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Trends of Winter Climate Conditions in Cold Snowy Regions of Japan

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ABSTRACT

In recent years, global warming has caused fluctuations in snowfall amounts and temperatures in cold snowy regions of Japan. Accordingly, when considering long-range plans for snow and ice control, it is necessary to identify trends related to snow and ice environments. Against such a background, this study involved a survey to clarify the trends of snowfall and snow depth based on data from the past about 30 years. The items surveyed were seasonal maximum snow depth (cm), the number of days with continuous snow cover, accumulated seasonal snowfall (cm), maximum 24-, 48- and 72-hour amounts from the onset of snowfall, and the frequency of 24-hour periods with snowfall exceeding 40 cm in winter. The results revealed that, although accumulated seasonal snowfall showed an overall decreasing tendency, the seasonal maximum snow depth and the frequency of 24-hour periods with snowfall exceeding 40 cm in winter were on the rise in eastern Hokkaido, which faces the Sea of Okhotsk and the Pacific Ocean. In general, this region is considered to have little snowfall as long as stable winter pressure patterns continue, while snowfall increases when low pressure develops over the Pacific Ocean and the Sea of Okhotsk. Changes in snowfall patterns and in the distribution of areas with short-term heavy snowfall were seen.

Keywords: winter climate conditions, cold snowy regions of Japan, short-term heavy snowfall

1 INTRODUCTION

In recent years, cold snowy regions of Japan have occasionally seen trends of lighter snowfall due to warm winters, heavy snow in areas that previously had little snowfall, very heavy localized snowfall and other unusual snowfall patterns. In winter 2010/11, heavy snowfall within short periods of time resulted in hundreds of vehicles becoming stuck on national highways. For example, approximately 300 vehicles were stranded on National Route 49 in Fukushima from December 25 to 27, 2010, and around 1,000 vehicles became stuck on National Route 9 connecting Shimane and Tottori from December 31, 2010, to January 2, 2011. Nishiaizu Town in Fukushima saw record daily snowfall of 138 cm on December 25, shattering the previous record of 81 cm, and cumulative snowfall exceeded 200 cm.

In winter, seasonal winds accompanied by cold air flowing from eastern Siberia pick up large amounts of moisture over the Sea of Japan and blow down to the backbone range of Japan. This causes ascending air currents and generates clouds, bringing heavy snow to areas on the Sea of Japan side. Conversely, dry winds blowing in areas along the Pacific Ocean on the leeward side of the backbone range result in little snowfall (Fig. 1). Figure 2 shows the normal values for the annual maximum depth of snow cover [1]. Areas with amounts exceeding 1 m are seen in Hokkaido and on the western side of the mountain ranges of mainland Japan. The values are between 0 and 10 cm in mainland Japan on the Pacific Ocean side.

Many people involved in the implementation of road snow and ice control measures have noted an increase in the amount of snow falling at one time and changes in the distribution of areas with heavy snowfall. It is considered important to understand the climate change-related metamorphosis of snow and ice environments in order to enable contribution to the development of long-term snow and ice control plans and measures. Accordingly, in this study, trends of change in snowfall and snow cover over the last about 30 years were surveyed using past data.

