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Radar Observations of Snowfalls in 1985 over the Shinjo Basin
—— Vertical Scanning ——

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Abstract

Radar observations of snowfalls were carried out from 20 January to 25 January, 1985 in the Shinjo basin, Yamagata Prefecture, Japan. Intense measurements of the vertical structure of snow echoes were made by REI scanning.

A weak and thin descending echo was observed from 1300 to 1545 JST on 23 January. This echo was concluded to be a snow echo which had a fall velocity from 0.7 to 1.0 $m \cdot s^{-1}$ according to the analyses of descent rate of its height, horizontal extent and echo duration.

A comparison of snowfall intensity on the ground estimated by eye measurements and distribution of PPI radar echoes showed a relatively good agreement from 20 to 25 January, except from 1200 to 1500 JST on 20 January. This exceptional disagreement was explained by a strong vertical wind shear which prevailed during this time.

1. Introduction

Snow storms in the winter monsoon season cause disasters by extra heavy snowfalls along the west coast of Japan. The northern part of Japan is one of the heaviest snowfall regions in the world. The synoptic and mesoscale structures of the snow storms have been studied by Matsumoto et al. (1965). Matsumoto et al. (1967) and others. Recent studies by radars and experiments on short term forecasts have promoted the understanding of the structure and characteristics of the snow storms in Japan.

Okamura (1981) made a comparison of accumulation of digital radar echo with snowfall depth on the ground in Niigata Prefecture. He took into consideration the drift of snow flakes by wind. Asuma et al. (1984) conducted an experiment for a short term prediction of snowfall arround Sapporo, Hokkaido with a digital radar. They showed a possibility of forecasts of one hour or two hours. Thus, by radar observations and intense analyses, the structures of snow storm in the regions along the west coast of Japan are becoming clarified.

However, the mechanisms of snowfall in the basins in Japan are not well understood as yet. One of the reasons is the lack of routine radar observation covering such basin areas. The modification on plains and hills of snow clouds, which originate over Japan sea, is an interesting problem. Intense radar observation would give a key to the understanding of how snow clouds are affected by hills and valleys prior to their arrival to a basin from the sea coast.

As the analysis on vertical structure of snowband by Sanders and Bosart (1985) shows, observations on the vertical structure of snow storms is very important to understand the mechanism of snowfall. Hobbs et al. (1980) also suggested the seeder-feeder effect relation on the vertical structure of clouds in fronts.

To understand the mechanism of snowfall in a basin, the authors made PPI (Plan Position Indicator) and REI (Range Elevation Indicator) radar observation of snowfall over Shinjo basin in January, 1985. Through the observation period, REI scanning was intensly made to analyze the vertical structure of snowfall. Yagi et al. (1986) have reported the characteristic features of the horizontal distribution of snowfall echoes over the basin. The present paper is concerned with that of the vertical structure.

2. Method of the observation

Radar observation of snowfalls was carried out from 20 January to 25 January, 1985 in the Shinjo basin. The observation range for PPI was 50 km in radius, as shown by the arc in Fig. 1. Mountainous regions over 500 m and 1000 m above sea level are expressed by hatched and cross-hatched markings, respectively. A transportable weather radar was set up on a hill (about 140 m above sea level) at the east end of Shinjo basin to observe the snowfall echoes over the plains, hills and basin. The specifications of the weather radar are listed in Table 1.

The program of radar observation was scheduled from 0800 to 2400 JST with a pause in operation from 1800 to 2000 JST for maintenace of the radar set.

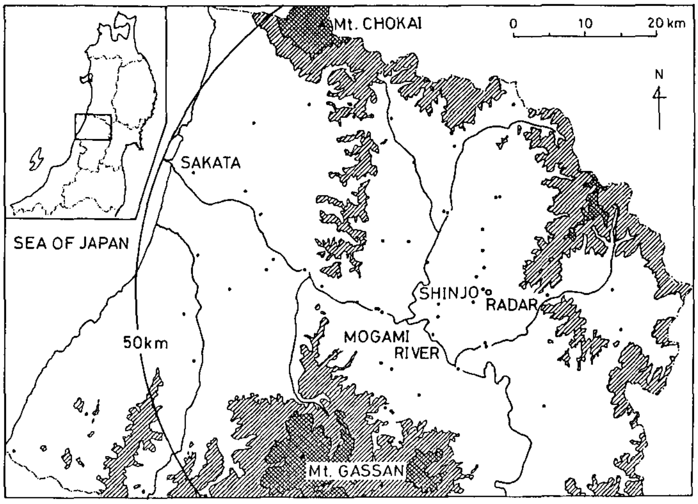

Fig. 1 Schematic map showing the location of a transportable weather radar set in Shinjo City, Yamagata Prefecture (○) and surface observation points (●). Radar observation range was 50 km in radius. Mountainous regions over 500 m and 1000 m above see level were hatched and crosshatched, respedtively. The insert shows the relative location of observation area in Tohoku district, Japan.

