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Simultaneous observations of cirrus clouds with a millimeter-wave Doppler radar and the MU radar

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1 Introduction

A cirrus cloud which consists of ice crystal is one of altostratus. It covers relatively wide area and persists for a long time, so it affects earth's radiation balance and may play an important role in earth's climate. However observations of cirrus clouds are not so easy because they appear in high altitude and are composed of ice crystals having various shapes and sizes. Therefore their detailed structure and radiative characteristics are still uncertain.

Recently new remote sensing techniques and *in situ* measurements permit to observe various dynamical and physical parameters for studies of cirrus clouds. A millimeter-wave radar is one of the new remote sensing techniques. Although conventional meteorological radars have no sensitivity for small ice crystals of cirrus clouds due to their relatively long wavelength (approximately 6 cm), a millimeter-wave radar has sensitivities for small crystals because of their short wavelength (approximately 8 mm). Therefore, it is one of the most effective instruments for cirrus cloud observations.

2 Observations

We conducted observations of cirrus clouds using a millimeter-wave Doppler radar as well as the MU (Middle and Upper atmosphere) radar to investigate physical structure of cirrus clouds at the Shigaraki MU Observatory in Shiga prefecture, Japan, in October, 2000, May, 2002, and, June, 2002. The millimeter-wave Doppler radar (hereafter referred to as the mm-wave radar) has a steerable antenna, so that we can observe three-dimensional structure of cirrus clouds (Hamazu et al., 2000, 2001). The MU radar, which is a kind of wind-profilers, can observe atmospheric motion especially including vertical velocity (Fukao et al., 1985a,b). Moreover, we launched radiosondes at the Observatory on October 5 and 6, 2000, May 18, 2002, and June 28, 2002. When we launched no radiosonde at the Observatory, we used radiosonde data launched at the Hamamatsu station of Japan Meteorological Agency in Shizuoka prefecture.

3 Vertical shear of horizontal winds

We compared echo power obtained by the mm-wave radar with the atmospheric motion obtained by the MU radar in six cases of October 3, 5, 6, and 7, 2000, May 18, 2002, and June 28, 2002. Time-height variations of echo power observed with the mm-wave radar during 0–24 LT on October 6, 2000 are shown in Figure 1, and time-height variations of the vertical shear of horizontal wind observed with the MU radar during the same period are shown in Figure 2. Similarly, time-height variations of echo power and of the vertical shear during 12–18 LT on October 5, 2000 are shown in Figures 3 and 4, respectively. On October 6, strong stratiform echoes appeared at 7–11 km altitude and the particularly strong vertical shear layer is situated at 7.5–8.5 km altitude. On October 5, weak stratiform echoes appeared at 7.5–9 km altitude and the strong vertical shear layer is situated at 7.8–8.5 km altitude. Vertical shear of horizontal velocities was strong above the cloud base in all cases. Vertical shear was particularly strong and the strong shear layer was thick on October 3, 6, and 7, 2000, and May 18, 2002. In the four cases, the clouds were thick and growth (over 1.5 km). On the other hand, in two other cases, vertical shear was not so large as the four cases, and the clouds were thin (under 1.5 km). Next, thickness of cirrus clouds to magnitude of vertical shear are shown in Figure 5. Generally, thickness is thicker as vertical shear is strong.

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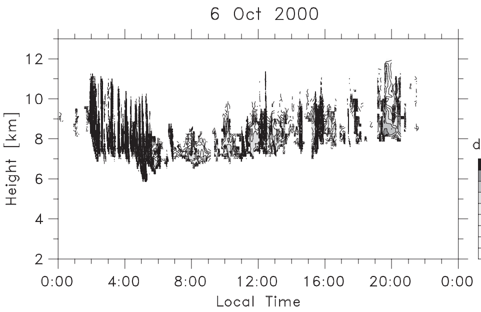

Figure 1: Time-height variations of echo power observed with the mm-wave radar during 0–24 LT on October 6, 2000.

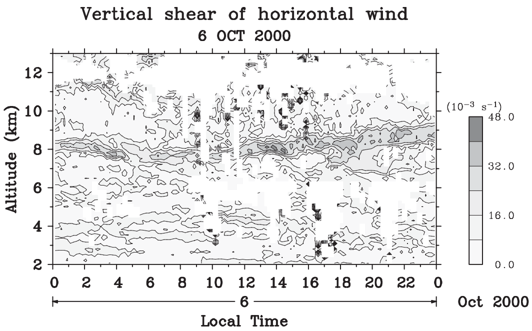

Figure 2: Time-height variations of the vertical shear of horizontal wind observed with the MU radar during 0–24 LT on October 6, 2000.