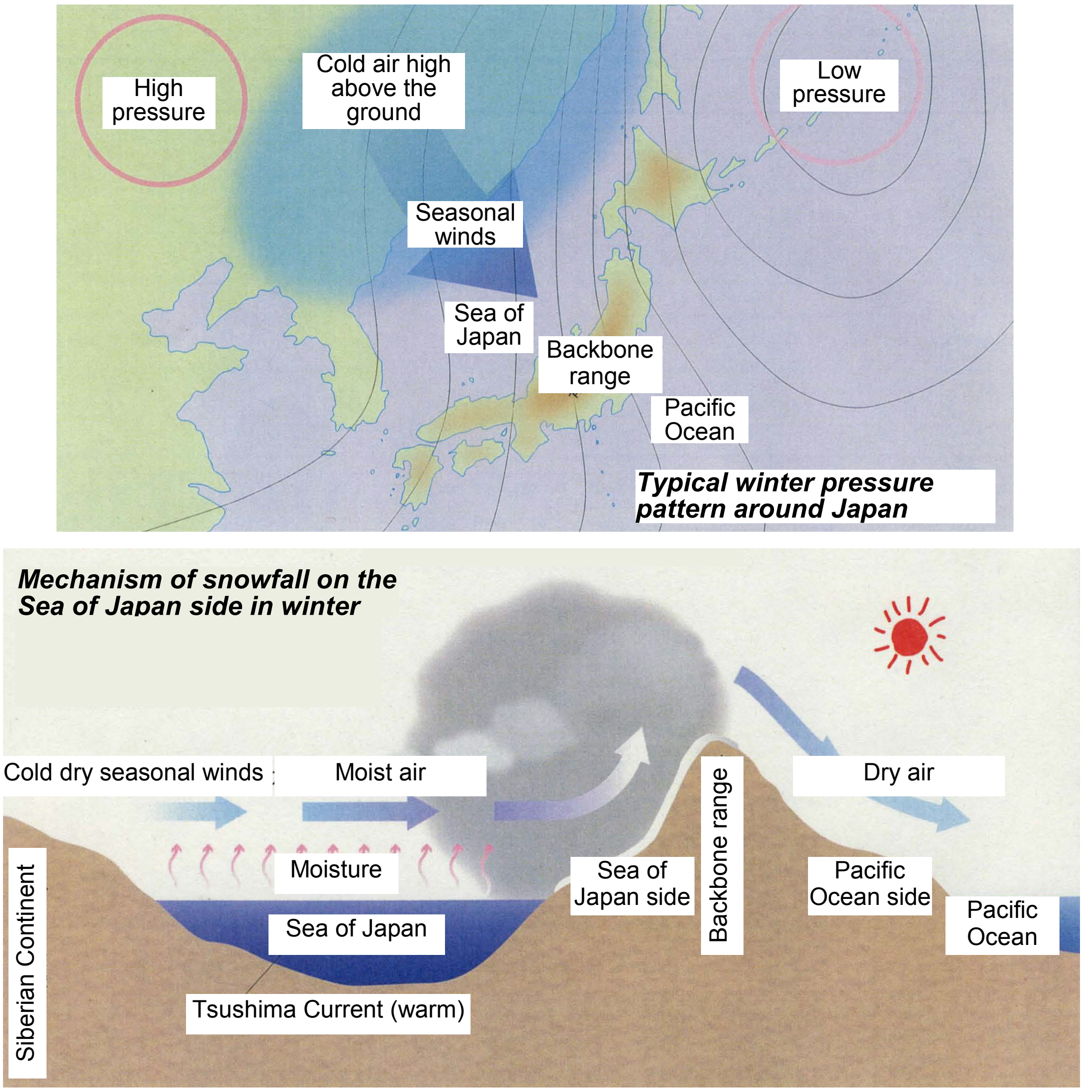

Figure 1. A Typical winter pressure pattern in around Japan and the mechanism of snowfall on the Sea of Japan side (bottom) [1].