Table 1 Specifications of the mobile weather radar set.

TERM	PERFORMANCE
FREQUENCY	9375 MHz
PEAK POWER OUTPUT	40 km
PULSE WIDTH	1 μs
PULSE REPETITION RATE	500 pps
REFLECTOR	1.2 mφ PARABOLA
BEAM WIDTH	2°
INDICATOR	PPI, REI, A/R
ISO ECHO	<100 km

The radar observation was terminated at 1200 JST, 25 January. Normal and ISO echoes of REI in several azimuths and PPI at the elevation angle of 2.5° were measured by the ISO device and recorded with a 35 mm cine camera. For one series of measurement, approximately 8 minutes were required. After this programmed manual operation, PPI echoes (normal or ISO 1) were automatically recorded every thirty seconds by the cine camera.

As the Z-R relation for snow, $Z=2000\ R^{2.0}$ was adopted. By this setting,

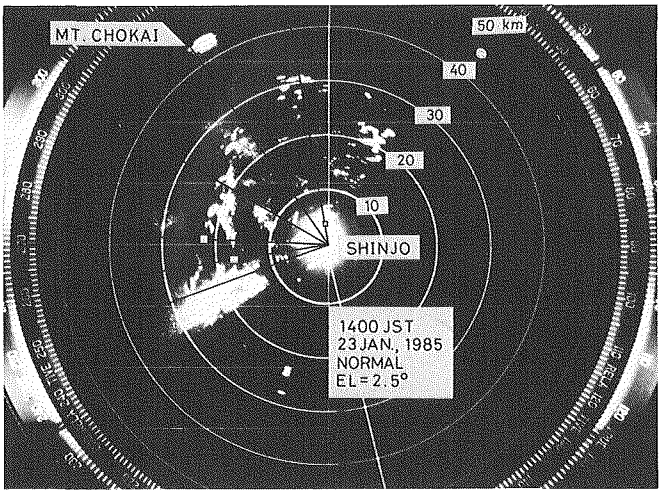

Fig. 2 The PPI normal echo at the elevation angle of 2.5° at 1400 JST, 23 January, 1985. The observation area was within a sector of azimuths from 240° to 30°. The vertical white line is the north mark. Squares on black lines are another group's surface observation points of snowfall intensity estimated by eye measurement (Nakamura et al., 1985). They are Furukuchi (az=261°, r=16.8 km), Kusanagi (az=272.5°, r=21.2 km) and Shinjo (az=350°, r=3.7 km).

ISO 1, ISO 2, ISO 3 and ISO 4 corresponded to the precipitation intensity levels of 1, 2, 4 and 8 mm/h respectively. For normal echoes, lower limits of intensity detection were 0.1 mm/h at the range of 10 km and 0.4 mm/h at the range of 30 km in case where the radar was used.

An example of PPI display is shown in Fig. 2. The observation area of PPI was in a sector from 240° to 30°. Ground echoes by hills at a range about 20 km to the west to the radar site are clear cut. Snow echoes over the ground is seen in the of 240°. The velocity of echo movements was obtained from photographs of two PPI scans with intervals of several minutes.

In order to examine the vertical structure of an echo, REI scannings were made every fifteen minutes at five azimuths of 261°, 272.5°, 300°, 325° and 350°. Where necessary, REI scans at other azimuths were added. Selected observation ranges for REI scans were 10 km or 25 km to observe precise structures of vertical sections.

The estimation of snowfall intensities by eye measurements were carried out by another group (Nakamura et al., 1985). Their recordings were made every five minutes from 10 to 15 hours on the 23, 24 and 25 January at three surface observation sites. The location of the observation sites are shown in

Fig. 2 by squares on the black solid lines, which are Furukuchi (az = 261°, r = 16.8 km), Kusanagi (az = 272.5°, r = 21.2 km) and Shinjo (az = 350°, r = 3.7 km). The intensity levels of snowfalls estimated by eye measurement were divided into eight steps from weak to heavy.

The group conducted a test, before the observation mentioned above, to compare the intensities recorded by several expert observers with the eye for a same snowfall, having shown that the difference among individuals is negligible.

