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Variation in amount of Snow, Winter Precipitation and Winter Air Temperatures during the Last 60 Years in Shinjo, Japan

By

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Abstract

Lesser amounts of snow in the last 8 winters from 1986/87 to 1993/94 at Shinjo correlate with a winter air temperature rise. The temperature rise over the last 100 years was calculated to be 0.58 °C. The maximum snow depth shows statistically an inversely positive correlation with mean winter air temperatures. Winter precipitation shows statistically an inversely positive lesser correlation than maximum snow depth with winter air temperatures. A positive correlation between winter precipitation changes and winter air temperature changes from one winter to the following winter was observed in 29 winter changes during the last 60 years. In another 29 winter changes, a negative correlation between winter precipitation changes and winter air temperature changes was noted. One winter change showed no correlation. The maximums for snow depth and winter precipitation were found in 1936. The maximum winter precipitation, and the maximum snow depth and second most abundant precipitation, obtained from statistically smoothed curves, were determined to be in 1940 and 1963, respectively. Fluctuation in deviation normalized by a mean value for maximum snow depth showed larger values than that in precipitation. The minimum winter mean air temperature obtained from a statistically smoothed curve was found to be in 1940, and a rapid temperature rise has been observed since around 1980. The rise in temperature may be attributable to global warming.

Key words : Climate change, Global warming, Snow depth, Precipitation, Air temperature

1. Introduction

Snow is a good indicator of the coldness of a given winter and of a place. Variation in snow amounts and accumulation provides a measure of local and global climate changes, including warming. The role of snow should be emphasized and has been discussed from a global change point of view (Meier, 1984 ; Houghton *et al*., 1990 ; Hall *et al*., 1992 ; World Data Center, 1993). In addition, snow is both a water resource and also may have disastrous impacts on man. The Tohoku District of Honshu Island, Japan has suffered from heavy snowfalls in the past. In addition, the Hokuriku District of Japan, part of Honshu Island, also has heavy snowfalls. Maximum snow depth is usually greater in the Hokuriku District than in the Tohoku District. Residents in the areas of Japan prone to heavy snow wish to have a timely and accurate prediction of snowfall. Due to heavy winter snowfalls, some hundreds of people have been killed. For example in the 1963 winter (a notoriously heavy snowfall winter), which was named the 38-Gosetsu winter, 231 persons were killed (Takahashi and Nakamura, editors, 1992). In the heavy snowfall winter of 1980/81 (in Japanese, 56-Gosetsu), the amount of snow on the Japanese Islands was calculated to be 1.3×10^{14}kg. In comparison, the average yearly amount of snow, 7.9×10^{13}kg (Nakamura and Abe, 1993), is much less than that of 1.3×10^{14}kg in the 1980/81 winter.

In a paper (Nakamura and Shimizu, 1996) the variation in snow, winter precipitation, and winter air temperatures at Nagaoka, which is located in the

*Current affiliation : Faculty of Agriculture, Iwate University middle of the heaviest snowfall area, the Hokuriku District in Japan was discussed. The authors of the present paper intend to discuss the variation in snow, winter precipitation, and winter air temperatures at Shinjo which is located in the middle of the Tohoku District of Honshu Island, the main island of the Japanese Archipelago.

2. Geographic Character of Shinjo

Shinjo (38° 47'N, 140° 19'E, 127m msl) is located in the middle part of the Tohoku District of the Honshu Island of Japan. The clouds which produce the heavy snowfalls develop over the Sea of Japan. This sea is the water vapor source for the winter storm system. In the Hokuriku District, heavy snowfalls usually occur without any wind. In the Tohoku area, however, the situation is slightly different with a slight wind present. On Hokkaido Island we have snow storms with stronger winds than in the Hokuriku and Tohoku Districts. The distance from Shinjo's nearest coast (Shinjo is 40 km away from the coast) to the Asiatic Continent is about 900km. Over this distance peculiar snow clouds develop over the sea of Japan (Hozumi and Magono, 1984). Shinjo is surrounded by small mountains. Therefore, snowfall is affected by topography. As the mean winter air temperature at Shinjo is lower than freezing, the precipitation is in the form of snow every winter, but in Nagaoka where the mean winter air temperature is about 2°C, a portion of precipitation is in the form of rain, and the rest is snow. As such, Shinjo is one of the best places to investigate snow amount as an indicator of global change. Figure 1 shows annual and daily changes in snow cover measured on the ground at Shinjo from winters in 1934/35 to 1993/94. The pattern of each box corresponds to one winter season. Snow in Shinjo varies rather frequently year to year with very small amounts of snow in some winters. The area under the curve is indicative of the amount of snowfall in a winter. The maximum snow depth is also a measure of the amount of snow as seen in the figure. The maximum snow depth is usually measured in February. For this study the maximum snow depth on the ground is used as an indicator of the snow amount.

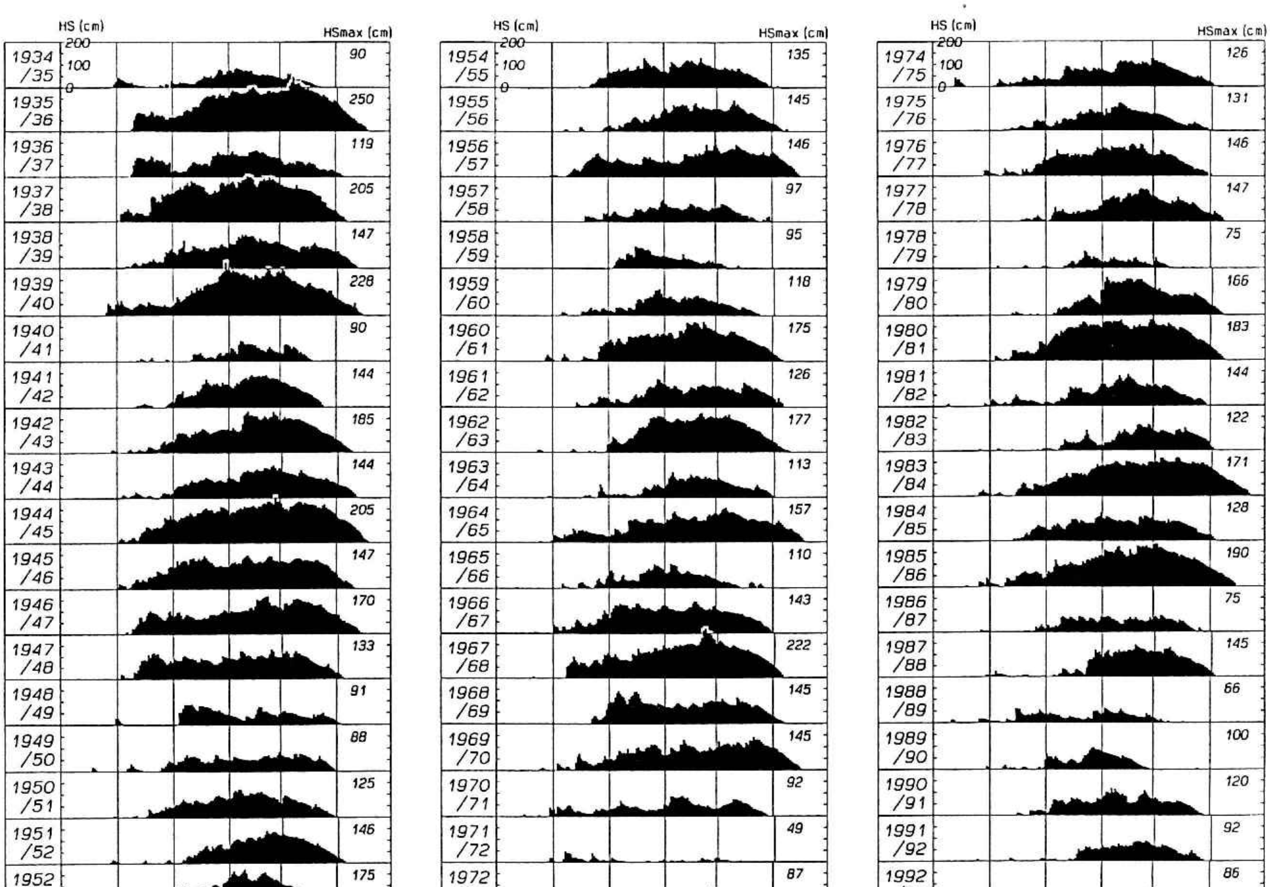

Fig. 1 Annual and daily changes in snow cover on the ground at Shinjo in the Tohoku district (1934/35 to 1993/94 winters). One pattern corresponds to one winter.