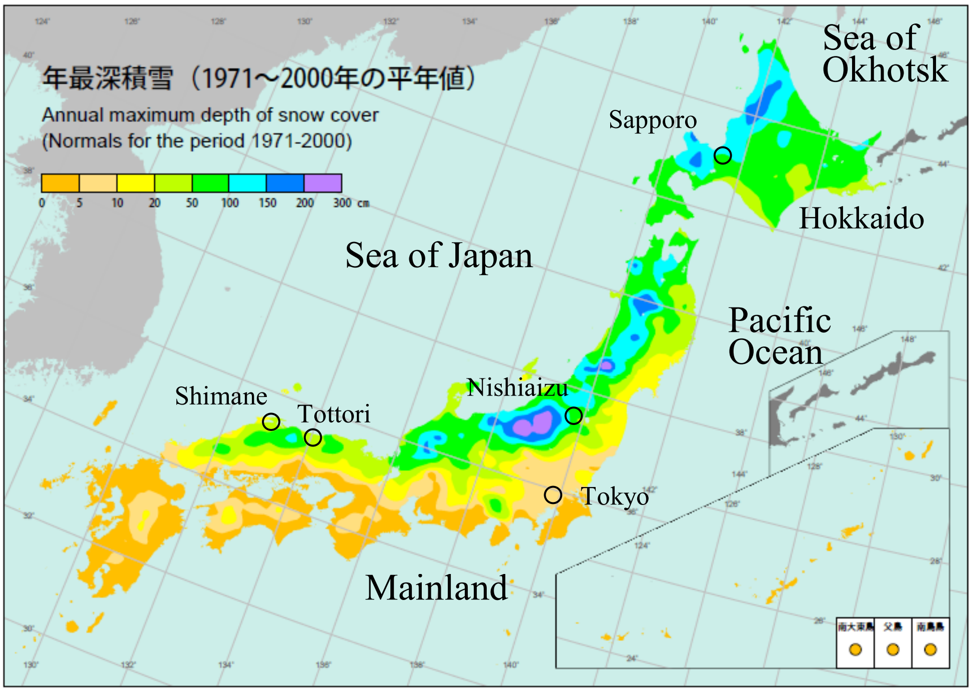

Figure 2. Normal values for the annual maximum depth of snow cover (1971 – 2000) [2].

2 SURVEY METHODOLOGY

Among cold snowy regions in Japan, Hokkaido and the northern part of the mainland above lat. 37° N were selected as the target regions for this study (Fig. 3). The data used for the survey consisted of hourly snow depth figures measured at 141 points in the target regions, which are covered by the Japan Meteorological Agency's AMeDAS (Automated Meteorological Data Acquisition System) network. The increase in hourly snow depth was considered to indicate the amount of snowfall in the hour concerned. The survey period was from the winter of 1981/82 (or from the start of observations in that season) to the winter of 2010/11. In this study, winter was deemed to run from November 1 to April 30 the following year.

The items surveyed were seasonal maximum snow depth (cm), the number of days with continuous snow cover, accumulated seasonal snowfall (cm), maximum 24, 48 and 72-hour snowfall from the onset of snowfall, and the frequency of 24-hour periods with snowfall exceeding 40 cm. As these items were changed every winter, linear approximation was used to visualize trends of overall changes during the survey period. For this calculation, the approximation expression shown in Eq. (1) was found using the least-squares method, and the "a" gradient was regarded as the trend of varying values. In this study, positive and negative "a" values were considered to represent increasing and decreasing trends, respectively.

$$y = ax + b \qquad (1)$$

(y: survey item; x:number of winters ; a, b: constants)

Figure 4 shows an example of the results. It shows the trend of change on seasonal snowfall during the survey period in Takinoue. The value " -11.9" was obtained as the "a" in the Eq. (1) by this calculation.

The 24-hour snowfall amount was determined by first finding the maximum value recorded during the winter and rejecting hourly snowfall data corresponding to it. Then, the process of finding the maximum value from the data after rejection was repeated until the extracted value was less than 40 cm. Figure 5 shows the flow of the extraction. This approach helps to prevent fragmentation of data collected over two days and extraction of the same hourly data more than once.

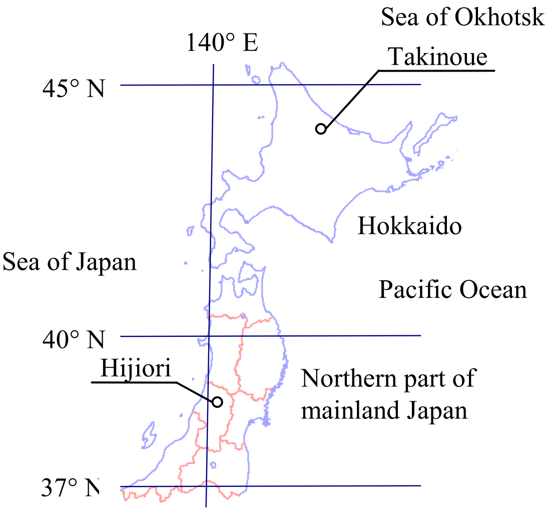

Figure 3. Overview of survey regions.

