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STRUCTURE AND MAINTENANCE PROCESS OF STATIONARY SNOWBANDS ALONG COASTAL REGION OBSERVED BY DOPPLER AND DUAL-POLARIZATION RADARS

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1 INTRODUCTION

When cold air outbreaks occur from the Eurasian Continent, convective snow clouds develop over the Sea of Japan. When snow clouds reach the Japan Island, they are usually modified or intensified around the coastal region. Takeda et al. (1982) showed from the echo structres by a radar in the Hokuriku District, which is located at the south of the Sea of Japan, that most of isolated convective snow clouds had the two stages of modification in their landing. Ishihara et al. (1989) clarified that land breeze produced or modified snowbands at an interval of 3 or 4 days along the coast in Hokuriku. They also analyzed snowbands using Doppler radar. The snowbands moved with the land breeze front toward the land and decayed after its landing. In Hokkaido, which is located at the northern part of Japan, land breeze also modifies or intensifies the snow clouds in its front (e.g., Tsuboki et al. 1989). But the studies, which concerns the intesifications or modifications of snow clouds around the coastal region, have not reported a snow cloud which stayed along a coastal region for a long time.

An observation of snow clouds was performed at Oshimizu in the Hokuriku District, Japan in winter of 2000 to 2001 using a X-band Doppler radar of Nagoya University. The radar range was overlapped by another C-band dual-polarization radar of Hokuriku Electric Power Company at Goishigamine. From 15 to 16 January 2001, two snowbands stayed along the coast of Hokuriku for 20 hours. The purpose of this study is to clarify the structure and maintenance process of the sta-

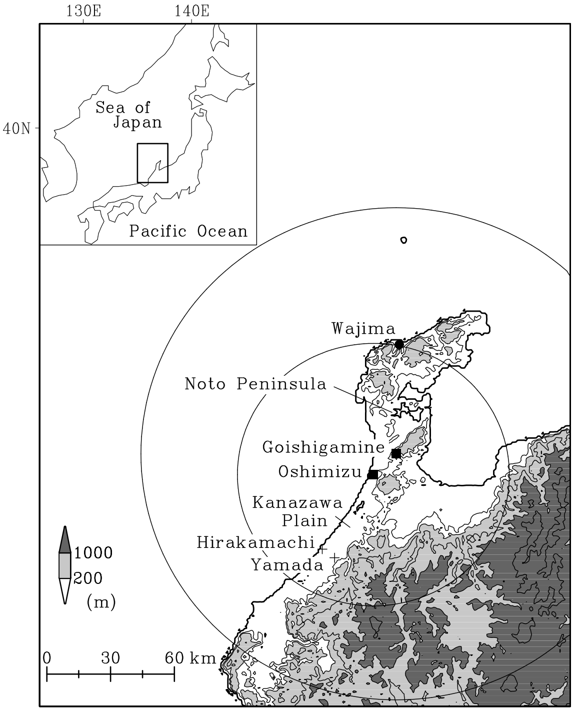

Fig. 1 Locations of each observation point. The marks of ■, ● and + indicate the locations of radar (Oshimizu and Goishigamine), upper-air sounding (Wajima) observations and the site in which pictures of snow particles were taken (Hirakamachi and Yamada), respectively. Circles show the ranges of radars. The altitude of topography is shown with contours and shades. The contours are drawn at 100 m, 200 m, 500 m, 1000 m and 2000 m.

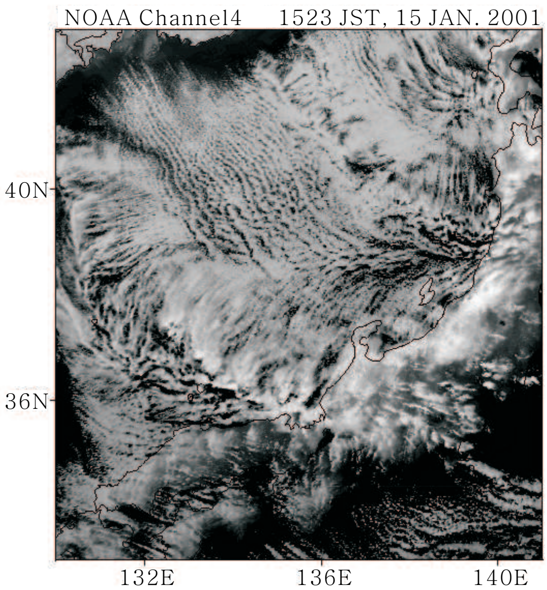

Fig. 2 Satellite imagery of NOAA-14 channel 4 (thermal-infrared) at 1523 JST, 15 January 2001.

