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# A Mesocyclone Generated in Snow Clouds Observed by Radar on the West Coast of Hokkaido Island, Japan

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**Abstract**

To investigate the detailed structure of snow clouds, the Convergent Band Clouds and mesoscale disturbances accompanied by them, a special radar observation was carried out at Haboro, which is located on the west coast of Hokkaido. The observation was made for one month from the middle of December 1986 to January 1987. During the observation period, several mesoscale vortex-like disturbances were observed. One of the typical cases on January 12, 1987 which formed at the edge of the Convergent Band Cloud was analyzed in this paper.

This meso-$\beta$ scale (20-200 km) vortex-like disturbance (mesocyclone) showed a 0.8 mb pressure drop (mesolow) and mesocirculation accompanied with a gust wind, identified as a mesocyclone accompanied by snow clouds in the winter season. This mesocyclone had outer band echoes of 30 km in diameter, an echo free area of 7 km in diameter in the mature stage of the disturbance and a life time of 2 hours. It was considered that the wind field of the confluence of three different air currents was important to generate the mesocyclone, and was liable to generate in this region which was not influenced by the topography under specific weather conditions. In fact, 6 cases of such disturbances were observed for one half month in this region. It is suggested therefore that mesocyclones generated in snow clouds could form frequently when certain synoptic and mesoscale situations were arranged.

## 1. Introduction

It is well known that heavy snowfalls in the winter monsoon seasons are brought to the coast of the Japan Sea of Japan Islands. Further, it is recognized that these heavy snowfalls are brought about convective cloud lines, namely, cloud streaks and cloud bands, especially, convergent cloud bands formed under conditions of northwesterly monsoon winds in a typical synoptic west-high, east-low pressure pattern.

Since the meteorological radar and satellite data were useful, mesoscale vortex-like disturbances associated with snow clouds have been reported frequently (Miyazawa, 1967; Magono, 1971; Yamaguchi and Magono, 1974; Nyuda et al., 1976; Asai and Miura, 1981). These mesoscale vortex-like disturbances which have a dimension of several tens of kilometers to several hundred kilometers in diameter have been referred to by many different names, i.e., "meso low", "small low", "small cyclone" and so on. However, the differences and resemblances of individual scale and the structures of the disturbances are not clarified to date.

These disturbances which are important in forecasting heavy snowfalls have been mainly investigated in the Hokuriku district using a special observation network of heavy snowfalls (Miyazawa, 1967). On the other hand, meso lows developed in the Ishikari Bay, Hokkaido, have been discussed also actively (Kono and Magono, 1967; Harimaya, 1970: Muramatsu et al., 1975; Yagi et al., 1979). Further, a strong cloud band that is formed along the west coast of Hokkaido Island over the Japan Sea, is called a Convergent Band Cloud (Okabayashi and Satomi, 1971). Since this Convergent Band Clouds (hereinafter, CBCs) which are of a particularly intense type of orographically and thermally influenced front occurring in mid-winter season are 250 to 300 km in length and several tens of kilometers in width, the small disturbances formed in the CBCs should be investigated in detail. Because the area covered by a radar is limited and radar data obtained are analyzed by photographs and sketches alone, the detailed echo structure of these mesoscale disturbances, has been unknown till the present. In addition, the development and movement of snow clouds in the northern area of Hokkaido have not been observed as yet by radar.

In other places except Japan, similar phenomena have been of interest to meteorologists. Particularly, hurricane-like mesoscale spiral cloud systems, so called "polar lows", that are generated over the North Atlantic and North Pacific Oceans and embedded in cold polar air masses, are investigated by satellites, aircrafts and radars (Shapiro et al., 1987). Polar lows are characterized by their shape of comma clouds and are less than 500 km in diameter with cloud-free inner eyes of 20-100 km in diameter and have a surface wind velocity stronger than 30 m/s on occasion.

Based on these circumstances, special radar observations were carried out from the middle of December 1986 through to the middle of January 1987 at Haboro Town (44°21′N, 141°42′E) located at the west coast of Rumoi Subprefecture of Hokkaido Island about 150 km far north from Sapporo. The observations were done in order to investigate the development, movement and structure of snow clouds near the coast of Hokkaido. During the observation period, typical cases of mesoscale vortex-like disturbances were observed by radar. These disturbances which have an echo area of 20 to 50 km in diameter, a pressure depression and a strong wind field are decided to be called mesocyclones. In this paper, the formation process of one of the mesocyclones generated in the CBC will be described using radar echo patterns.