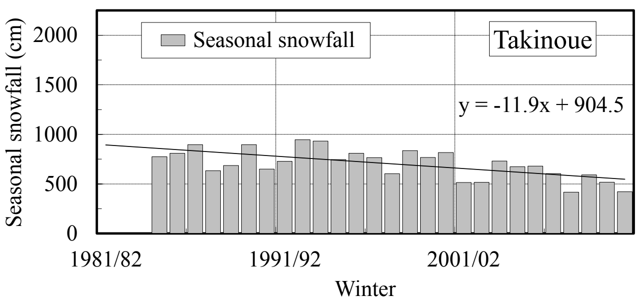

Figure 4. Example results showing the trend of seasonal snowfall change in Takinoue.

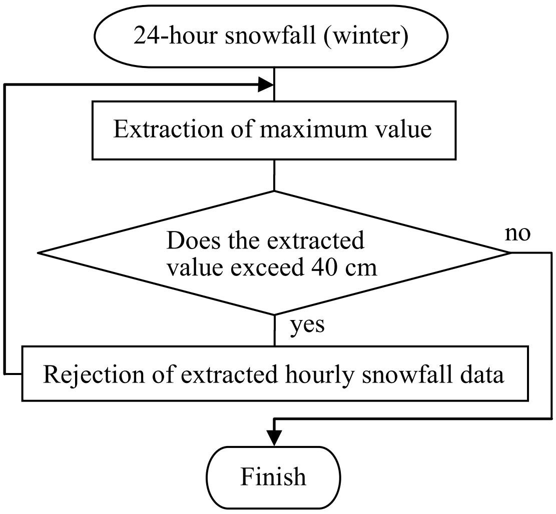

Figure 5. Flow of 24-hour snowfall extraction.

3 RESULTS

The seasonal maximum snow depth showed a tendency of increase in western Hokkaido on the Sea of Japan side, in inland Hokkaido, in eastern Hokkaido along the Sea of Okhotsk and the Pacific Ocean, and on the northern part of the mainland facing the Sea of Japan (Fig. 6). The number of days with continuous snow cover showed an increase in western and eastern Hokkaido (Fig. 7). Seasonal snowfall showed a tendency of decrease in most areas of the target regions (Fig. 8).

The seasonal snowfall and the maximum 24-, 48- and 72-hour snowfall measured at two points (Takinoue and Hijiori; see Figure 3) representing eastern Hokkaido along the Sea of Okhotsk and on the northern part of the mainland facing the Sea of Japan are shown in Fig. 9. At both points, the seasonal snowfall showed a decreasing tendency, but the maximum 24-, 48- and 72-hour snowfall figures did not show the same declining trend. In Hijiori, no remarkable increase in the maximum 24-, 48- and 72-hour snowfall figures was seen, whereas Takinoue showed an increasing trend from 2000 onward. Differences in the maximum 24-, 48- and 72-hour snowfall figures were smaller for Takinoue than for Hijiori. This was caused by transient snow brought by low pressure in Takinoue, where it snowed continuously for approximately 24 hours. In Hijiori, the maximum snowfall increased over time, indicating that snow fell more heavily as it continued. The average maximum 24-, 48- and 72-hour snowfall figures at the target points were approximately 40, 50 and 60 cm, respectively.