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tionary snowbands along the coast. This study contributes to clarify a form of intesification of snow clouds around the coast.

Upper air sounding data at Wajima, satellite imagery of NOAA and pictures of snow particles at Hirakamachi and Yamada were also utilized. Figure 1 indicates the topography and the locations of the observational points.

2 SYNOPTIC SITUATION

In the middle of January, a cold air outbreak occurred over the Sea of Japan. On 15 January, the cold air less than −36 °C was present at 500 hPa over Hokuriku. The convective mixing layer with a thickness of 4 km was formed over the Sea of Japan near Hokuriku. In the convective mixing layer, convective clouds developed (Fig. 2). The coastal region of the Kanazawa Plain, in which the snowbands developed, was located in the downward side of the transverse mode clouds. The upper air sounding at Wajima indicated that the north-westerly monsoon wind in the lower level was weaker than in typical cold air outbreaks.

3 STRUCTURE AND MAINTENANCE PROCESS OF SNOWBANDS

The snap shot of reflectivity at 1808 JST (Japan Standard Time), 15 January 2001 shows that two snowbands were present along the coast; Snowband 1 and Snowband 2 (Fig. 3). Snowband 1 was located over the sea and had strong reflectivity. Snowband 2 was formed over the land and had relatively weak reflectivity. The X and Y axes are defined normal and parallel to the snowbands. The origin is on the Oshimizu radar site. The period which the snowbands stayed is shown in time-distance cross section of reflectivity (Fig. 4). The reflectivity was averaged from Y = −24 km and −8 km in the Y-direction. The two snowbands stayed for about 20 hours from 0730 JST, 15 to 0400 JST, 16. The two snowbands gradually became clear. Therefore, the clear period from 1500 JST, 15 to 0400 JST, 16 was analyzed in the following. The development of convective cells in both snowbands were investigated (Fig. 5). The successive development of convective cells (SB1-1, SB1-2 and SB1-3 in Snowband 1, and SB2-1 and SB2-2 in Snowband 2 in Fig. 5) maintained both snowbands. The development of the cells in Snowband 2 (SB2-1, SB2-2) followed the decay of the cells in Snowband 1 (SB1-1, SB1-2).

The horizontal wind over the Oshimizu radar derived from VAD method showed that the south-easterly land breeze developed from the morning on 15 and had a thickness of 400 m. The time-averaged vertical cross section normal to the snowbands shows that the north-westerly monsoon wind and the south-easterly land breeze made strong convergence (Fig. 6), which resulted in strong updraft. A strong divergence zone was present over the strong convergence zone in Snowband 1. In Snowband 2, the weak convergence zone was formed and contributed to the formation of weak updraft.

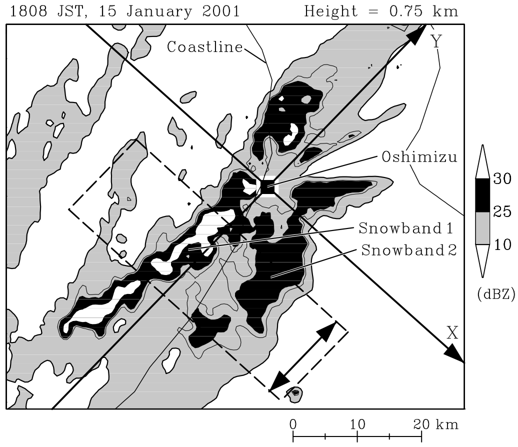

Fig. 3 Horizontal reflectivity pattern at 1808 JST, 15 January 2001 at a height of 0.75 km. The mark of ■ indicates the location of the Oshimizu radar. The thick lines with an arrow show the X and Y axes. The rectangle with broken lines corresponds to the averaged area in Fig. 4 .

