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Statistical Properties of Winter Convective Precipitating Clouds from Three-Dimensional Radar Data

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Abstract

This paper is an attempt to obtain new data on statistical properties of snowstorm clouds over Ishikari Bay, Hokkaido, Japan using modern observation and data processing techniques. The need to verify results obtained in earlier researches on this subject and complement them with new data arise from the advance of radar meteorology and increased computational capabilities. In the present work by use of multiple reflectivity thresholds and advanced echo tracking procedure it was possible to obtain some new results contributing to a study of this important phenomenon. Another problem considered is comparison of results obtained by processing full three-dimensional data fields and their horizontal sections.

1. Introduction

Studies on precipitating clouds in the winter season over the Ishikari Bay, Hokkaido, Japan already have a long history starting with works of Higuchi (1963), Magono et al. (1965, 1966), Kikuchi (1967) and others. Such clouds, mostly of convective type, are usually associated with the winter monsoon circulation and often bring heavy snowfalls to the Ishikari Plain, particularly in its coastal areas. Statistical properties of these clouds have been thoroughly investigated for the first time by Kikuchi et al. (1989). The aforementioned study included evaluation of various statistical characteristics : both of the echo coverage in general and of individual echoes, including frequency distribution of echo areas, echo lifetimes, spatial distribution of maximum development locations etc. for different synoptic situations and predominant wind directions. That paper is still a valuable source of climatic and statistical information, however it has a shortcoming of the use of only two-dimensional data and a very rough reflectivity resolution (only two predefined reflectivity levels).

The present study is based on more recent data sets and new data processing algorithms and is aimed at filling these gaps. In particular, the dependence of statistical properties on the reflectivity threshold, used to determine cloud boundaries, and the effect of utilizing three-dimensional rather than two-dimensional data are investigated. Both spatial and temporal resolution of the utilized data set is also higher than those used in the earlier researches thus making echo tracking more reliable and results available, in particular, for small scale convective echo cores. On the other hand, the amount of original data in terms of the number of analyzed scans and the length of temporal interval covered is considerably less than that in the previous study. This led to generally less reliable results and made a climatic analysis impossible. Thus this work has inevitably a more limited scope and can be regarded rather as an evaluation of the need to implement new researches on the subject than a comprehensive study.

2. Data set and methods of processing

The radar data used in this study consist of the results of 4 days of observations from January 21 to January 24, 1996. They were implemented within the framework of the project "Study on Areal Prediction Techniques of Drifting Snow and Development of a Warning System" conducted by the National Research Institute for Earth Science and Disaster Prevention (NIED) in cooperation with Hokkaido University. This data set includes observations made with three radars, one of which, placed at Atsuta near Sapporo, conducted a number of series of continuous volume scan observations with a 6 minutes period. It was data obtained with this radar that have been used because a preliminary analysis had shown that greater time intervals between observations would lead to a less reliable tracing of small-scale elements of reflectivity field structure. The original radar data were recorded with a radial resolution of 250 m for a sequence of elevation angles with a 0.5 to 3.0 increment. Prior to processing original data are interpolated to a three-dimensional Cartesian grid. In order to ensure a greater smoothness of the resulting fields for the needs of subsequent analysis, interpolation is combined with averaging. The final grid resolution (0.5 km$\times$0.5 km$\times$0.5 km) was selected as an acceptable

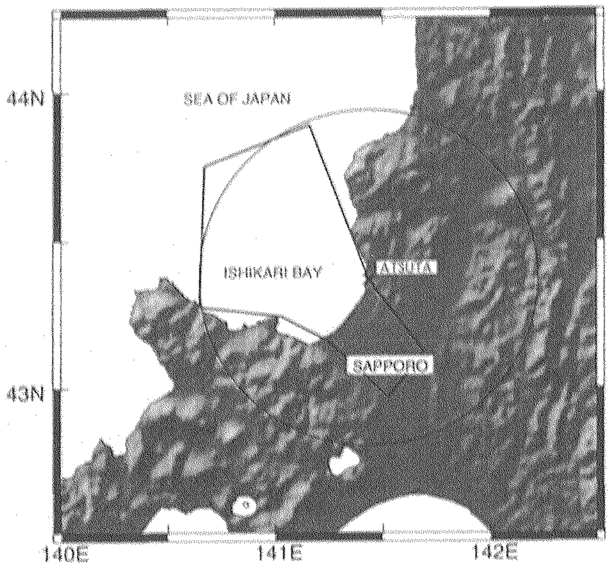

Fig. 1. Location of the radar site and observation range.

trade-off between resolution and smoothness.

