Mem. Natl Inst. Polar Res., Spec. Issue, **51**, 239–246, 1996

Scientific Paper

VARIATION OF MONTHLY PRECIPITATION AND FREQUENCY OF RADAR ECHO EXISTENCE AT SOME ALTITUDES IN NY-ÅLESUND, SVALBARD, ARCTIC

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Abstract: Atmosphere, precipitation, snow cover and glaciers have been observed or surveyed around Ny-Ålesund (78°55′N, 11°56′E) in Svalbard, Arctic for studying the Arctic climate and environment by scientists from Norway, Germany, Japan and other countries. The authors, especially, have observed characteristics of clouds and precipitation using vertically pointing radar and a 37 GHz microwave radiometer. There were two minimum peaks of precipitation in a year from monthly data obtained from the observations between August 1992 and March 1995. One of them was in January, when the monthly mean cloud amount was relatively small, and the other was in June, when the monthly mean cloud amount was relatively large.

1. Introduction

Effects due to climate change are expected to be stronger in the polar regions than in middle and lower latitude regions (*e.g.*, SIMMONS and BENGTSSON, 1984; GATES *et al.*, 1992). For monitoring climate change, observations of clouds, especially cloud amount and precipitation, are important together with observation of temperature.

The Norwegian Polar Institute, which has cooperated with the Norwegian Meteorological Institute, has already observed basic meteorological elements such as temperature, precipitation etc. in Ny-Ålesund since 1969 (AUNE *et al.*, 1982; HANSSEN-BAUER *et al.*, 1990). They have used a rainfall/snowfall gauge, which collects rain/snow in a bucket; the total water content in the bucket is measured every 12 hours to estimate precipitation. Our group started meteorological radar observations in Ny-Ålesund, Svalbard, Arctic in 1992. Our radar has some problems for measurement of accurate snowfall/rainfall rate. One of them is that it is hard to obtain the reflectivity intensity near ground level of our radar because of a switching device for controlling the transmitting and receiving waves . Another is that the relationship between radar reflectivity factor and rainfall rate, so called the *Z-R* relation, is due to the size distribution of rainfall/snowfall particles (*e.g.*, BATTAN, 1973). It is difficult to observe many cases of the size distribution. Besides, minor gain drift due to the instability of the radar devices cannot be noticed, because our radar observations are unmanned. Snowfall measurement by the gauge also will be inaccurate if wind is strong because of drifting snow. It is difficult to measure the height of clouds by eye observation, although the cloud amount is observed usually three times a day (06, 12, 18 UTC).

Radar observation, nevertheless, is important. The radar detects rapidly changing phenomena, *i.e.* obtains nearly continuous data on the time scale of clouds variation. Radar observations also provide information on precipitable particles and the frequency of radar echo at many altitudes. This paper describes some results obtained from the observations, although they are being continued now. Seasonal variations of clouds and precipitation are discussed using our results and other data obtained from Norwegian observations.

2. Instruments, Observations and Calculations

We have observed clouds and precipitation in Ny-Ålesund since August 1992 using an X-band vertically pointing radar. The specifications of the radar were reported in WADA and KONISHI (1992). We have also operated a microwave radiometer for measuring column cloud liquid water in the atmosphere, an infrared radiation thermometer for measuring the cloud base height and an electric field meter for a few years. Recording of snow crystals by an instrument with a video camera and measurement of snowfall rate using an electric balance have been carried out only for short periods until now because of difficulty of maintenance. Temperature, humidity, wind speed and wind direction have been observed and recorded every 5 min there.