The variation tendency of 24-hour snowfall in winter was summarized with focus on localized heavy snowfall. Reflecting the average maximum 24-hour snowfall in winter (approximately 40 cm), the threshold value of localized heavy snowfall was set as 40 cm or more, and the tendency of each region was identified. The winter snowfall and frequency of 24-hour snowfall exceeding 40 cm in the target period were presented for Takinoue and Hijiori. In Takinoue, the frequency showed a tendency of increase, rising from 0.8 times on average until 2000 to 2.2 times from 2001 onward. The frequency in Hijiori varied between 5 and 12 times depending on the amount of winter snowfall (Fig. 10). The overall frequency of 24-hour snowfall exceeding 40 cm was therefore determined by dividing the target period into the 20 earlier winters between 1981/82 and 2000/01, and the 10 most recent winters between 2001/02 and 2010/11. The outcome showed a trend of frequency increase in eastern Hokkaido along the Sea of Okhotsk and the Pacific Ocean as well as in mountainous areas of northern mainland Japan (Fig. 11).

The collected results revealed that the annual maximum depth of snow cover and the frequency of 24-hour periods with snowfall exceeding 40 cm were on the rise in eastern Hokkaido and in mountainous areas of northern mainland Japan. Eastern Hokkaido faces the Sea of Okhotsk and the Pacific Ocean. In general, this region is considered to have little snowfall as long as stable winter pressure patterns continue, while snowfall increases when low pressure develops over the Pacific Ocean and the Sea of Okhotsk. Figure 12 shows typical surface weather map patterns at the time of snowfall. Hijiori (on the Sea of Japan side of the northern mainland area) is a cold region with snow brought by conditions with high pressure in the west and low pressure in the east. Takinoue (on the Sea of Okhotsk side of Hokkaido) is also a region with snow brought by the approach and passage of low-pressure areas.

The results of this study clarified changes in snowfall patterns and in the distribution of areas with heavy snowfall (Fig. 13). It can be considered that localized heavy snowfall may occur within a short time due to winter low-pressure systems in the future, which may result in related disasters.

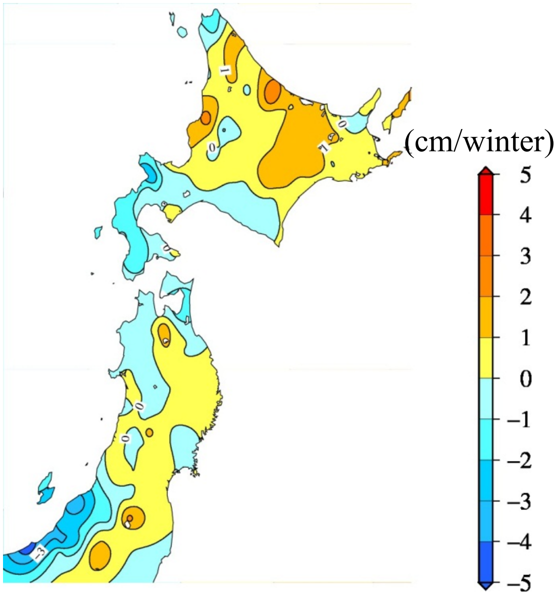

Figure 6. Trends of change in seasonal maximum snow depth.

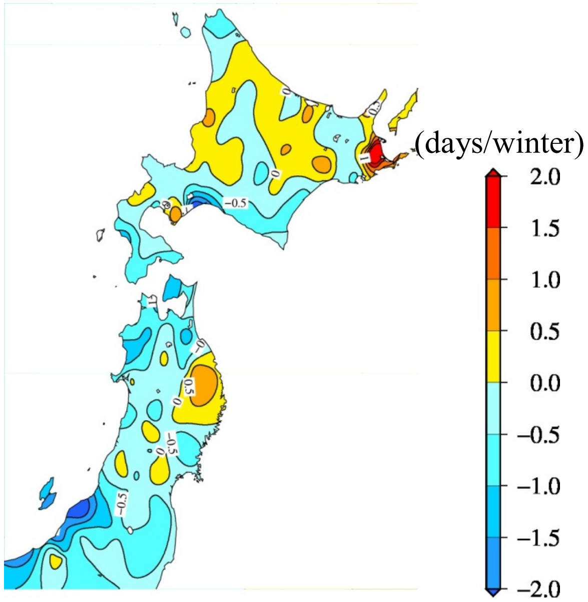

Figure 7. Trends of change in the number of days with continuous snow cover.