The location of the radar site and the observation range are shown in Fig. 1. It also represents a relief of the land surface and the data clipping region which has been used to eliminate the effect of strong ground clutter and shadows from the slopes surrounding the observation site.

The method of data processing used in this work is described by Menshov (1997). At the first step, reflectivity fields are segmented into separate echoes for a set of reflectivity thresholds and formalized descriptions of these elements of the echo field are stored in a compact vector form coupled with dependencies between the elements of each pair of successive fields in a series. Preprocessed data are further used to evaluate various statistical properties of the echo fields. This approach enables separation of time-consuming echo tracking and subsequent utilization of its results which becomes much easier and faster due to elimination of the need to repeat echo tracking procedures for each calculation. It, in turn, leads to a greater flexibility and effectiveness of data processing. Besides, preprocessed data contain full information about original three-dimension raster fields with predefined reflectivity resolution (3 dBZ in the present work) and thus it becomes possible to dispose of original files with glided data and instead use archives consisting only of compact preprocessed files to diminish data storage needs.

Sufficient temporal, spatial and reflectivity resolution of the original data set enabled also greater flexibility in selecting echo tracking procedures. Calculations of statistical properties of individual clouds in this work were done using two different echo tracking models : fixed reflectivity level and maximum tracking. In the former each reflectivity level is processed independently without regard of reflectivity changes, varying property of each echo being the volume of echo region with reflectivity above the given threshold. In the latter model only local reflectivity maximum (echo cores) are tracked. In this case echo volume no longer has sense and the varying property is the current value of the reflectivity maximum. To make the statistical properties obtained with these two methods comparable, results calculated by the latter method were attributed to a reflectivity level corresponding to a highest reflectivity value developed by a particular echo core during the tracking period.

3. Statistical characteristics of radar echoes

3.1 Overall statistical properties

Following Kikuchi et al. (1989) we first estimated the frequency distribution of echo sizes. Figure 2 shows these distributions for echo volumes and echo areas (calculated as an area of horizontal echo section at the level 0.5 km). The distribution in both cases is close to log-normal (appearing as a straight line in selected coordinates) which confirms that the data sampling is representative and the statistical results obtained from it are generally valid even for the less frequent high-reflectivity echoes. A deviation from a straight line is more noticeable for the upper 1-2% of echoes depending on the reflectivity level. These results, as well as the absolute values of echo areas are in an acceptable agreement with those reported in the previous research. Total number of registered echoes (Fig. 3) increases towards lower reflectivity with the exception of the lowest level used in the analysis, 12 dBZ. Individual echoes for this reflectivity often appear to be merged into a few clusters whose sizes are on the average almost one order of magnitude larger than those for the next reflectivity level 15 dBZ.

The next plot (Fig. 4) shows relations between volume and area of individual echoes. A noticeable feature of each scatter plot is an almost constant volume/area ratio (average echo height) for large echoes and very high variability of this ratio for small echoes. It shows that at least theoretically echo properties calculated for three-dimensional data may vary from those for two-dimensional ones. However, influence of the vertical dimension obviously can