Estimating precipitation from the radar reflectivity, we measured the snowfall rate

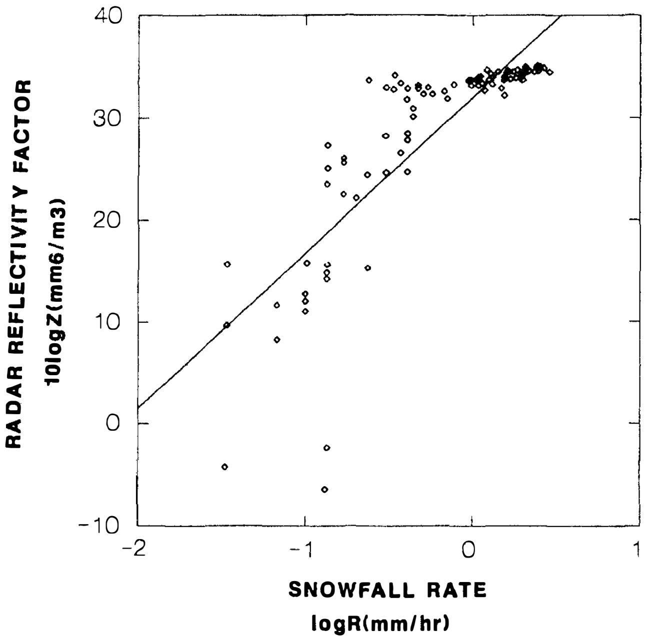

Fig. 1. The relationship between snowfall rate and radar reflectivity on March 5, 1995. The horizontal axis shows snowfall rates R (mm/hr) on a logarithmic scale. The vertical axis shows radar reflectivity factor Z (mm^6/m^3) at 350 m altitude. The dBZ is expressed by 10 × log10(Z). The solid line is an equation calculated by the least squares method.

using an electric balance (KONISHI *et al.*, 1988; FUJIYOSHI *et al.*, 1990) from February to March 1995. Figure 1 shows the relationship between the snowfall rate and the radar reflectivity factor on March 5, 1995. Monthly precipitation mentioned in this paper was estimated from an equation calculated by the least squares method in Fig. 1:

$$Z = 1585\ R^{1.52}, \tag{1}$$

where Z is the radar reflectivity factor in mm^6/m^3 at 350 m altitude and R is the snowfall rate in mm/hr. We regard the snowfall on March 5 as a typical snowfall in Ny-Ålesund because the temperature in the day was around freezing point and the amount of snowfall was normal.

The radar data were obtained every 10 s and the data for 5 min were averaged. Snowfall data were obtained every 4 or 5 s and the amount of snowfall for 5 min was calculated. Equation (1) was deduced from comparison of both data over 5 min.

If the 5-min mean radar reflectivity was stronger than 0 dBZ at any altitude, we determined that the radar echoes existed at the altitude during the 5 min. Based on this determination, the frequency of radar echo existence in each month was calculated. The existence of precipitation was determined by the intensities of radar reflectivity at 350 and 700 m altitudes. When the radar reflectivity at 350 m and 700 m was stronger than 9 dBZ and 0 dBZ, respectively, we determined that precipitation existed during the 5 min. The reason for using the values at two altitudes is the relatively large fluctuation of the noise signal of 350 m. Frequency of precipitation in each month was calculated from 350 m and 700 m radar reflectivity data mentioned above.

3. Results

Figure 2 shows the variation of monthly precipitation from August 1992 to March 1995 obtained from rainfall/snowfall gauge. The data were collected by the Norwegian

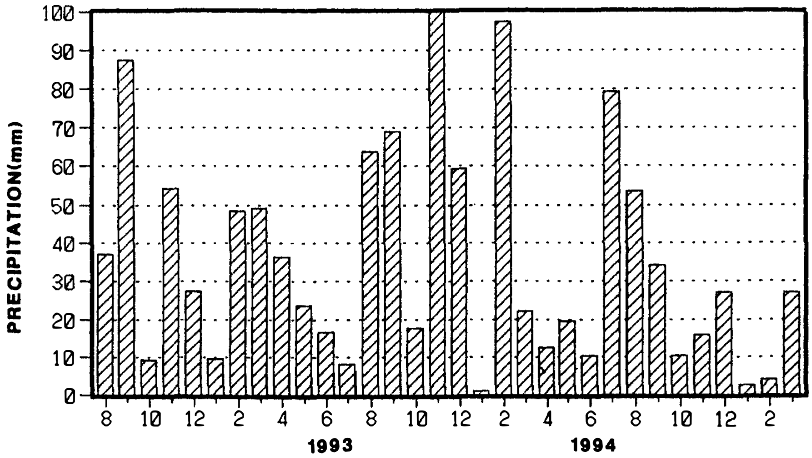

Fig. 2. Variation of monthly precipitation in the same period obtained from a rainfall/snowfall gauge. After AUNE *et al. (1982) and* HANSSEN-BAUER *et al. (1990).*

