—研究論文—
Scientific Paper

A Study of Precipitation in the Coastal Area of Antarctica as Observed at Syowa Station Using a Vertical Pointing Radar

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南極沿岸域昭和基地での垂直レーダーを用いた降水量の研究

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要旨: 1987 年から始まった「南極域の気候変動に関する総合研究」計画の中で，雲降水の観測用として 1988 年に昭和基地に新しい垂直レーダーを設置した．このレーダー観測から 1988 年の降水量は，1989 年の降水量の約半分であることが見積もられた．1988 年 2 月 23 日から 1989 年 2 月 22 日までの 1 年間の降水量は，約 200 mm，1989 年 2 月 1 日から 1989 年 11 月 30 日までの降水量は約 390 mm であった．毎年の昭和基地の海氷上の最大積雪深の観測データ，昭和基地に近い大陸上の旅行ルート沿いの年積雪量のデータも 1988 年は非常に小さい値を示していた．1988，1989 年の降水量の季節変動データ，マラジョージナヤ基地のデータなどから判断すると，1988 年の昭和基地の降水量が非常に少なかった理由は，秋ではなく，冬と春の降水量が平年に比べて少なかったことにあると考えられる．

Abstract: A new vertical pointing radar was installed at Syowa Station in 1988 for observing precipitation and clouds in Antarctic Climate Research project started in 1987. The precipitation of 1988 was approximately half of that of 1989. The total precipitation was estimated at about 200 mm from 23 February 1988 to 22 February 1989 and about 390 mm from 1 February 1989 to 30 November 1989. The tendency of little snow accumulation in 1988 can be seen in the year-to-year data of the maximum snow depth measured on the sea ice near Syowa Station and in the annual data of snow accumulation around the coastal area of the continent near Syowa Station. The small precipitation of 1988 at Syowa Station seems to be mainly due to small precipitation in winter and spring of 1988, compared with that of 1989.

1. Introduction

It is very difficult to measure precipitation using snow gauge in the cold area, especially in Antarctica, because of strong wind and blowing and drifting snow. DOLGANOV (1986) compiled the precipitation data of the Antarctic some stations every month recently. However, he described the difficulty in measurement of precipitation, referring to an early work of RUSIN (1964). Moreover, the difficulty in precipitation measurement was explained by BROMWICH (1988). No measurement of precipitation

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using the snow gauge has been done at Syowa Station, but only measurement of accumulation of snowfall is continued using snow stakes on the sea ice.

Estimations of precipitation without accumulation based on the blowing and drifting snow is being hoped for by researchers. A vertical pointing radar was operated at Syowa Station for about 2 years from February 1988 to December 1989. The estimation of precipitation by radar is rarely affected by the blowing and drifting snow, although it is difficult to decide an accurate relationship between radar reflective factor and rainfall rate.

The installation of a meteorological radar in the Antarctic was already reported by WARBURTON (1977). However, it had been installed at Palmer Station in the Antarctic Peninsula and it had been probably the only meteorological radar in the Antarctic. The detail results of the radar observation, especially precipitation measurement by the radar could not be found except for WHINNERY *et al.* (1979) and WARBURTON *et al.* (1981). Annual precipitation of 1989 at Syowa Station was already reported from the data of our radar by KONISHI *et al.* (1992a). In this paper we reported the results of precipitation measurements of 1988 and 1989 by our radar. Thereafter, we discuss the characteristics of precipitation in 1988 and 1989 at Syowa Station using the data of two years and the previous data of some stations in Antarctica.

2. Instruments

A vertical pointing radar was installed in February 1988 at Syowa Station (69.0°S, 39.6°E) which is located on the island near the Antarctic continent, as shown in Fig. 1. Specifications of the radar are shown in Table 1. System diagram is shown in Fig. 2. The 128 radar reflectivity data at 50 m intervals along a vertical line from 50 m to 6.4 km were collected every 10 s and the all data were recorded on the 8″ floppy disks every 5 min.