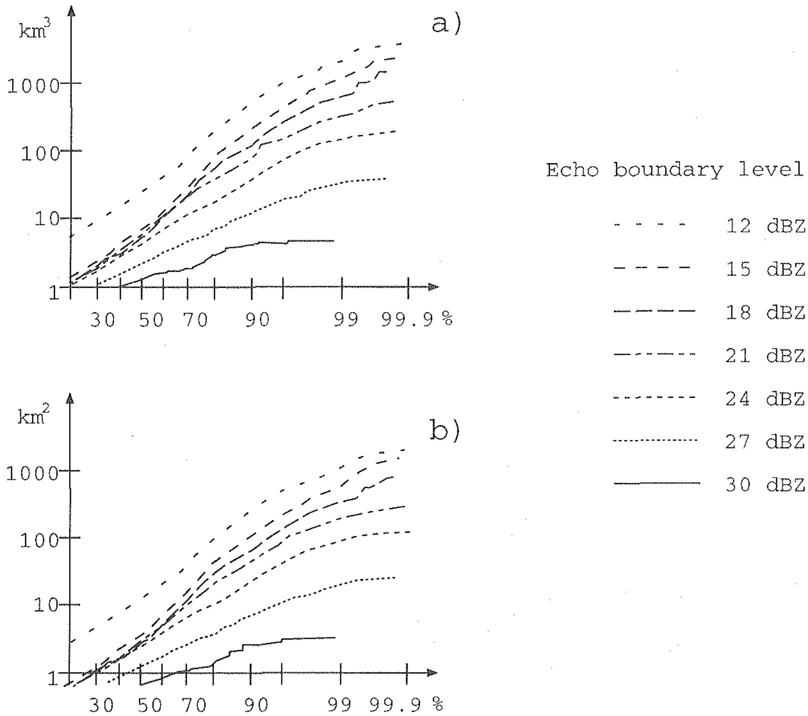

Fig. 2. Frequency distribution of observed echo sizes for different reflectivity levels. a) echo volumes, b) echo areas.

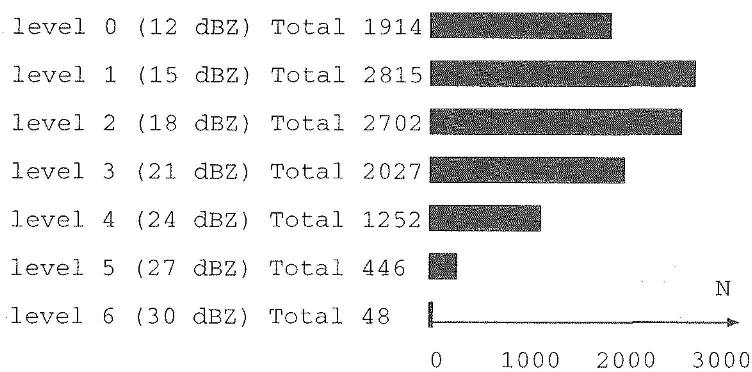

Fig. 3. Total number of echoes for different reflectivity levels.

hardly exceed an order of magnitude which is significantly less than the scale of horizontal variability.

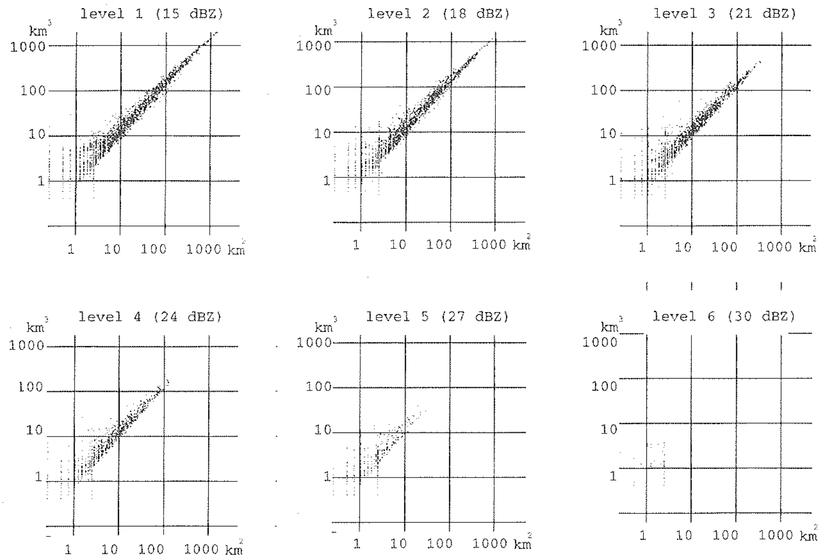

Fig. 4. Scatter-plot of volume versus area of individual echoes.

3.2 *Statistics based on echo tracking*

Echo tracking results were used to obtain distribution of echo centers at the moments of maximal development in the same way as it was done by Kikuchi et al. (1989). The results presented in that work coincided well with the photographic observations and findings of other authors: that clouds reach their maximal development soon after invading the coastal area from the sea. However, the results obtained in the present study, as can be seen from comparison of Figs. 5 and 6, did not reveal equally noticeable concentration of echo centers in the coastal area. This discrepancy can be explained by many factors. First of all, an influence of low pressure systems has been significant throughout all the period of observations used in the present study and thus the results may be best comparable with the L type distribution in the reference figure (which also doesn't show pronounced concentration). Originally it was suggested that the different results can be attributed to the use in the present study of echo volume as the criterion of maximal development rather than echo area. But similar calculations made for the area of horizontal echo section at a fixed elevation (0.5 km) give almost identical results (not shown here). Thus the only other possible explanation is that in case of data obtained using only one elevation angle, as in the cited work, the echoes located below or above the radar beam could have remained unregistered. This effect must be more

