Sci. Rept., Inst. Geosci., Univ. Tsukuba,
Sect. A, Vol.14, 1993

Recent Global Warming and Variation of Winter Snow Cover in Japan

BY

Yuki MORINAGA and Tetsuzo YASUNARI

Contents

Abstract

The interannual variation of the maximum snow depth in Tohkamachi city for 1918-1990, was analyzed with surface air temperature and 500 hPa geopotential height of the Northern Hemisphere. Results indicate that though the effect of recent hemispheric warming cannot be directly detected in the variation of the maximum snow depth, the snow depth in this region is closely associated with the change of the hemispheric-scale atmospheric teleconnection patterns known as EU and PNA patterns.

1. Introduction

Many studies have addressed the questions of climate change, particularly the "global warming" which might arise from human activities. It is reported that the global mean surface air temperature has increased by 0.3 ℃ to 0.6 ℃ over the last 100 years, with the five warmest years being in the 1980s (IPCC, 1990).

Figure 1 shows the annual surface air temperatures (land plus marine data) of the Northern and the Southern Hemispheres for 1854-1990 (Jones and Bradley, 1992). The warming of 0.5 ℃ is observed in the annual temperature of the both hemispheres since 1850s. Northern Hemisphere surface air temperature started to increase slowly since the

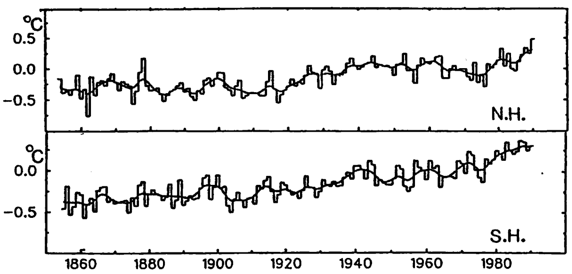

Fig.1 Annual surface air temperatures (land plus marine) of the Northern and the Southern Hemispheres for 1854-1990. Data are expressed as anomalies from 1950-1979. The smooth curves were obtained using a 10-year Gaussian filter (Jones and Bradley, 1992).

beginning of this century and showed some decreasing trend during 1960s-70s. However, it again started to show the increasing trend since the end of 1970s, and the highest temperature were recorded during 1980s. This recent increase of temperature since the end of 1970s is sometimes referred to as the "global warming" in a narrow sense. The annual temperature increase in the Southern Hemisphere is similar to that of the Northern Hemisphere except that the warming has occurred more linearly since the end of the 19th century.

How would this "global warming" affect the regional climate? For example, is the decrease of winter snow since 1987 in Japan due to this "global warming"? The purpose of this study is to clarify the influence and implications of the hemispheric temperature changes on regional climate, especially, on the snow cover in Japan. The snow and other meteorological data of Tohkamachi city, which has the long record of snow for 1917-1990 in Japan, was used, since it represents the snowfall and meteorological conditions over the major part along the Sea of Japan (Section 4).

2. Data

The following data were used in this analysis:

1) Maximum snow depth, accumulated snow depth, monthly total snowfall amount, duration of snow cover on the ground and surface air temperature of Tohkamachi city, in Niigata Prefecture for 1917-1990 produced by Forestry and forest products research institute, (1990).

2) Northern Hemisphere surface air temperature (land and marine) (NHT) 1917-1990 produced by Jones *et al.*, (1986, 1988).

3) Northern Hemisphere 500hPa geopotential height gridded $10° \times 10°$ for 1946-1990 compiled by Japan Meteorological Agency.

3. Characteristics of Seasonal Surface Air Temperature Anomalies for the Northern Hemisphere

Figure 2 shows NHT for every season. Data are expressed as anomalies from 1950-1979. "Winter" indicates the monthly mean for DJF (December, January and February) and "Spring", "Summer" and "Autumn" indicate MAM, JJA and SON, respectively. The smooth curves were obtained using a 10 year Gaussian filter. The warming is prominent in winter while the lack of warming frend is noted in summer.

Figure 3 shows the seasonal NHT for 1981-1990. Anomalies are deduced from the average of 1950-1979 period. As Jones and Bradley (1992) noted, the warming have not occurred uniformly. Regions of prominent temperature increase are found in the inland of the Eurasian continent and Alaska, while temperature is decreasing over the northern oceans such as the North Pacific Ocean and the North Atlantic Ocean. In short, though NHT shows the increasing trend, it must be noted that temperature increase is mostly due to the increase over the continents. Over Japan, the northwestern periphery of the North Pacific Ocean, the trend shows negative rather than positive, especially in winter. This indicates that it is not so simple for us to directly relate the snow in Japan to the "global warming".

4. Maximum Snow Depth in Tohkamachi City and Surface Air Temperature Anomalies in the Northern Hemisphere

Figure 4 shows the distribution of the 1st component of the empirical orthogonal function of daily snowfall amount over Japan which is deduced from the variation of snowfall of 100 stations (Sugiyama, 1987). This component represents the pattern of snowfall over the major part of the regions along the Sea of Japan. Tohkamachi city, where the meteorological data including information

