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Variation of snow, winter precipitation and winter air temperature during the last century at Nagaoka, Japan

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ABSTRACT. Reduced amounts of snow in the eight winters from 1986–87 to 1993–94 at Nagaoka, Japan, seem to be due to a winter air-temperature rise. The winter air temperature has shown a cyclic variation with a gradual increase in the past 100 years. The linear rate of the temperature rise in the past century was calculated as 1.35°C per 100 years. Both the maximum snow depth and winter precipitation showed an inversely positive correlation with winter mean air temperature. The square of the statistical correlation coefficient r^2 was calculated as 0.321 and 0.107, respectively. Statistically smoothed curves of the maximum snow depth and winter precipitation showed maximum values in 1940. Fluctuations in deviation of the maximum snow depth showed smaller values than in precipitation. The minimum winter mean air temperature obtained from a 10 year moving average curve was found in 1942, and the deviation from the climatic mean changed from negative to positive in 1949. The change in sign of the temperature deviation and the increase of the deviation may be attributable to global warming.

INTRODUCTION

Snow and ice are good indicators of the coldness of a given winter and area. Variations of snow and ice amounts and accumulation are a measure of local and global climate changes, including warming, and have been discussed from a global-change point of view (Meier, 1984; Houghton and others, 1990; Hall and others, 1992; Barry and others, 1993). In addition, apart from being a water resource, snow is important for the disastrous human consequences it can have.

The Hokuriku district of Honshu island, Japan, has suffered from heavy snowfalls ("Gosetsu" in Japanese) in the past such as 36, 38, 56, 59, 60 and 61 Gosetsu winters. In a Gosetsu winter, snow reaches maximum depths of more than 4 m on the ground in Tokamachi, a city of 50 000 people in Hokuriku district. In Nagaoka in the 1963 winter, the maximum snow depth on the ground reached 3.18 m. In these extreme winters, hundreds of people may be killed because of heavy snowfalls. For example, in the 1963 winter, 231 persons were killed (Takahashi and Nakamura, 1986). Therefore, residents of Hokuriku district, as well as of other snow-covered areas of Japan, need to have timely and accurate predictions of snowfall.

GEOGRAPHIC CHARACTER OF NAGAOKA

Nagaoka (37°25′ N, 138°53′ E, 97 m a.s.l.) is located in the northern part of the Hokuriku district of Honshu island. Storms, which produce heavy snowfalls, develop over the Sea of Japan, which is the water-vapor source for winter storm systems. In Hokuriku district, there is usually no wind when heavy snowfalls occur. The distance from the nearest coast to Nagaoka (20 km away) to mainland Asia is about 1000 km, the longest of any part of the Sea of Japan coast. In this space specific snow clouds develop over the Sea of Japan (Hozumi and Magono, 1984). Nagaoka is located close to 1000 m high mountains, in the northernmost area of the heavy-snowfall district. The winter air temperature is the coldest in the district, and snow as a percentage of the total precipitation in winter is the highest in the district. Therefore, Nagaoka offers one of the best locations to investigate snow amount as an indicator of global change. Figure 1 shows annual and daily changes of snow cover measured on the ground at Nagaoka between the winters of 1935–36 and 1993–94. (Data from two winters were added to those from the Nagaoka City Office (1992).) Each pattern corresponds to one winter season. The area under the curve indicates the amount of snowfall in a given winter. The maximum snow depth is also a measure of the amount of snow as seen in the figure. The maximum snow depth occurs around February except in the 1945 and 1984 winters. In this paper the maximum snow depth on the ground is used as an indicator of the snow amount.

