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LONG-TERM CHANGES IN THE SNOW DAYS OVER NORTHERN JAPAN

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Abstract The long-term changes in the snowfall of the three districts over northern Japan, the Hokkaido, Tohoku, and Hokuriku districts, were investigated by analyzing the increasing and decreasing trends for the number of snow days during the 1962–2020 winters. Statistically significant increasing trends were recognized in the Sea of Japan side of the Hokkaido district, the northernmost region, in seasonal timescale. On the other hand, the statistically significant decreasing trends were recognized in the Hokuriku district and the Pacific side of the Tohoku district located in the south. Many stations showed a statistically significant decreasing trend around the beginning and end of winter. The mean surface air temperature during precipitation days had a statistically significant increasing trend in November, February, and March at most of the stations in Northern Japan. Whether the area is along the Sea of Japan or other oceans, whether the area is the windward or leeward side to monsoon northwesterlies, and the climatological surface air temperature are considered to play a role in the regional characteristics of the long-term changes in the number of snow days over the Hokkaido district and among the three districts.

Keywords: long-term trends, northern Japan, precipitation days, snow days

1. Introduction

The heavy snowfall areas are mainly on the Sea of Japan side in Japan. During winter, cold and dry monsoon northwesterlies blow from the Eurasian Continent. The cold and dry air is moistened over the Sea of Japan and brings in a mass of snowfall in the Sea of Japan side of the Hokkaido, Tohoku, and Hokuriku districts.

The Hokkaido district is located in the northernmost part of Japan (Fig. 1). According to Sapporo District Meteorological Observatory (2017), the areas in this district are influenced by different ocean currents, which create regional characteristics. The western, northeast, and south and east areas face the Sea of Japan, the Sea of Okhotsk, and the Pacific Ocean, respectively. The Sea of Japan side of the Hokkaido district is relatively warm because of the warm Tsushima Current and has heavy snowfall due to the monsoon northwesterlies s during winter. The dry seasonal wind influences the Sea of Okhotsk side of the district in summer and winter. Thus, the precipitation is relatively low in this area. The climate of the Pacific Ocean side of the district is different between east and west. The eastern area is relatively cold, and the western area is relatively warm because

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cold and warm currents run near each area.

According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), the global mean temperature has increased since the late 19th century (Hartmann et al. 2013). Since snowfall is sensitive to temperature, global warming is expected to influence the long-term changes in snowfall for present and future climate. Sapporo District Meteorological Observatory (2017) reported a decreasing trend for the annual maximum snow depth in the Sea of Japan side of Hokkaido district. Takahashi (2021) investigated the long-term changes in snowfall during 1962–2012 and reported that the amount of snowfall decreased in most parts of Japan except the Hokkaido district, but there was no particular trend for the maximum depth of snow. Hara et al. (2008) conducted numerical experiments using a regional atmospheric model to investigate the future projections of snow amount in Japan. They reported that the snow water was projected to decrease in areas with an altitude of less than 1,500 m at the end of December.

Since snow is included in precipitation, it is considered that characteristics of snowfall are related to the regional and seasonal differences of precipitation. Sato and Sugimoto (2013) investigated the role of the Sea of Japan in the long-term changes of the precipitation in Japan. They reported that the offshore sea surface temperature (SST) anomaly affected the terrestrial precipitation over the Sea of Japan side of northern Japan. Yasunaga and Tomochika (2017) reported an increase in precipitation in December over the Sea of Japan side of Japan's main island during 1980–2015, which was related to the warming of the Sea of Japan and enhance of the winter monsoon flow.

To further understand the long-term changes in the snowfall of northern Japan this paper investigated the increasing and decreasing trends in snowfall for Hokkaido, Tohoku, and Hokuriku districts during 1962–2020 by using the number of snow days as an index.