In order to compare the intensity of PPI echo and the snowfall intensity by eye measurement at the three sites, the echo intensity on the 2 km × 2 km mesh over the each surface observation point was measured. For the analyses, figures of hodographs, sounding curves and so on were produced with the data from routine observations by the Japan Meteorological Agency.

3. Results

3.1 Echo height

Echo heights measured every hour on the hour by REI scanning through the observation period were summarized in Fig. 3 to observe the diurnal variation of snow cloud activities. The heights of the most intense echo of REI scan among several azimuths for one series of REI scanning were chosen and plotted as an index of echo intensity at the time.

On 20 January, a low pressure passed to the north of the radar area. The

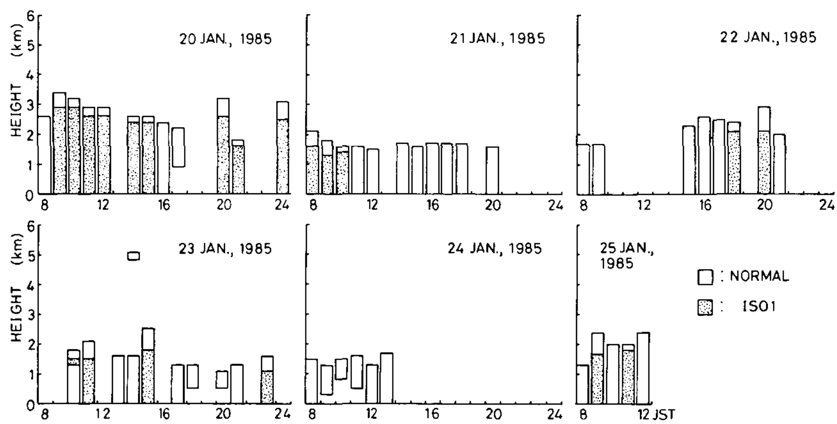

Fig. 3 Hourly echo heights at the most active azimuth. Stippled and non-stippled columns show echo intensity of ISO 1 and normal, respectively.

heights of echo tops were about 3 km on 20 January: these heights of winter cloud echoes are higher than usual in this district From 21 January to 25 January, the observation area was under winter monsoon conditions. On these days, the height of echo tops were about 2 km or less: such heights are commonly known for winter echo top in the district. However on 23 January, a thin echo at 5 km in height is seen in Fig. 3. In the next section, pictures of REI scans of the day will be shown. And in Section 3.3 the case of a large vertical shear on 22 January will be shown with the comparison of PPI echo and snowfall intensity measured by eye measurement.

3.2 Descending of weak-thin echo

A weak and thin layer echo wys observed to descend slowly on 23 January. In Fig. 4, REI scannings at six azimuths (245° (or 250°), 261°, 272.5°, 300°, 325° and 350°) at 1400 JST, 23 January are shown. The weak-thin normal echo clearly exists at a height of 5 km. As normal echoes were identified up to 14 km in range, the echo intensity corresponded to larger than 0.1 mm/h. The echo intensity changed from azimuth to azimuth and from range to range. However it can be clearly said that the height of this layer echo was almost around 5 km and that the thickness of the echo was less than 500 m for each scan.

An example of the descent of the echo height at the azimuth of 325° is shown in Fig. 5 at every fifteen minutes from 1400 to 1530 JST. Such a descent of the

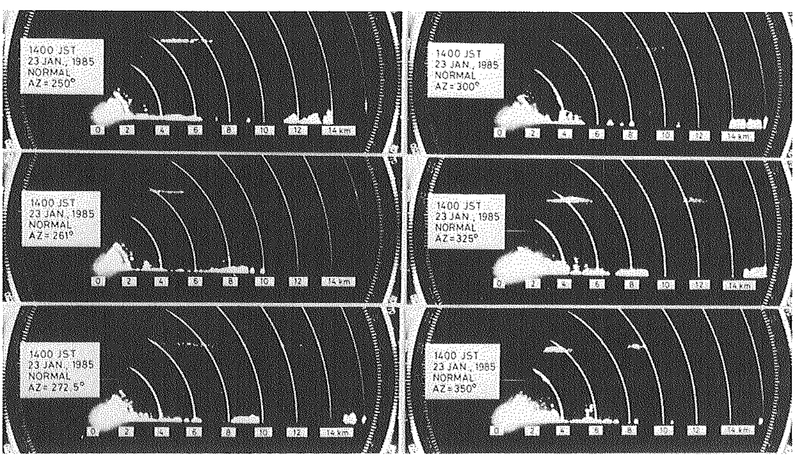

Fig. 4 An example of weak and thin echoes aloft in REI scanning at six azimuths at 1400 JST, 23 January, 1985. Range marks are 2 km intervals, so that the echoes exists at the height of about 5 km in every cross sections.