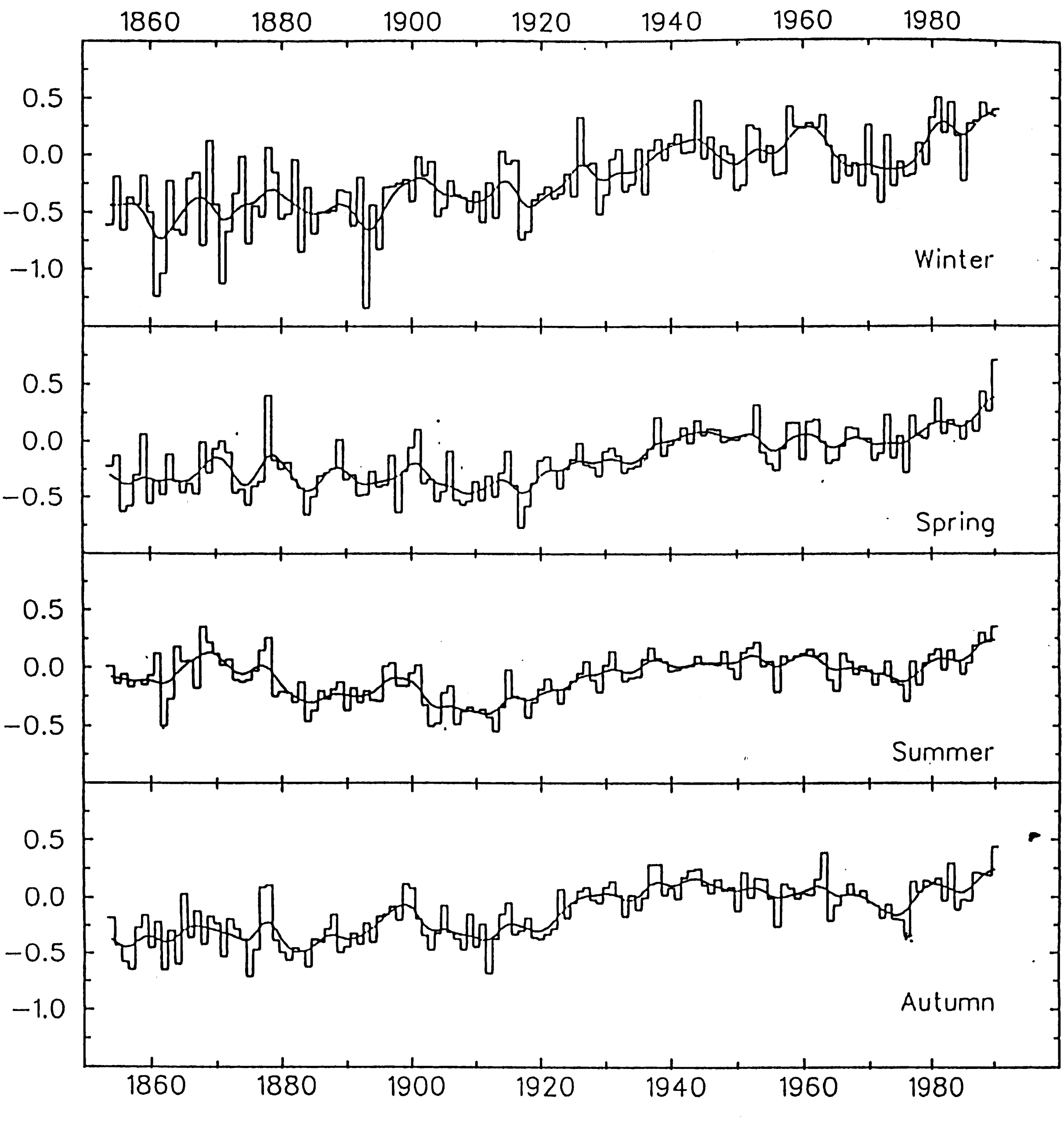

Fig.2 Same as in Fig. 1 except for Northern Hemisphere surface air temperatures by season.

