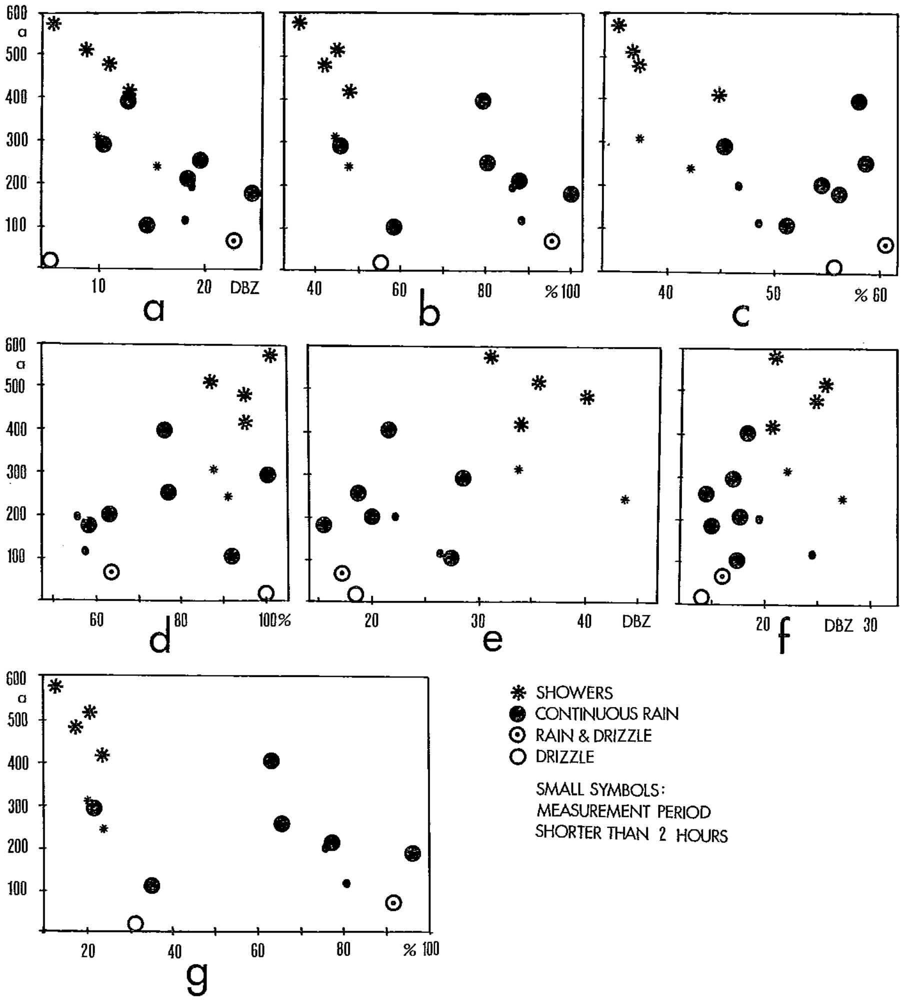

Fig. 2. The best value of coefficient a in the Z-R relation $Z = a R^{1.6}$ for each storm as a function of the corresponding storm mean value of a) A0 (average DBZ)
b) A1 (echo coverage) c) A4 (per cent of total area $DBZ >$ A0) d) A5 (per cent of echo area $DBZ >$ A2)
e) A7 (difference between maximum DBZ and average DBZ A0)
f) A8 (difference between maximum DBZ and average DBZ A2)
g) A1/(A2/A0)