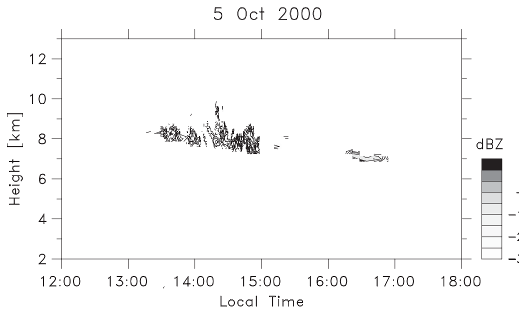

Figure 3: Same as Figure 1 except for 12–18 on October 5, 2000.

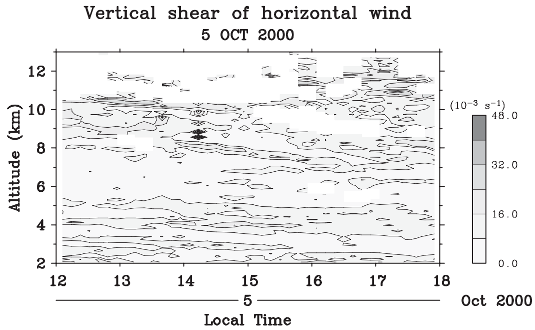

Figure 4: Same as Figure 2 except for 12–18 on October 5, 2000.

Therefore, we consider that the vertical shear of horizontal winds play an important role in the growth of cirrus clouds.

4 Atmospheric profiles

We compared atmospheric profiles obtained by radiosonde with echo power obtained by mm-wave radar. Height profiles of humidity, potential temperature, Brunt-Väisälä frequency (N^2) obtained with a radiosonde launched at the Shigaraki MU Observatory at 15:12 LT on October 6, 2000 and Richardson number calculated from vertical shear of horizontal winds obtained with the MU radar and N^2 are shown in Figure 6. Figure 7 shows the same as Figure 6 except for launched time of 15:52LT on October 5, 2000. The layer from cloud base to strong shear layer was stable in both cases. On October 6, Richardson number was under 0.25 inside the strong shear layer where equivalent potential temperature was almost constant. On the other hand, on October 5, atmosphere was stable inside clouds. The layer from cloud base to strong shear layer was stable in all cases. When vertical shear was enough strong to generate KHI, the strong shear layer was mixed layer where equivalent potential temperature was almost constant, and clouds were developed. Moreover, when the atmosphere above the mixed layer was conditionally unstable, clouds were more developed and very thick (over 2 km). On the other hand, when vertical shear was not enough strong to generate KHI, the strong shear layer was stable, and clouds were undeveloped.

5 Horizontal structure of cirrus clouds

Figure 8 shows the horizontal structure of cirrus clouds at 8 km altitude during 11:58–12:04

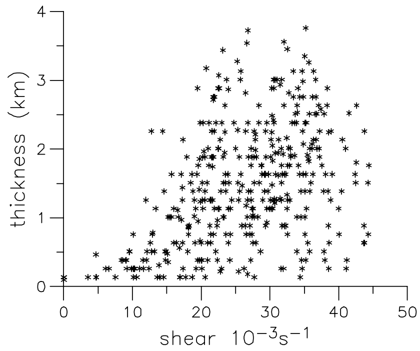

Figure 5: Thickness of cirrus clouds to magnitude of vertical shear

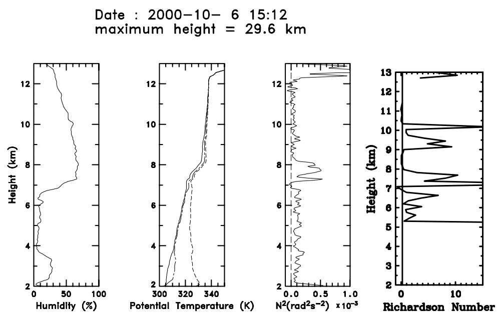

Figure 6: Height profiles of humidity, potential temperature, equivalent potential temperature, saturated equivalent potential temperature, Brunt-Väisälä frequency obtained with a radiosonde launched at 15:12 LT on October 6, 2000 and Richardson number. The vertical line in the right panel indicates 0.25 of Richardson number.