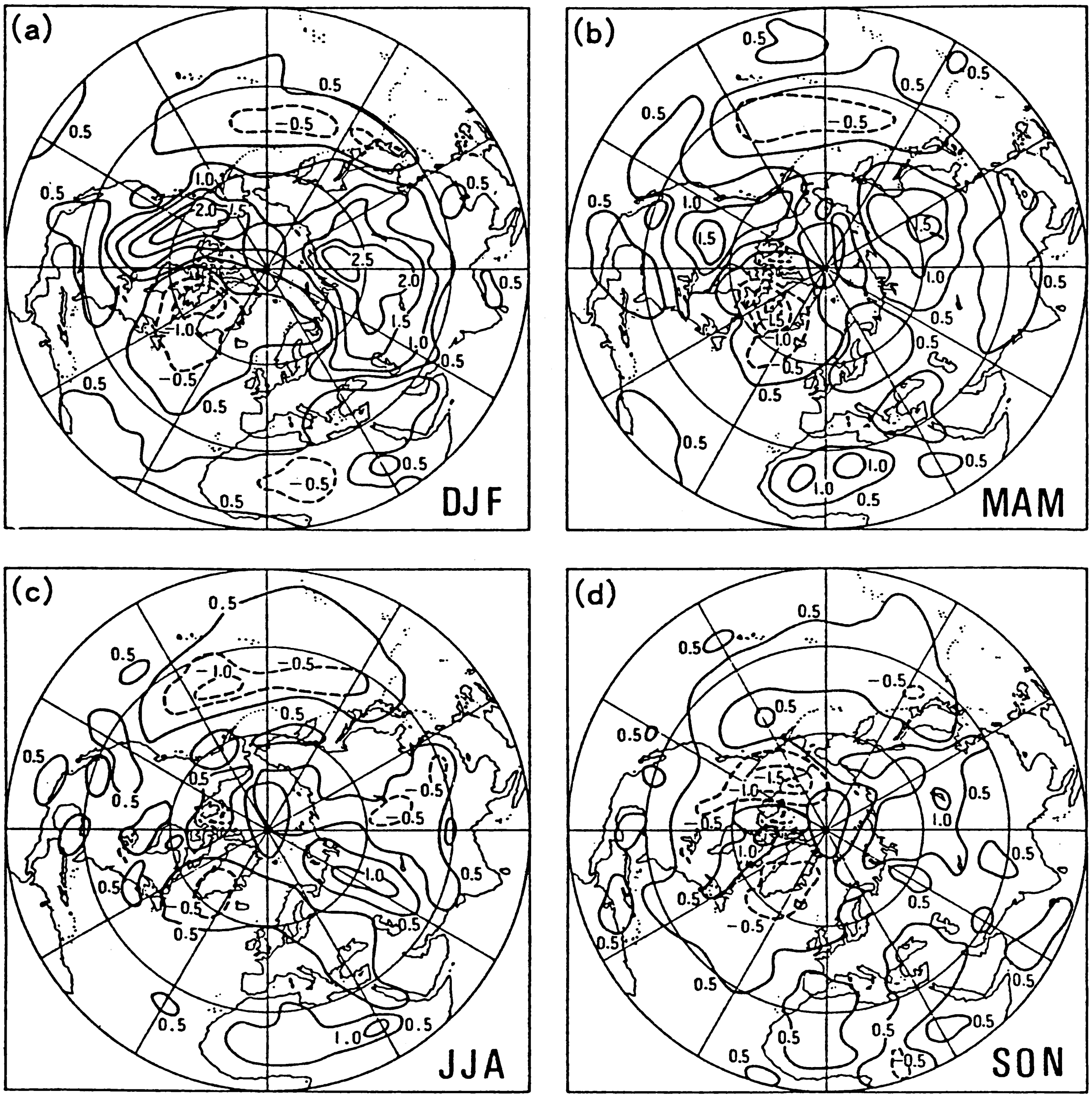

Fig.3 Seasonal temperature anomalies for the Northern Hemispheres for 1981-1990. Anomalies are from the average of the 1950-1979 period. Contour interval is 0.5℃ with negative anomalies dashed (Jones and Bradley, 1992).

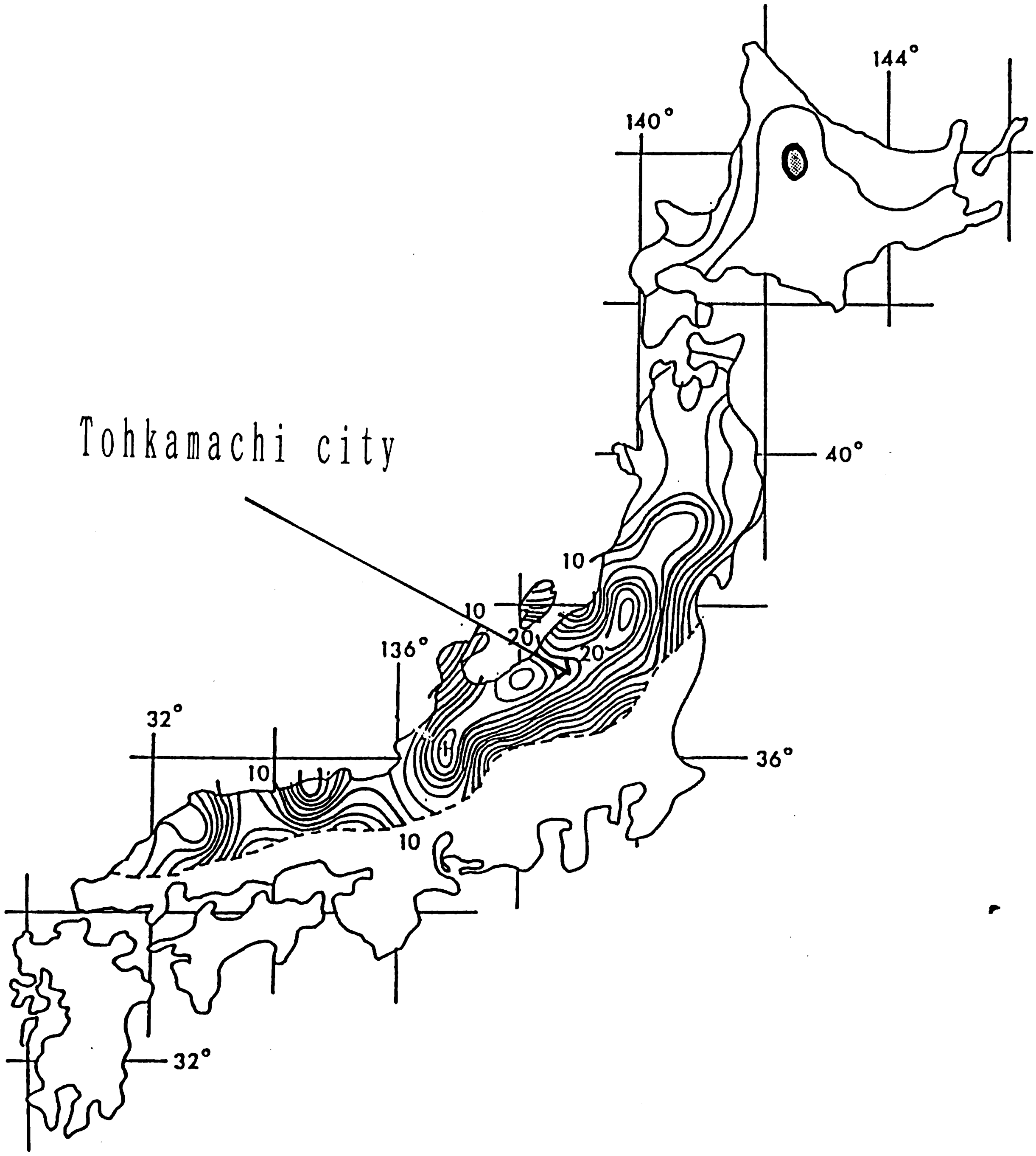

Fig.4 Distribution of the 1st component of the empirical orthogonal function of daily snowfall amount over Japan deduced from the variation of snowfall of 100 stations for winters of 1951-1982 (Sugiyama, 1987).