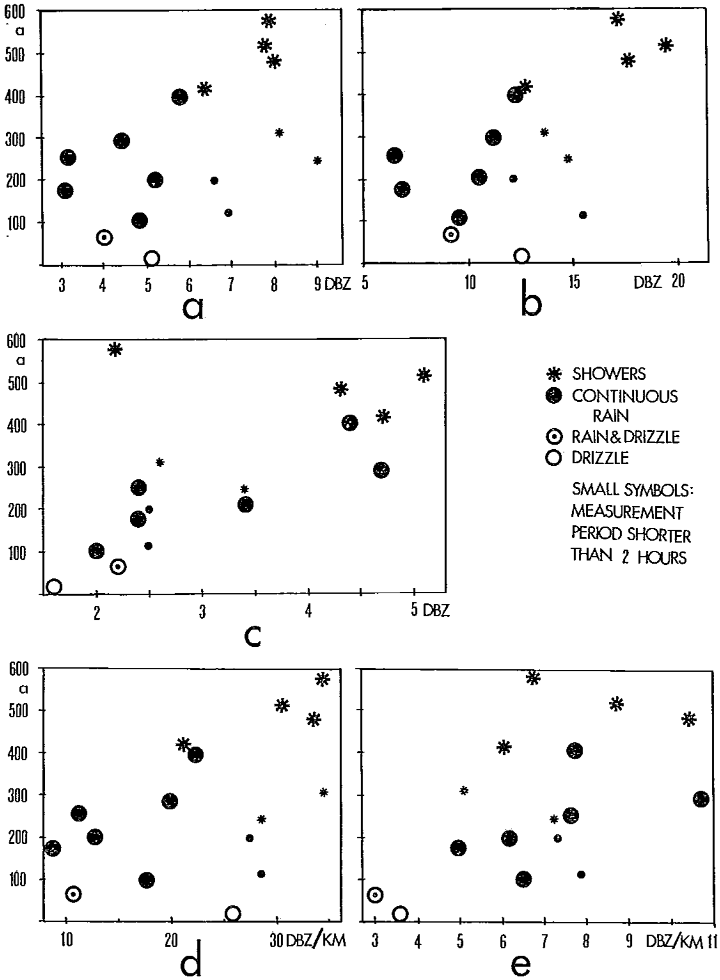

Fig. 3. The best value of coefficient a in the Z-R relation $Z = a\,R^{1.6}$ for each storm as a function of the corresponding stormwise

a) mean of B1 (standard deviation of DBZ) b) mean of B8 (difference between maximum DBZ and average DBZ) c) standard deviation of B8

d) mean of B9 (maximum gradient of DBZ) and

e) standard deviation of B9.

the storm with rain and drizzle (16. Sept.) nearly always seems to belong to the group of continous rains (see Figs. 2a, 2b, 2g and 3d). The total amount of precipitation (9.2 mm) measured during the relatively short storm with rain and drizzle indicates that the dominating rainfall type

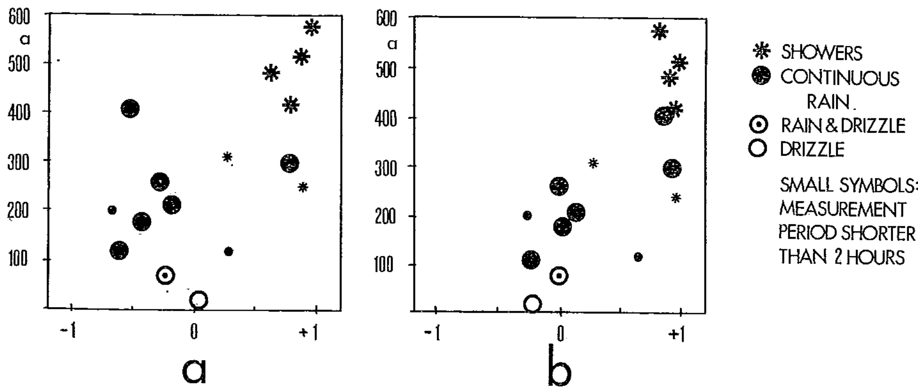

Fig. 4. The best value of coefficient a in the Z-R relation $Z = a\,R^{1.6}$ for each storm as a function of correlation coefficient between
a) B0 and B1 (average *DBZ* and standard deviation of *DBZ*)
b) B4 and B1 (maximum *DBZ* and standard deviation of *DBZ*).

on that day must have been normal rain. Thus the classification of that storm as rain and drizzle may be an observational error.

Although only one proper drizzle is included in the material it seems to be true and physically well justified that in drizzle the mean of the average *DBZ* (mean of A0) is relatively low, 5.5, as seen in Fig. 2a. A value as low as this is obtained only in one shower. For all continuous rains the value is greater than 10. The same effect is even stronger in the B-data, where the mean of B0 has the value 8.3 in drizzle, while in all other storms it is greater than 15. Similarly the mean of the average *DBZ* on the echo area (mean of A2) and also the mean of maximum *DBZ* value (mean of A3 or B4) have much lower values in drizzle than in other types of rain as seen below:

Mean of	A2:	in drizzle	10,	other rains greater than	16
—»—	A3:	—»—	24,	—»—	34
—»—	B4:	—»—	21,	—»—	27
—»—	B0:	—»—	8.3,	—»—	15

In the light of Figs. 3c and 3e the variances of items B8 (the difference between maximum and average *DBZ*) and B9 (maximum gradient of *DBZ*) are relatively weak in drizzle. The same effect is also clear especially in the case of items B1, B11, B12 and B18 and also in the case of items B6 and B15.