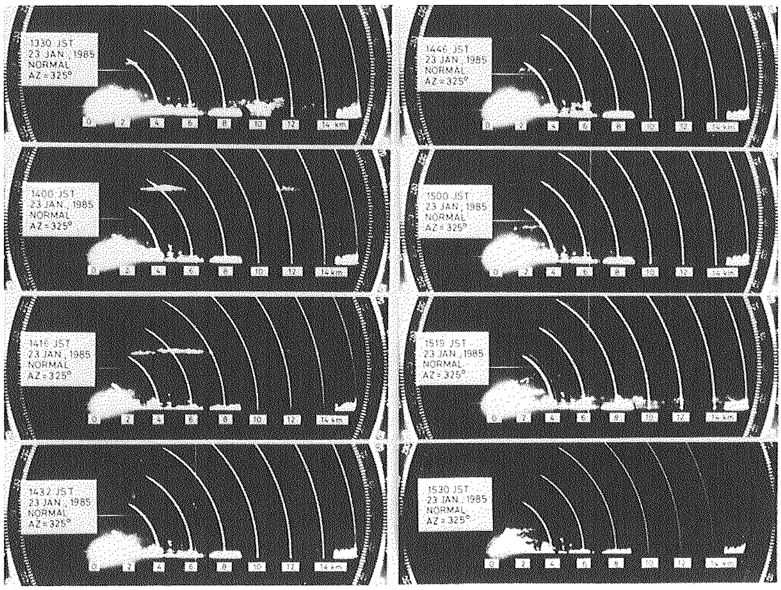

Fig. 5 Time series of REI echoes at the azimuth of 325° which show descent of weak and thin echo from 1400 to 1530 JST.

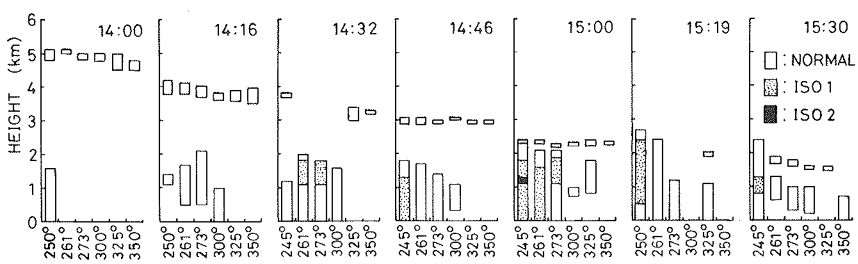

Fig. 6 Echo heights at six azimuths of 245° (or 250°), 261°, 272.5°, 300°, 325° and 350° in fifteen minutes interval from 1400 to 1530 JST in 23 January, 1985. Open, Stippled and solid columns represent normal, ISO 1 and ISO 2, respectively. Descent of weak and thin echoes and their margence in underlying echoes are noticed.

layer echo was also seen at other azimuths. The top left picture of Fig. 5 indicates that another weak-thin echo was seen at a height of 3.8 km at 1330 JST before the descent of the layer echo which started from 1400 JST.

In Fig. 6, the echo heights at six azimuths at about fifteen minute intervals were illustrated. The azimuth written as 273° was actually 272.5°. The thin echo at 5 km in height at 1400 JST descended to lower than 2 km in height at

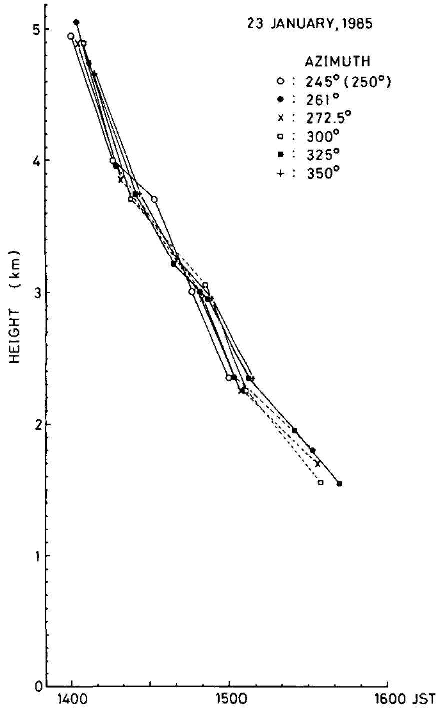

Fig. 7 Fall velocity of weak and thin echoes at six azimuths. Heights of the echo measured in every fifteen minutes are connected. When the echoes were not identified at a REI scanning, the echo heights were suposedly connected by a dashed line.