Table 1 Data sources for maximum snow depth.

Winters	Publications
1934/35～1951/52	Report of the Meteorological Observatory Shinjo for 1934−1952 (Shinjo Meteorological Observatory <Zaidan-hojin Yukiguni Kyokai, Shinjo Kisho Kansoku-sho>, 1953)
1952/53～1973/74	Monthly Meteorological Data Report of Yamagata (Yamagata Meteorological Observatory, JMA, 1953～1974)
1974/75～1983/84	Review of Research for Disaster Prevention, No.106 (Abe *et al.*, 1985)
1984/85～1993/94	Technical Notes of NIED, No.175 (Abe *et al.*, 1997)

Table 2 Data sources for air temperatures and precipitation.

Periods	Publications
Sep.1934～Dec.1952	Report of the Meteorological Observatory Shinjo for 1934−1952 (Shinjo Meteorological Observatory, 1953)
Jan.1953～Aug.1957	Monthly Meteorological Data Report of Yamagata (Yamagata Meteorological Observatory, JMA, 1953～1957)
Sep.1957～Dec.1984	Climate of the Tohoku Area (Sendai District Meteorological Observatory, JMA, 1986)
Jan.1985～Dec.1994	Monthly Meteorological Data Report of Yamagata (Yamagata Meteorological Observatory, JMA, 1985～1994)

3. Source of Data

Data for maximum snow depth analyzed in this paper was taken from three sources. Detailed data sources are shown in Table 1. The data recorded from 1934/35 to 1951/52 came from the Shinjo Meteorological Observatory, the data from 1952/53 to 1973/74 came from the Yamagata Meteorological Observatory, and the other data, from 1974/75 to 1993/94, came from the Shinjo Branch of Snow and Ice Studies, NIED. Precipitation and air temperature data from 1934/35 to 1993/94 were collected from publications of the Shinjo Meteorological Observatory and the Japanese Meteorological Agency (Table 2). The original data are shown in Appendixes 1 and 2.

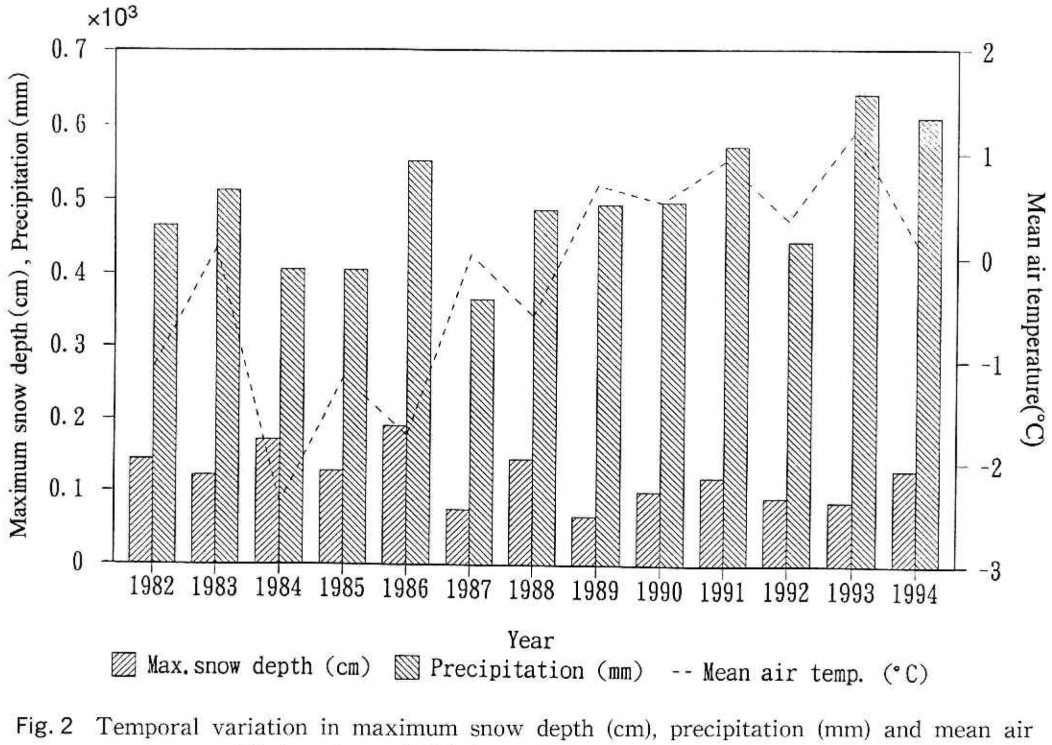

Fig. 2 Temporal variation in maximum snow depth (cm), precipitation (mm) and mean air temperature (°C) for winters (DJF) from 1982 to 1994.

4. Snow and Winter Air Temperatures over the 13 most Recent Years at Shinjo

Figure 2 shows the observed maximum snow depth on the ground, total precipitation in winter (December, January and February), and winter (December, January and February) mean air temperatures from 1982 to 1994 at Shinjo. The winter mean air temperatures are the mean values of the monthly mean air temperatures for December, January and February. This figure shows that in the last 13 winters, precipitation, including both rain and snow, has gradually increased, though the maximum snow depth has decreased. The decrease in the maximum snow depth seems to be due to a winter mean air temperature rise as shown in the figure.

5. Snow and Winter Air Temperatures over the Last 60 Years at Shinjo

Figure 3 shows annual variation in maximum snow depth measured on the ground from 1934/35 to 1993/94 at Shinjo. In the last 60 years the maximum snow depth of 2.50 m was observed in the winter of 1935/36, the mean depth being 1.36 m with standard deviation of 0.44 m. A smoothed curve shows a ten year moving average and was constructed to show trends by decade and on a longer time scale more clearly. These ten year averages were calculated from values in the previous four years, the present year and the succeeding five years. Figure 4 shows annual variation in winter (December, January and February) precipitation measured in Shinjo. The maximum value of 992.5 mm was measured in 1935/36, the mean being 615.8 mm with standard deviation of 147.5mm. A smooth curve was also developed for total precipitation in winter. The maximum winter precipitation obtained from this smooth curve is found to be in 1963. The second highest value is found in 1940. Figure 5 shows annual variation in winter (DJF) mean air temperatures measured at Shinjo. The maximum and minimum mean air temperatures were observed in 1949 and 1945, respectively. Maximum and minimum mean air temperatures were observed in the same years of 1949 and 1945, respectively at both Shinjo and Nagaoka (Nakamura and Shimizu, 1996). The annual winter mean air temperature over the last 60 years at Shinjo was −0.66°C with a standard deviation of 1.0°C. The same standard deviation was also observed in Nagaoka. In almost all of the last 60 years winter mean air temperatures in Shinjo were observed to be below zero degrees Celsius. However, in the most recent 6 years the temperatures were observed to be greater than zero Celsius. A smooth curve shown in Fig. 5 is also drawn as for maximum snow depth and winter precipitation. The minimum winter mean air temperature obtained from a statistically smoothed curve is found in 1940, and a rather rapid temperature rise is observed since around 1980. Figure 6 shows annual variation by decade of the filtered value of the winter