## 2. Observation network and data

Figure 1 shows the observation network around the radar site. The mobile meteorological radar of the Meteorological Laboratory, Faculty of Science, Hokkaido University marked by a star in the figure was set up on a cliff of 30 m in height along the coast line from north to south in Haboro Town. Long period recording wind vane and anemometers, thermometers and microbarometers were also placed at the two special observation sites, namely, Yagishiri Island and Onishika 25 km apart to the south from Haboro marked by solid

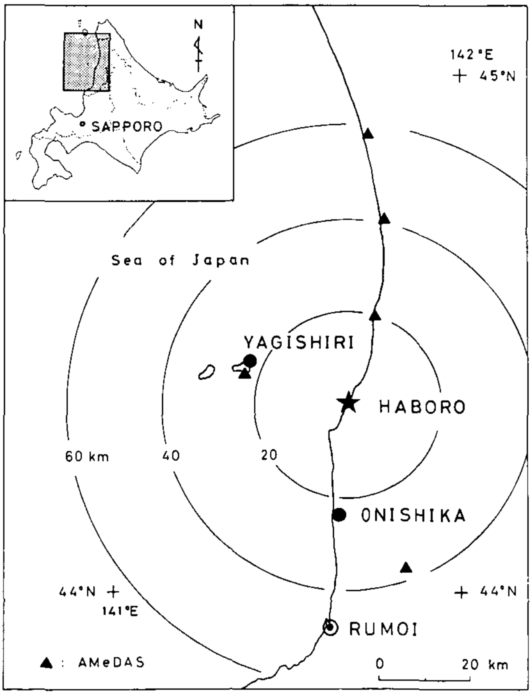


Fig. 1 The observation network around the radar site at Haboro (star mark). Solid and open circles denote special observation station and JMA weather station, respectively. AMeDAS stations are denoted by solid triangles.

circles, respectively. Weather stations of JMA (Japan Meteorological Agency) are located in Haboro and Rumoi, and the AMeDAS stations marked by solid triangles covered this area.

The range scrutinized by the radar was 63.5 km in radius. Fortunately, there were no obstacles to hinder radar detection around the radar site. Radar data were recorded on magnetic tapes with CAPPI and RHI modes at every 10 minute intervals. For the analysis, radar data were recorded on an average over 1 km×1 km mesh in horizontal and 0.5 km in vertical. Weather data observed at Yagishiri and Onishika sites and Haboro (JMA) station were used and satellite pictures of GMS taken by Meteorological Satellite Center of JMA and NOAA data received at the Meteorological Laboratory in Hokkaido University were also taken into account in the analysis.

## 3. A case study of mesocyclone on January 12, 1987

Figure 2 shows a GMS (Geostationary Meteorological Satellite) infrared image just before the development of this mesocyclone. There was a distinct curved band cloud southward from the Soya Strait. According to the time change of GMS pictures, this band cloud was formed clearly on 18 JST, January 11, 1987 and was regarded to be in the dissipating stage of the CBC. The

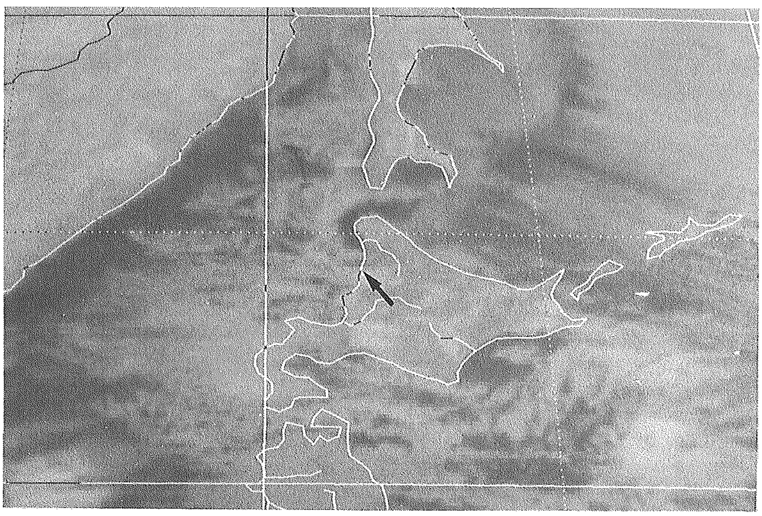

Fig. 2 GMS infrared image at 03 JST January 12, 1987. An arrow indicates the location of Haboro radar site. (after J.M.A.)