about snow of the past 70 years exists, is located very close to the center of action of this component. Therefore, we consider it appropriate to analyze the relation between the variation of snow in Tohkamachi city and NHT to understand the regional effect of the hemispheric temperature change,*i.e.*, the effect of "global warming" on the snow along the Sea of Japan.

Table 1 shows the matrix of correlations among several parameters of snow, such as monthly total snowfall amount, duration of snow cover on the ground, accumulated snow depth and the maximum snow depth. The correlation coefficients of the maximum snow depth and other parameters have proved that the maximum snow depth well represents the snowfall and snow cover.

Figure 5 shows the correlation coefficients between the maximum snow depth and the average temperature for each month in Tohkamachi city. The maximum snow depth is usually observed in February, but significant negative correlations are noted with the monthly temperature of the preceding December through the following May. Temperature of January shows the highest correlation with the maximum snow depth as shown in Figure 6. Therefore, the temperature of Tohkamachi city in January seems to be an adequate index to express the variation of snow cover along the Sea of Japan.

The relation between NHT and temperature of Tohkamachi city seems not so simple. No significant relation is found between temperature of Tohkamachi city and NHT in January as shown in Fig. 7(a). The time series of these two temperatures since 1917 (Fig. 7(b)) suggest that they fluctuate in a similar way in some phases, however, since 1960s, their correlation seems to have changed to be negative. At the beginning of 1980s when the"global warming" became evident, lower than usual temperature was observed in Tohkamachi city. Especially, in the winter of 1980/81, record-breaking snow fall occurred along the Sea of Japan.

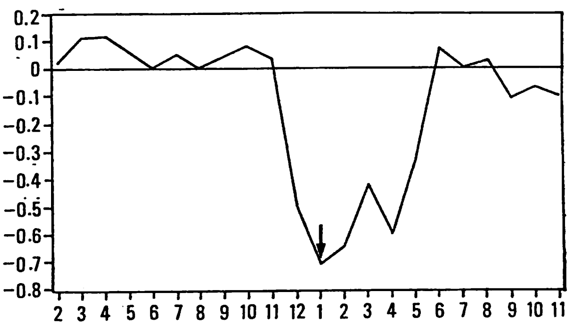

Fig.5 Correlation coefficients between the maximum snow depth and the average temperature for each month in Tohkamachi city (r>0.30 : 0.01 level).

Table 1. Correlation coefficients between the maximum snow depth and other parameters of snow in Tohkamachi for 1917-1989.

	MAXIMUM SNOW DEPTH (cm)	DURATION OF SNOW (days)	TOTAL SNOW DEPTH Nov-May(cm)	TOTAL SNOW AMOUNT Feb(mm)
MAXIMUM SNOW DEPTH	1.00(73)	0.72(73)	0.94(70)	0.70(66)
DURATION OF SNOW	0.72(73)	1.00(73)	0.77(70)	0.51(66)
TOTAL SNOW DEPTH 11-5	0.94(70)	0.77(70)	1.00(70)	0.67(66)
TOTAL SNOW AMOUNT 2	0.70(66)	0.51(66)	0.67(66)	1.00(66)