LT on October 6, which were deduced from echo power in CAPPI (Constant Altitude Plan Position Indicator) mode. Figure 9 shows the horizontal structure of clouds at 9.5km altitude during 15:52–15:57 on June 28, 2002. When cirrus clouds were developed, the horizontal structure of clouds were inhomogeneous and striped. On the other hand, when cirrus clouds were undeveloped, the horizontal structure was almost homogeneous.

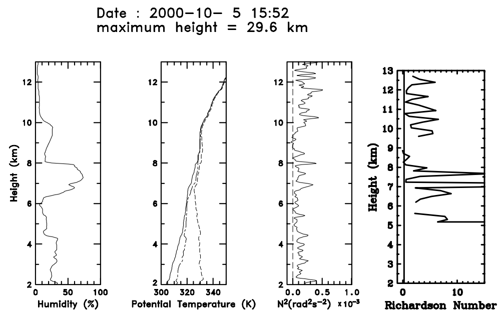

Figure 7: Same as Figure 6 except for launched at 15:52 on October 5, 2000

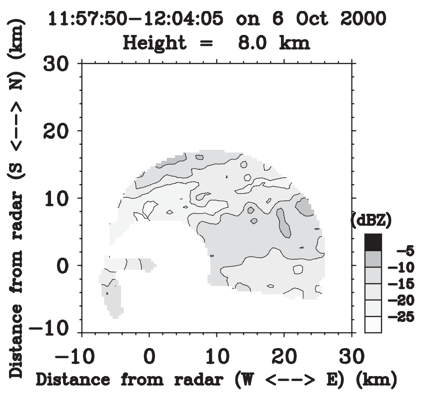

Figure 8: Horizontal structure of cirrus clouds at 8 km altitude during 11:58–12:04 LT on October 6, which were deduced from echo power in CAPPI mode.

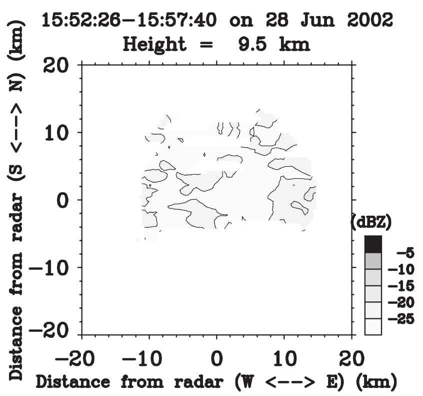

Figure 9: Same as Figure 8 except for 9.5km altitude during 15:52–15:57 on June 28, 2002

6 Summary

We conducted observations of cirrus clouds using a mm-wave Doppler radar as well as the MU radar at the Shigaraki MU Observatory in Shiga prefecture, Japan, in October, 2000, May, 2002, and, June, 2002, and we observed cirrus clouds on October 3, 5, 6, and 7, 2000, May 18, 2002, and June 28, 2002. When vertical shear was enough strong to generate KHI, clouds were developed. The horizontal structure of the clouds were inhomogeneous and striped. On the other hand, when vertical shear was not enough strong to generate KHI, clouds were undeveloped. The horizontal structure of the clouds were almost homogeneous. Therefore, we consider that KHI may play an important role in the growth of cirrus clouds.

References

Fukao, S., T. Sato, T. Tsuda, S. Kato, K. Wakasugi, and T. Makihira, 1985a: The MU radar with an active phased array system: 1. Antenna and power amplifiers, *Radio Sci.*, **20**, 1155–1168.

Fukao, S., T. Tsuda, T. Sato, S. Kato, K. Wakasugi, and T. Makihira, 1985b: The MU radar with an active phased array system: 2. Inhouse equipment, *Radio Sci.*, **20**, 1169–1176.

Hamazu, K., T. Wakayama, S. Watanabe, H. Hashiguchi, and S. Fukao, 2000: Development of a Ka-band Doppler radar for cloud and fog observations, *The transactions of the institute of electronics, information and communication engineers*, **J83-B**, No.4, 582–593 (in Japanese).

Hamazu, K., T. Wakayama, H. Hashiguchi, H. Tanaka, and S. Fukao, 2001: Preliminary field evaluation of a Ka-band Doppler radar for cloud and fog observation, *The transactions of the institute of electronics, information and communication engineers*, **J84-B**, No.3, 582–593 (in Japanese).