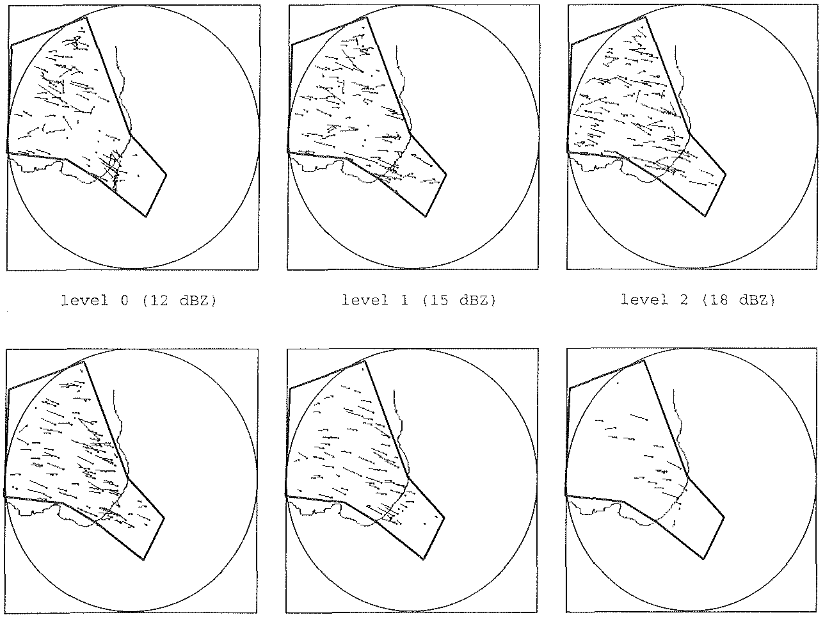

Fig. 5. Locations of echo centers at the time of maximal development for a volume criterion by reflectivity levels (fixed level tracking).

noticeable at larger distances, resulting in a loss of some points of maximum development over the sea surface (at a larger distance from the radar than the coastal area).

Similar calculations have also been made using reflectivity instead of volume as a criterion of the maximal development (maximal tracking procedure used). These results are presented in Fig. 7. In this case, the overall distribution is also close to uniform. However, comparing the results for different maximal reflectivities reached we can find that the clouds which reached the maximal development after landing, in general displayed higher maximal reflectivity. This also may be the cause of the aforementioned discrepancy since the echoes with low reflectivity were not analyzed in the cited paper.

Interesting data were obtained on lifetime-reflectivity dependence. In the following analysis the lifetime of a particular echo is defined by the time interval between the first and the last identification of the echo (tracking time) not depending on the cause of tracking disruption. When one echo merged with a smaller echo (in terms of echo volume) it was considered to continue to exist. Similarly, whenever an echo split, the largest of the resulting echoes was treated

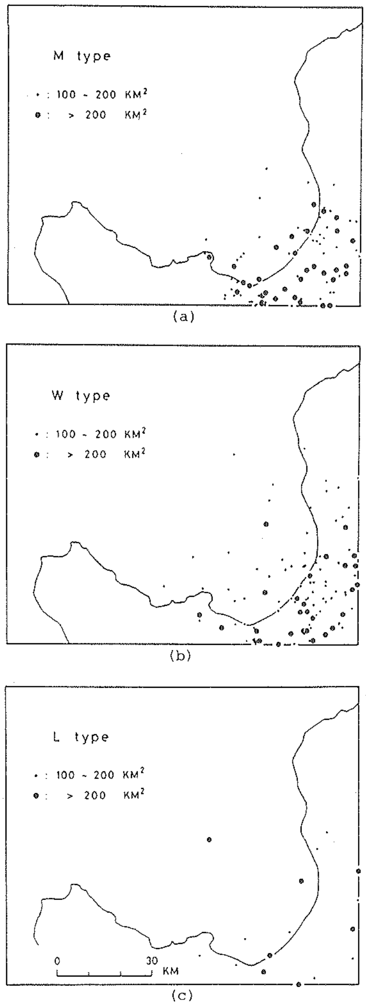

Fig. 6. Distributions of echo centers at the time of maximal echo sizes. Letters M, W, and L denote monsoon type, final period of monsoon type and low pressure type of the general weather pattern respectively. (After Kikuchi et al. (1989))

as the same echo while the rest were considered to be newly appeared ones. The results of these calculations include average lifetimes, average maximal cloud volumes and numbers of individual echoes used in the calculations for each reflectivity level. "Maximal volume" above is the largest volume each individual echo attained during its tracking period, and the averaging is done for an ensemble of tracking sequences, not the appearance of the same echoes in successive fields. Figure 8 shows the results for each separate 24-hour interval

