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Analysis of Time Series of Three-Dimensional Radar Echo Fields Using Simple Graphic Displays

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Abstract

A combination of simple graphic displays is suggested as a means of representing time variations of integral properties of radar reflectivity fields throughout long series of observations. Simultaneous rendering of the data for a set of reflectivity levels makes possible 2-dimensional time-reflectivity representation of integral parameters describing total echo volume and essential features of its spatial structure. Application of this technique for analysis of data obtained during 4 days of continuous observations in Ishikari Bay revealed a number of details about reflectivity fields that could not be obtained using conventional methods of analysis. Obtained results confirm that the suggested technique can be very useful both for off-line and real-time data analysis.

1. Introduction

It is well known that analysis of large sets of data obtained with meteorological radars is a very time-consuming operation. Increasing operational and data storage capacities lead to accumulation of large data archives that usually have to be browsed visually in order to select cases for study or follow echo transformation patterns. The situation has become even more difficult with the introduction of volume scan techniques in which a number of PPI scans for different antenna elevations are used to retrieve three-dimensional fields. In this case even the most sophisticated visualization techniques can not help in grasping the entire contents of a single data field with one glance, as is the case with 2-dimensional data. A number of methods for analysis of three-dimensional fields have been suggested in recent years: contour frequency by altitude diagrams (CFAD) (Yuter and Houze, 1995), separation of convective and stratiform regions using three-dimensional echo patterns (Stainer et al, 1995;

Rosenfeld et al. 1994). These methods however can not be directly used to study time variations of the echo fields.

In order to facilitate the task of analyzing a series of radar reflectivity observations, particularly when three-dimensional fields are obtained, we suggest the use of a number of simple plots, displaying variations of major integral characteristics of the echo field throughout a sequence of observations. The main objective we tried to attain was to represent the main features of an observed echo field in a compact and easy to understand form. The way to achieve this goal is to choose a few parameters that are most significant to the echo field description as well as a compact graphical representation that makes it possible to "compress" the results of many hundreds of volume scans into a one-page display.

The four suggested parameters for use in the data analysis are: total volume of the echo regions, average non-advective change rate of that volume (reflectivity tendency), average volume of a single isolated echo, average and maximum echo top heights. All these parameters are calculated and plotted for a set of reflectivity levels (usually increasing with a constant step) and thus the results are in fact two-dimensional, expressing both changes in time and dependence upon the level of reflectivity. Such plots representing variation of main integral features of the echo field can be used both in off-line analysis as an effective means of browsing through large data archives and in real-time processing to monitor the overall changes of the echo field. The suggested technique can be equally well used to represent changes of the echo fields within arbitrary subregions or within a single cloud. This paper contains results of analysis of radar reflectivity fields observed in the vicinity of Sapporo, Hokkaido (Ishikari Bay and Ishikari Plain) compared with VISSR-IR data and surface weather maps.

2. Forms of graphic data representation for radar reflectivity

As a principal integral characteristic of radar reflectivity fields we have chosen the total volume occupied by radar echoes (in case of 2-dimensional data the total area can be used instead). This quantity explicitly depends on a reflectivity threshold defining echo boundaries, and thus a combination of plots using uniformly increasing values of this threshold provides a distribution of echo volume by reflectivity. When color rendering is possible it is convenient to shade the plots using the same color map that is used for conventional section displays. Figure 1 shows a simple sequence of actions necessary to produce