DATA SOURCE

Data for the maximum snow depth analyzed in this paper were taken from the paper by Ikarashi and others (1992), in which the maximum snow-depth data in Nagaoka

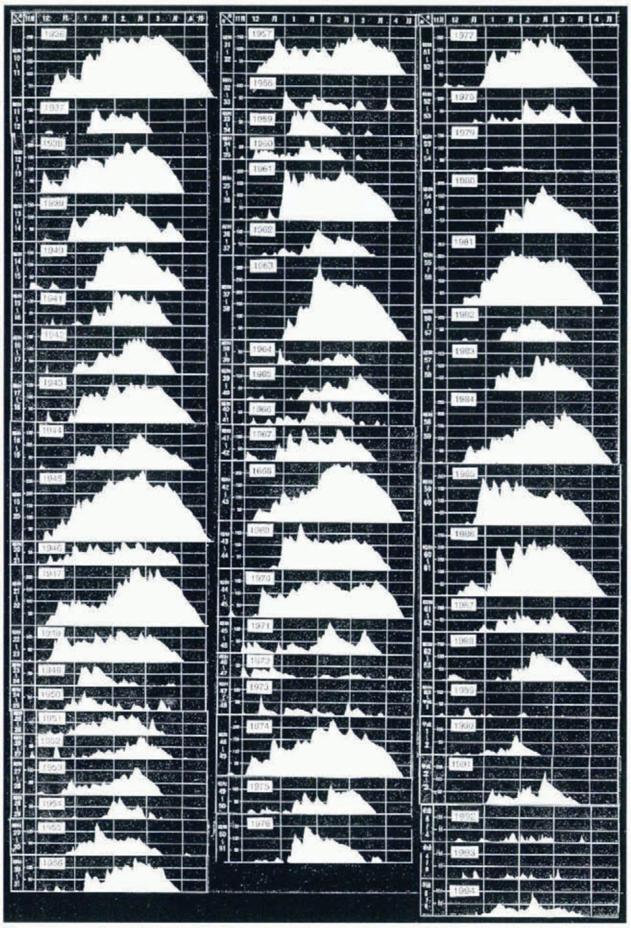

Fig. 1. Annual and daily changes of snow cover on the ground at Nagakoa, Hokuriku district (1935–36 to 1993–94 winters). Each pattern corresponds to one winter.

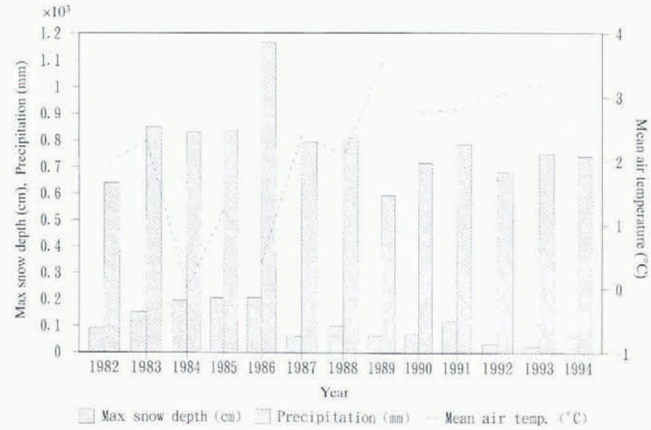

Fig. 2. Temporal variation in the maximum snow depth (cm), precipitation (mm) and mean air temperature (°C) of winters (December–February), 1982–94.

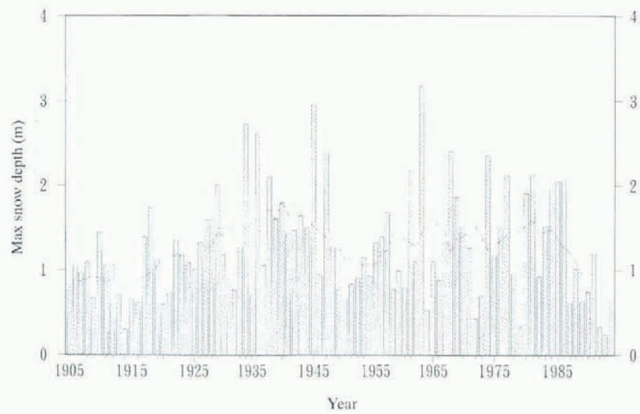

Fig. 3. Temporal variation of the maximum snow depth (m), 1905–94. A smooth curve is a filtered value designed to show decadal and longer time-scale trends more clearly.

from 1989 to 1992 were compiled. For the present study only the snow data set from 1905 to 1994 was analyzed due to the lack of air-temperature data from 1989 to 1904. Precipitation and air-temperature data for winters from December to February 1905–94 were collected at the Japanese Meteorological Agency in Niigata which has gathered and compiled them.