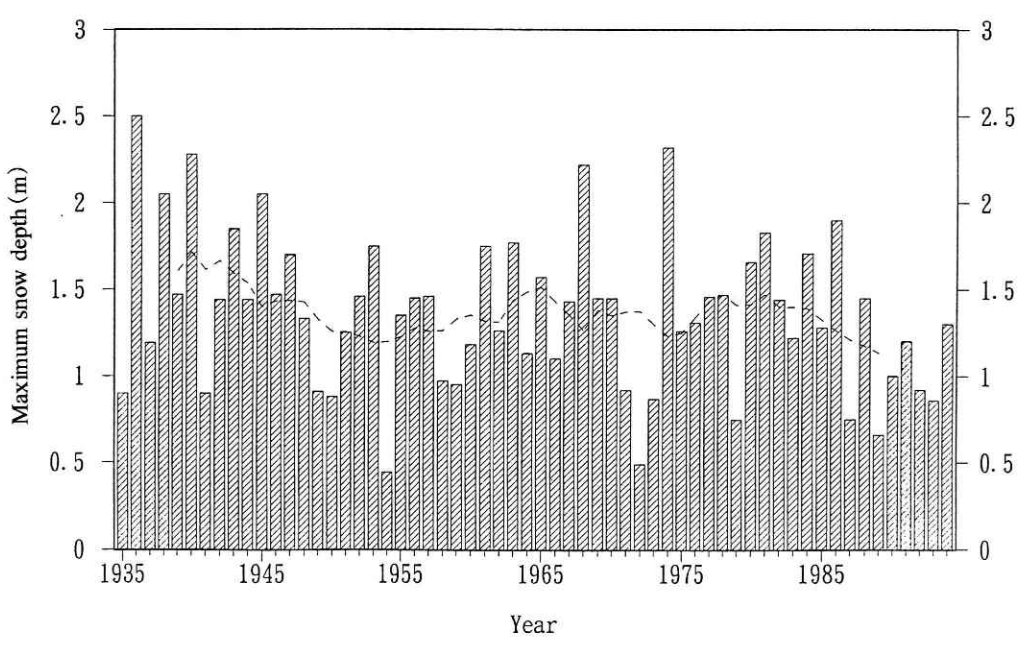

Fig. 3 Temporal variation in maximum snow depth (m) from 1935 to 1994 in Shinjo. The smooth curve is a filtered value designed to show trends calculated by decade and on a longer time scale more clearly.

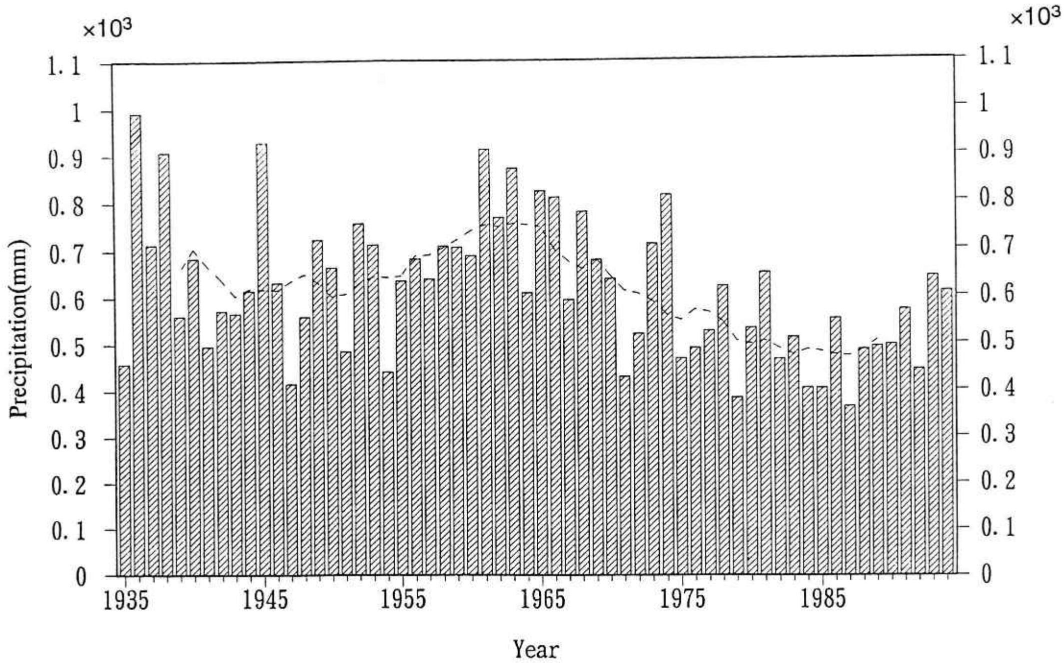

Fig. 4 Temporal variation in precipitation (mm) in winters (DJF) from 1935 to 1994 at Shinjo. The smooth curve is a filtered value designed to show trends calculated by decade and on a longer time scale more clearly.

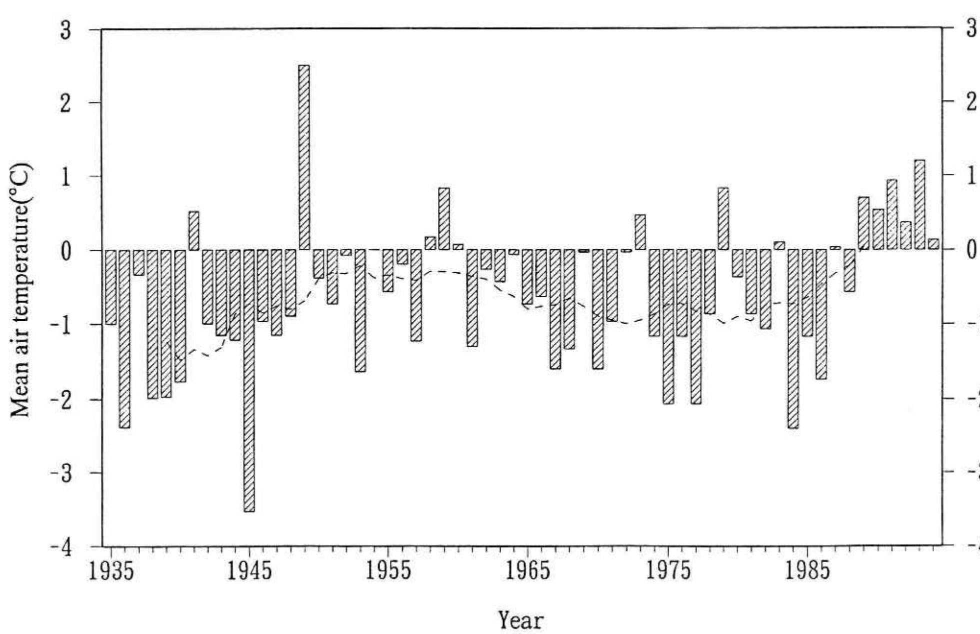

Fig. 5 Temporal variation in mean air temperature (°C) in winters (DJF) from 1935 to 1994 at Shinjo. The smooth curve is a filtered value designed to show trends calculated by decade and on a longer time scale more clearly.

mean air temperature with a regression line of the filtered values obtained in 1935 to 1994. The equation for the regression line with a correlation coefficient r was expressed as ;

$$T=5.77\times10^{-3}t-12.0, \quad (1)$$
$$r^2=0.0665,$$

where T is winter mean air temperature in °C and t year (AD). The equation shows that the temperature rise over the last 60 years was 0.35°C. If we extend this rate to cover the last century, the increase is 0.58°C.

Correlation between maximum snow depth and winter mean air temperature measured on the ground at Shinjo is shown in Figure 7. The figure shows that there is an inversely positive correlation between the

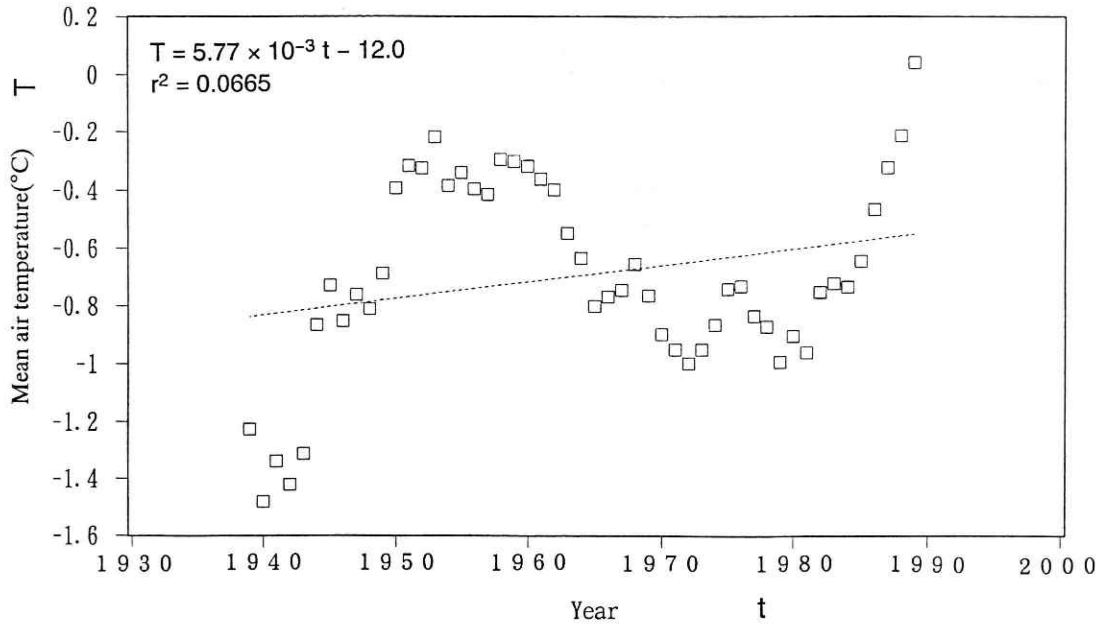

Fig. 6 Variation by decade in mean air temperature (DJF) filtered value in Shinjo with a monotonic trend line.