2. Data and Methods

Data

In most stations, the instrument to measure snowfall amount changed in October 2005, and the homogeneity of the data may affect the long-term changes. Thus, we used the number of snow days as an index to consider the difference in the instrument to measure the snowfall amount between before and after 2005. To investigate the long-term changes of the snow days over the Hokkaido district, we examined the monthly and seasonal total of precipitation and snow days for 60 winter seasons from 1962 to 2020. The numbers of precipitation and snow days were calculated based on daily precipitation and daily total snowfall amount from the meteorological stations over Japan. The daily mean surface air temperature was analyzed to understand the relationship between the long-term changes in the snow days and temperature. The three components were observed by the meteorological stations over Japan and were downloaded via the Japan Meteorological Agency website (https://www.data.jma.go.jp/gmd/ risk/obsdl/). Forty-six stations were analyzed: 22 stations for the Hokkaido district, 15 stations for the Tohoku district, and nine stations for the Hokuriku districts (Fig. 1). The Tohoku and Hokuriku districts were also investigated to understand the characteristics of the Hokkaido district because comparing with other districts may highlight the characteristics of the district.

Definitions of numbers of precipitation and snow days

We defined days that the daily precipitation was more than 1 mm as precipitation days. Snow days were defined as days that the precipitation was more than 1 mm and the daily total snowfall

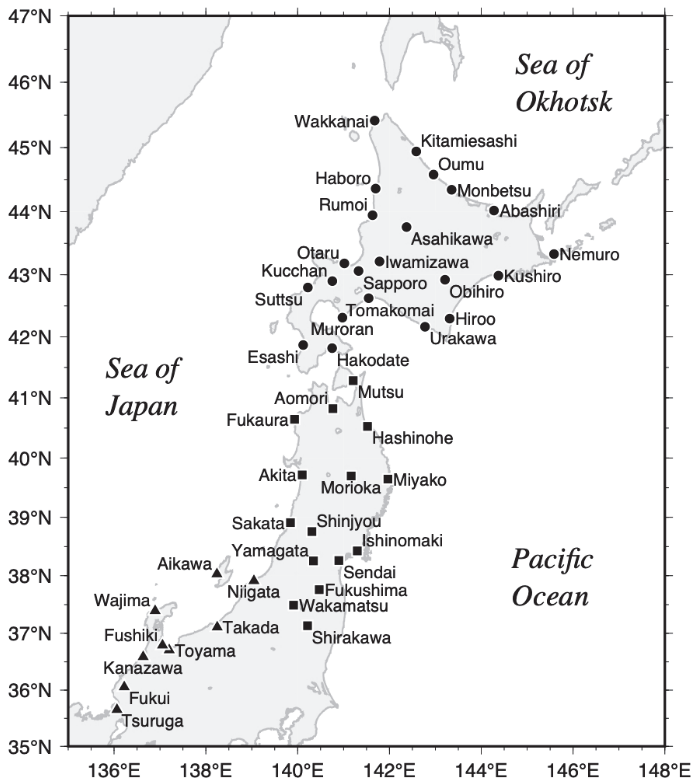

Fig. 1 46 meteorological stations that were analyzed in this study. Circles, squares, and triangles mean that the stations belong to the Hokkaido, Tohoku, and Hokuriku districts, respectively.

amount was more than 1cm. The boundary of a day is 00:00 JST. In this study, we counted the numbers of the monthly and seasonal total of precipitation and snow days from November to March. For seasonal total, we counted during December–February (DJF). The DJF in 1962 stands for December 1961 to February 1962.

Methods

The long-term trends of numbers of precipitation and snow days for each station during each month of seasons were analyzed as follows. First, we calculated the ratio between the numbers of snowy and precipitation days (s/p ratio). Secondly, we performed the Mann–Kendall test at the 95% significance level on the numbers of precipitation and snow days, and s/p ratio, respectively, to examine whether the components have an increasing or decreasing trend during the 60 years. We also examined the long-term changes in the mean surface air temperature during the precipitation days to understand its relationship with the long-term changes in the number of snow days. The trends were calculated based on Sen's slope method.