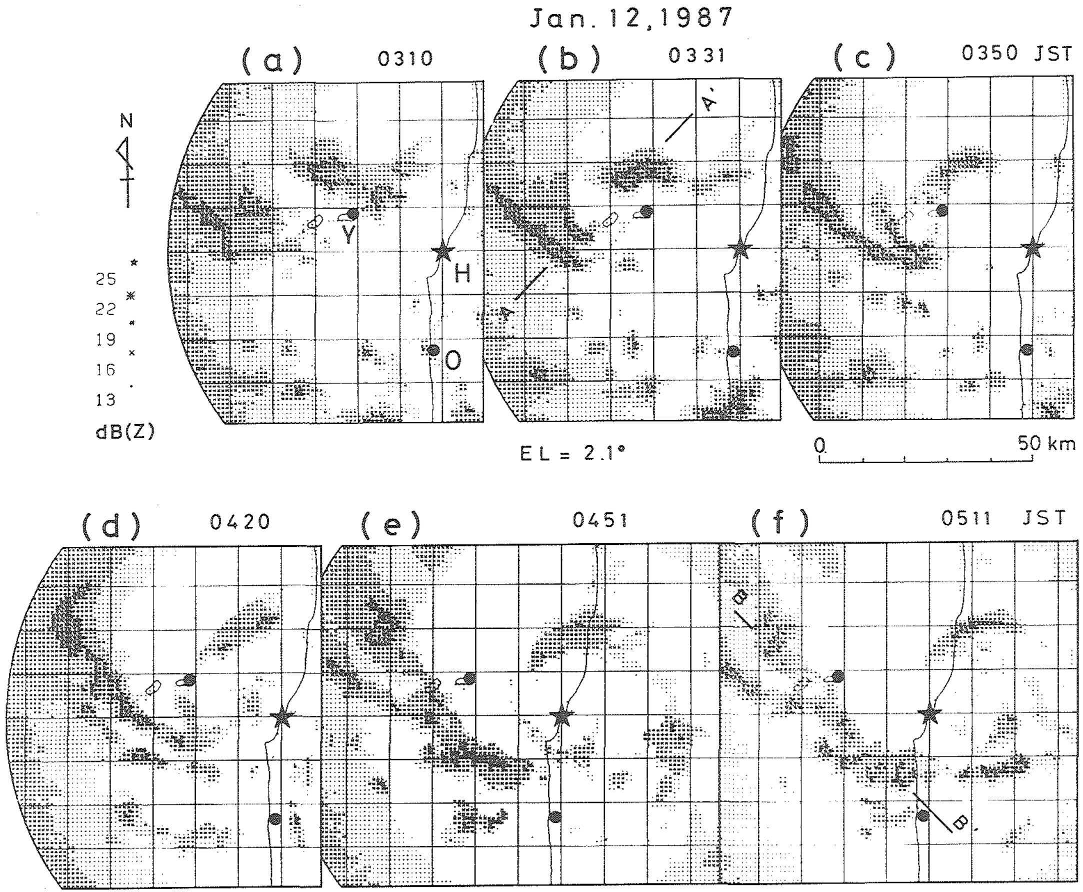


Fig. 3 Time sequence of the PPI radar echo patterns through a life cycle of the mesocyclone. Star marks show the radar site (Haboro) and solid circles denote the locations of Yagishiri and Onishika stations, respectively.

southern end point of this band had moved northward gradually and a mesoscale vortex disturbance (mesocyclone) was formed in the band cloud. Because of the lack of the time and space resolution, however, a vortex disturbance could not be found in the image picture.

### *3.1 Radar echo structure*

Figure 3 indicates the time sequence of the PPI radar echo patterns of the mesocyclone. Before this disturbance, a distinct band shaped echo which was located in the southern region of the radar coverage and corresponding to the band cloud mentioned in Fig. 2, began to shift in a northward direction from 2100 JST, January 11. When the band shaped echo arrived at the west end of the radar coverage area, the location of the band echo was stationary (corresponding to "the initial stage" of disturbance). As shown in Fig. 3(a), the echo pattern was formed from an isolated echo located northward of Yagishiri Island and the main band echoes progressing from the northwest direction. Afterwards, the isolated echo elongated and showed a cyclonic curvature at the point of the main band echo as shown in (b). At 0350 JST, the cyclonic echo pattern characterized by these echo bands was distinguished about 30 km offshore of Haboro near Yagishiri Island as shown in (c). At this time, the cyclonic echo pattern took on a shape of a mesocyclone in "the mature stage" showing a spiral band echo pattern. The scale was 30 km in diameter including the outer band and an echo

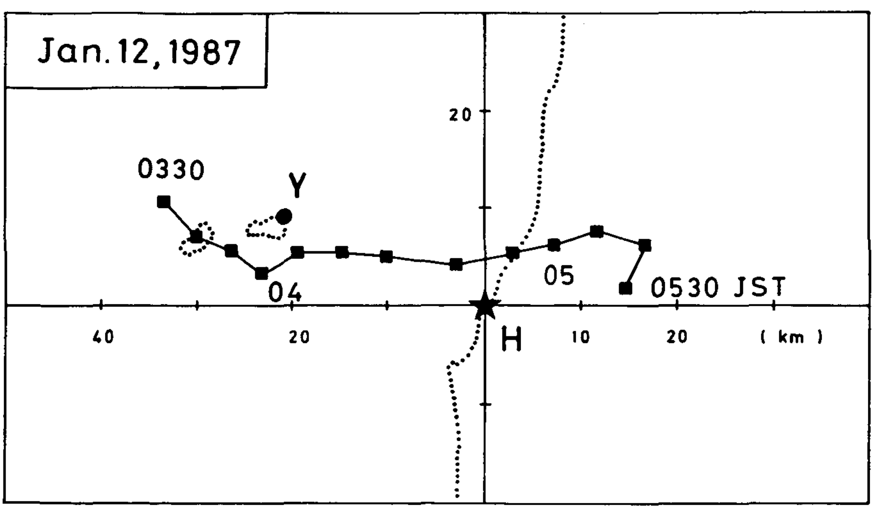


Fig. 4 The movement course of the center of echo free area of the mesocyclone indicated by 10 minute intervals.