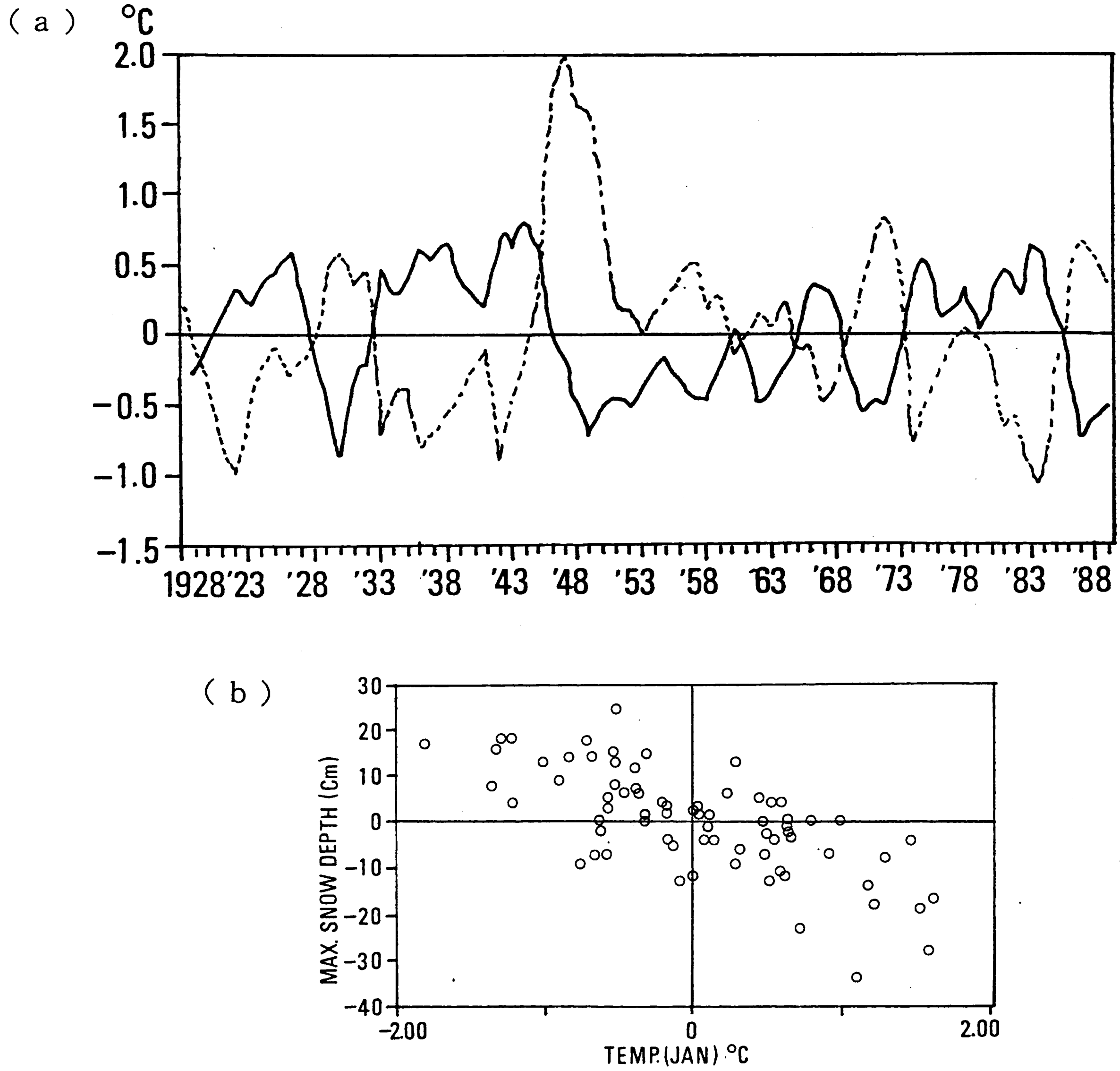

Fig.6 (a) Time series of the maximum snow depth (solid line) and January surface air temperature (dashed line) in Tohkamachi city (4 year running means). (b) Scatter diagram of the maximum temperature and January surface air temperature in Tohkamachi city (r =−0.71 : 0.01 level).

5. Hemispheric Circulation Patterns Associated with Temperature and Snow along the Sea of Japan

500 hPa geopotential height field in the Northern Hemisphere was analyzed to understand the circulation patterns associated with temperature and maximum snow depth in Tohkamachi city. Figure 8 shows the distribution of correlation coefficients between the maximum snow depth in Tohkamachi city and the geopotential height of 500 hPa in the Northern Hemisphere of the preceding December. Among the month of the preceding October to February, the overall correlation pattern of December was most statistically significant. The positive (negative) anomaly shows that the geopotential height is higher (lower) than the average when the maximum snow depth is large. Large areas with negative anomalies of geopotential height are dominated over Japan and Europe, while the area with positive anomalies prevails over Central Asia. This pattern is followed by positive snow depth anomaly in Tohkamachi