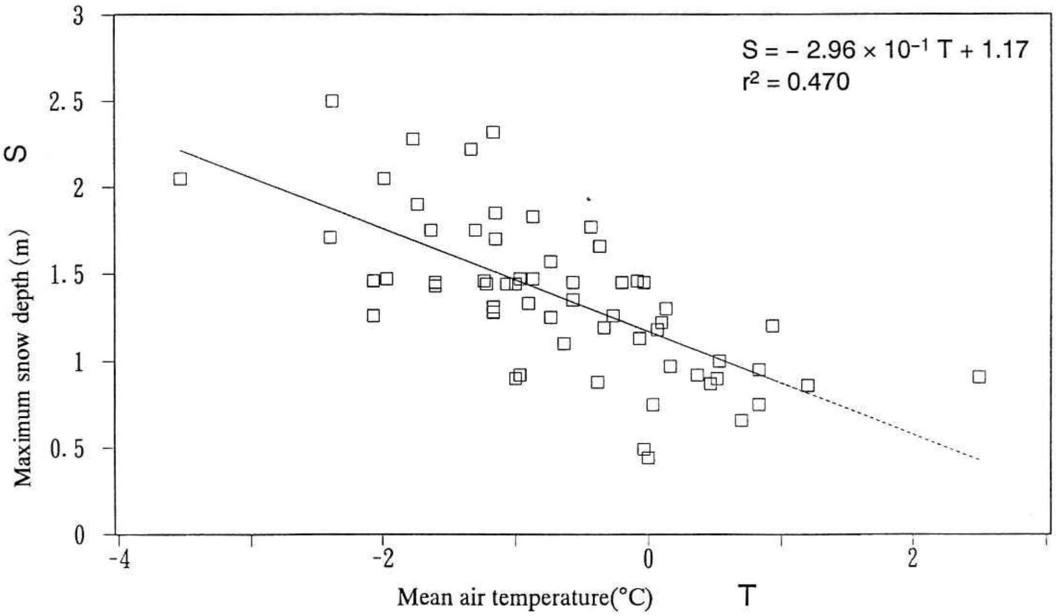

Fig. 7 Correlation between maximum snow depth (m) and mean air temperature (°C) in winters (DJF) from 1935 to 1994 at Shinjo.

maximum snow depth and the mean air temperature. The regression equation with the correlation coefficient r was expressed as ;

$$S=-2.96\times10^{-1}T+1.17, \quad r^2=0.470, \tag{2}$$

where S is maximum snow depth in cm and T winter mean air temperature in °C. Figure 8 shows a positive correlation between winter precipitation and maximum snow depth. The regression line with the correlation coefficient r was expressed as ;

$$P=174.5S+378.0, \quad r^2=0.275, \tag{3}$$

where P is precipitation in mm and S 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 the correlation coefficient r was obtained as ;

$$P=-26.0T+598.8, \quad r^2=0.0328, \tag{4}$$

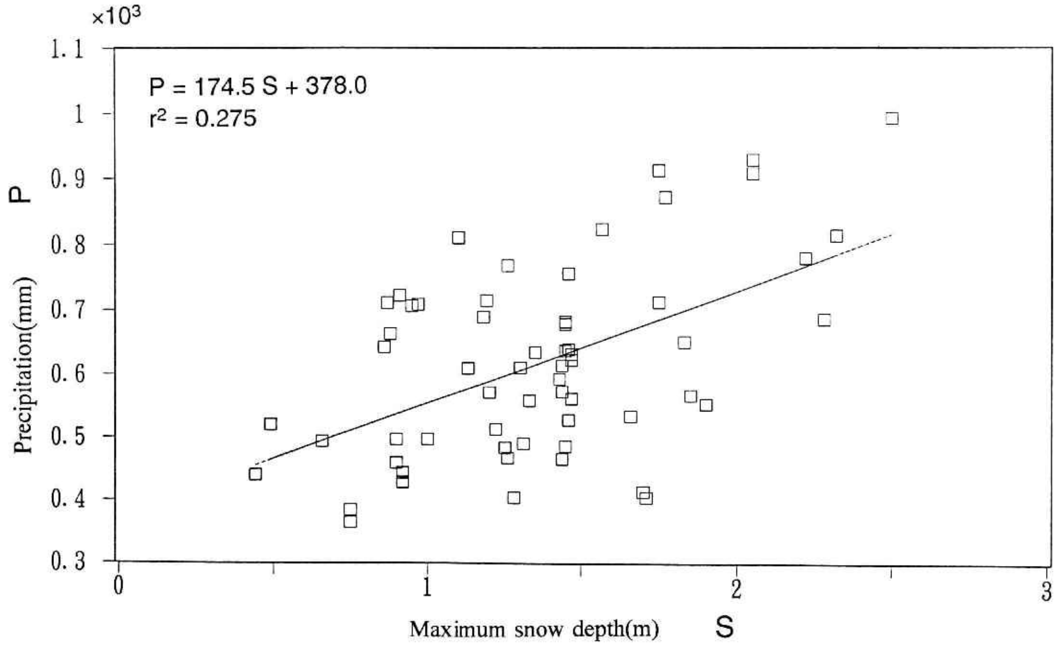

Fig. 8 Correlation between precipitation (mm) in winters (DJF) and maximum snow depth (m) from 1935 to 1994 at Shinjo.

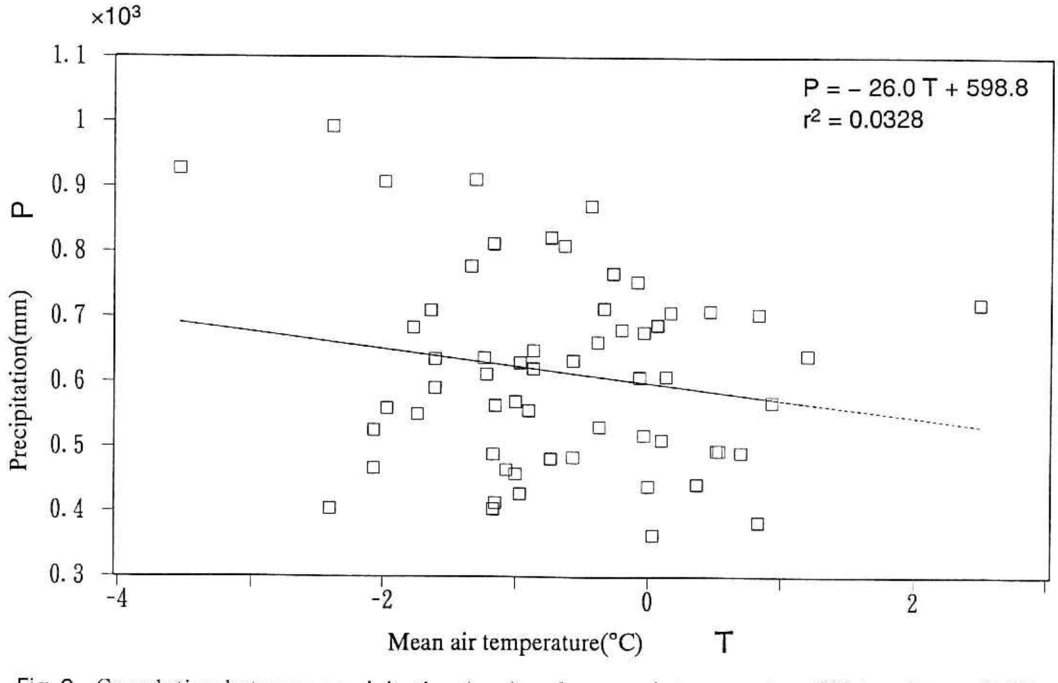

Fig. 9 Correlation between precipitation (mm) and mean air temperature (°C) in winters (DJF) from 1935 to 1994 at Shinjo.