For deciding a Z-R relation a high sensitivity snow gauge (FUJIYOSHI *et al.*, 1990) composed of an electric balance which was shielded with wooden wall for preventing

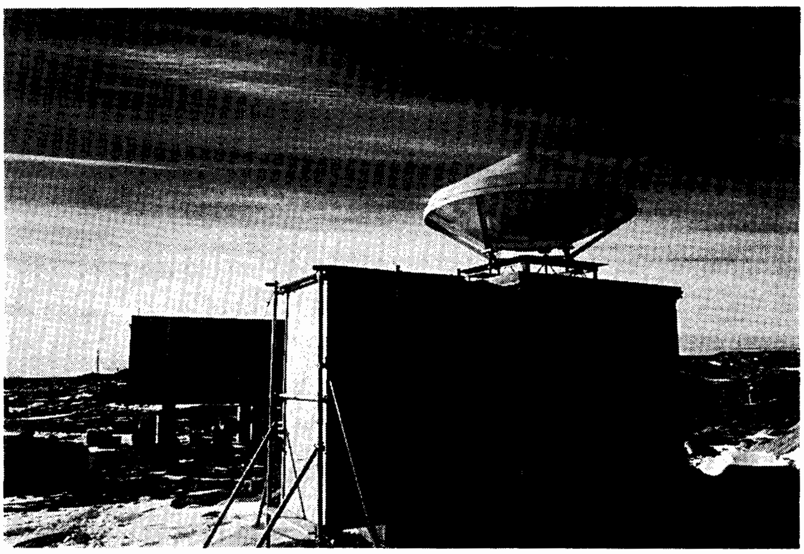

Fig. 1. Vertical pointing radar at Syowa Station.

Table 1. Specification of the vertical pointing radar.

Antenna	
Parabolic antenna with radome in 2.4 m diameter	
Antenna gain	44 dB
Beam width	1.0°
Transmitter and receiver	
Carrier frequency	9410 MHz
Peak power	40 kW
Pulse width	0.5 μs
Repetition frequency	750 Hz
Receiver sensitivity	−106 dBm
Log amp linearity	70 dB

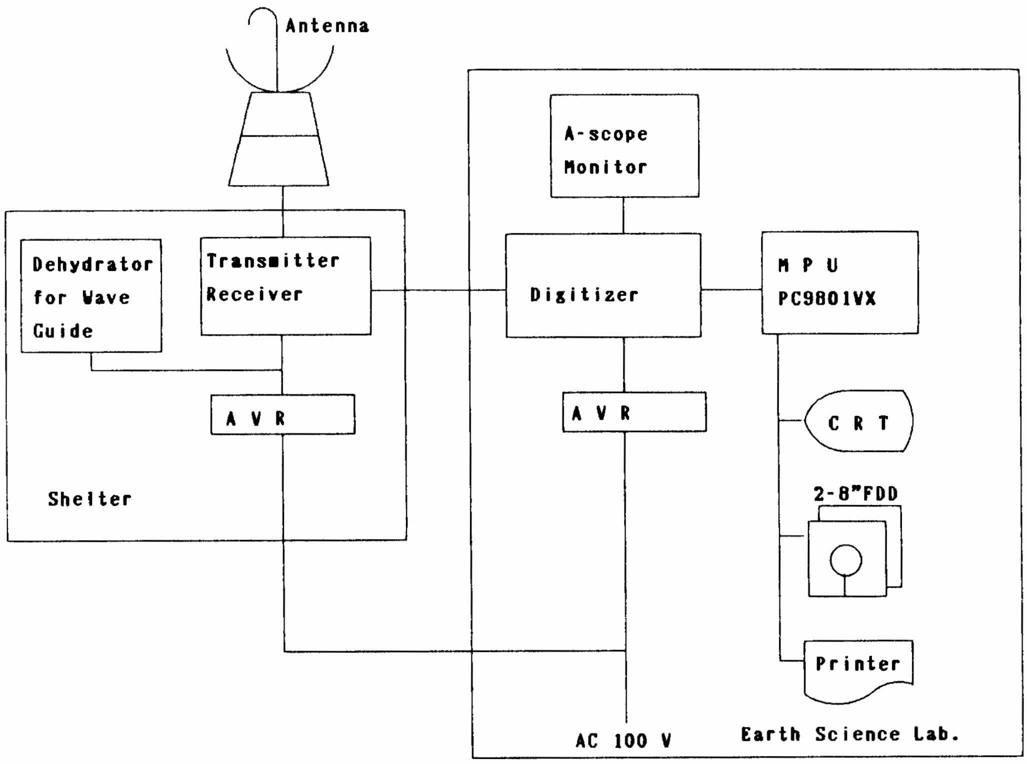

Fig. 2. System diagram of the vertical pointing radar.