free area of 7 km in diameter which is generally called the cyclone eye. At this stage, the disturbance was called a mesocyclone. Afterwards, the mesocyclone moved eastward and the echo free area surrounded by a spiral echoes increased in diameter. The southward echo band corresponding to the main band was extended in a southeastward by slow degrees as in (d). As shown in (e), after the mesocyclone landed near Haboro in "the dissipating stage", it began to stagnate and disappeared while the echo area and the echo free area spread to about 40 km and 20 km in diameter, respectively as in (f). The movement course of the center of echo free area of the mesocyclone indicated by 10 minute intervals is shown in Fig. 4. It revealed that the mesocyclone moved eastward uniformly with an average velocity of 30 km/h. The mesocyclone disappeared 15 km inland after landing. The life time of the mesocyclone was approximately 2 hours.

Figure 5 shows the formation process of mesocyclone at three different times at 1.1, 1.7 and 2.5 km above the sea level which made from CAPPI mode

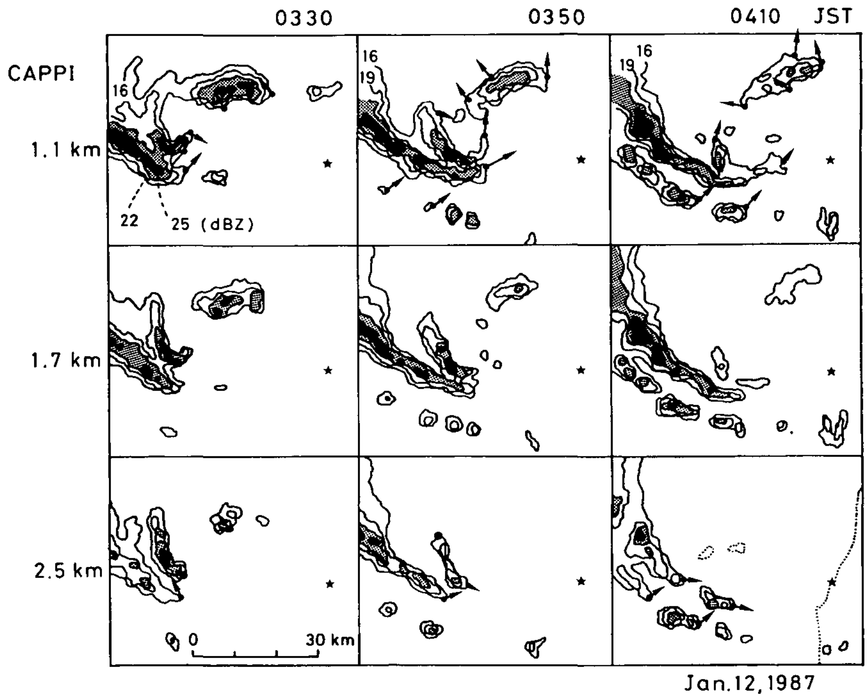


Fig. 5 Three different time of CAPPI displays of 1.1 km, 1.7 km and 2.5 km, respectively. Each vector shows the storm relative 10 minute displacement vector.

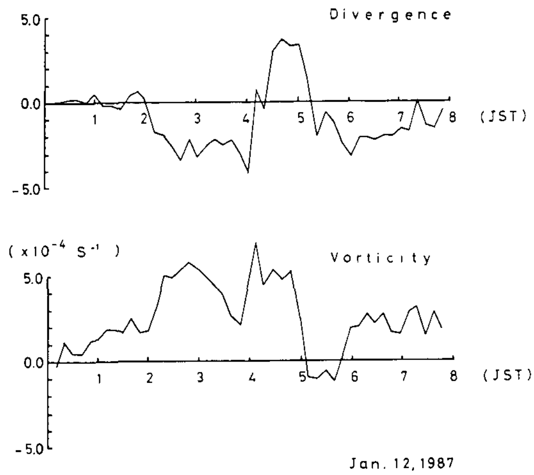


Fig. 6 Time changes of Divergence (top) and Vorticity (bottom), calculated by 10 minute average wind data of Haboro, Yagishiri and Onishika shown in Fig. 1.