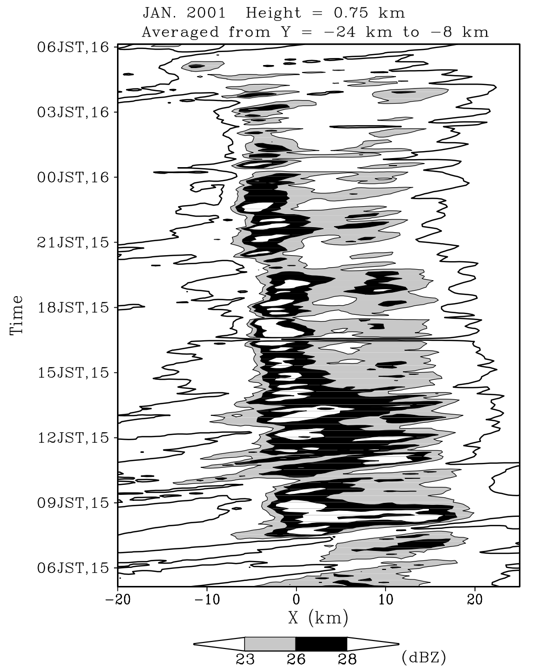

Fig. 4 Time-distance cross section of reflectivity at a height of 0.75 km. The reflectivity is averaged in the Y-direction (from Y = −24 km to −8 km).

The Z and Z_{DR} relationships were investigated in 7 boxes which were located along the trajectories of cellular echoes in both snowbands to clarify the microphysical process in the developments of snowbands (Fig. 7). The Z_{DR} of Snowband 1 co-

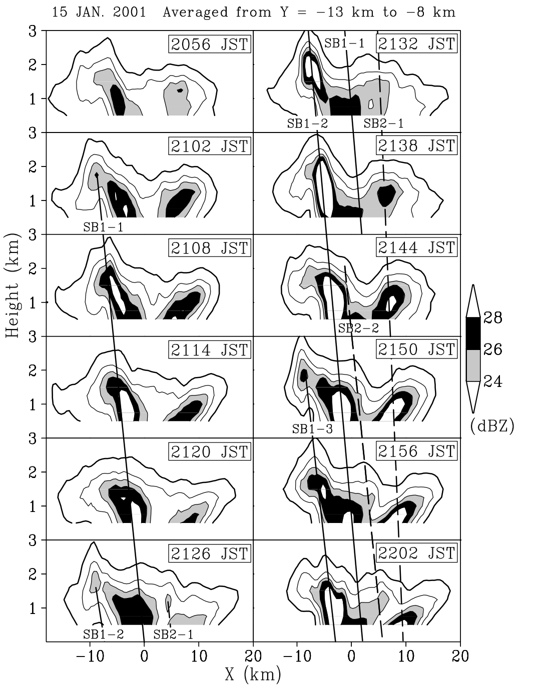

Fig. 5 Time-series of the vertical cross section of reflectivity from 2056 JST to 2202 JST, 15 January 2001 every 6 minutes. The reflectivity is averaged from −13 km to −8 km in the Y-direction.