Because some of the echo pattern properties seem to indicate in drizzle even such values which are typical of showers, it is essential first to decide whether the rainfall in question is drizzle or not and only after that whether the result was »not drizzle», to decide whether the rain is continuous or convective. On the other hand, the occurence of real drizzle may be rather infrequent in Finland and the amounts of precipitation in drizzle are also relatively low. Thus in many applications no significant error is made if the drizzle rains are measured using Z-R relations valid for continuous or even convective rains.

3.2. Determination of the Z-R relationship

If the type of rainfall has been determined using a radar echo pattern, then one can use the best possible average Z-R relationship for the type of rain in question, for instance $Z = 360\ R^{1.6}$ in showers, $Z = 196\ R^{1.6}$ in continuous rain and $Z = 56\ R^{1.6}$ in drizzle as suggested in [4]. In so doing the results will very likely be improved with respect to the results derived using one single Z-R relation. In any case, this is still a rather rough step towards the estimation of the best possible Z-R relationship to be used.

An examination of Figs. 2 and 3 gives one a feeling that many of the indices describing the radar echo pattern of a particular storm are directly related to the variations of coefficient a in the Z-R relation (1). In order to find the most effective indices in this respect, linear correlation coefficients were calculated between the best value of a for each storm and the corresponding value of each index.

In Table 2 indices are listed for which the absolute value of the correlation coefficient was higher than 0.5. In column 1 of correlation coefficients the values are based on the whole data consisting of all 16 storms. If the four short measurement periods (25. Aug., 2. Sept., 6. Sept. and 15 Sept.) are left out of the analysis, almost all correlations calculated from the B-data become stronger (column 2). In the A-data such an effect cannot be observed. The reason for this may be, as already stated earlier, that the lack of data in time has obviously been compensated for by the wider aerial extent of the A-data and hence the representativeness of short measurement periods is better in the A-data than in the B-data. This result suggests that one should use digitized data from a wider area than about 30 sq. km so that the estimation

Table 2. Linear correlation coefficient between some of the radar echo parameters describing individual measurement periods and the corresponding best values of a in the Z-R relation $Z = a R^{1.6}$. Column 1 of correlation coefficients: correlations are calculated from the entire material (16 storms), column 2: four storms which lasted less than 2 hours are excluded, column 3: as column 2 except that also the drizzle on 27 th Aug. are excluded.

The quantity used to describe each measurement period	correlation coefficients			corresponding figure
	1 (n = 16)	2 (n = 12)	3 (n = 11)	
Mean of				
A0: average *DBZ*	−.49	−.46	−.83	fig. 2a
A1: echo coverage	−.60	−.59	−.74	fig. 2b
A4: per cent of total area > A0	−.69	−.79	−.80	fig. 2c
A5: per cent of echo area > A2	.42	.35	.61	fig. 2d
A7: max *DBZ* − average *DBZ* A0	.58	.75	.73	fig. 2e
A8: max *DBZ* − average *DBZ* A2	.48	.81	.78	fig. 2f
B0: average *DBZ*	−.07	−.07	−.62	
B1: standard dev. of *DBZ*	.52	.78	.85	fig. 3a
B3: stand. dev. for *DBZ* > 20	.43	.62	.45	
B8: max *DBZ* − average *DBZ* B0	.60	.73	.85	fig. 3b
B9: max gradient of *DBZ*	.49	.67	.88	fig. 3d
B11: stand. dev. of $\nabla^2(DBZ)$	.56	.76	.88	
B12: mean of negat. $\nabla^2(DBZ)$	.62	.80	.88	
B13: stand. dev. of. neg. $\nabla^2(DBZ)$	.52	.63	.88	
B14: min $\nabla^2 (DBZ)$	−.51	−.61	−.87	
B15: percent of area $\nabla^2(DBZ) < -40$	.57	.80	.88	
B16: percent of area $\lvert\nabla^2(DBZ)\rvert < 5$	−.52	−.68	−.77	
B18: max $\nabla^2(DBZ)$	.48	.78	.88	
Standard deviation of				
B3: stand. dev. for *DBZ* > 20	.51	.62	.56	
B8: max *DBZ* − average *DBZ* B0	.64	.64	.55	fig. 3c
B9: max gradient of *DBZ*	.54	.64	.55	fig. 3e
B10: average of $\nabla^2(DBZ)$	.51	.67	.68	
B15: percent of area $\nabla^2(DBZ) < -40$	.42	.82	.83	
B16: percent of area $\lvert\nabla^2(DBZ)\rvert < 5$	−.45	−.67	−.79	
B18: max $\nabla^2(DBZ)$	.39	.81	.76	

of the Z-R relation could be made using data from as short a time interval as possible.