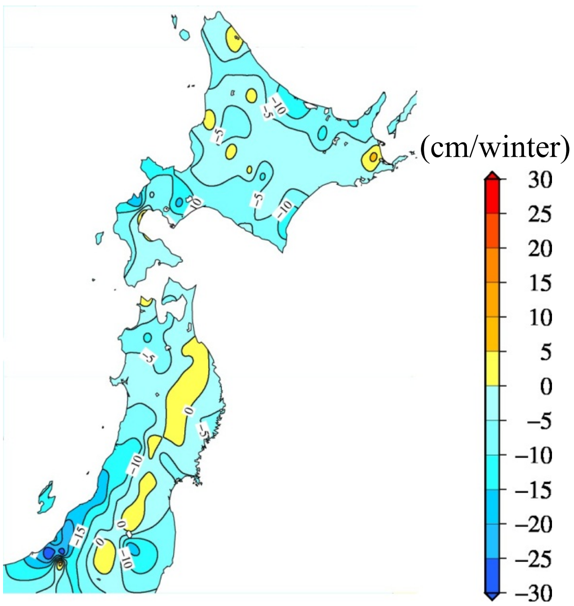

Figure 8. Trends of change in seasonal snowfall.

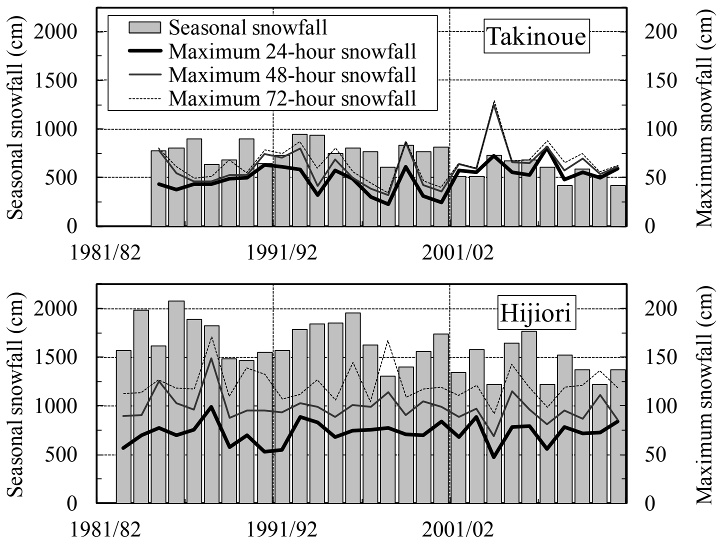

Figure 9. Seasonal snowfall and maximum 24-, 48- and 72-hour snowfall (at Takinoue and Hijiori).

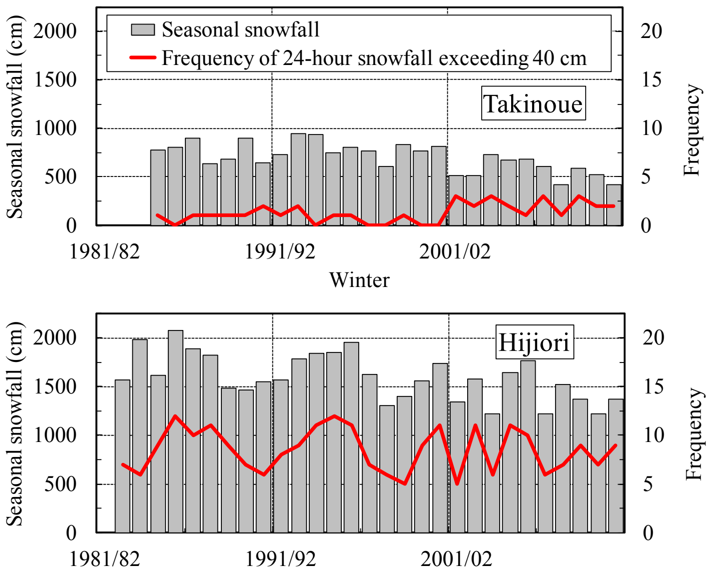

Figure 10. Seasonal snowfall and the frequency of 24-hour snowfall exceeding 40 cm (at Takinoue and Hijiori).