where P is precipitation in mm and T mean air temperature in °C. The square of the correlation coefficient, r^2 is very small. This shows that the inversely positive correlation between winter precipitation and winter air temperature is small. In Fig. 9 each plot was obtained from total winter (DJF) precipitation and winter mean air temperature for each winter of the last 60 years. All the data is based on data for each winter shown in Figs. 4 and 5. Table 3 shows the correlation between winter precipitation change and winter air temperature change from one winter to the next obtained by Figs. 4 and 5. There are two types of correlations between the values: (1) Inversely positive correlation; If winter air temperature for the present winter increased (decreased) in comparison with the previous winter, winter precipitation decreased (increased) in comparison with the previous winter. That is, if a winter became warmer

Table 3 Two types of correlation between winter precipitation change and winter mean air temperature change from one winter to the next.

	Correlation between precipitation and air temperature		
Two Types	Inversely positive correlation (The higher the temperature, the less the precipitation)	Positive correlation (The higher the temperature, the more the precipitation)	No remarkable correlation
Years	'35-'39, '40-'42, '43-'46, '53-'55, '58-'59, '60-'66, '68-'69, '70-'71, '73-'74, '76-'77, '78-'81, '85-'88, '89-'90	'39-'40, '42-'43, '46-'53, '55-'58, '59-'60, '66-'68, '69-'70, '71-'73, '74-'76, '77-'78, '81-'84, '88-'89, '90-'94	'84-'85
No. of Years	29	29	1
%	50%	50%	0%

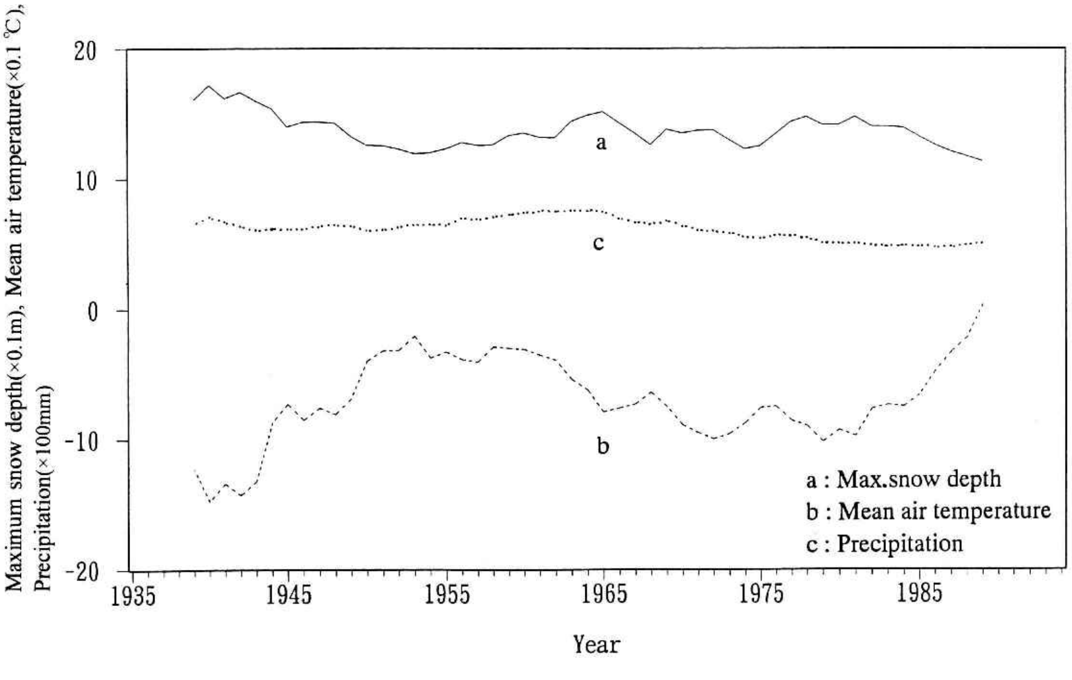

Fig. 10 Inverted positive correlation between maximum snow depth on the ground (a) and mean air temperatures (b) in Shinjo over the last 60 years. Also a slight inverted positive correlation between precipitation (c) (DJF) and air temperature is seen.

(colder) than the previous winter, then precipitation was less (larger). (2) Positive correlation ; If the winter air temperature increased (decreased), winter precipitation increased (decreased). That is, if a winter became warmer (colder) than the previous winter, precipitation increased (decreased). The number of the year, i.e., the number of winter changes, was the same in each correlation, namely, the percentage was the same.

Figure 10 shows annual variation in three filtered values calculated by decade for maximum snow depth, winter mean air temperature and total winter

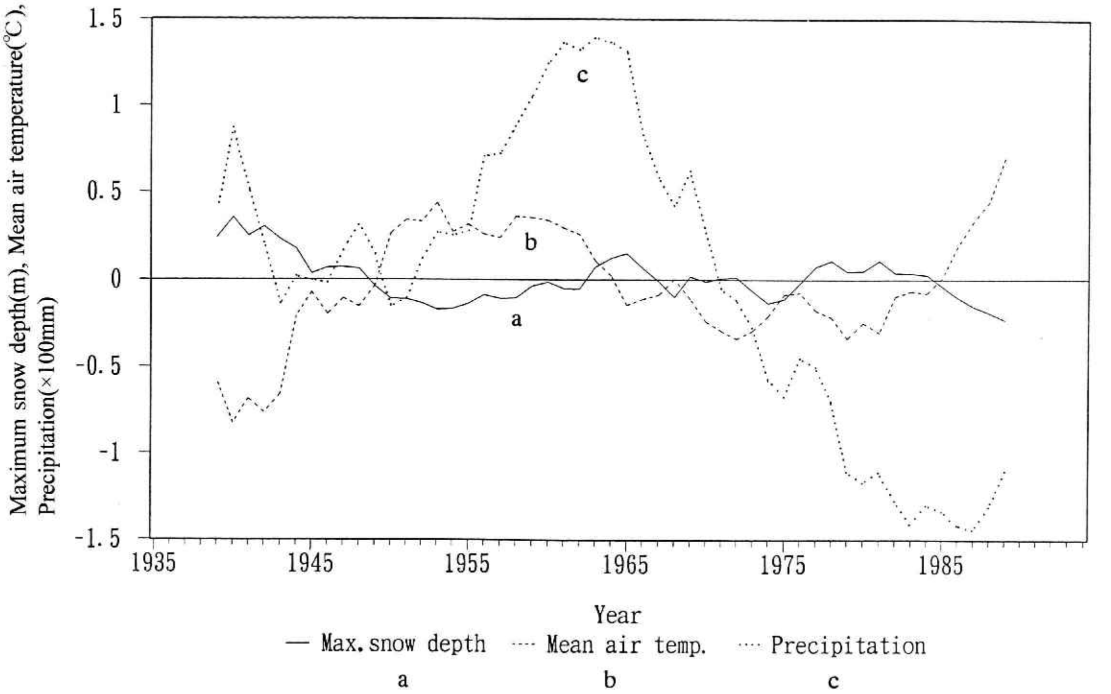

Fig. 11 Temporal variations in deviation of the filtered values from the climatic mean for maximum snow depth, precipitation and mean air temperature over the last 60 years at Shinjo.

precipitation in Shinjo. As shown in Fig. 10 both values of maximum snow depth and of winter precipitation were found to be in 1940 which also had the minimum mean air temperature. Magnitudes of temperature correspond well with magnitudes of maximum snow depth in opposite direction. In other words, the lower the air temperatures, the larger the maximum snow depth. Also temperature changes correspond fairly well with changes in maximum snow depth in an inverse direction. For example, increase in temperature from 1940 to 1953 corresponds to a decrease in maximum snow depth. Also increase in air temperature from 1979 to the present is reflected in a decrease in maximum snow depth. Also it is shown in Fig. 10 that small peaks for air temperature correspond to troughs for maximum snow depth and vice versa.