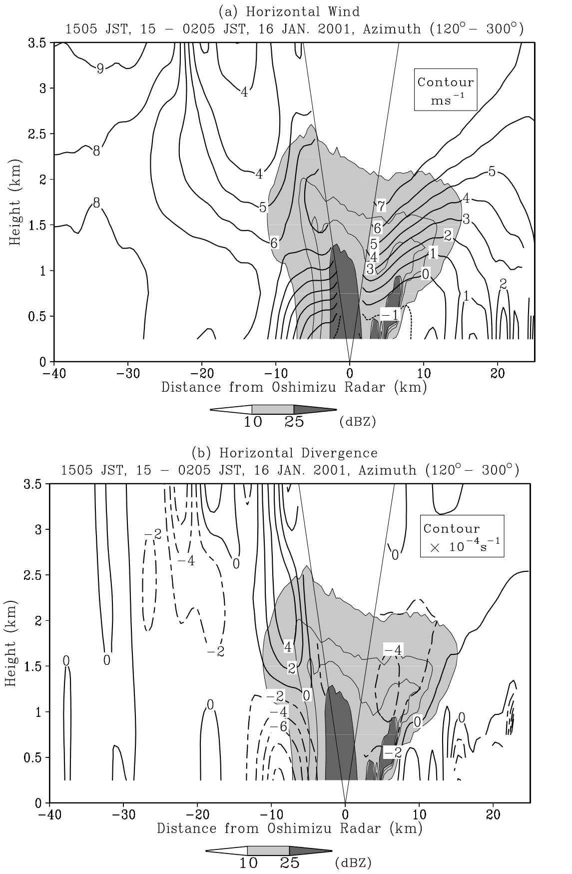

Fig. 6 Vertical cross sections of (a) the horizontal wind and (b) the horizontal divergence in the section and the reflectivity averaged from 1505 JST, 15 to 0205 JST, 16 January 2001 derived from RHI scans with the direction of 120° - 300°. The right hand side in the figure is the land side. (a) The averaged horizontal wind in the section is shown with the contours drawn every 1 m s^{-1}. The contours of positive values show the wind from the sea to the land. (b) The contours drawn every −2 × 10^{-4} s^{-1} indicate horizontal divergence calculated from the horizontal wind in the section.

centrated in −0.5 dB when the reflectivity became strong from Box 1 to Box 4 via Boxes 2 and 3. This probably indicates the developments of graupels. On the other hand, the Z_{DR} of Snowband 2 (Boxes 5, 6 and 7) concentrated in 0 dB and the variances of Z_{DR} were larger than Snowband 1. All pictures of snow particles taken at the ground under Snowband 2 showed aggregates. The aggregates were constituted of many heavily rimed crystals, and a few lightly rimed and unrimed crystals such as dendrites. The values of about 0 dB in Z_{DR} and its large variance probably resulted from that the irregularly shaped aggregates were macroscopically observed by radar.

4 DISCUSSION

Figure 8 shows the schematic representation of the structure and maintenance process of the snowbands. Land breeze developed in relatively weak monsoon wind. The north-westerly monsoon wind and the south-easterly land breeze made strong convergence over the sea near the coast, and produced the strong updraft. The strong updraft probably made a lot of supercooled water from abundant water vapor. Therefore, the riming process was able to affect on the formation of the falling particles in Snowband 1. The relatively small values with about −0.5 dB of Z_{DR} reflects the shape of graupel. The large friction over the layer of land breeze, which flowed against the monsoon wind, probably decelerated the monsoon wind. Consequently, weak updraft was formed in Snowband 2 over the land breeze layer. The strong divergence in Snowband 1 in the middle layer contributed to intensify the updraft in Snowband 2. In the weak updraft, aggregates were formed by the aggregation and deposition processes. Many heavily rimed crystals in aggregates in Snowband 2 were probably formed in the upper part of Snowband 1 and flowed toward Snowband 2 because the weak updraft in Snowband 2 was not able to produce the supercooled water sufficiently necessary for the riming growth.

5 SUMMARY

Two snowbands stayed along the coastal region in Hokuriku, Japan for 20 hours from 15 to 16 January 2001. The structure and maintenance process of the stationary snowbands were investigated mainly using Doppler radar and dual-polarization