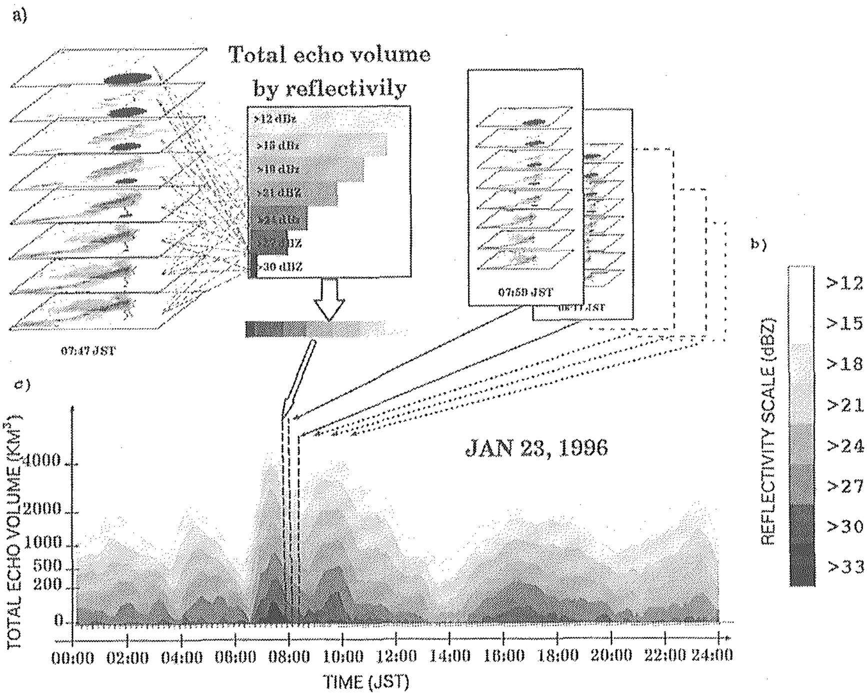

Fig. 1. Plots of a total echo volume by reflectivity. a) Set of CAPPI displays representing fragment of original three-dimensional field (solid circles represent the no data region). b) Grayscale/color chart showing distribution of echoes by reflectivity for this field, c) The final plot—a combination of such charts for a sequence of fields. Small ticks below the plot mark the moments of individual observations.

such a plot, which can be viewed either as a combination of charts displaying the distribution of echo volume by reflectivity for each successive field or as a combination of time plots of echo volume for different reflectivity levels. The same figure shows an example of the final plot for 24 hours of observations. More than 200 individual fields were processed and yet the results well fit into a single display with a simple and clear structure. In order to make variations of different level plots comparable and spacing among them more uniform we used a square root scale. The choice is apparently not very common, this scale however seems to fit best the observed distributions of echo volume by reflectivity levels.

Depending on specific aims the principal (echo volume) plots can be accompanied by a number of other displays to provide more information about the echo fields. As can be seen from Fig. 1 the plots of total echo volume by reflectivity give an instant view of the overall echo intensity variations and maximum reflectivity observed at any particular moment. These, indeed, are the most important factors in evaluating reflectivity fields. No less important, the plots show the tendency of reflectivity within observation volume. However, this tendency may be disguised or even inverted by the effect of clouds leaving and entering the radar field of view. Another shortcoming is an absence of information about spatial structure of the echo fields. These considerations determined the choice of three other displays, supplying information that partly fills the gap. First of all, it is very important to evaluate the true reflectivity tendency, not masked by the effect of echo advection through the boundaries of the observation region. In order to eliminate this influence, for each pair of successive fields we used the values of an average horizontal echo displacement to exclude the areas that fall beyond the observation region when the fields are superimposed (see Fig. 2). After that, echo volumes within the remaining