data. Each vector in the figure indicates the relative wind to disturbance and indicates out the cyclonic echo flow pattern. Whereas the vortex circulation of echoes appeared at low altitude (1.1 km) alone, at 2.5 km level the main band echo from the northwest direction was obvious. Therefore, it is considered that the convergent field was strong at the lower level. In fact, the time change of divergence and vorticity calculated from wind data averaged at 10 minute intervals using Yagishiri, Onishika and Haboro stations corresponded with both the time of development and the position of the mesocyclone (Fig. 3) shown in Fig. 6. The calculated values showed $4\times10^{-4}\,s^{-1}$ for the maximum convergence and $7\times10^{-4}\,s^{-1}$ for the maximum vorticity at 0400 JST when the mesocyclone moved and developed in the calculated area. These results were quite reasonable compared with that of other case studies such as Miyazawa (1967) and Asai and Miura (1981).

Three vertical cross sections perpendicular to the 315° direction as shown A–A′ line in Fig. 3(b), are shown in Fig. 7 as a form of the RHI radar display which made from CAPPI mode data. From the figure, the vertical structure of the mesocyclone in the mature stage at 0350 JST in Fig. 3(c) indicated that convective cells with an echo top of 4 km in height were confirmed in the southward main band. On the other hand, the northern echo was at a relatively low height with an echo top of only 2.5 km. In particular, an inner cell of the main band inclined to the center of the mesocyclone behind the mesocyclone

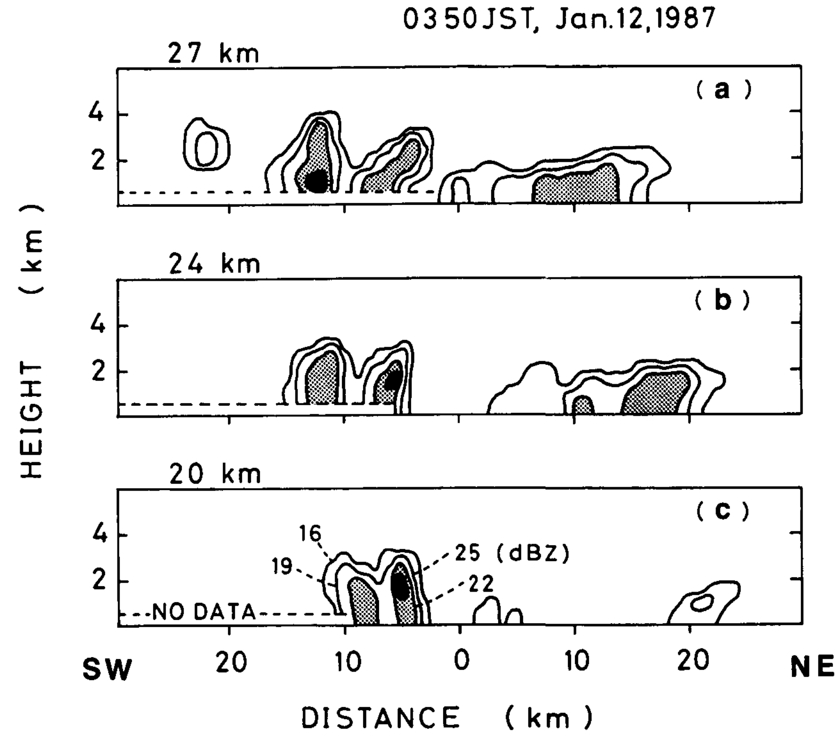


Fig. 7 RHI radar displays at 0350 JST perpendicular to the 315° direction as shown A-A′ line in Fig. 3. Three cross sections of 27 km (a), 24 km (b) and 20 km (c) correspond to the rear of the mesocyclone center, the center of the mesocyclone and the front of the mesocyclone center, respectively.

center. Thus, the mesocyclone was clarified to have an asymmetric echo structure.

### *3.2 Characteristics of meteorological elements*

Time changes of weather records caught our interest when the mesocyclone passed by the south side of Yagishiri site and by the north side of Haboro station. It was recognized that each meteorological element changed remarkably at the passage of the mesocyclone. As seen in Fig. 8, the pressure decreased from 0430 to 0530 JST at the passage of echo free area and the maximum pressure drop was 0.8 mb. This pressure drop of about 1.0 mb corresponded to the typical pressure change of mesoscale low pressure systems. The wind direction also changed systematically, at Yagishiri, namely, the northwesterly gust wind recorded the maximum velocity of 17 m/s at 0400 JST