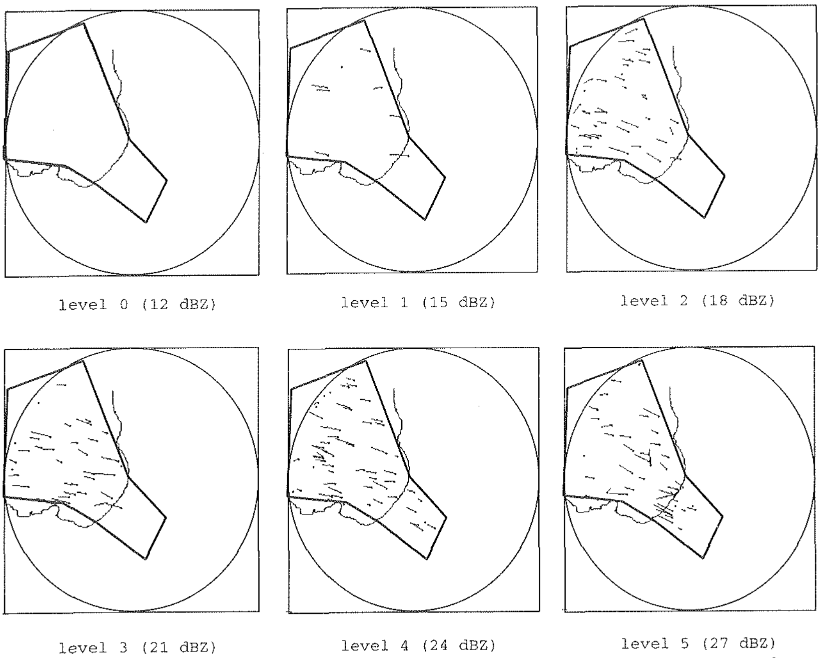

Fig. 7. Distributions of maximal echo development by reflectivity levels for a maximal reflectivity criterion.

of the observations, based on the fixed reflectivity tracking. All these charts show roughly similar patterns. It is not difficult to interpret the observed dependence of the total number of echoes upon reflectivity level: only very few cells reach the highest reflectivity, and at the lowest levels echoes usually merge forming large clusters. Thus, the maximum number of separate echoes can be observed at some intermediate level (in our case 15-18 dBZ). The distribution of average maximum volumes is also quite straightforward showing a very rapid increase towards lower reflectivities. (Similar tendencies have been already noted in the analysis of frequency distribution of echo sizes).

The dependence of cloud lifetime upon reflectivity is more complicated with one maximum at the lowest 12 dBZ and another on the average around 24 dBZ. The former is explained by the already mentioned merging of echoes at the lowest reflectivity level. The resulting large echo region can exist within the radar field of view for hours while individual echoes that form it develop and dissipate (or enter and leave the region). As the reflectivity level is raised, the echo field becomes more fragmented resulting in a sharp increase in the total number of echoes but still individual echo regions are relatively large, and as a