1530 JST. Looking at each graph, for example the left one, the height of weak and thin echo decreased slightly as the angle of azimuth increased from 250° to 350°. The reason for this is considered as follows. It took about one minute to record one REI scan at one azimuth. This makes the total time of a series of scannings at six azimuths about 6 or 7 minutes. Within those 6 or 7 minutes, there is little doubt that the echo descended a somewhat more. This would account for a decrease in height with the increase of azimuth in Fig. 6, that is, the apparent inclination in the figure does not mean the actual one of the layer echo. The descent rate of this echo from 1400 to 1530 JST estimated from Fig. 6 is roughly $0.7\ m \cdot s^{-1}$.

The descent rate of the weak and thin echo from 1400 to 1530 JST at the azimuths from 245° (or 250°) to 350° was calculated from the echo height plot as

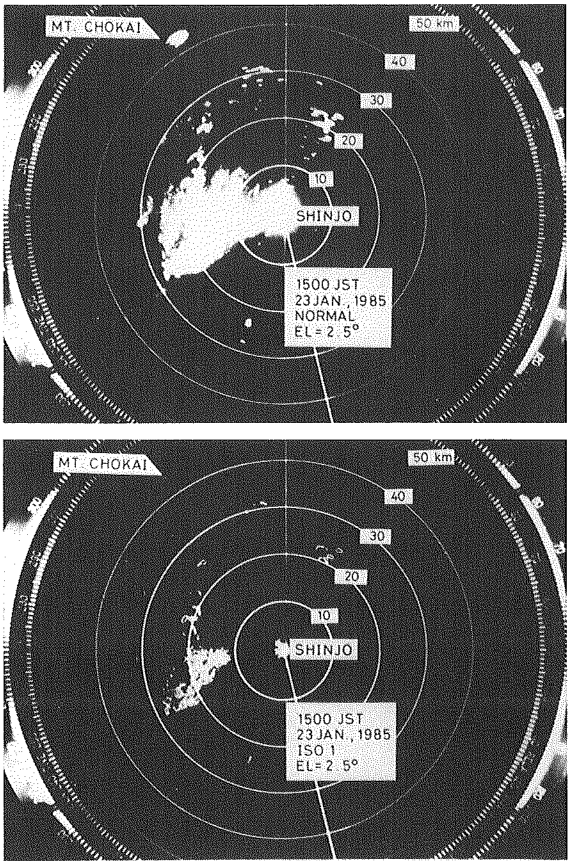

Fig. 8 The PPI echoes of normal (top) and ISO 1 (bottom) at 1500 JST, 23 January, 1985. The elevation angle was 2.5°.

shown in Fig. 7. The fall velocity of the thin echo decreased from about 1.0 to 0.7 m • s^{-1} with the lapse of time. For example, at the azimuth of 325°, the fall velocity was 1.0 m • s^{-1} from 1400 to 1416 JST and 0.69 m • s^{-1} from 1519 to 1530 JST. In the case of the other azimuths, the descent rates were almost the same with time. The descent rate of thin and weak echo was closer to that of rimed snowflakes with small diameters (Magono (1953) and Locatelli and Hobbs (1974)) than that of individual snow crystals (Kajikawa, 1972).

It is noticeable that the intensity of underlying echo increased up to ISO 2 at most when the thin echo reached close to the lower echo at 1500 JST in Fig. 6. The PPI echoes of normal and ISO 1 at 1500 JST are shown in Fig. 8. Relatively intense echo (ISO 1) was seen around the azimuth of 260° and from 10