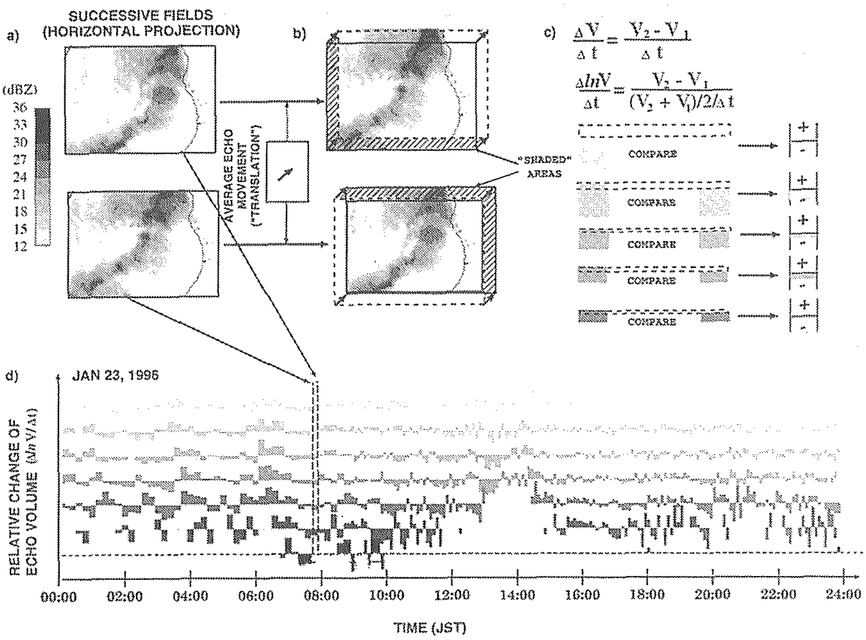

Fig. 2. Plots of echo volume change rate (reflectivity tendency). a) Two successive fields and region of analysis, b) Vector of average echo displacements is used to eliminate non-aligned areas, c) Comparison of echo volumes within the aligned region, and d) Resulting plot (relative tendency).