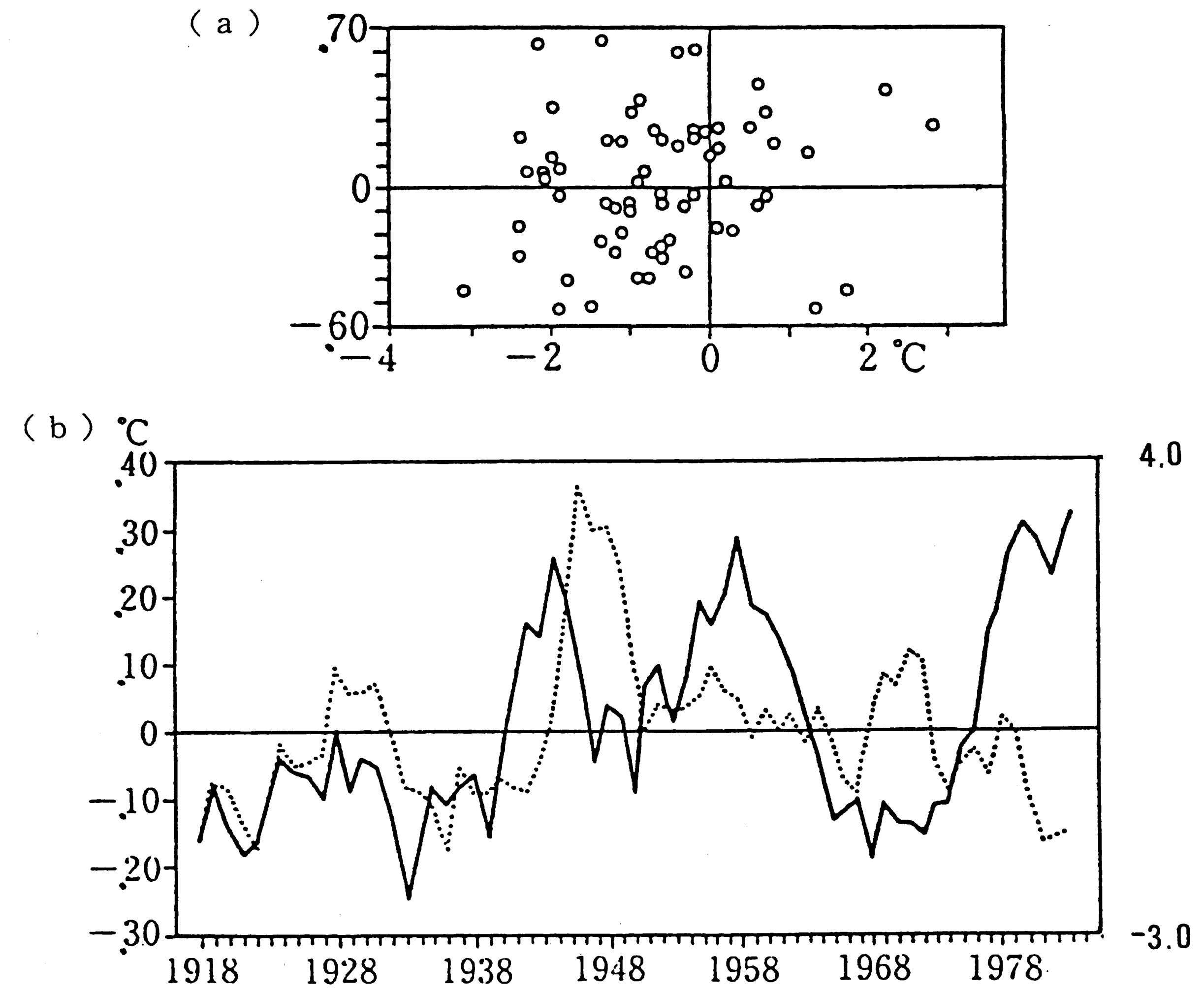

Fig.7 (a) Scatter diagram of NHT and surface air temperature in Tohkamachi city in January. (b) Time series of NHT (solid line) and surface air temperature in Tohkamachi city (dashed line) in January.

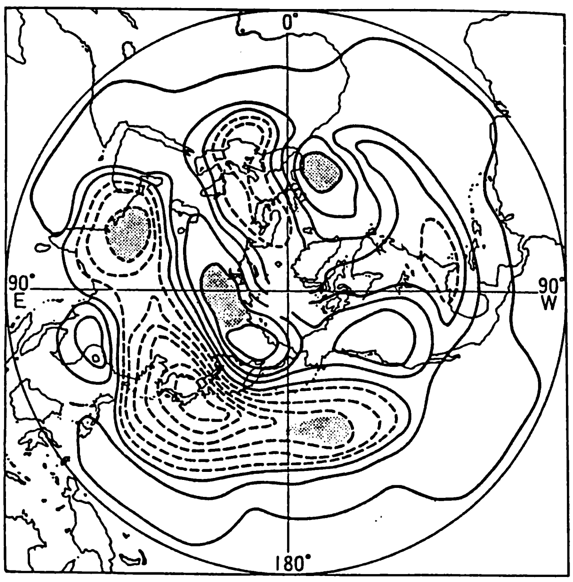

Fig.8 Distribution of correlation coefficients between the maximum snow depth in Tohkamachi city and the geopotential height of 500 hPa in the Northern Hemisphere of the preceding December. Solid line indicates positive and dashed line indicates negative anomalies. Shaded area indicates the region which is significant at 0.05 level.

city. This height anomaly pattern is known as the Eurasian Pattern (EU, Wallace and Gutzler, 1981), one of the typical winter patterns which appears in the Northern Hemisphere. That is, the maximum snow depth in Tohkamchi city is found to be closely related to the hemispheric or continental-scale pattern over Eurasia.

6. Anomalously Light Snow Depth in Tohkamachi City and the "Global Warming" since 1986/87

In the previous sections, we have shown that in the linear sense, the temperature and the maximum snow depth in Tohkamachi city and NHT is not significantly correlated with each other. As seen from Fig. 6(a), since 1986/87, however, high winter temperature anomaly in Tohakamachi city has been observed and the maximum snow depth has become abnormally light. In short, NHT and temperature in Tohkamachi in winter are both showing high anomalies recently. Figure 9 shows the variation of seasonally (November through March) accumulated snow depth for 1918 - 1990. As the accumulated snow depth is related to the maximum snow depth (*see* Table 1), the variation of these two looks similar to each other, but the recent decreasing trend of snow can be seen more clearly in the accumulated snow depth. This decreasing trend is also found in the average temperature of Tohkamachi city for November through March (*see* Fig. 10). This may indicate that in Tohkamachi city, the long-term trend of temperature has changed since 1986/87 and affects the snow depth.

If this snow depth change has occurred due to the climate change, i, e. large-scale changes of the atmospheric circulation field, the pressure pattern which brings about the recent light snow in Tohkamachi city should differ from that for the former light snow years. Therefore, the composite map of 500 hPa geopotential height of December for the past four winters (1986-89) and the former light snow years (1948, 58, 63 and 71) were compared as shown in Figure 11. It should be noted that the pressure pattern of December in the former light snow years shows large