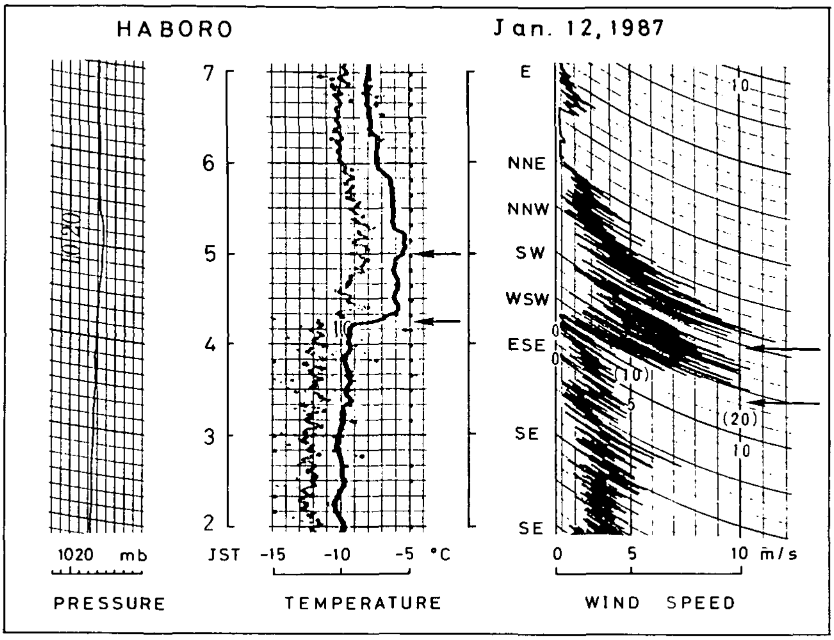


Fig. 8 Surface weather records of the pressure (mb), temperature (°C), and wind velocity (m/s) at Haboro. Arrows indicate the time of gust winds.

just after the passage of the mesocyclone center. On the other hand, the gust wind was recorded two times at Haboro as shown in Fig. 8. The first gust was recorded at 0420 JST when the eastern edge of the outer spiral echo band arrived at the radar site and the second gust was at 0500 JST when the spiral band entered from northwest behind the mesocyclone center. The maximum wind velocity was recorded at 10.5 and 11.5 m/s, respectively. The gust wind was in good correspondence with the time and space of the spiral echo bands. Corresponding to the time of these gust winds, two remarkable temperature rises of 3°C/10 min and 1°C/10 min occurred, respectively. The temperature rises suggested that the relatively cold land breeze from the southeast direction was replaced with the relatively warm and moist northwest monsoon wind at the generation of the mesocyclone and the main echo band. Figure 9 which was the temperature field at the landing of the mesocyclone was made from continuous weather records of Haboro, Onishika and Yagishiri data using the time-space inversion method. From this figure, it was revealed that a relatively warm area warmer than −7°C accompanying the mesocyclone and band echoes invaded inland. As a result, a sharp temperature gradient between both air

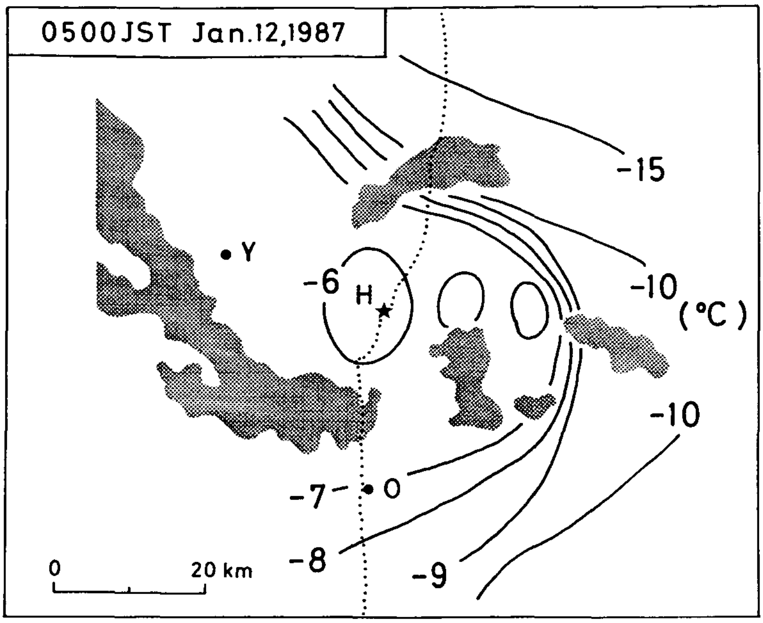


Fig. 9 The temperature field at 05 JST. Shaded areas indicate radar echoes larger than 16 dbZ.

masses was formed. Furthermore, near the center of the mesocyclone, the most warm area characterized by −6°C isotherm appeared and corresponded to the location ahead of the spiral band echoes. These features implied the existence of a gust front which was located to the southeast ahead and the northeast behind the mesocyclone center as shown in Fig. 10.