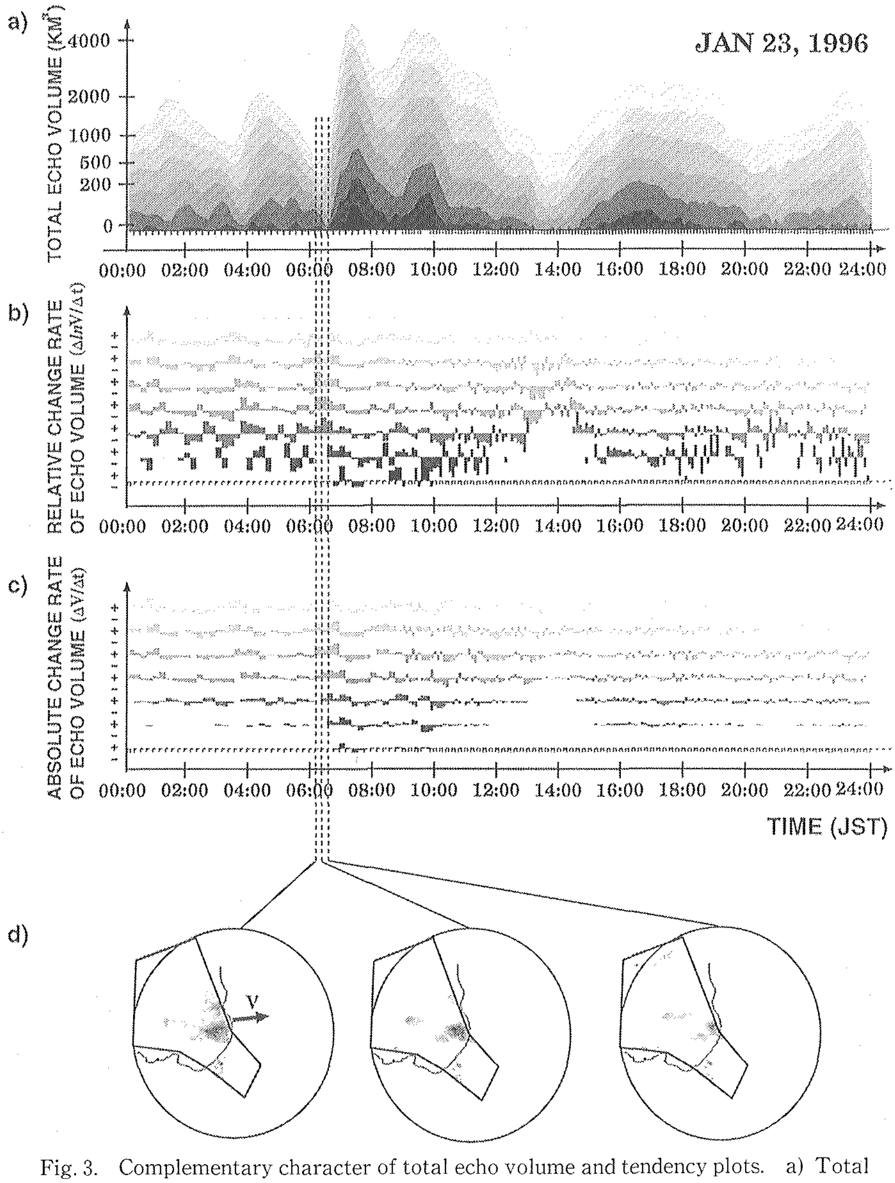

Fig. 3. Complementary character of total echo volume and tendency plots. a) Total echo volume by reflectivity plots, b) Plots of the relative echo volume tendency by reflectivity, c) Plots of the absolute echo volume tendency by reflectivity, and d) Examples of PPI scans explaining discrepancy between apparent and true tendencies.

common region are calculated for the chosen set of reflectivity thresholds and either relative or absolute changes of these volumes are plotted. We use relative changes in the subsequent discussion, but comparison of two plots in Fig. 3 shows that the difference is not significant. The same figure shows an example of how the "true" reflectivity tendency and the same tendency observed within a region with fixed boundaries can have opposite signs. The exact scale for the tendency plots is not shown because the information is mostly qualitative due to instability of radar calibration, fields matching etc. that cause significant "noise", particularly for higher reflectivities.

The main features of spatial echo structure are represented in two more displays. For three-dimensional data we plotted the average upper and lower cloud boundaries combined with maximum cloud heights. Finally using an image segmentation technique (e.g. Haralick and Shapiro, 1985) modified to process three-dimensional fields it is possible to separate isolated echoes for different reflectivity levels as described by Menshov et al. (1995). Utilizing results of this analysis are the plots revealing either the number of isolated echoes or their average volumes (these quantities are unambiguously related via the total echo volume). In both cases again combinations of plots for different reflectivity levels are used. Such plots representing the extent of echo segmentation are primarily important for distinguishing between convective and stratiform cloud systems, but they are also very useful for the analysis of echo fields containing cloud clusters. Horizontal echo structure as well as cloud shapes are only implicitly presented in these plots via the average volume of a single echo. However it is this elimination of individual echo shapes that enables a better understanding of overall echo field properties. Thus combination of the four types of data displays described above contains the most generally useful information about three-dimensional echo fields.

3. Results

The data of 4 days of continuous observations from January 21 till January 24, 1996 were analyzed using the above described technique. Figure 4 shows the location and observation range of the radar placed at Atsuta near Sapporo on the coast of Ishikari Bay. It also shows a region used for data processing. Data clipping was used to eliminate the effect of a strong ground clutter and shadows from the slopes surrounding the observation site (explicit boundaries are necessary for correct calculation of reflectivity tendency). The results of data processing for this interval of time are shown in Fig. 5. Analysis of the