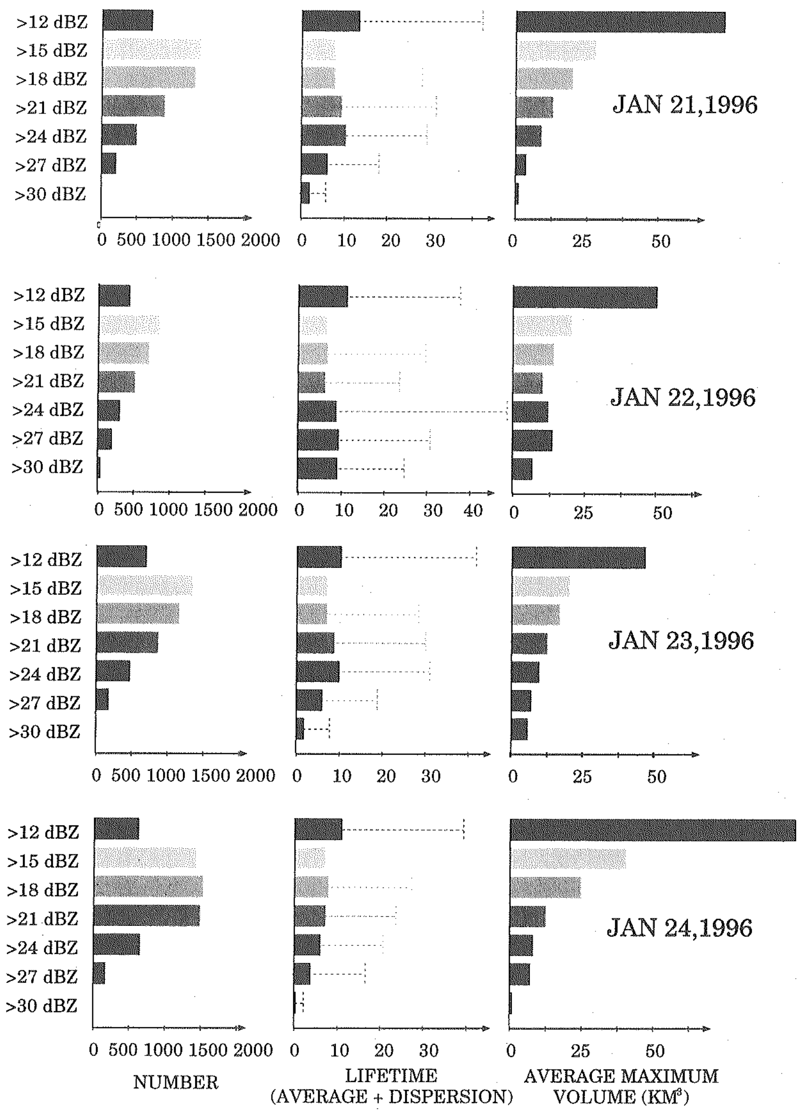

Fig. 8. Average lifetime of separate echoes (fixed reflectivity level tracking)

result, echo merging and breaking up occurs very often. In this case relatively few echoes can be traced for a long time and this is the most likely explanation of the shorter lifetimes observed for these levels (15–18 dBZ on the average). As the effect of interaction diminishes with the further decrease of echo volumes, the second maximum of lifetime is observed, after which the lifetime