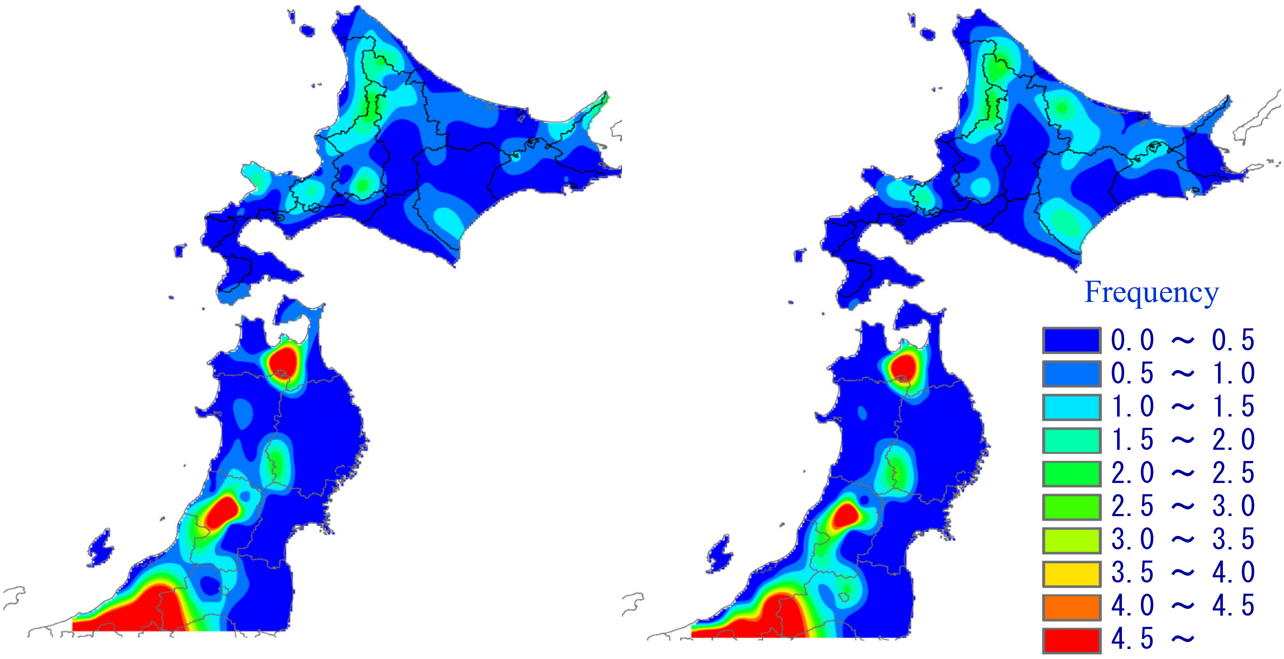

Figure 11. Frequency distribution of 24-hour periods with snowfall exceeding 40 cm. Mean values in the winters of 1981/82 to 2000/01 (left) and 2001/02 to 2010/11 (right).