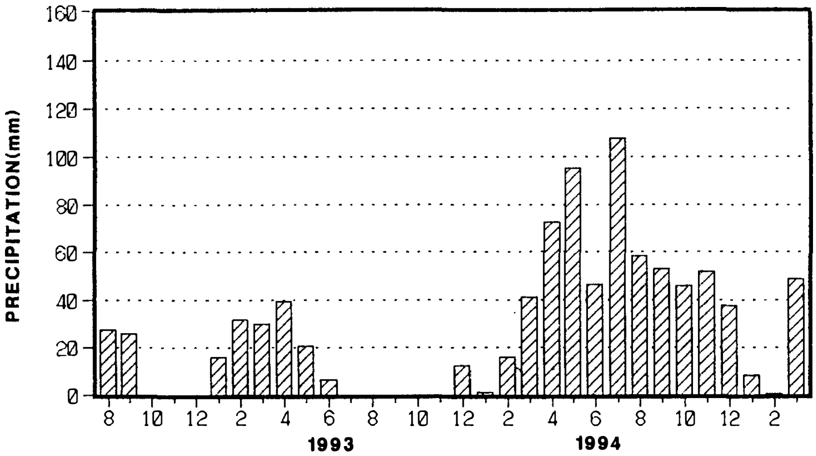

Fig. 3. Variation of monthly precipitation from August 1992 to March 1995 obtained from radar data using eq. (1). From October to December 1992 and from July to November 1993 there were no data.

Meteorological Institute. The monthly values have wide variations. Many minimum months are shown in Fig. 2. It is clear that there are up to three minima in a year, in January, June/July and October. Minima were October 1992, January, July and October 1993, January, June and October 1994 and January 1995.

Figure 3 shows the variation of monthly precipitation in the same period obtained from our radar data using eq. (1). From October to December 1992 and from July to November 1993 there were no data because of radar trouble. Between February and March 1994 the gain of a logarithmic amplifier in the radar receiver was changed. Each monthly precipitation before February 1994 was, therefore, fairly small compared with after March 1994. It is believed that the monthly variation can be discussed before February and after March, separately, although absolute values cannot be discussed. The monthly precipitation in January and June showed minima in 1994. February also showed a minimum in 1995. January and June were minima in 1993, although there were many months without data. A weak minimum was found in October 1994, but we have no data in October in other years. According to the data report (HANSSEN-BAUER *et al.*, 1990), two precipitation minima, in January and June, exist, but the minimum in October is not shown from averaging data from 1975 to 1989. Although the October minimum shown in Fig. 2 may show the characteristic phenomenon in 1992, 1993 and 1994, we do not discuss it in this paper as the radar data did not show the minimum in October.

The precipitation estimated from radar data is higher resolution than that from the rainfall/snowfall gauge data. The amount of precipitation in weak snowfall, therefore, can be estimated in the case of radar observation. On the contrary, the amount of precipitation in weak snowfall could not be counted in the case of the rainfall/snowfall gauge. The rainfall/snowfall gauge is often affected by drifting snow when wind is strong. Radar observation, however, does not depend on drifting snow because the used data are above 350 m altitude. It is considered that the variation of the monthly precipitation obtained from radar data has a smooth curve compared with that obtained from the rainfall/snow-