Figure 11 shows annual variations for the filtered three values of maximum snow depth, winter precipitation and mean air temperature expressed in deviations from the 60 year's climatic mean.

The maximum snow depth has a mean value of 1.36 m with a standard deviation of 0.44 m. Precipitation mean is 615.8 mm with a standard deviation of 147.5 mm. These two standard deviations normalized by the mean values of maximum snow depth and precipitation are 0.32 (0.44 m/1.36 m) and 0.24 (147.5 mm/615.8 mm), respectively. Annual mean air temperatures over the last 60 years were −0.66℃ with a standard deviation of 1.0℃.

When we look at Fig. 11 carefully, the figure shows that changes in winter air temperatures correspond inversely to changes in maximum snow depth, i.e., an increase or decrease in temperature corresponds to a decrease or increase in maximum snow depth, respectively. Conversely, an increase or decrease in temperature does not necessarily correspond to a decrease or increase in total precipitation. In some years an increase (decrease) in air temperature corresponds to an increase (decrease) in precipitation.

6. Discussion and Conclusions

Decrease in maximum snow depth on the ground in the most recent 8 years in comparison with the previous seven winters at Shinjo seemed to be due to the winter air temperature rise as shown in Figs. 1 and 2, despite the fact that precipitation in recent winters has increased slightly. As shown in Fig. 6 variation in the winter (DJF) mean temperature of the filtered values calculated by decade showed a periodic pattern with a gradual increase over the last 60 years with some peaks and troughs. This general trend is the same as reported by Houghton *et al.* (1990). Some of the details in our present paper, i.e., a recent temperature rise from 1984, two troughs in 1972 and 1980, two peaks around 1953 and 1958, and a decrease from 1940 to 1953 correspond to the following details from Houghton *et al.*; namely a temperature rise from

1985, two troughs in 1969 and 1977, two peaks in 1952 and 1960, and a decrease from 1940 to 1952. Houghton's data cited here was obtained in the 20° to 50°N region. Note that a minimum value trough found at Shinjo around 1940 is not found in the Houghton report. In our work, the rate of linear increase in air temperature was calculated as 0.35°C/60 years, or 0.58°C/century. This rate corresponds well to the upper rate of around 0.6°C over the last 80 to 100 years reported by Houghton *et al.* (1990).

It was found that there was an inversely positive correlation between the maximum snow depth and the mean winter air temperature, namely if the air temperature decreased (increased) the maximum snow depth increased (decreased). Also the less inversely positive correlation between winter precipitation and winter air temperature was shown by a statistical analysis. But temperature change from one winter to the next did not necessarily correspond to this inversely positive correlation. Twenty-nine years (twenty-nine winter changes) showed an inversely positive correlation between winter precipitation change and winter air temperature change, but another twenty-nine years showed a positive correlation between the values over the last 60 years. That is, if a winter was warmer (colder) than the previous winter, then precipitation was less (greater) than in the previous year in 29 years. But in another 29 years when the winter was warmer (colder) than the previous winter, the precipitation was greater (less) than that of the previous year. One year showed no remarkable change.

Precipitation in the last 60 years reached a maximum in 1963. The second highest value is found in 1940 as shown in Fig. 11.

The maximum value for maximum snow depth was found in 1940. This result does not necessarily correspond to the maximum for precipitation as shown in Fig. 11. Fluctuation in deviation normalized by a mean value of the maximum snow depth showed a larger value than that of precipitation.

The minimum for winter mean air temperature observed on a ten year moving average (i.e., a statistically smoothed curve) was found to be in 1940, with great deviation about this mean over the last 60 years. A rather rapid increase in temperature is observed from around 1980. This change may be due to global warming.

Winter air temperatures in both Shinjo and Nagaoka showed similar patterns. Recent temperature rises have been observed in these two areas. Two peaks, one in 1968 and one in 1975 were found in both areas. In Shinjo two additional peaks are found in 1952 and 1958. Also in these two areas the minimum air temperature obtained from a statistically smoothed curve over the last 60 years is found in 1940.

Should global temperature rise continue in the future, it may be expected that snow in Shinjo will decrease. Also in Nagaoka, it was shown that there is a statistical correlation between years of heavy snowfall and La Nina years (Ferguson *et al.*, 1994). Furthermore, the effect of Asian Monsoon systems on snow in Shinjo should be investigated.

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Appendix 1-a Monthly and annual precipitation (mm) and maximum snow depth; S_{max} (cm) in Shinjo. DJF: Total value for the three months of December, January and February.

Year \ Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual	DJF	Smax
1934									267.1	70.6	331.9	116.2			
1935	169.5	172.7	125.5	105.5	138.2	101.9	140.2	134.7	120.9	263.4	115.0	273.8	1861	458	90
1936	488.0	230.7	215.5	129.6	67.2	68.4	194.4	333.1	186.7	181.1	216.2	281.4	2592	993	250
1937	209.6	222.4	129.7	121.5	199.0	103.7	206.0	139.9	113.6	110.8	249.1	422.9	2228	713	119
1938	274.5	209.8	60.7	128.3	126.9	136.3	187.5	89.5	131.2	201.3	258.5	219.5	2024	907	205
1939	198.8	141.9	158.4	103.7	61.9	78.3	71.1	96.4	188.4	145.4	282.3	222.6	1749	560	147
1940	292.5	168.6	60.2	98.0	68.9	55.1	360.0	183.0	236.5	87.0	127.8	174.7	1912	684	228
1941	180.5	140.2	183.5	81.0	95.8	189.0	274.4	56.2	208.9	85.6	72.9	180.1	1748	495	90
1942	278.0	113.0	51.6	110.2	66.7	86.7	161.0	124.3	135.1	136.5	272.9	205.0	1741	571	144
1943	183.3	176.5	74.5	74.4	76.1	80.1	13.2	328.5	141.3	252.5	177.6	229.8	1808	565	185
1944	208.7	174.5	68.4	111.8	103.0	66.3	494.8	76.9	170.7	108.7	173.6	493.4	2251	613	144
1945	273.5	161.0	203.6	95.4	89.6	100.2	147.9	61.8	220.0	221.6	238.8	334.8	2148	928	205
1946	162.7	132.9	74.2	99.3	89.1	629.9	66.2	65.2	159.6	143.1	129.2	124.1	1876	630	147
1947	52.5	237.0	204.3	136.3	73.3	176.5	336.8	229.5	221.6	133.5	126.4	296.5	2224	414	170
1948	134.4	125.8	132.7	50.3	88.0	88.8	169.4	250.4	231.8	281.8	220.9	197.0	1971	557	133
1949	333.7	190.5	123.5	154.9	97.5	94.9	69.2	83.5	118.8	130.2	171.6	271.6	1840	721	91
1950	200.5	189.5	120.7	97.0	98.5	240.3	99.7	117.9	229.3	193.7	179.0	245.0	2011	662	88
1951	124.9	112.5	183.7	142.8	76.2	58.3	73.3	62.7	167.2	168.7	212.0	298.4	1681	482	125
1952	308.0	148.2	84.2	118.0	73.5	166.1	300.3	180.9	177.4	113.7	117.6	285.1	2073	755	146
1953	258.2	167.0	152.6	150.4	79.5	87.5	225.9	245.5	142.2	89.9	211.8	215.2	2026	710	175
1954	97.7	126.3	201.7	116.3	129.9	191.5	106.7	24.6	152.1	159.4	153.9	184.9	1645	439	44
1955	268.5	180.2	113.5	93.4	186.4	251.3	110.0	82.4	128.2	280.0	196.4	258.5	2149	634	135
1956	238.9	183.0	176.4	100.5	114.7	244.7	185.8	229.7	98.8	119.4	284.7	302.2	2279	680	145
1957	153.0	182.2	172.9	126.5	82.1	86.6	325.8	103.3	116.3	153.2	109.3	264.7	1876	637	146
1958	274.1	168.6	165.0	97.5	41.2	67.0	560.2	190.6	241.7	174.5	146.9	286.0	2413	707	97
1959	281.0	138.0	221.1	144.0	75.8	159.0	331.8	246.1	129.9	148.2	174.2	229.2	2278	705	95
1960	268.5	189.9	152.7	165.6	100.2	132.7	107.8	109.1	160.9	79.1	184.4	424.6	2076	688	118
1961	291.9	195.3	65.5	111.8	52.6	205.0	188.2	181.3	130.8	107.2	250.0	253.5	2033	912	175
1962	335.4	178.6	190.8	122.2	96.8	181.0	144.9	214.7	144.8	177.0	185.7	264.9	2237	768	126
1963	397.8	208.0	122.2	89.7	145.3	114.3	236.5	163.2	272.4	122.5	286.1	214.6	2373	871	177
1964	185.0	208.3	107.1	149.9	83.7	65.0	326.1	58.2	318.1	117.4	250.9	303.2	2173	608	113