drifting snow and strong wind was installed near the radar site in January 1989. The minimum detectable snowfall rate of the gauge was 0.062 mm/hr (KONISHI *et al.*, 1992b). Routine observations such as surface meteorological and rawinsonde observations were also operated at Syowa Station.

3. Equation for Calculating the Precipitation

KONISHI *et al.* (1992b) deduced *Z-R* relationships using the average of radar reflectivity factor *Z* (mm^6/mm^3) at the altitude of 400 m during 5 min and the precipitation rate (mm/hr) obtained from the total precipitations during 5 min by the high sensitivity snow gauge. Although they gave notice that the data for deciding a *Z-R* relation were selected in the case of weak wind conditions, they deduced three Z-R relationships from three different snow particle types. The first type was aggregate of bullets and crossed-plates, the second was aggregate of dendrite crystals and the last was heavy rimmed crystal. The *Z-R* relationships are shown in Fig. 3.

When the strong radar echo is observed, the value of precipitation at the time occupies the large rate of total precipitation, such as annual precipitation. KONISHI *et al.* (1992b) also showed the maximum precipitation rates of three different snow particle types in their observations. Three maximum radar reflectivity factors can be calculated from the maximum precipitation rates using three *Z-R* relationships shown in Fig. 3. On the other hand, WADA (1992) reported two echo types, which were convective and stratiform types. He explained that heavy rimmed crystals or graupels were often observed on the ground when the convective type echoes were found and that crystals of combination of bullets were often observed on the ground when the stratiform type echoes were found.

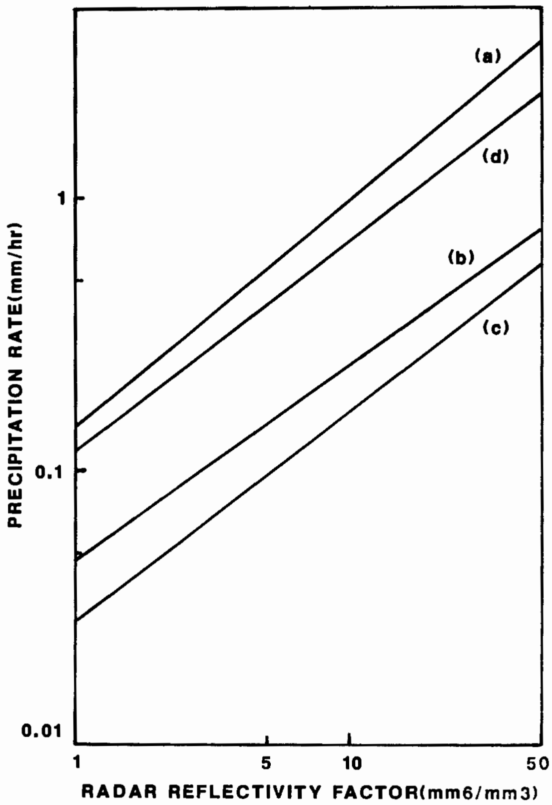

Fig. 3. Three Z-R relationships after KONISHI et al. (1992a). Relationship (a) for heavy rimmed crystals, relationship (b) for aggregates of bullets and crossed-plate, and relationship (c) for aggregates of dendrite crystals. Relationship (d) was applied for estimating monthly precipitations.