SNOW AND WINTER AIR TEMPERATURE, 1982–94

Figure 2 shows the observed maximum snow depth on the ground, precipitation in winter (December–February) and winter mean air temperature from 1982 to 1994. It shows that in the last 13 winters, precipitation including both rain and snow has not varied greatly, though the maximum snow depth has decreased drastically. This drastic decrease seems to be due to a winter mean air-temperature rise as shown in the figure.

SNOW AND WINTER AIR TEMPERATURE IN THE LAST CENTURY

Figure 3 shows annual variation of the maximum snow depth measured on the ground from 1905 to 1994. In the past century the maximum depth of 3.18 m was observed in the winter of 1963 (38 Gosetsu year) with a mean depth of 1.27 m and a standard deviation of 0.62 m. A smoothed curve shows a 10 year moving average and was constructed to show a decadal and longer time-scale trend more clearly. These 10 year averages were calculated from values in the four previous years, the present year and the five following years. Figure 4 shows annual

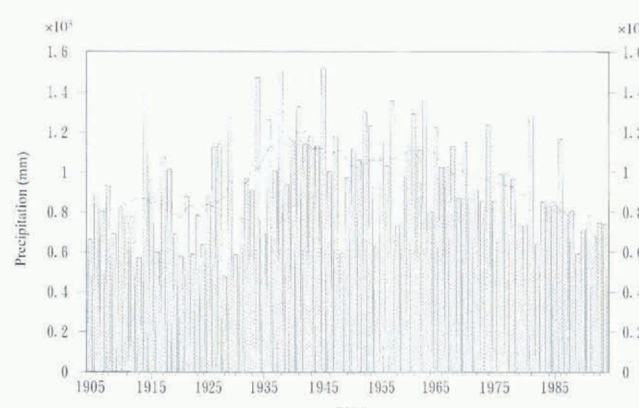

Fig. 4. Temporal variation of precipitation (mm) in winter (December–February), 1905–94. A smooth curve is a filtered value designed to show decadal and longer time-scale trends more clearly.

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variation of the winter (December–February) precipitation. The maximum value of 1516.5 mm was found in 1945, with a mean of 951.8 mm and standard variations of 243.5 mm. A smoothed curve is also developed for total winter precipitation. Figure 5 shows annual variation of the winter (December–February) mean air temperature. The maximum and minimum mean air temperatures were observed in 1949 and 1945, respectively.

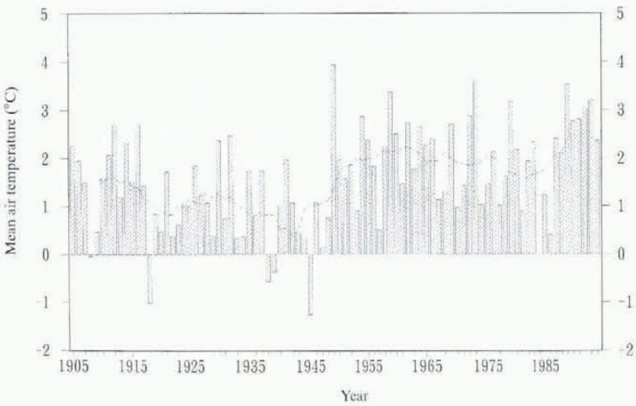

Fig. 5. Temporal variation of mean air temperature (°C) in winter (December–February), 1905–94. A smooth curve is a filtered value designed to show decadal and longer time-scale trends more clearly.