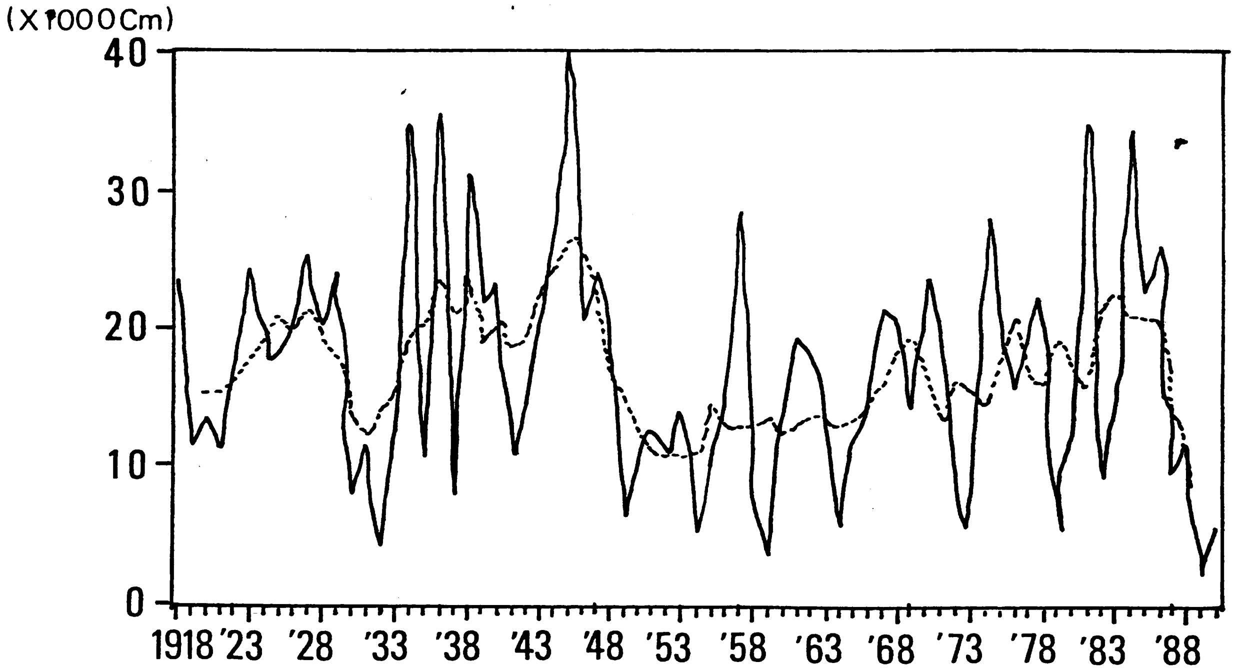

Fig.9 Time series of accumulated snow depth in Tohkamachi city, November through March. Dashed line indicates 5 year running mean.

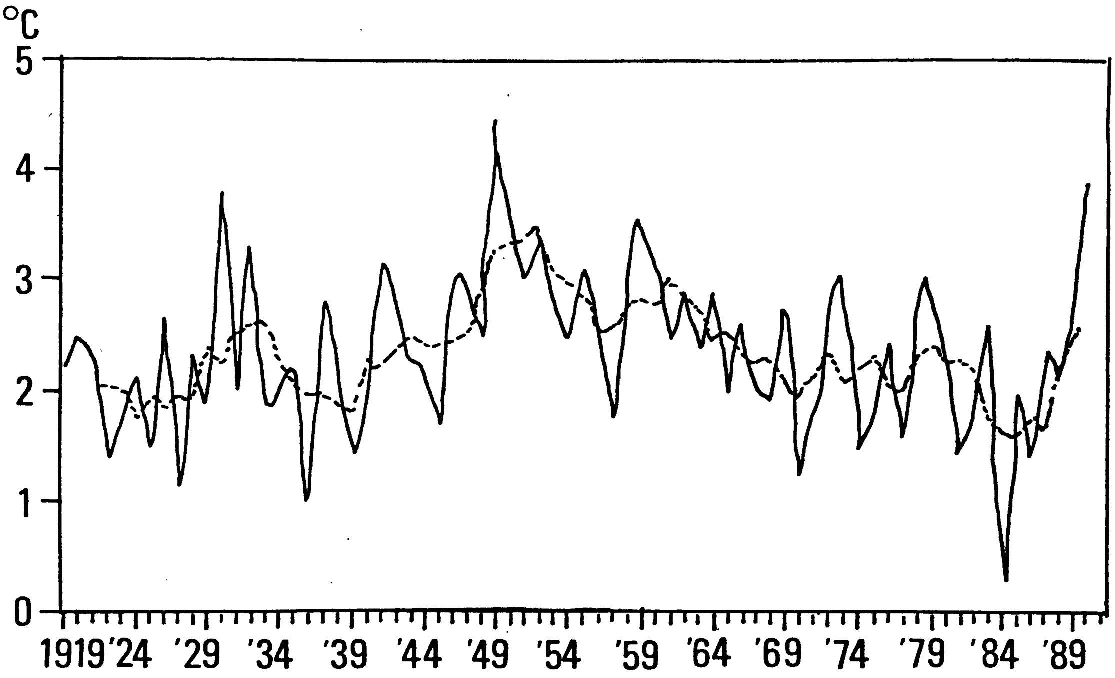

Fig.10 Same as in Fig. 9 except for surface air temperature.