## 4. Discussion and concluding remarks

A meso-$\beta$ scale vortex-like disturbance (a mesocyclone) with an echo free area of 7 km in diameter accompanied by the Convergent Band Cloud (CBC) in the winter monsoon seasons was observed for the first time by a mobile weather radar in detail on the west coast of Hokkaido Island, Japan. The characteristics of the mesocyclone described in this paper revealed that a distinct wind circulation and an asymmetric gust wind field was in good correspondence with the location of the spiral echo band area around the echo free area. These mesocyclones accompanying the circulating echo system and gust winds should be distinguished from other disturbances.

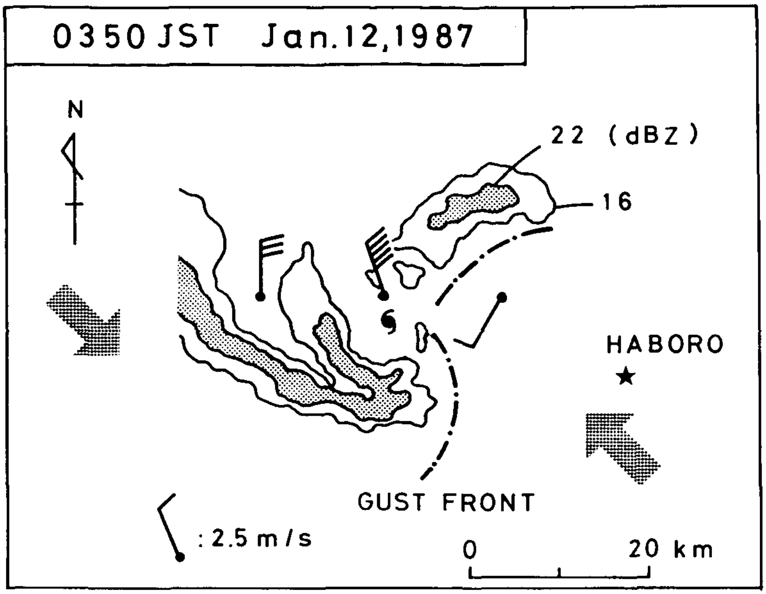

Fig. 10 The schematic figure of gust fronts in the mesocyclone. Wide arrows indicate northwesterly monsoon wind and the southeasterly land breeze, respectively.

The term of mesocyclone has attracted attention as thunderstorm disturbances which produce tornadoes. In this connection, a number of mesocyclones have been observed by doppler radars to analyze wind fields in United States of America, and the average mesocyclone was known to last for over an hour with a rotational velocity of 23 m/s, a core diameter of 5 km, and a vertical extent of 6 km in Oklahoma spring storms in 40 cases (Zrnic' et al., 1985). Of course, while the weather conditions between the disturbances over the Japan Sea in the winter monsoon seasons and that of over central United States of America in warm seasons were quite different, whereas warm season mesocyclones were organized by a strong thunderstorm cumulonimbus, mesocyclones of snow clouds was characterized by the confluence of convective clouds having a lower cloud top. Yet both disturbances were quite similar in scale and behavior of the disturbances.

It could be considered that the formation process of mesocyclones depends upon following two conditions. First is the vertical temperature gradient condition in which an unstable layer develops in the middle troposphere reflecting the cold air mass advection. As a result, a strong cold dome is formed over Hokkaido Island. In addition, the warm sea current in the Japan

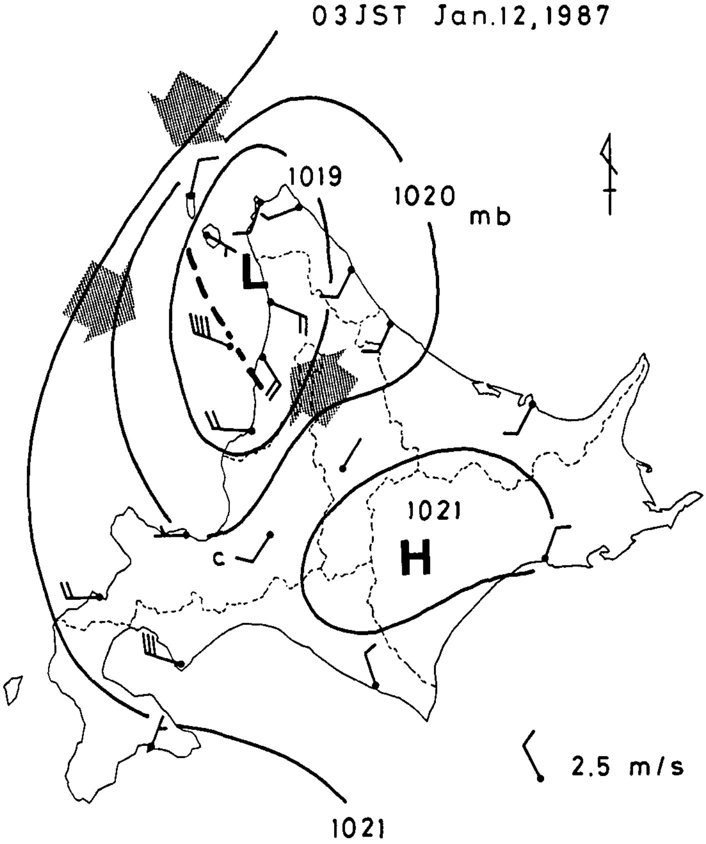


Fig. 11 Mesoscale weather chart at 03 JST January 12, 1987. Thick dashed line denotes a wind shear line characterized by the band clouds in Fig. 2 and wide arrows denote wind directions of three different air currents.