Appendix 1-b Monthly and annual precipitation (mm) and maximum snow depth ; S_{max} (cm) in Shinjo (continued).

1965	313.7	205.8	158.6	78.1	126.4	112.9	390.2	67.3	145.3	114.4	270.6	370.7	2354	823	157
1966	284.2	154.6	225.5	56.0	104.5	241.5	297.8	37.1	146.2	216.7	173.6	241.7	2179	810	110
1967	268.3	81.4	92.5	118.1	31.6	109.1	149.8	284.3	138.5	153.0	129.3	402.4	1958	591	143
1968	209.5	166.5	87.0	58.0	128.0	56.5	102.0	273.5	18.0	111.5	160.0	262.0	1633	778	222
1969	278.5	136.5	108.5	133.0	70.0	63.0	246.0	371.5	168.5	136.0	176.5	285.0	2173	677	145
1970	204.5	146.0	111.0	51.0	41.5	90.0	66.0	96.0	165.5	132.5	221.0	193.0	1518	636	145
1971	101.5	133.0	109.0	58.0	97.5	159.5	501.5	113.0	180.5	164.5	159.5	215.5	1993	428	92
1972	168.5	135.0	105.5	73.5	129.5	102.5	221.5	167.5	133.5	99.5	309.0	292.5	1938	519	49
1973	219.5	198.0	172.0	83.0	98.5	117.0	21.5	106.5	229.0	151.0	415.0	409.5	2221	710	87
1974	211.5	191.5	135.0	95.0	70.5	122.0	248.0	319.0	150.5	159.5	250.0	160.0	2113	813	232
1975	156.0	150.5	193.0	61.5	86.0	54.5	139.5	124.0	72.0	162.5	172.0	126.0	1498	467	126
1976	199.5	163.5	75.0	93.0	62.0	121.0	80.5	368.5	134.0	184.5	147.5	252.0	1881	489	131
1977	145.5	128.5	103.5	115.0	150.0	56.0	140.5	265.5	157.0	37.5	204.5	220.5	1724	526	146
1978	220.0	180.5	113.5	122.0	73.0	269.5	36.0	232.5	153.0	103.5	113.5	120.5	1738	621	147
1979	135.0	128.0	121.0	139.0	74.5	176.0	232.0	205.0	136.5	175.0	223.0	149.5	1895	384	75
1980	189.5	193.0	86.5	104.5	101.0	121.0	333.0	239.0	44.0	272.0	122.5	309.0	2115	532	166
1981	214.0	126.0	99.0	132.5	135.0	258.5	94.5	228.5	121.5	300.5	254.5	208.0	2173	649	183
1982	158.5	98.5	127.0	169.5	139.5	129.0	80.0	28.5	167.0	156.0	196.5	256.5	1707	465	144
1983	98.5	156.5	126.5	117.0	89.0	92.5	339.0	87.0	189.0	175.5	179.0	188.5	1838	512	122
1984	130.5	85.5	61.5	107.5	87.0	99.5	159.0	45.0	178.0	166.5	124.5	145.5	1390	405	171
1985	142.5	115.5	99.0	56.5	141.5	55.0	182.0	50.0	202.5	168.5	300.5	167.5	1681	404	128
1986	221.0	162.5	112.5	97.0	111.5	130.5	165.5	152.5	104.5	131.5	154.0	135.0	1678	551	190
1987	138.5	90.0	108.5	37.5	99.0	28.0	244.5	266.5	51.0	90.0	141.0	108.5	1403	364	75
1988	216.0	160.5	64.5	113.5	112.5	83.0	128.5	144.5	129.0	208.5	251.0	247.5	1859	485	145
1989	132.5	112.0	72.5	160.0	51.0	67.5	46.0	145.5	281.0	113.5	166.0	187.5	1535	492	66
1990	214.0	93.5	90.5	109.5	66.0	288.5	100.5	177.0	134.5	111.0	207.0	220.0	1812	495	100
1991	175.5	174.0	61.5	43.0	101.5	228.5	423.0	169.0	152.0	216.0	191.5	108.5	2044	570	120
1992	180.0	154.0	95.5	118.5	181.0	61.5	163.0	117.5	72.0	146.5	163.5	224.0	1677	443	92
1993	182.5	234.5	101.5	98.5	133.0	160.0	274.0	129.5	172.5	170.0	203.0	227.0	2086	641	86
1994	244.5	137.5	105.0	30.0	68.0	78.0	145.0	82.0	272.0	70.0	64.0	247.0	1543	609	130

Appendix 2-a Monthly and annual mean air temperature (°C) in Shinjo. DJF : Mean value for the three months of December, January and February.