Relationships of (b) and (c) in Fig. 3 probably can be used for stratiform type echoes, and relationship of (a) in Fig. 3 can be used for convective type echoes. We selected the following *Z-R* relationship for estimating monthly observations as the averaged relationship of (b) and (a) shown in Fig. 3 in the section of the radar reflectivity factor *Z* between 2 and 20 which were related to the maximum radar reflectivity factors calculated by KONISHI *et al.* (1992b);

$$Z=16\cdot R^{1.3}\,. \qquad (1)$$

This relationship is also shown in Fig. 3. This equation was also used in KONISHI *et al.* (1992a).

4. Results and Discussion

Using eq. (1), monthly precipitations were estimated from March 1988 to November 1989 and are shown in Fig. 4. Three peaks of the monthly variation can be found in autumn, winter and spring in 1989, but the two peaks in winter and spring cannot be found in 1988. The maximum monthly precipitations of 1988 and 1989 were about 40 mm and 75 mm, respectively. Moreover, total precipitation was estimated at about 200 mm from 23 February 1988 to 22 February 1989, and about 390 mm from 1 February 1989 to 30 November 1989. The precipitation of 1988 was a nearly half of that of 1989.

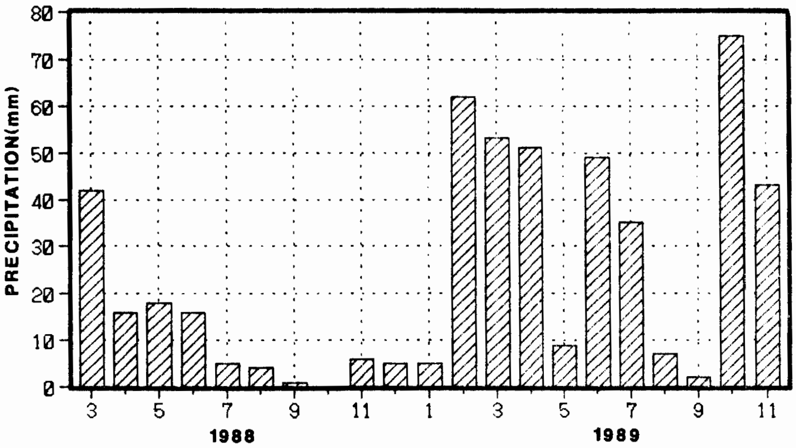

Fig. 4. Monthly precipitation from March 1988 to November 1989 at Syowa Station.

4.1. Annual precipitation

KIKUCHI *et al.* (1981) estimated the total precipitation of 1968 at Syowa Station using the data of glass slides obtained with the replica solution method. They said that the annual amount of precipitation was 430 mm. KOBAYASHI (1985) estimated the annual precipitation of 1980 at Mizuho Station, located about 270 km interior from Syowa Station, using the snowfall density and the fall velocity of blowing snow particles and obtained the value of about 140 mm of the annual amount of precipitation. TAKAHASHI (1985) also estimated the precipitation of 1982 at Mizuho Station using the data of the drift flux at 1 m height and the drift density at 30 m height. He estimated the annual precipitation at 230 mm and 260 mm. We calculated the precipitation of 1988 (from January to November) at Molodezhnaya Station, which is a coastal station, located at about 300 km east of Syowa Station, using monthly telex data from Molodezhnaya and obtained the value of 295 mm. DOLGANOV (1986) collected the annual precipitation data of Molodezhnaya for a long period of time (probably 10 years) and showed the average value of 350 mm. DOLGANOV (1986) also collected the annual precipitation data at Mowson, a coastal station, to be 527 mm.

Considering from the data of the annual precipitation at Molodezhnaya from 1964 to 1973, although the data were not the values amended but raw values measured by precipitation gauge, the difference between maximum and minimum values of annual precipitations for 10 years was about 450 mm (DOLGINA and PETROVA, 1977). This result suggests that the annual precipitation changes largely. The maximum snow depth of each year on the sea ice near Syowa Station was reported by MATSUBARA *et al.* (1990). Figure 5 shows the year-to-year change of maximum snow depth from 1969 to 1989 (the value of 1989 was added to MATSUBARA *et al.*, 1990). Moreover, the averaged annual snow accumulations along a traverse route "S" in the Antarctic continent near Syowa Station from 1979 to 1988 calculated with the data of JARE reports are shown in Fig. 6. The values of 1988 in Figs. 5 and 6 are abnormally small.