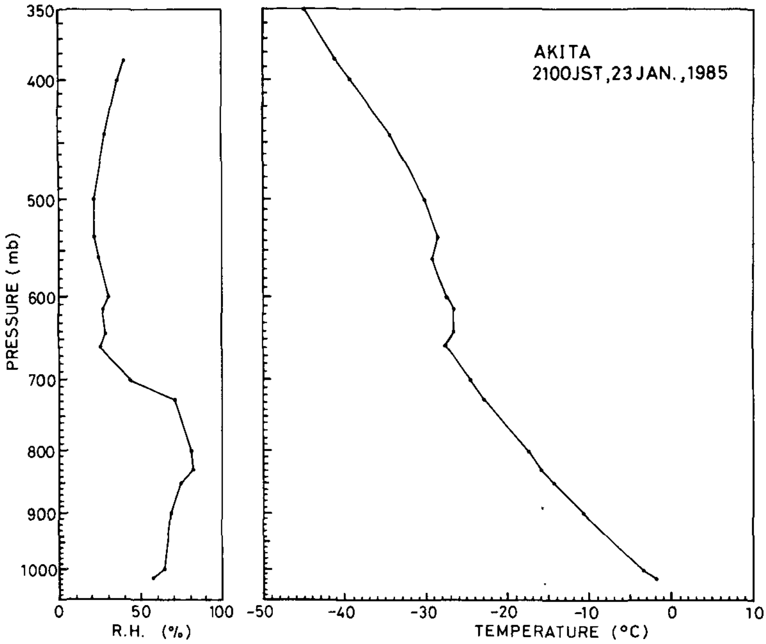

Fig. 9 Sounding curve of Akita at 2100 JST, 23 January, 1985.

to 20 km in range. This indicates the possibility of seeder-feeder effect or intensification of snowfall at lower altitudes by snowfall from above.

The sounding curve of 2100 JST, on 23 January, 1985 at Akita (which is about 100 km north of Shinjo city) is as shown in Fig. 9. It was ascertained that a stable layer from 500 mb (5500 m) to 700 mb (3000 m) was prominent and a moist layer was below 700 mb. The sounding at 2100 JST was used to compare the result shown in Fig. 7 because the sonde launched routinely at 1500 JST was only for wind profiles.

The weak and thin echo was not identified from visible and infrared photographs of GMS-III at 1500 JST. At 1400 JST when the most prominent echo was observed, no phtograph of GMS-III was available.

3.3 *Snowfall intensity at the ground and PPI echo intensity*

Precipitation gauge measurement is not effective in measuring weak snowfall intensity, however a trained observer's eye can sometimes identify the intensity of snowfall better. Nakamura et al. (1985) estimated the snowfall intensity on the ground by eye measurement at the same time with radar

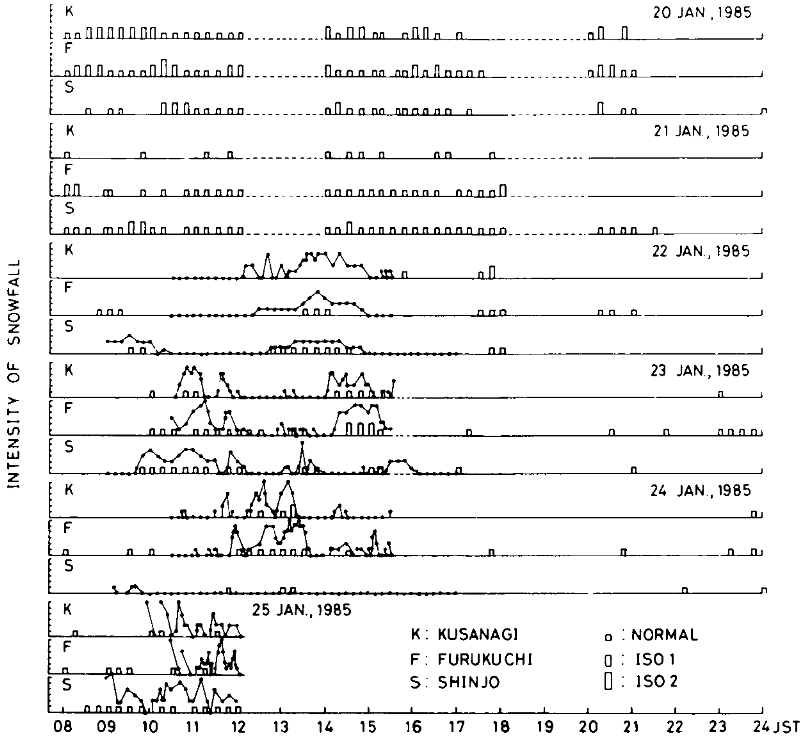

Fig. 10 Snowfall intensity on the ground estimated by eye measurement (after Nakamura et al., 1985) and PPI echo intensity over three locations (K: Kusanagi, F: Furukuchi and S: Shinjo). Snowfall intensity was shown by arbitrary measure with eight grades. Up to sixth grade (strong) was observed. Echo intensity was shown by the height of column. Dashed horizontal axis shows the period when no data was obtained for maintenance of a radar.