The annual winter mean air temperature in the past century was 1.6°C with a standard deviation of 1.0°C. A smooth curve is also developed for mean winter air temperature as for maximum snow depth and precipitation. The minimum of the smoothed curve of mean air temperature occurred in 1942 as shown in Figure 5. Figure 6 shows annual variation of the decadal filtered value (10 year moving average) of the winter mean air temperature with a regression line of the filtered values obtained from 1905 to 1994. The annual variation of 10 year moving average shows a periodic pattern similar to a pattern in the Northern Hemisphere produced by Houghton and others (1990). The equation of the regression line with a correlation coefficient r was expressed as:

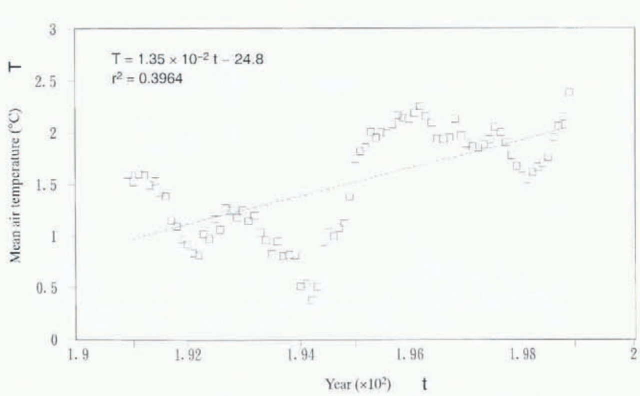

Fig. 6. Variation of mean air temperature (December–February) filtered with decades with a monotonic trend line.

$$T = 1.35 \times 10^{-2}t - 24.8$$
$$r^2 = 0.3964, \quad (1)$$

where T is winter mean air temperature in °C and t is years AD. The increase in winter mean air temperature of 1.35°C in the past century is rather large. An air-temperature rise calculated by using only two means (average data), of the decades 1905–14 and 1985–94, was obtained as 0.79°C.

Correlation between the maximum snow depth and the winter mean air temperature measured on the ground at Nagaoka is shown in Figure 7. The figure shows that there is an inverse negative correlation between the maximum snow depth and the mean air temperature. The regression equation with a correlation coefficient r was expressed as:

$$S = -0.335P + 1.80$$
$$r^2 = 0.3212, \quad (2)$$

where S is the maximum snow depth in cm, and T winter mean air temperature in °C.

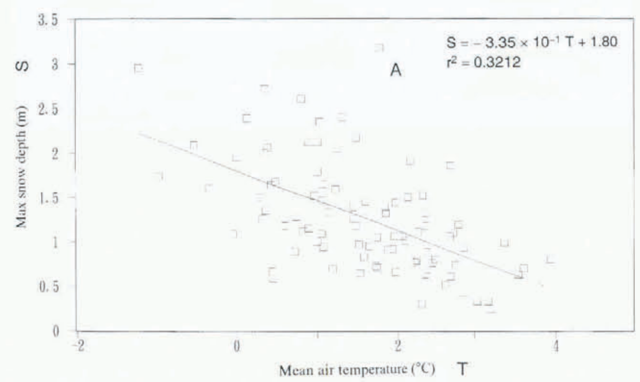

Fig. 7. Correlation between maximum snow depth (m) and mean air temperature (°C) in winter (December–February), 1905–94.

Figure 8 shows a positive correlation between the winter precipitation and the maximum snow depth. The

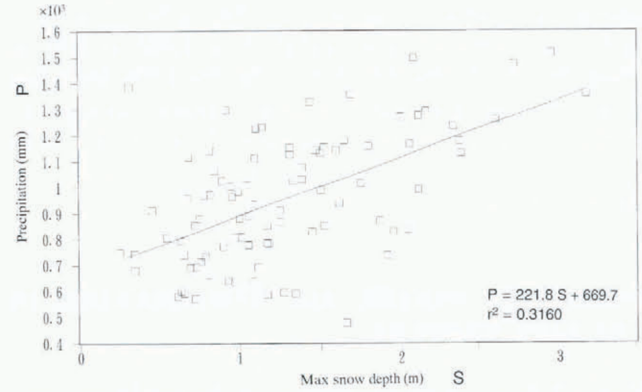

Fig. 8. Correlation between precipitation (mm) in winter (December–February) and maximum snow depth (m), 1905–94.