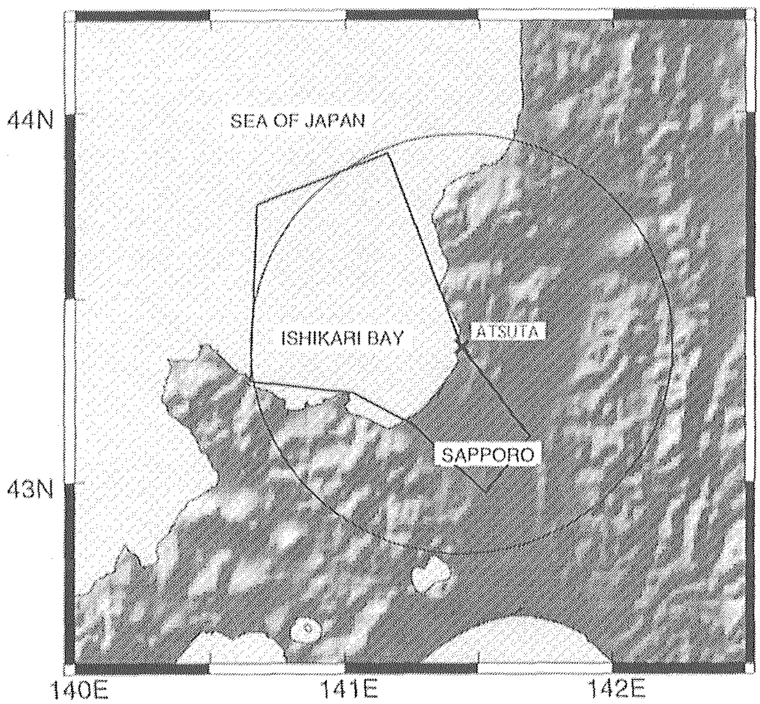

Fig. 4. Location of the radar observation site and a data clipping polygon. Circle indicates the radar observation range (same as in Fig. 7).

echo volume variation reveals that there were four periods (one during each day of observations) when strong reflectivities (above 30 dBZ) and echo volume above 2,000 km^3 were observed. Correspondent time intervals are marked by letters A, B, C and D in the figure. The patterns of echo volume variation and other parameters significantly differ for each of these periods and, as will be shown below, are probably indicative of mesoscale or synoptic phenomena associated with particular cloud fields.

Comparing variation of the total echo volume with other displays, it is possible to notice a strong positive tendency at the final stage of the period A (which suggests that a cloud field, while still developing, was moving out of the observation region at this time) and the equally strong tendency immediately before and in the beginning of period B (indicating strong echo generation within the observation region). Similar, but a less prominent positive relative tendency is observed shortly before each major surge of echo volume and intensity.