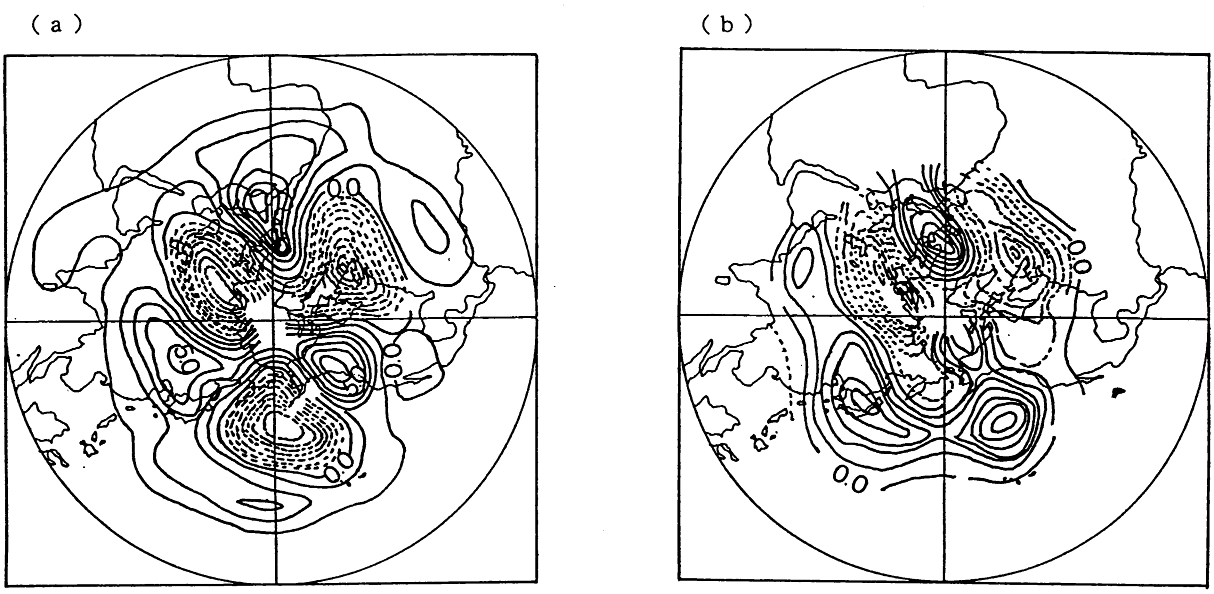

Fig.11 (a) Composite map of 500 hPa geopotential height anomalies in December, for the recent 4 years (1986-89). (b) Same as in Fig. 11 (a) except for the former years with small maximum snow depth (1948, 58, 63 and 71).

negative anomalies over the pole to Central Asia and is just the same pattern of Fig. 9. The recent light snow years' pattern, however, shows that the large positive anomalies over Japan are extended to the polar region.

Interestingly, the largest difference found between Fig. 11 (a) and (b) appears over the North Pacific Ocean, and over the North American continent. That is, in the recent years, the pattern with negative anomalies over the Aleutian low region and positive anomalies over Alaska, which is called the Pacific North

American pattern (PNA, Wallace and Gutzler, 1981) has been intensified.

Recent studies have pointed out that this pattern as well as the EU pattern may have contributed to the recent warming in the Northern Hemisphere (Trenberth, 1990; Nitta and Yamada, 1989, Yasunari, 1990 etc.), which may, further, be related to the snow depth variation in Japan.

As has been mentioned in the previous sections, the effect of the hemispheric warming has not uniformly occurred, and the direct effect of the"global warming" is not found in the variation of snow depth in Tohkamachi city in this study. Temperature and the maximum snow depth in Tohkamachi city, however, are closely related to the hemispheric circulation patterns as well as regional patterns, and would certainly be affected by the recent large-scale change of circulation patterns, Especially, the recent patterns which bring forth high winter temperature and light snow differ from the former patterns for light snow. Therefore, it is necessary to keep watching the variation of snow along the Sea of Japan associated with the changes in the Northern Hemisphere circulation patterns.

Acknowledgments

The authors would like to acknowledge Prof. Takeshi Kawamura and Dr. Hiroshi Tanaka for their useful comments.

References

IPCC Report (1990): *Climate Change, The IPCC Scientific Assessment.* Houghton, J.T., Jeskins, G.J., Ephraums J.J. (Eds.). Cambridge University Press, UK. 365 pp.

Jones, P.D., Raper, S.C.B., Bradley, R.S., Diaz, H.F., Kelly, P.M. and Wigley, T.M.L. (1986): Northern Hemisphere surface air temperature variations: 1851-1984. *J. Climate Appl. Meteor.*, **25**, 161-179.

Jones, P.D. (1988): Hemispheric surface air temperature variations: recent trends and an update to 1987. *J. Climate,* **1**, 654-660.

Nitta, T. and Yamada, T. (1988): Recent warming of tropical sea surface temperature and its relationships to the northern hemisphere circulation. *J. Meteor. Soc. Japan.* **67**, 359-374.

Sugiyama, T. (1987): Snowfall distribution in Japan and atmospheric general circulations. Master's thesis for University of Tsukuba, 61 pp (*in Japanese*).

Tohkamachi Experiment Station, Forestry and forest products research institute (1990): *Meteorological statics during the past 70 years in Tohkamachi city, Niigata (1918-1987).* Bulletin of the forestry and forest products research institute, no.357, 230 pp (*in Japanese*).

Trenberth, K.E. (1990): Recent observed interdecadal climate changes in the northern hemisphere. *Bull. Amer. Soc.,* **71**, 7, 988-993.

Wallace, J.M. and Gutzler, D.S. (1981): Teleconnections in geopotential height field during the Northern Hemisphere winter. *Mon. Wea. Rev.,* **109**, 784-812.

Yasunari, T. (1990): Changes in atmospheric circulation patterns associated with the recent warming in the Northern Hemisphere. In "*Observed Climate Variations Changes: Contribution in support of section 7 of IPCC scientific assessment.*" Chap. XXIII, 1-7.