regression line with a correlation coefficient r was expressed as:

$$P = 221.8S + 669.7$$
$$r^2 = 0.3160, \qquad (3)$$

where P is the precipitation in mm and S is the maximum snow depth in cm. As shown in Figure 9, winter precipitation decreases as the winter mean air temperature increases. The regression line with a correlation coefficient r was obtained as:

$$P = -76.2T + 1071.2$$
$$r^2 = 0.1065, \qquad (4)$$

where P is precipitation in mm, and T mean air temperature in °C. Figure 10 shows annual variation of three decadally filtered values of maximum snow depth, winter mean air temperature and winter precipitation. As shown in Figure 10, both the maximum snow depth (1.8 m) and maximum winter precipitation (1200 mm) were found in 1940 with the minimum mean air temperature of 0.4°C occurring in 1942.

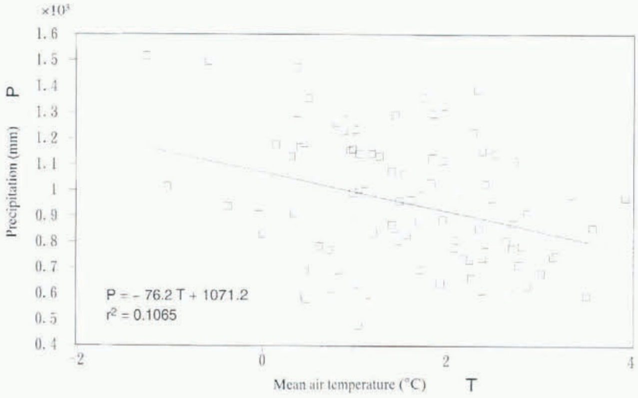

Fig. 9. Correlation between precipitation (mm) and mean air temperature (°C) in winter (December–February) 1905–94.

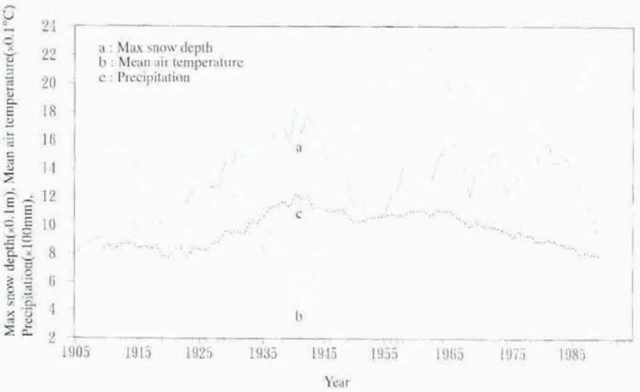

Fig. 10. Inverse positive correlation between maximum snow depth on the ground (a) and mean air temperature (b) in the last century. Also inverse positive correlation between precipitation (c) (December–February) and air temperature.

Temperature drops from 1909 to 1921 and from 1927 to 1942 are related to an increase in maximum snow depth. On the other hand, the temperature rise from 1942 to 1962 reflects a decrease in maximum snow depth and winter precipitation. Small peaks in the air-temperature record correspond to troughs in the maximum snow depth and precipitation from 1949 to 1989.

Figure 11 shows annual variation of the three values of maximum snow depth, winter precipitation and mean air temperature expressed in deviations from the 100 year climate means.

The maximum snow depth has a mean value of 1.27 m with a standard deviation of 0.62 m. The precipitation mean is 951.8 mm with a standard deviation of 243.5 mm. The annual mean air temperature was +1.6°C with a standard deviation of 1.0°C.

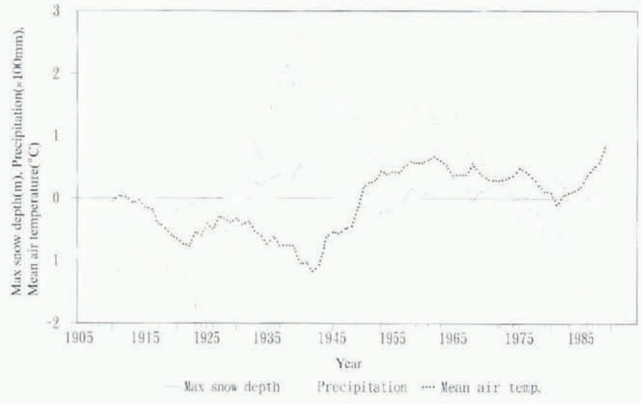

Fig. 11. Temporal variations of deviations from the climatic mean of maximum snow depth, precipitation and air temperature in the past century.