Plots of average and maximal echo top heights show an abrupt increase at

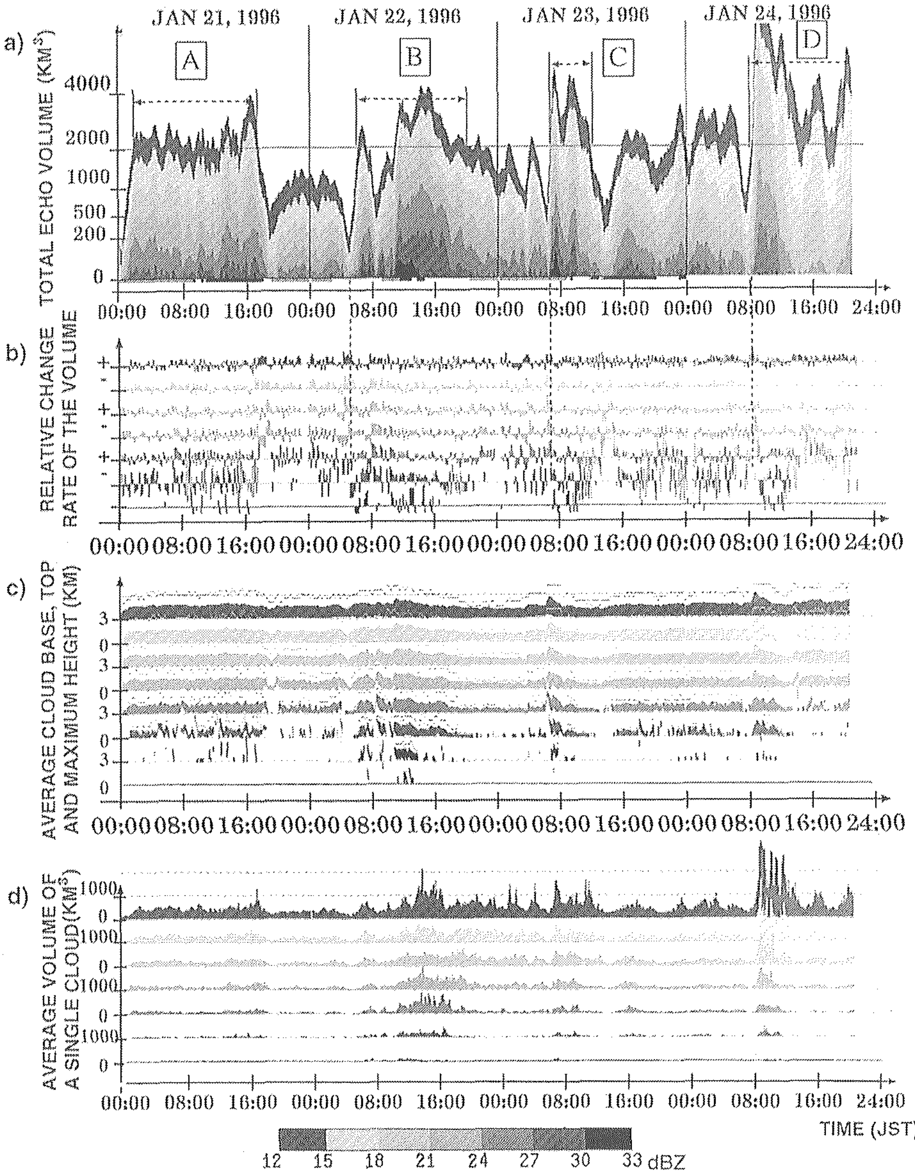

Fig. 5. Combination of plots showing variation of integral parameters of the echo fields during the period of analysis (Jan. 21-24, 1996). a) Total echo volume by reflectivity plot, b) Relative tendency by reflectivity plot, c) Plots of vertical echo extension, and d) Average volume per echo plots. Letters A, B, C and D mark periods of reflectivity surges discussed in Chapters 3 and 4. Dashed lines show moments immediately before such surges occurred.

the beginning of periods C and D, while the increase was slow in the case of period B and almost absent in period A. Finally, the analysis of average echo volumes (the lower plot in Fig. 5) shows that only during period A was there a significant number of isolated echoes. During period B an echo band with a continuous region of reflectivity above 24 dBZ and a few cells reaching 33 dBZ was observed. These were the highest reflectivities registered during the analyzed period. At the beginning of period D the echo almost totally covered the observation region, however the continuous fraction reached only level of 21 dBZ, with higher reflectivities split among a large number of isolated cells. Echo fragmentation increased towards the end of the period. In the case of period C the relation between total and average echo volume shows that mostly present were medium-size clusters or cloud chains.

4. Discussion

Surface weather maps for the same period are shown in Fig. 6 and VISSR-IR images corresponding to selected cases are in Fig. 7. It may be seen that during the analyzed period the general winter monsoon weather pattern was influenced by a number of local pressure disturbances. In case A the convection was developing in the rear part of a low pressure system located to the north-east of Hokkaido and gradually moving further east until the area with strong pressure gradients had shifted eastwards from Hokkaido. During all this period moderate convective echoes were present within the observation region. Reflectivity levels were almost uniform showing only a slight increase towards the end of the period. In case B after the initial appearance of a number of strong echo clusters a wide echo band moved through the observation region. Gradual decline of maximum reflectivity and echo top height after an initial strong increase suggests a possible asymmetric structure similar to a cold front. In case C a ridge of high clouds associated with a developing low pressure system can be clearly seen on satellite images. It existed only for a short time during which echoes reaching an elevation above 5 km with high reflectivity were observed. Case D is represented on the IR images by a wide region of very low cloud top temperatures associated with a pressure trough. At this time indications of a front structure were absent, yet there was an initial "roll" of a high and strong continuous echo that gradually turned into highly fragmented echo lines with intermittent orientation. Subsequent smaller surges of the echo volume show possible presence of a number of convective bands that followed the initial roll. On the whole a stable weather pattern with uniform convective