Because some of the echo pattern properties have a value in drizzle which is typical of showers while some other properties indicate a continuous type of rain, it may be better to handle real drizzle cases alone Evidence for this can be seen in column 3 of table 2, where the correlation coefficients are based on the material without the ordinary drizzle case (27. Aug.) and without the four short measurement periods. Almost all correlations have became stronger.

By comparing the correlations calculated using A-data and B-data in general one notices that on the average the B-data give stronger correlations. A possible reason for this may be the versatility of the digitized data: Properties describing the horizontal variation of radar echo in one single iso-echo picture (e.g. echo variance, echo gradients) can be calculated only from digitized data and this kind of properties also seems to be the most effective for describing the strength of the convection, if only horizontal data are available.

As in the rainfall type classification, also in the determination of the best possible Z-R relationship, a multivariable regression analysis might give the most reliable model. However, due to the small number of storms the significance of the possible improvement in the results after such an analysis is rather uncertain. Hence no attempt is made to combine more variables into the analysis.

All methods of predicting the relationship with the echo pattern properties discussed above are based on data originating from the whole storm period. Thus the appropriate Z-R relation can be determined only after the whole storm or at least a couple of hours after its beginning. In most applications this is sufficient. As a first real time estimate of rainfall rate results derived with either the relation $Z = 200\,R^{1.6}$ or the relation achieved earlier during the storm in question may be used. This estimate can be corrected as more data is available.

In any case, the best possible method would be to predict the most suitable Z-R relationship continuously in real time. This requires a method by which one could decide the Z-R relation using radar data collected during a very short period of time (for instance using one single PPI picture). For this reason the author also tried to find a correlation between the instantaneous values of the various items and the corresponding instantaneous best values for the coefficient a (average values for 15 min periods were treated here as »instantaneous» because the actual rainfall was measured only to that time resolution). The whole data consisted of 225 such instantaneous observations. In 171 cases the average areal rainfall rate was greater than 0.15 mm/h and only these 171 observations were taken into the analysis. This was done in order that observations, which surely can contain large errors due to the difficulties in measuring very weak echoes, would not have an effect on the result. Of the 171 observations 109 belonged to continuous rains, 37 belonged to showers and 25 were classified as drizzle or rain and drizzle.

The attempt did not, however, give any clear indication of the expected correlations. Although some of the items were slightly correlated with the instantaneous values of coefficient a if the whole material was included in the analysis, no correlation was found if each rainfall type was studied separately. This indicates that the slight correlations found were mainly related to the differences between rainfall types rather than to the individual variations in coefficient a. The result would perhaps be better if digitized data were available from a wider area and in three dimensions. The roughness of data collected by gain-stepping method has also probably caused random errors in the instantaneous values of coefficient a. These errors are smoothed out if longer time periods are considered.

4. *Conclusions and discussion*

Based on the results obtained it seems to be clear that it is possible with some relatively simple parameters derived from the radar echo pattern to decide whether a particular rainfall is drizzle, continuous rain or convective rain. This knowledge can possibly be used to select the average Z-R relationship for the rainfall type in question so as to improve radar rainfall measurements. In some cases the results achieved seem to lead to an even better choice of the Z-R relationship than if some conventional synoptic observations of rainfall type were used. Moreover, the results indicate that not only the type of rainfall but also the best value of coefficient a in individual storms may be estimated using echo pattern statistics. Because no independent radar data are available at this moment, the accuracy of estimates cannot be ascertained. Also based on 16 cases, only 12 of which are representative, no general conclusions or final models can be obtained.

The data used in this preliminary experiment were not originally collected for the purpose of this study. Thus the form of the data was not the best possible. Improvements in results can be expected if radar data are available in digital form from a wider area than in the present study. Further improvement may be reached if vertical data are also included in the analysis, because the strength of the convective processes and the vertical structure of convective clouds (heights and vertical intensity distribution of echoes) are interrelated. In the near future radar data will be collected at the Detertment of Meteorology, University of Helsinki, in digital form threedimensionally. This will make it possible to investigate more thoroughly the usefullness of the echo pattern statistics as a predictor of the Z-R relationship.

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