Year \ Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual	DJF
1934									9.3	11.4	5.4	-0.5		
1935	-1.7	-0.9	1.3	8.0	13.1	18.6	22.9	23.1	19.4	14.0	6.6	-0.6	10.3	-1.0
1936	-3.8	-2.9	-0.1	5.9	13.6	19.5	22.3	23.7	21.2	12.1	6.8	0.6	9.9	-2.4
1937	-1.8	0.1	0.7	6.7	12.5	17.5	24.1	25.2	18.4	12.3	6.8	-0.9	10.1	-0.3
1938	-2.5	-2.6	1.8	7.8	14.8	18.2	22.8	26.0	20.0	13.2	6.8	0.2	10.5	-2.0
1939	-4.0	-2.1	0.9	7.5	13.4	19.2	24.6	25.1	21.4	14.3	7.5	0.2	10.7	-2.0
1940	-3.5	-2.1	1.8	6.4	13.2	18.6	23.7	23.4	19.6	14.0	8.7	1.8	10.5	-1.8
1941	0.7	-0.9	3.1	7.8	14.8	18.6	21.2	24.1	18.7	13.9	7.8	2.0	11.0	0.5
1942	-2.1	-2.9	4.1	9.2	13.5	20.0	24.8	24.6	20.5	12.7	6.1	1.0	10.9	-1.0
1943	-2.9	-1.6	0.3	6.8	13.6	19.5	25.1	26.5	21.9	13.4	6.5	0.8	10.8	-1.2
1944	-2.2	-2.2	2.9	6.4	14.6	20.2	23.7	25.6	20.0	14.2	7.1	-0.9	10.8	-1.2
1945	-5.3	-4.4	-0.1	6.9	12.4	18.4	20.1	26.1	19.4	14.2	7.1	0.3	9.6	-3.5
1946	-1.8	-1.4	0.2	8.1	13.7	20.7	24.5	26.0	19.2	14.0	8.8	0.4	11.0	-1.0
1947	-1.5	-2.4	0.6	6.3	13.6	16.5	23.8	25.3	19.8	13.9	6.3	-1.4	10.1	-1.2
1948	-0.4	-0.9	1.7	9.0	15.0	19.1	24.7	25.7	19.6	13.6	7.2	4.3	11.5	-0.9
1949	1.7	1.6	0.6	7.0	15.2	18.3	23.0	25.5	20.3	13.4	6.1	1.0	11.1	2.5
1950	-1.4	-0.8	2.0	9.7	16.1	19.2	25.2	26.4	21.7	12.0	7.3	1.2	11.5	-0.4
1951	-2.9	-0.5	2.0	8.2	14.3	18.8	22.4	25.4	17.7	14.1	6.6	3.4	10.8	-0.7
1952	-0.6	-3.0	1.4	8.0	14.0	19.2	22.8	24.1	19.3	13.0	6.3	-0.6	10.3	-0.1
1953	-1.8	-2.5	2.0	6.9	12.9	18.2	22.2	21.9	17.9	11.7	5.0	2.2	9.7	-1.6
1954	-2.0	-0.2	1.8	9.0	13.0	16.0	20.0	23.3	20.7	11.6	5.9	1.4	10.0	0.0
1955	-1.7	-1.4	1.5	8.2	13.2	18.7	24.4	23.7	18.1	13.2	5.8	2.9	10.6	-0.6
1956	-1.4	-2.1	1.6	7.1	14.4	17.9	22.1	21.8	19.4	13.4	6.3	-0.6	10.0	-0.2
1957	-1.3	-1.8	-0.2	6.3	13.5	17.0	21.8	24.2	17.3	12.5	6.3	2.1	9.8	-1.2
1958	-1.5	-0.1	1.0	7.9	13.4	18.8	22.1	22.6	18.6	11.9	5.8	3.5	10.3	0.2
1959	-1.4	0.4	3.9	10.2	14.3	18.1	21.7	22.9	19.6	12.8	7.0	1.6	10.9	0.8
1960	-1.3	-0.1	1.7	7.2	14.1	18.4	22.1	24.0	19.2	11.8	7.9	1.0	10.5	0.1
1961	-2.7	-2.2	0.6	8.2	15.2	18.6	24.0	23.3	20.7	13.5	7.0	1.2	10.6	-1.3
1962	-0.9	-1.1	0.7	7.5	14.6	17.6	23.0	23.7	19.3	10.6	5.8	2.0	10.2	-0.3
1963	-1.8	-1.5	0.2	7.9	14.1	18.3	22.4	23.3	16.6	11.7	6.3	2.2	10.0	-0.4
1964	-0.6	-1.8	1.7	9.3	14.8	17.8	22.1	24.5	17.3	11.0	6.0	0.5	10.2	-0.1
1965	-0.8	-1.9	-0.1	4.2	13.1	18.3	20.4	23.3	18.3	11.0	5.4	0.5	9.3	-0.7
1966	-1.6	-0.8	1.9	8.5	13.2	17.4	20.9	24.0	18.4	13.5	5.6	-1.1	10.0	-0.6
1967	-2.2	-1.5	1.5	8.7	15.1	18.4	23.6	23.3	18.7	11.8	5.4	-0.2	10.2	-1.6
1968	-1.5	-2.3	1.8	7.8	13.3	18.8	22.4	22.9	18.4	11.1	6.7	3.3	10.2	-1.3
1969	-1.7	-1.7	-0.2	8.3	13.7	18.2	21.9	22.7	17.7	11.4	5.7	-0.9	9.6	0.0
1970	-2.7	-1.2	-1.6	6.2	15.6	18.1	22.4	23.6	18.8	11.8	4.9	-0.3	9.6	-1.6
1971	-1.0	-1.6	0.8	7.2	13.5	18.0	22.7	23.3	17.4	10.9	5.7	0.3	9.8	-1.0
1972	0.4	-0.8	3.5	9.5	13.7	18.4	22.8	23.2	18.8	13.2	6.5	2.2	11.0	0.0
1973	-0.4	-0.4	0.4	9.3	13.6	17.8	23.3	25.1	19.1	11.7	5.3	-0.3	10.4	0.5
1974	-1.7	-1.5	0.1	6.5	14.3	18.9	20.8	23.5	18.2	11.8	3.6	-1.1	9.5	-1.2

Appendix 2-b Monthly and annual mean air temperature (°C) in Shinjo (continued).

1975	-2.4	-2.7	1.0	9.4	13.9	18.6	22.3	23.8	20.1	12.0	6.8	0.4	10.3	-2.1
1976	-2.0	-1.9	1.0	6.9	13.8	18.1	21.1	20.6	17.4	11.5	4.3	-0.1	9.2	-1.2
1977	-4.1	-2.0	1.1	7.3	12.8	18.3	22.7	22.0	18.8	12.1	7.8	1.9	9.9	-2.1
1978	-1.3	-3.2	1.1	7.0	14.1	19.9	25.0	24.4	17.6	11.1	5.4	2.2	10.3	-0.9
1979	-0.2	0.5	1.8	7.1	13.1	20.5	21.4	23.3	18.6	13.9	7.5	2.9	10.9	0.8
1980	-1.4	-2.6	0.2	5.6	14.4	19.7	20.3	20.8	18.0	11.7	6.3	1.0	9.5	-0.4
1981	-2.4	-1.2	0.5	6.6	11.9	16.8	23.5	22.4	16.7	11.8	4.3	0.9	9.3	-0.9
1982	-1.9	-2.2	1.1	8.2	14.9	18.0	21.1	24.1	18.1	12.3	6.9	2.6	10.3	-1.1
1983	-0.3	-2.0	1.1	10.7	14.6	17.0	20.4	24.2	19.6	11.3	5.0	-0.4	10.1	0.1
1984	-3.3	-3.5	-1.6	4.2	13.0	19.8	23.8	24.9	18.1	11.0	4.8	0.9	9.3	-2.4
1985	-3.6	-0.8	1.2	8.9	14.7	17.9	22.6	26.0	18.3	11.9	6.4	0.0	10.3	-1.2
1986	-2.5	-2.7	1.4	7.9	13.6	18.0	20.2	24.1	19.5	10.9	4.9	2.4	9.8	-1.7
1987	-1.5	-0.8	1.9	7.9	14.8	19.5	22.7	23.3	19.8	12.9	6.2	1.6	10.7	0.0
1988	-0.4	-2.9	1.4	7.7	13.3	19.2	19.9	25.1	19.3	11.4	3.9	1.1	9.9	-0.6
1989	0.3	0.7	4.1	10.4	14.3	17.7	22.8	24.5	19.5	11.7	8.5	2.4	11.4	0.7
1990	-2.2	1.4	4.0	9.7	14.9	19.9	22.5	25.0	20.6	13.9	8.8	4.2	11.9	0.5
1991	-0.9	-0.5	2.4	9.5	14.9	20.5	21.9	22.5	19.8	13.8	5.7	1.8	11.0	0.9
1992	0.3	-1.0	2.8	8.8	12.7	18.0	22.5	23.9	18.1	12.8	6.8	2.0	10.6	0.4
1993	0.5	1.1	2.2	7.0	13.4	18.4	19.9	21.1	18.3	11.2	7.9	1.6	10.2	1.2
1994	-1.4	0.2	1.3	8.3	15.0	18.8	24.6	26.3	20.9	14.0	6.0	1.0	11.3	0.1

新庄における過去60年間の積雪深，冬期降水量および冬期平均気温の変動

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要　旨

新庄における1986/87年から1993/94年までの8冬期の寡雪傾向は，冬期の気温上昇と正の相関関係にあった．過去1世紀における新庄の気温上昇率は，0.58°C/百年と求められた．最大積雪深は，統計的には冬期平均気温と逆相関を示した．冬期降水量は，最大積雪深と冬期平均気温の場合よりも弱い逆相関を示した．過去60年間のうち29例については，気温が，ある冬から次の冬へ上昇するときは降水量も同様に増加するという正の相関関係にあった．残りの29例については，気温が，ある冬から次の冬へ上昇するときに降水量が減少するという逆の相関関係にあった．また1例については，特段の関係がなかった．最大積雪深および冬期降水量の極大はどちらも1936年に出現した．10年間の移動平均の冬期降水量と最大積雪深の極大は1963年に，2番目の冬期降水量の極大は1940年にそれぞれ出現した．最大積雪深の平均値で標準化された偏差の変動は冬期降水量のそれより大きかった．10年ごとに移動平均した冬期平均気温の最低値は1940年に出現したが，1980年頃から急な上昇が観測された．この温度上昇は地球温暖化の影響とみられる．

キーワード：気候変動，地球温暖化，積雪深，降水量，気温

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