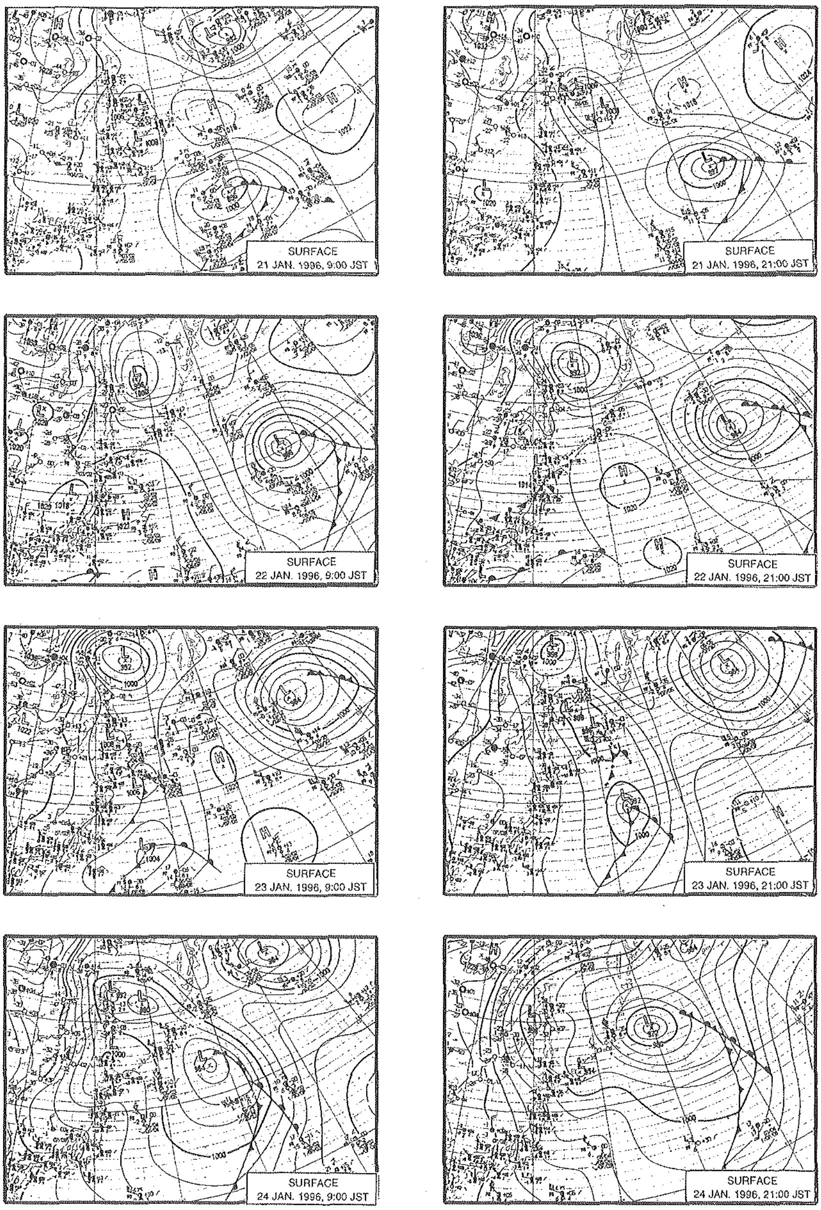

Fig. 6. Surface weather maps from January 21 to January 24, 1996.