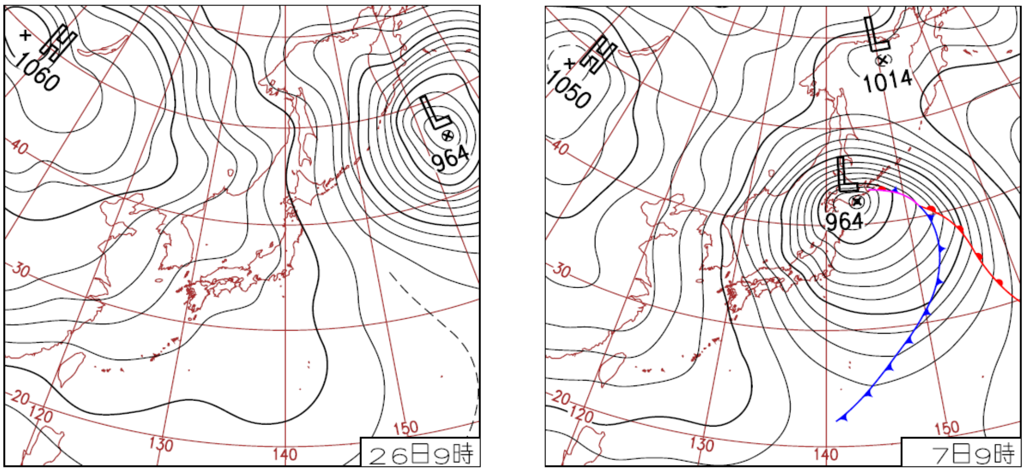

Figure 12. Typical surface weather map patterns seen at the time of snowfall. On the Sea of Japan side, snow brought by conditions with high pressure in the west and low pressure in the east (left). On the Pacific Ocean and the Sea of Okhotsk side, snow brought by low-pressure area approach and passage (right).

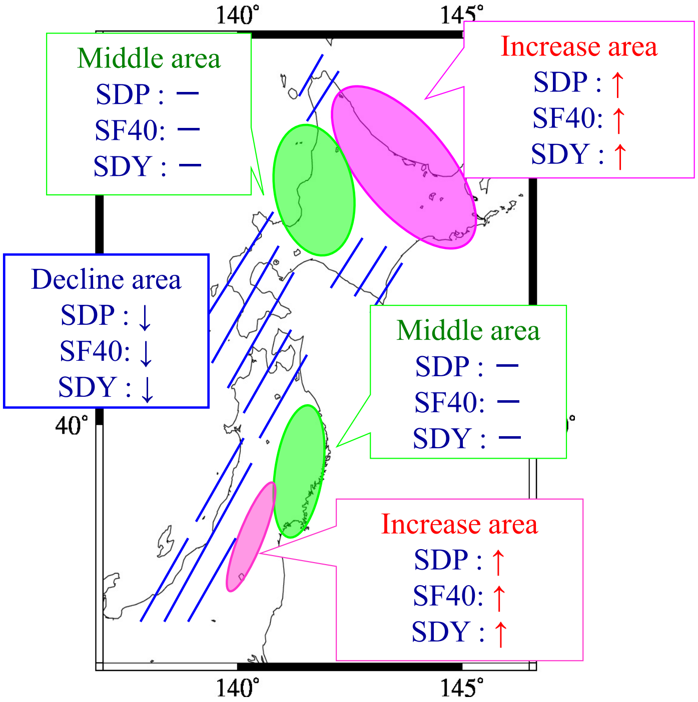

Figure 13. Summary of recent trends of change in seasonal snowfall/snow cover. SDP: seasonal maximum snow depth; SF40: frequency of 24-hour periods with snowfall exceeding 40 cm; SDY: days of continuous snow cover. Seasonal snowfall shows a decline in all areas.

4 CONCLUSION

In this study, trends of change in snowfall and snow cover over the last about 30 years were surveyed using past data measured at 141 weather observatory stations. The items surveyed were seasonal maximum snow depth (cm), the number of days with continuous snow cover, accumulated seasonal snowfall (cm), maximum 24-, 48- and 72-hour snowfall from the onset of snowfall, and the frequency of 24-hour periods with snowfall exceeding 40 cm. The results revealed an increase in the annual maximum snow depth and the frequency of 24-hour periods with snowfall exceeding 40 cm in eastern Hokkaido and mountainous areas of northern mainland Japan. Changes were seen in snowfall patterns and in the distribution of areas with heavy snowfall. As maximum snow depth and maximum daily snowfall are taken into account in the discussion of snow control plans, it is important for trends of change in snowfall and snow depth to be considered in such plans and in the design of related protection facilities.

5 REFERENCES

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