Since the amount of precipitable water at Syowa Station along the coast of Antarctica was relatively large compared with that at Mizuho Station which is an inland station (WADA, 1985), the annual precipitation at Syowa Station would be larger than that at Mizuho Station. Since Syowa, Molodezhnaya and Mowson Stations are in the coastal area, the annual precipitation of them would be approximately same.

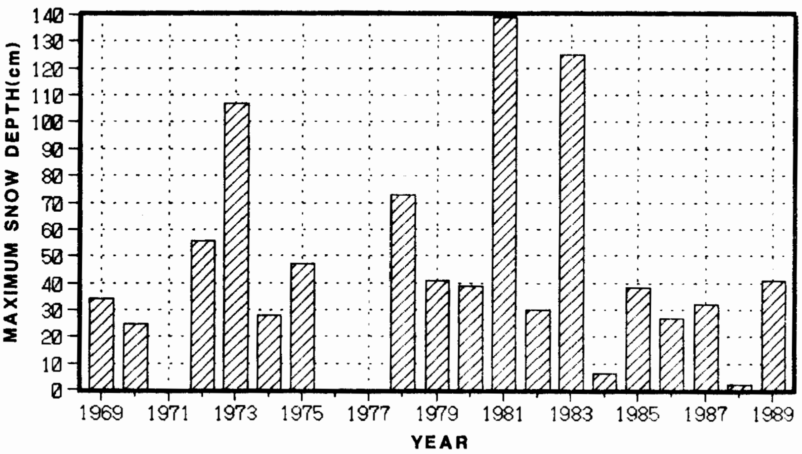

Fig. 5. Year-to-year changes of maximum snow depth. No observation in 1971, 1976 and 1977. Add the data of 1989 to MATSUBARA et al. (1990).

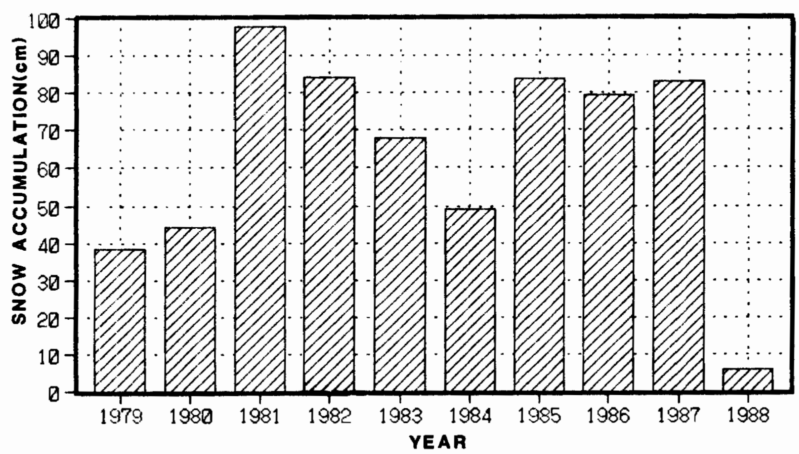

Fig. 6. Averaged annual snow accumulations along a traverse route in the Antarctic continent near Syowa Station. The averaged values of the data of 14 snow stakes along S-route (S17 to S30) are shown in this figure.

According to DOLGANOV (1986) annual precipitations at Molodezhnaya and Mowson Stations were 350 mm and 527 mm, respectively. The result that an annual precipitation of 1989, seemingly a normal annual precipitation, was about 400 mm at Syowa Station, would be reliable.

However, the annual precipitation varied widely, from the data of DOLGINA and PETROVA (1977) at Molodezhnaya Station. The maximum snow depth on the sea ice near Syowa Station of 1988 was much smaller than that of 1989 as shown in Fig. 5. Moreover, the annual snow accumulation of 1988 along a traverse route near Syowa Station, as shown in Fig. 6 was also smallest of all years since 1979. The result that an annual precipitation of 1988 was about 200 mm, approximately half of that of 1989, would be highly possible.