observations. This was compared with PPI echo intensity over the three surface points. Fig. 10 shows the snowfall intensity on the ground and PPI echo (with the elevation angle of 2.5°) at the three points. Initials of location names K, F and S correspond to Kusanagi, Furukuchi and Shinjo, respectively as indicated in Fig. 2. The horizontal axis indicated by the dashed line shows that the radar observation was not made for maintenance of the radar set. Measurements with the eye on the ground were made at the time plotted by dots. Radar echo intensity was measured at 15 minute intervals throughout the observation period. Snowfall intensity on the ground was only measured in the day-time on 22nd, 23rd, 24th and 25th of January, 1985. It is seen in the figure that when snowfall was identified by eye measurement on the ground, radar

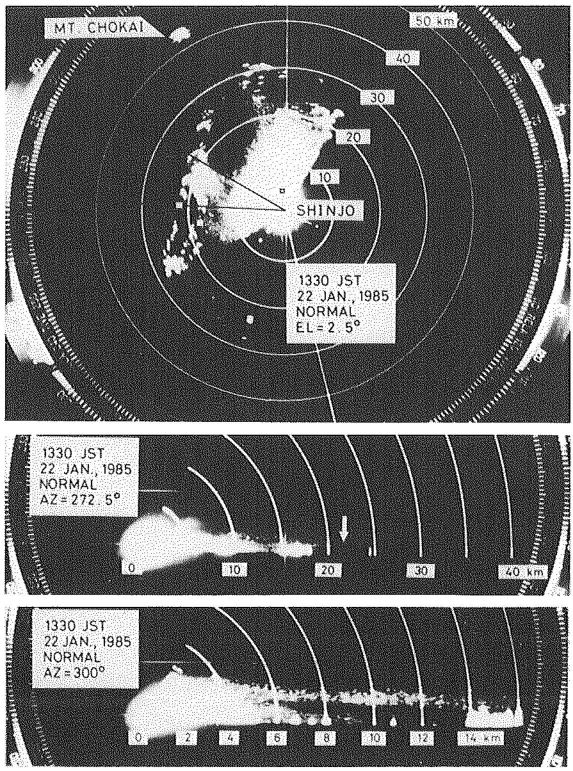

Fig. 11 PPI and REI normal echoes at 1330 JST, 22 January, 1985. (a) PPI echo at the elevation angle of 2.5°. (b) REI echo at the azimuth of 272.5°. The white arrow indicates the location of Kusanagi. (c) REI at the azimuth of 300°. Leaning echo streaks suggest strong vertical wind shear.

echoes were identified over the surface observation point, likewise.

The coincidence between snowfall intensity by eye measurement and PPI radar echo was relatively good almost throughout the observation period. However, on 22 January, PPI radar echo was not identified over Kusanagi from 12 to 15 JST, although a relatively intense snowfall was recorded by eye measurement on the ground. Such a treand is seen also at Furukuchi from 12 to 15 JST. In contrast to these two points, at Shinjo, PPI echo was identified from 1230 to 1500 JST while snowfalls were recorded by eye measurements.

In order to understand the disagreement of snowfall intensity on the ground and PPI echo, vertical wind shear was calculated with a vertical cross section of REI scanning.

AT 1330 JST, on 22 January, 1985, no echo was seen on PPI scope over

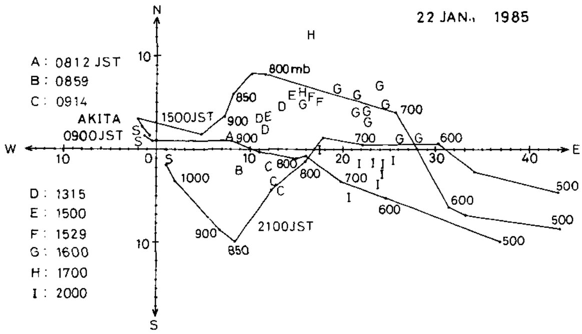

Fig. 12 Hodograph of 22 January, 1985 at Akita. Characters A, B, ···, I indicate the translation vectors of echo movements.

Kusanagi as shown in Fig. 11(a). The REI scan over Kusanagi (az=272.5°) shows that the echo height decreased with the increase of range as shown in Fig. 11(b). Echoes were not seen over Kusanagi (shown by white arrow). In this case, it is easy to understand that no echo would be identified over Kusanagi on PPI scope because the radar beam with an elevation angle of 2.5° shot higher altitudes. Namely, the snow was observed at the ground, because echo extended to Kusanagi at lower altitudes in REI scan, at the time.