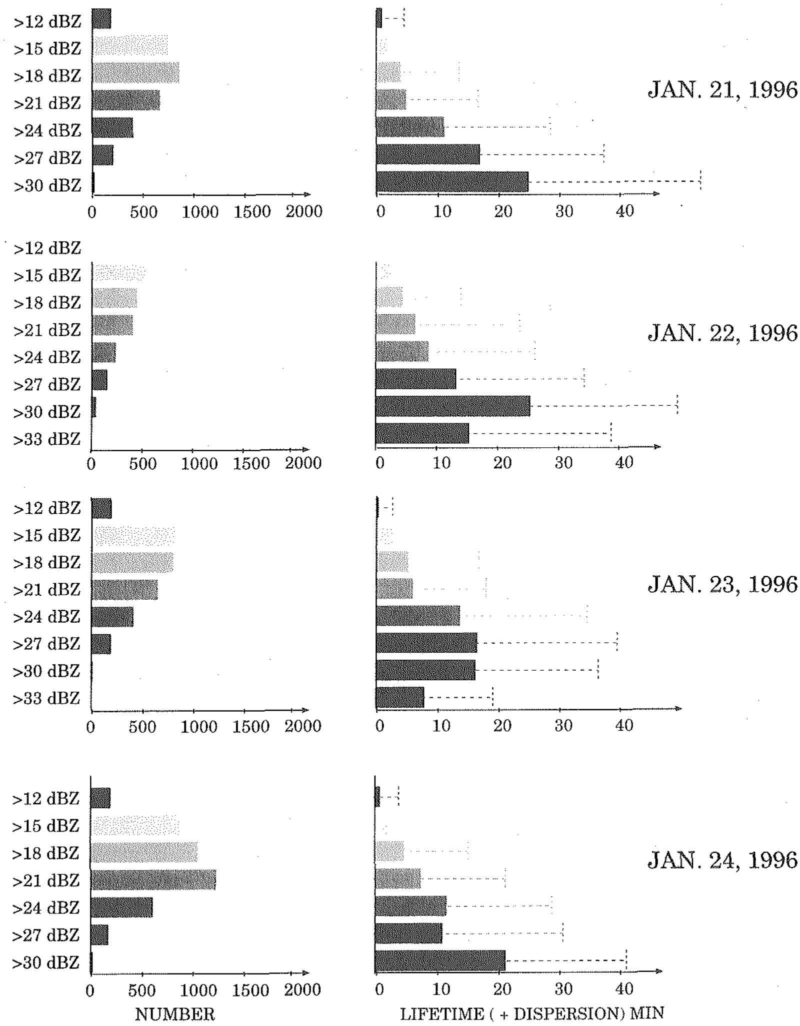

Fig. 9. Average lifetime of echo cores (maximal tracking).

decreases again towards the highest reflectivity level.

The variation of the general pattern on a day-to-day level was not significant, which can be explained by the similar nature of observed echoes (mostly convective with occasional presence of large echo bands). It is also necessary to notice that the effect of a plain averaging over significantly different echo types may lead to a not quite representative result. For example, the effect of the presence of a wide cloud band that can contribute significantly to the overall echo volume (as well as the amount of precipitation etc.), will be negligible in terms of the lifetime, compared to a large number of small echoes.

On the whole, as can be seen from Fig. 8, the average lifetime decreases with an increase of reflectivity. This seemingly controversial result is explained by the fact that tracking at fixed reflectivity levels was used in this case. It means that echo is traced only during the period when it surpasses the given level of reflectivity, while its development before and after that period is not taken into account. The results are still valid as long as the above is taken into account, and yet this is certainly a major shortcoming of using fixed level tracking for evaluation of echo lifetimes.

The charts in Fig. 9 represent similar results obtained using tracking of individual reflectivity maximum. As mentioned above, the results were sorted by the maximal reflectivity attained by echoes, to make them comparable with those for the fixed level tracking. A very similar distribution of the total number of traced echoes by reflectivity confirms validity of this comparison. This time, however, dependence of obtained lifetimes upon reflectivity is significantly different. The general tendency, as opposed to the fixed level tracking, is a strong increase of lifetime for the clouds that have developed higher reflectivity. But it is very significant that echoes which reached the highest reflectivity level (33 dBZ) had noticeably shorter average lifetimes. In both cases when such reflectivities were observed they occurred under specific conditions of wide convective bands. Nevertheless, such results can be an indication of existence of a certain balance between the lifetime and maximal reflectivity. Examples of a very rapid echo development and dissipation observed by the authors in other data sets suggest similar conclusions. Dependence of the lifetime upon reflectivity was also generally found very similar suggesting a certain regularity of the discovered patterns.

4. Conclusions

A study of temporal and spatial statistical properties of winter convective precipitating clouds was implemented using high-resolution three-dimensional radar data set and a flexible echo tracking procedure. Results of investigation did not reveal significant differences between statistical properties obtained using three-dimensional and two-dimensional echo fields, especially for clouds with areas larger than 10 km^2 that appear to have almost uniform volume/area ratio. Still three-dimensionality probably must be considered for smaller echoes that account for about 60% of the total echo number depending on the level of reflectivity used to identify cloud boundaries.

By means of varying this level new data have been obtained concerning dependence of average echo lifetime on its reflectivity. It was found that this dependence show common patterns specific for different echo tracking procedures. Results obtained using echo maximum tracking appear to be more consistent and, in particular, help to reveal an interesting feature of a slight decrease in average lifetime for echoes reaching highest observed reflectivities (as opposed to general tendency). On the other hand, fixed level tracking helps to understand the process of echo field structure transformation with change of boundary threshold level.

An attempt was made to verify results reported in previous researches concerning spatial distribution of echo centers at the moment of maximal development. Unfortunately, the amount of available data was not sufficient to attribute the discovered difference to any particular factor of which most important may be: different synoptic situation, use of three-dimensional data and incompatible choice of reflectivity levels.

In general the results of this research show that statistical properties of winter convective precipitating clouds need to be further investigated. A more comprehensive study would be useful to clarify a few remaining unclear points and confirm or refute the drawn conclusions using larger sets of original data that would ensure more reliable results and enable use of climatic analysis.

Acknowledgments

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