4.2. Monthly and seasonal variations of precipitation

The precipitation in winter showed the maximum in a seasonal variation at Mizuho Station from KOBAYASHI (1985) and TAKAHASHI (1985). The maximum values of monthly precipitation at Mizuho Station were about 20 mm by KOBAYASHI (1985) and was about 60 mm by TAKAHASHI (1985). Figure 7 shows the monthly variations at Molodezhnaya Station as based on the data from DOLGANOV (1986), which were the monthly average data of a long term, and the data by annual telex of 1988. The variation curve by DOLGANOV (1986) seems to be approximately flat from late autumn to early spring. However, the monthly precipitation amounts of 1988 changed greatly. The maximum value of monthly precipitation in 1988 at Molodezhnaya Station was about 80 mm.

On the other hand, the monthly variation of 1989 at Syowa Station as shown in Fig. 4 has three peaks, *i.e.* from February to April, from June to July and from October to November, though the variation curve is not flat from late autumn to early spring. Considering that the data of DOLGANOV (1986) are average data over a long period of time, three peaks of precipitation in 1989 could be understood. Namely, the months showing peak value of precipitation in the seasons would be different from year to

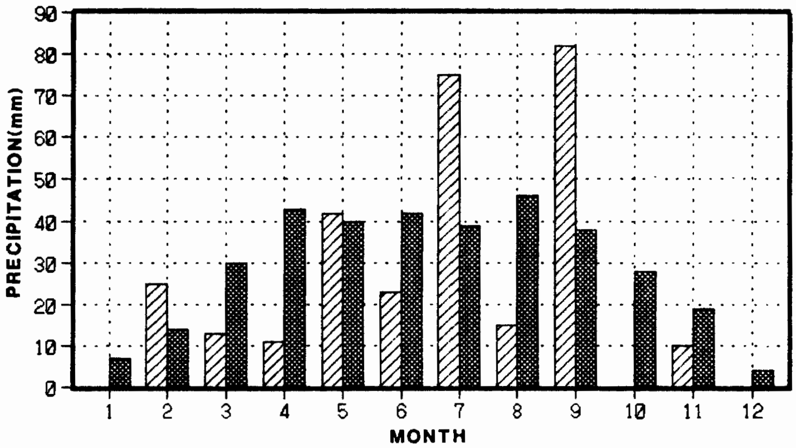

Fig. 7. Monthly precipitation at Molodezhnaya Station. Thin hatched bars show the average monthly precipitation for a long time from DOLGANOV (1986) and thick hatched bars show the monthly precipitation in 1988 by telex data.

year and if we took the average of them over several years, the variation curve of precipitation would become nearly flat from autumn to spring. The peaks of autumn and spring are probably related to the seasonal change of zonal wind (*e.g.* TALJAARD *et al.*, 1969). The peak of precipitation in winter also can be found at inland Mizuho Station. The peaks of Mizuho and Syowa Stations in winter seemed to be due to a same origin.

The precipitation of 1988 at Syowa Station in Fig. 4 is abnormally small. From the variation curve of precipitation at Syowa Station, small precipitation in winter and spring but autumn seems to account for small annual precipitation of 1988.

5. Summary

Monthly precipitations were estimated by the data of a vertical pointing radar. The total precipitation was estimated at about 200 mm from 23 February 1988 to 22 February 1989 and about 390 mm from 1 February 1989 to 30 November 1989. The precipitation of 1988 was approximately half of that 1989. Moreover, little snow accumulation of 1988 can be found in the data of year-to-year change of the maximum snow depth on the sea ice near Syowa Station and in the data of annual snow accumulation along the traverse route near Syowa Station. The characteristics of precipitation in the coastal area observed at Syowa Station are as follows: The bimodal variation of precipitation which seems to be caused by the seasonal change of zonal wind can be found and besides, a winter peak of precipitation which is also seen in the variation of precipitation at Mizuho Station, inland of Antarctica, can be found. The small precipitation of 1988 at Syowa Station would be ascribed to small precipitation in winter and spring but autumn of 1988.

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