The cause of such a feature as mentioned above is a vertical wind shear. A vertical cross section in the direction of 300° at 1330 JST is shown in Fig. 11(c). From the tilt of the echo, the vertical wind shear is estimated to be 16.6 m • s^{-1} km^{-1}. The azimuth of 300° was close to the direction of shear vector from 700 to 850 mb at 1500 JST obtained from the Rawin sonde as shown in Fig. 12. The characters A, B, C, ······, I indicate the translation vector of echo movements calculated from displacement of echoes on PPI scope for several minutes. The translation vector of echo veered as the hodograph changed their shapes. They were roughly close to wind speeds from 900 mb to 700 mb (Yagi et al., 1981). It is said that strong shear between 700 mb and 800 mb at 1500 JST is prominent enough to explain the discrepancy in intesity between snowfall on the ground and radar echo at a few hundred meters over the ground.

4. Discussion

The REI observation of snow echoes was made at several azimuths at 15 minute intervals. One of the most interesting echoes was a weak and thin echo. The thin echo observed from 1400 to 1530 JST on 23rd January is presumed to be descending snow echoes according to the following four reasons.

(1) The descent rate of the echo was from 0.7 to 1.0 m • s^{-1} which is close to the fall velocity of rimed snowflakes with a small diameter by Magono (1953) and Locatelli and Hobbs (1974). (2) The thin echo lasted for more than one hour. This shows that the echo was not a spurious one. Although the horizontal scale was not estimated because of low reflectivity, the extent of normal echoes guaranteed that the horizontal scale was larger than 15 km. (3) The echo extended almost horizontally in a vertical section and did not have a tilt such as seen in Fig. 11. Therefore the echo should not be a drift of snowflakes by the vertical wind shear. (4) Before the series of descending from 1400 to 1545 JST, another weak-thin echo was identified at a lower height at 1330 JST. This might indicate that such echoes passed over the radar site intermittently.

When the thin echo reached the top of underlying echo, it was intensified as shown in Fig. 6. This indicates the possibility of seeder-feeder interaction in snow clouds.

The thin echo was first observed at 5 km. This height is rather high for snow echoes in mid winter than usual. However it is considered that snow echo fell through the deep stable layer below 500 mb as shown in the sounding curve in Fig. 9. One argument would be on the larger descent rate of the echo than that of the fall velocity of individual snowflakes. Another possibility of an explanation of the thin echo is an angel echo. However it is very difficult to explain the large descent rate and intermittency by an angel echo. To clarify the mechanism of such an echo, a more intense observation by radars of a higher quality and other functions would be required.

Snowfall intensity estimated by eye measurement on the ground showed a coincidence with PPI echo intensity observation as shown in Fig. 10. However at two observation points from 1200 to 1500 JST on 22nd January, a disagreement of snowfall intensity and PPI echo intensity was obtained. The disagreement was explained by a strong vertical wind shear as shown in Fig. 11. As a strong vertical wind shear is common in the winter monsoon season, the disagreement between snowfall on the ground and PPI echo aloft would occur occasionally when the snowfall intensity and echo intensity are not so large.

The vertical structure of snow echoes seems to be of considerable importance to understand snowfall mechanism in winter. Even to understand a snowfall over a basin, not only geographic factors but also the structure of the snow cloud itself, espesially at high altitudes, are important. It has been clarified through this observational study that, as convective cloud of snow in winter monsoon is not higher than three kilometers, observations of vertical structures of radar echo and effect of seeder cloud would be very important.

5. Conclusion

Radar observations of a snowfall were carried out from 20 January to 25 January, 1985 in Shinjo basin. Intense measurements of vertical structure of snow echo was made by REI scanning.

A weak and thin descending echo was observed from 1300 to 1545 JST on 23 January. This echo was determined to be snow echo with a fall velocity from 0.7 to 1.0 $m \cdot s^{-1}$ by the analyses of descent rayte, the horizontal extent, and duration of the echo. Such echoes are very important to consider the intensification of snowfall echo if a seeder-feeder relation is suggested. A more intensive observation is required to determine the precise structure and role of the weak and thin echoes.

The comparison of snowfall intensity estimated by eye measurement and PPI radar echo showed a relatively good agreement from 20 to 25 January, except from 1200 to 1500 JST on 20 January. This disagreement of snowfall intensity on the ground and echo intensity at a certain height was explained by the presence of a strong vertical wind shear. Thus, it is suggested that a comparison of PPI radar echo and snowfall amount on the ground must be carried out carefully, when the snowfall intensity is small and vertical wind shear is strong.

The geographical effect on a snowfall over a basin is to be studied by a planned observation in Tohoku district in the winter of 1986-1987. Further detailed structure is expected to be revealed.

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