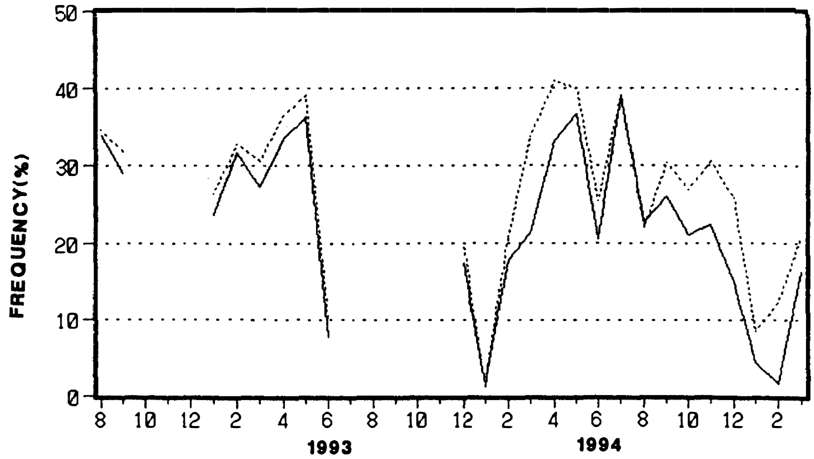

Fig. 4. Variations of monthly frequency of precipitation (solid line) and of radar echo existence at 1 km altitudes (dotted line) from August 1992 to March 1995. From October to December 1992 and from July to November 1993 there were no data.

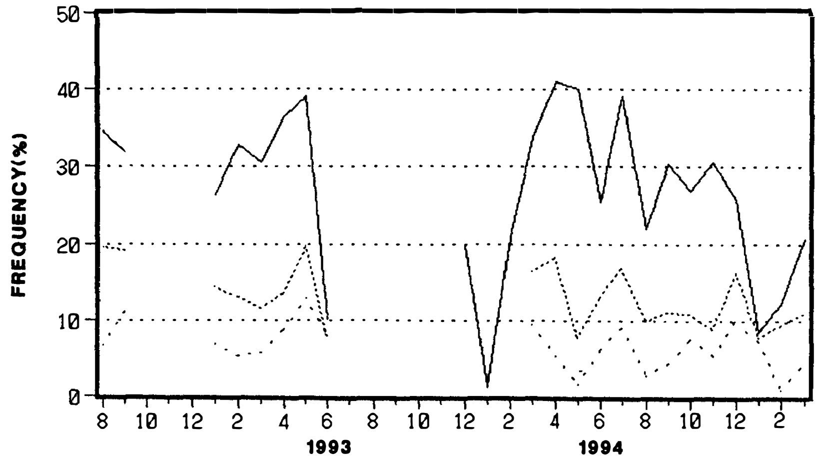

Fig. 5. Variations of monthly frequency of radar echo existence at 1 (solid line), 3 (fine dotted line) and 5 (coarse dotted line) km altitudes in the same period as in Fig. 4. From October to December 1992 and from July to November 1993 there were no data.

fall gauge for the two reasons mentioned above. We believe that the precipitation data obtained from the radar would be more useful than that obtained from the gauge for studying seasonal or annual variations, although there are still many months without data.

Figure 4 shows variations of monthly precipitation frequency and of radar echo existence at 1 km altitudes from August 1992 to March 1995. The monthly precipitation frequency and 1 km radar echo existence have a similar variation, and show minima in January or February and June. Figure 5 shows variations of monthly frequencies of radar echo existence at 1, 3 and 5 km altitudes at the same period as Fig. 4. The monthly frequencies of 3 and 5 km radar echo existence show no remarkable seasonal variation compared with of 1 km radar echo existence and vary between 10 and 20%, and a few

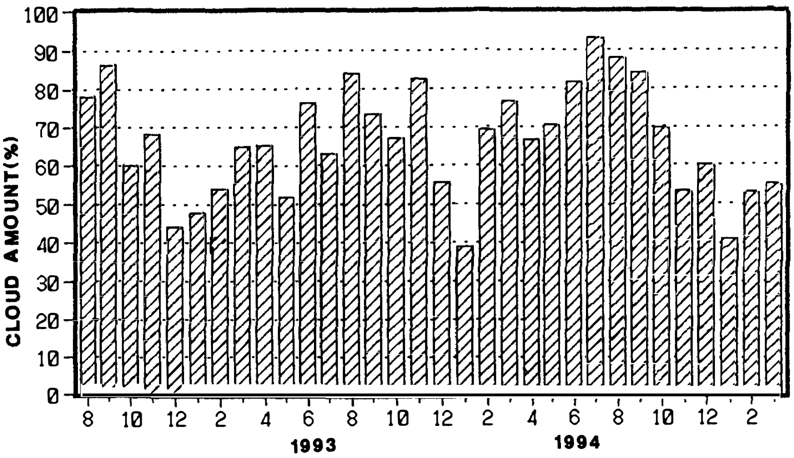

Fig. 6. Variation of monthly cloud amount in the same period as in Fig. 4. After AUNE et al. (1982) and HANSSEN-BAUER et al. (1990).

and 10%, respectively.