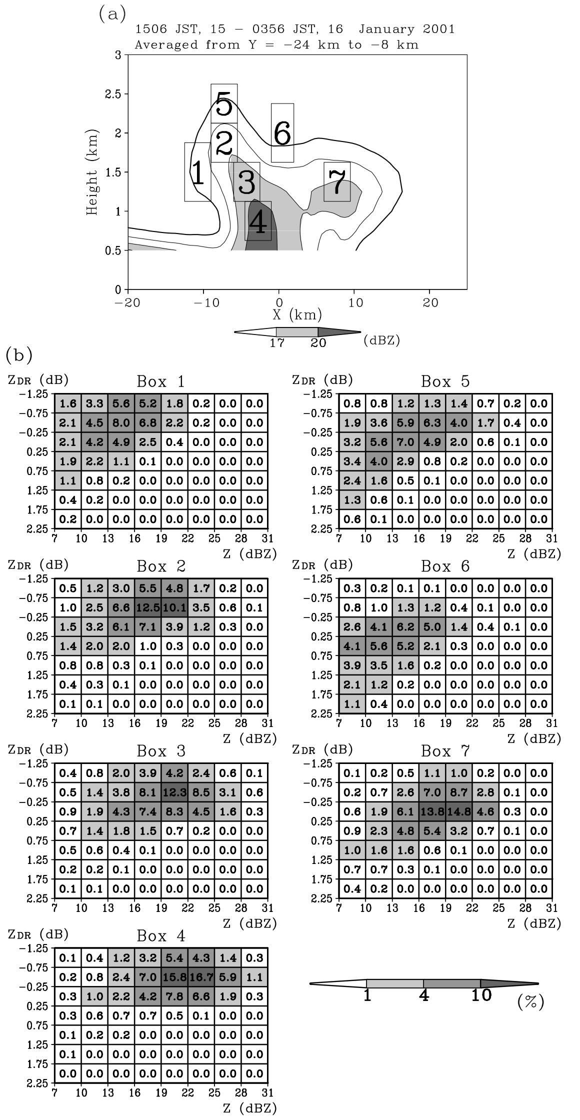

Fig. 7 Z-Z_{DR} relationships. (a) The vertical cross section of time-averaged reflectivity and (b) the Z-Z_{DR} relationships in each box in (a) derived from dual-polarization radar. The number in (b) indicates the ratio of grids in each Z-Z_{DR} region to all grids in each box between Y = −24 km and −8 km from 1506 JST, 15 to 0356 JST, 16 January 2001.

radar.

Land breeze with a thickness of about 400 m developed in the relatively weak monsoon wind. The strong convergence betweeen the monsoon wind and the land breeze formed strong updraft. The strong updraft at the land breeze front maintained Snowband 1. The formation of snow particles in Snowband 1 was mainly by the riming process. The large friction over the land breeze layer probably decelerated the monsoon wind and formed weak updraft. The strong divergence in Snowband 1 in the middle layer contributed to intensify the weak updraft in Snowband 2. In the weak updraft, the aggregates were formed by the aggregation and deposition processes.

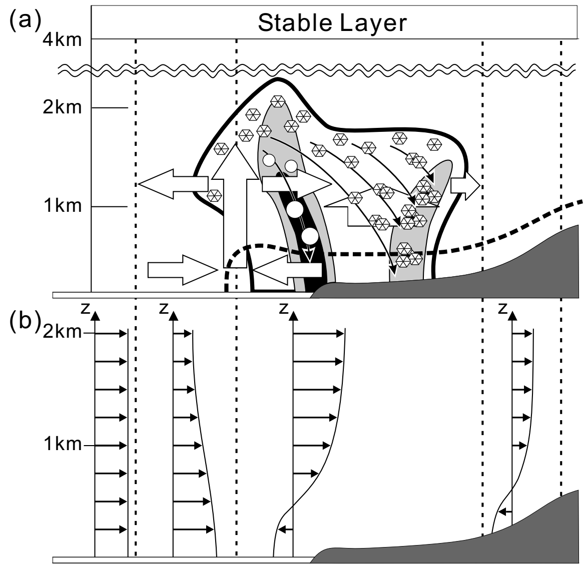

Fig. 8 Schematic representation of structure and maintenance process of the snowbands. (a) The thick line indicate the echo region. The shaded regions indicate strong echo. The thick arrows indicate the wind relative to the surrounding wind, and the thin arrows the trajectories of particles. The broken line indicates the land breeze. (b) The vertical profiles of horizontal wind.

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