Sea along the west coast of Hokkaido is found to be related to the generation of the mesocyclones. Further, the mesocyclones are liable to occur in specific regions in synoptic situations. The formation process of echo patterns of these mesocyclones closely resembles the formation process of polar lows observed over the Norwegian Sea (Shapiro et al., 1987).

The second is a wind field in the mesoscale, namely, three different air currents are observed in northern Hokkaido as shown in Fig. 11. They are northwesterly monsoon winds under a synoptic situation which is relatively warm and moist, and northeasterly wind which are important to form the CBCs along the west coast of Hokkaido, and lastly the southeasterly cold land breeze with a shallow colder and drier current which is formed in central Hokkaido under the nocturnal cooling pointed out by Kobayashi et al., (1987). The location where the mesocyclones occurred coincided with that of the confluence of three different air currents. Therefore, the mesocyclones are considered to be able to generate if the synoptic and mesoscale weather conditions are present any time any where. Besides, Motoki, (1974) pointed out that a small cyclonic echo pattern is formed inland of the Ishikari Plain under the mesoscale weather conditions of three different air currents in the plain which is closely similar to this case.

Actually, as many as 6 cases of mesoscale vortex-like disturbances were observed only for one half month during the Haboro special observation period as shown in Table 1. Each value of gust winds, pressure drop, temperature change was decided from continuous weather records of Yagishiri and Haboro. Maximum values of divergence and vorticity were calculated from hourly wind data of three AMeDAS stations, Yagishiri (13146), Haboro (13181) and Shosanbetsu (13121). Except for one case, each disturbance have some similarities in its scale and life time and have pressure drops of 1.0-2.0 mb, gust winds of 15-25 m/s over the sea and 10-20 m/s at the coast line under the convergent and positive vorticity field. The change of temperature appear as both rise and

Table 1 List of 6 mesoscale vortex-like disturbances during Haboro special radar observation.

| DATE | SCALE | LIFE TIME | YAGI. | HABORO | | | MAX. DIV. | MAX. VOR. |
|---|---|---|---|---|---|---|---|---|
| | | | GUST | GUST | ΔP | ΔT | | |
| | (km) | (hours) | (m/s) | (m/s) | (mb) | (℃) | $\times 10^{-4}$ ($s^{-1}$) | |
| 1 03JST Jan. 4, '87 | ~ 50(S)* | 2 | 16 | 14 | −1.0 | +1.8 | −6.1 | 4.7 |
| 2 13JST Jan. 4 | ~200(S) | 9 | 26 | 19 | −2.0 | −2.0 | −1.3 | 1.4 |
| 3 15JST Jan. 9 | ~ 50(S) | 3 | 15 | 12 | ±0.7 | +0.9 | −4.6 | 4.0 |
| 4 04JST Jan. 12 | 30(R) | 2 | 17 | 10 | −0.8 | +3.2 | −5.9 | 1.7 |
| 5 06JST Jan. 14 | 20(R) | 0.5 | — | — | — | — | −4.4 | 7.0 |
| 6 00JST Jan. 15 | 30(R) | 2 | — | 15 | −2.0 | −1.0 | −1.8 | 1.5 |

* (S): Satellite, (R): Radar

descent which means that this change is placed under the control of the different air masses mentioned above. As a result, it is considered that mesocyclones are (20-50 km) generated in snow clouds more frequently than our expectation.

In conclusion, the mesoscale vortex-like disturbances observed in the special radar observation around Haboro at 03 JST January 12, 1987, showed an outer band echo of 30 km in diameter, 7 km of echo free area and 2 hours of life time. Considering the mechanism, it was suggested that the disturbance was strongly influenced by wind fields of the confluence of three different air currents. Surface weather records indicated that the mesoscale disturbance was characterized by the mesocirculation from wind fields and by the mesolow from the pressure situation. As a result, it was identified as a mesocyclone accompanied by precipitating snow clouds in the winter monsoon season.

Further studies would be required to investigate mesocyclones with doppler radars to clarify the wind fields and structure of them. Moreover, the synoptic and mesoscale features and behaviors that generate the CBCs accompanying mesoscale disturbances would be required for analyzing in detail.

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