Figure 6 shows the variation of monthly mean cloud amount. The data were collected by the Norwegian Meteorological Institute. The minimum in January/December is remarkable but the minimum in June is not.

Radar echo cannot be detected if particles are not large compared with cloud particles in the atmosphere because of weak reflection from small particles in the clouds. High altitude clouds such as cirrus, cirrostratus and cirrocumulus, therefore, cannot be detected. The observation of cloud amount, of course, measures the percentage of cloud cover in the sky including high altitude clouds. The difference between the monthly variations shown in Figs. 4 and 6 is probably connected with the existence of clouds which cannot be detected by our radar.

4. Discussion

From the results mentioned in Section 3, the variation of monthly precipitation and monthly mean cloud amount had a minimum in or around January every year. This means that the period in which water vapor was not transported much from the sea to around Ny-Ålesund lasted for about a month on average in or around January. Although the variation of monthly mean cloud amount did not show a minimum in or around June, the variation of monthly frequencies of precipitation and of 1 km radar echo existence, and of monthly precipitation showed a minimum in and around June. This means that the period in which high clouds, which were not sensitive for X-band radar, and clouds which were not precipitating clouds, covered Ny-Ålesund for about a month on average in or around June.

WALLEN (1970) noted that there were two types of air circulation over western Europe. One was a zonal type air circulation, which all year around dominated western Europe, and the other was a meridional type air circulation, which was found when the normal westerly stream of air over Europe was stopped or "blocked" by a warm high pressure system. He also described a quasi-stationary high in the eastern North Atlantic between 5°W and 15°E that split the westerly upper air "jet" stream into two branches, one flowing northward around the "blocking" high and the other southward and into the Mediterranean.

The center of "blocking" highs is located in the North Atlantic between 5°W and 15°W. The blocking actions were observed more in December to May than in June to November (REX, 1950). Warm air from the south along the west side of the "blocking" highs comes into Svalbard, and relatively strong convection occurs around Svalbard because of a temperature difference between warm air from the south and cold air over sea ice. This means that the frequency of clouds contributing to precipitation is high in December to May, because, we think, their convective type clouds would have higher efficiency for precipitation than stratiform type clouds. This is considered a reason why the variation of monthly mean cloud amount, precipitation, frequency of precipitation and of 1 km radar echo existence showed similar variations in winter through spring. In contrast, the stratiform type clouds are formed more than convective type clouds in the vicinity of Svalbard in early summer as the frequency of the "blocking" situation is not high. This is considered a reason why the variation of monthly mean cloud amount was different from the variations of monthly precipitation and of frequency of precipitation and of 1 km radar echo existence in early summer. Namely, some clouds counted by the observation of cloud amount are not precipitating clouds in early summer.

5. Summary

Clouds and precipitation have been observed using vertically pointing radar in Ny-Ålesund since August 1992. From the observations during the period between August 1992 and March 1995, two remarkable minimum peaks in a year were found in the variation of monthly precipitation. One was January, in which the monthly mean cloud amount was relatively small; the other was June, in which the monthly mean cloud amount was relatively large. It is important for understanding the difference between January and June mentioned above to know what proportion of clouds are precipitating clouds in the period. It is considered that the difference of cloud types is related to the air circulation. Especially, the frequency of the 'blocking' high is important for forming precipitating clouds.

Acknowledgments

The authors would like to express their sincere thanks to the Norwegian Polar Research members in Ny-Ålesund and in Oslo for maintaining our instruments, and also to the Norwegian Meteorological Institute for sending their collected Ny-Ålesund data. Part of this work was supported financially by the Ministry of Education, Science, Sports and Culture through Grants-in-Aid No. 05044065 and No. 06640564.

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(Received February 6, 1996; Revised manuscript accepted May 16, 1996)