DISCUSSION AND CONCLUSIONS

Snow amounts in Nagaoka vary widely from winter to winter as shown in Figure 1. Decrease of the maximum snow depth on the ground in the recent 8 years in comparison with the previous three winters of heavy snowfalls (Gosetsu) in 1984 to 1986 at Nagaoka appears to be due to the hibernal rise in air temperature shown in Figure 2, despite the fact that precipitation in recent winters has decreased slightly. The maximum snow depth varies widely from year to year, but the peak of maximum snow depth, derived from a statistically smoothed curve covering the last 100 years, was found to have occurred in 1940. The statistically obtained maximum value of winter precipitation was also found in 1940. Two years later, the statistically obtained minimum air temperature was found (Figs 3–5). As shown in Figure 6, variation in the winter (December–February) mean temperature of the decadally filtered values showed a gradual cyclic increase in the past century with some peaks and troughs. This general trend is the same as reported by Houghton and others (1990), obtained between 20° and 50° N in the Northern Hemisphere. Some of the details in the present paper, i.e. a temperature rise since 1980, two troughs in 1981 and 1972, two peaks around 1960 and 1927, a trough around 1920 and a decrease from 1952 to 1940, correspond to the following specifics from Houghton and others (1990): a temperature rise since 1985, two troughs in 1977 and 1989, two peaks in 1960 and 1927, a trough in 1918 and a decrease from 1952 to 1940, although it should be noted that a minimum value found at Nagaoka around 1940 is not found in Houghton and others' report. In our work, the rate of linear increase in air temperature was calculated, using 90 years' data, as 1.35°C per century. The large rate of temperature rise might include the temperature rise due to city effect, because it was found in a smaller city, Shinjo, about 250 km from Nagaoka, that the rate of temperature rise observed was 0.58°C per 100 years (Nakamura and Abe, 1995). The rate seems to be rather large even if the negative albedo feed-back mechanism in the Northern Hemisphere (Manabe and Stouffer, 1980) was involved. Temperature rise in the Northern Hemisphere should also be discussed from the point of view of the effect of the latent heat released when snow crystals are formed in the atmosphere.

It was found that there was an inverse positive correlation between the winter precipitation or the maximum snow depth and the mean winter air temperature, i.e., if the air temperature decreased, the precipitation or maximum snow depth increased.

Statistically it is found that the maximum precipitation in the last 90 years occurred in 1940. The deviation of the precipitation from the 90 year climatic mean had positive values from 1932 to 1974, but negative values from 1905 to 1932 and from 1974 to 1994.

The statistical maximum value of the annual maximum snow depth was found in 1940, thus corresponding to the statistical maximum in precipitation. Fluctuation of the deviation of the maximum snow depth from the climatic mean did not show values as large as those associated with the fluctuation of the precipitation.

The minimum winter mean air temperature, observed in a 10 year moving average curve, was found in 1942, with the deviation about this mean changing from negative to positive in 1949. This change in sign may be due to global warming.

If the global temperature rise continues, it may be expected that snow in Nagaoka will decrease further, because there is an inverse positive correlation between maximum snow depth on the ground and winter air temperature in Nagaoka. But there must be a mechanism other than the usual coldness of the atmosphere when snow falls heavily. For example, as seen in Figure 7, a point marked as A corresponds to a heavy snowfall. The mechanism of heavy snowfall must be analyzed from a meterological point of view. In addition, it has been shown statistically that snow in Nagaoka is correlated with the "La Niña" (Ferguson and others, 1994). But not all heavy-snowfall years necessarily correspond to the La Niña years. Further investigation is necessary to predict the dependence of snowfall in Nagaoka on many factors, including the Asian monsoon.

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