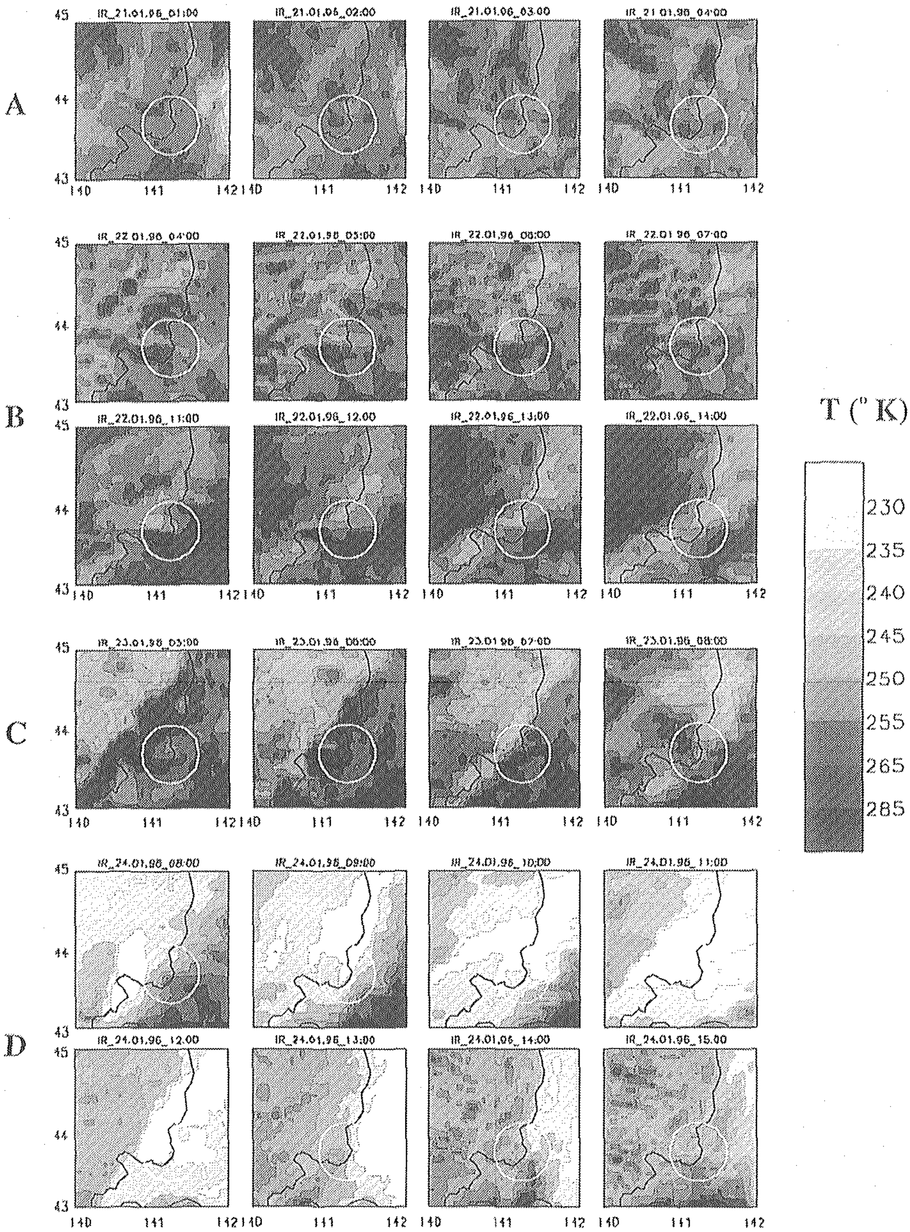

Fig. 7. VISSR-IR images corresponding to the periods of reflectivity surges A, B, C and D. Circles indicate the radar observation range (same as in Fig. 4).

activity was observed during the first day (January 21), then followed by a period of rapid weather changes during three subsequent days when major reflectivity surges were associated with wide echo bands passing through the observation region. Each of these latter surges had it's own specific features that can be linked with the synoptic situation and local mesoscale phenomena.

5. Conclusions

Radar echo fields observed in the Ishikari Bay area were analyzed using the technique of integral echo parameters plots. Results of the study confirm the importance of this kind of analysis for a better understanding of overall echo field properties and its variations. Besides, these variations are evidently indicative of the present mesoscale weather patterns that often can not be directly observed with radar because of its limited range. Further investigations are necessary to confirm whether specific types of reflectivity variations can be reliably linked with certain mesoscale phenomena and synoptic patterns, however there are strong suggestions of such possibility at this time.

Inclusion of the displays of reflectivity tendency and spatial characteristics into the analysis enables a sufficiently comprehensive representation of the original fields if not for detailed analysis then at least for picking up cases for such analysis and describing the overall situation. The relative reflectivity tendency display can be used in real-time analysis to warn about approaching reflectivity surges, because the majority of such surges were immediately preceded by the appearance of strong positive tendencies while the total echo volume was not yet increasing. All this makes the suggested method a very useful tool for both off-line and real-time data analysis.

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