3. Results

Seasonal timescale

To understand the long-term changes in the seasonal number of snow days, we performed the

Mann–Kendall test for each station to understand whether the number of snow days increased or decreased during the past 60 years (Fig. 2a). The results for DJF showed that the increasing and decreasing trend of the number of snow days differed over the Hokkaido district. The stations in the western part of the Hokkaido district, where most stations face the Sea of Japan side, showed an increasing trend. Five stations showed a statistically significant increasing trend. On the other hand, there were no distinct trends for the stations in the Pacific Ocean and Sea of Okhotsk sides. For the Tohoku and Hokuriku districts, many stations showed a decreasing trend. Particularly, the stations in the Pacific Ocean side of the Tohoku district and the Sea of Japan side of the Hokuriku district showed a statistically significant decreasing trend.

Moreover, we investigated the increasing and decreasing trends of the number of precipitation days (Fig. 3a) and the s/p ratio (Fig. 4a) to understand the relationship between the long-term changes in the snowy and precipitation days. The increasing and decreasing trend of the number of precipitation days during DJF also showed regional characteristics over the Hokkaido district (Fig. 3a). Most stations in the western part of the Hokkaido district showed an increasing trend. One station (Sapporo: All stations that appear in the text are shown in Fig. 1.) showed a statistically significant increasing trend. Stations that showed increasing or decreasing trends were few in the Pacific Ocean and Sea of Okhotsk sides. One station in the Pacific Ocean (Urakawa) showed a statistically significant decreasing trend. For the Tohoku and Hokuriku districts, the results showed a similar tendency as in the case of the number of snow days. For the Tohoku district, the stations in

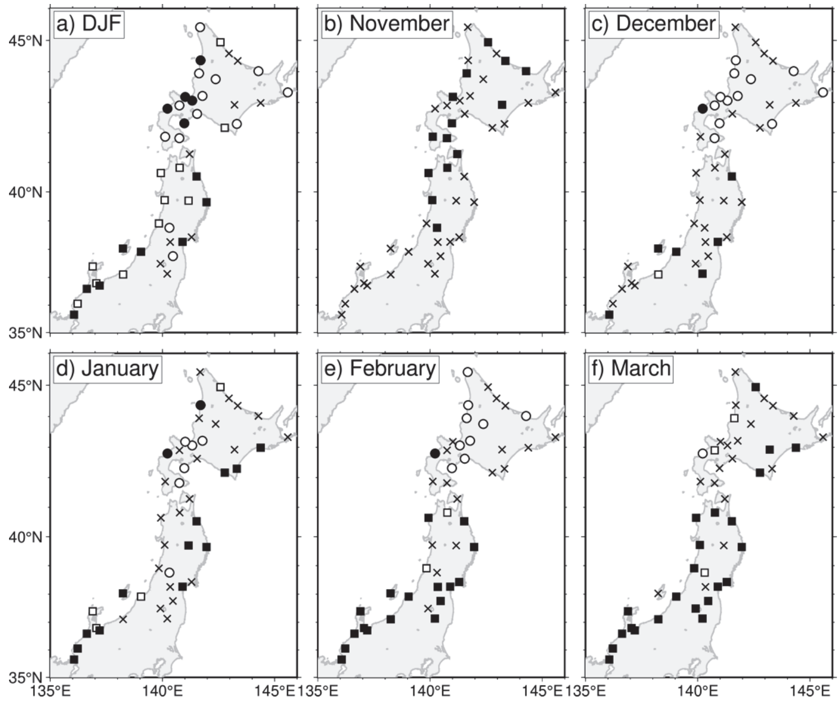

Fig. 2 Results of the Mann–Kendall test for the number of snow days for (a) DJF, (b) November, (c) December, (d) January, (e) February, and (f) March. Circles and squares stand for increasing and decreasing trends, respectively. Closed circles and squares mean that the trends are significant at the 95% significance level. Cross marks mean the trend for the station is non-significant, or the value is too small to consider its trend.

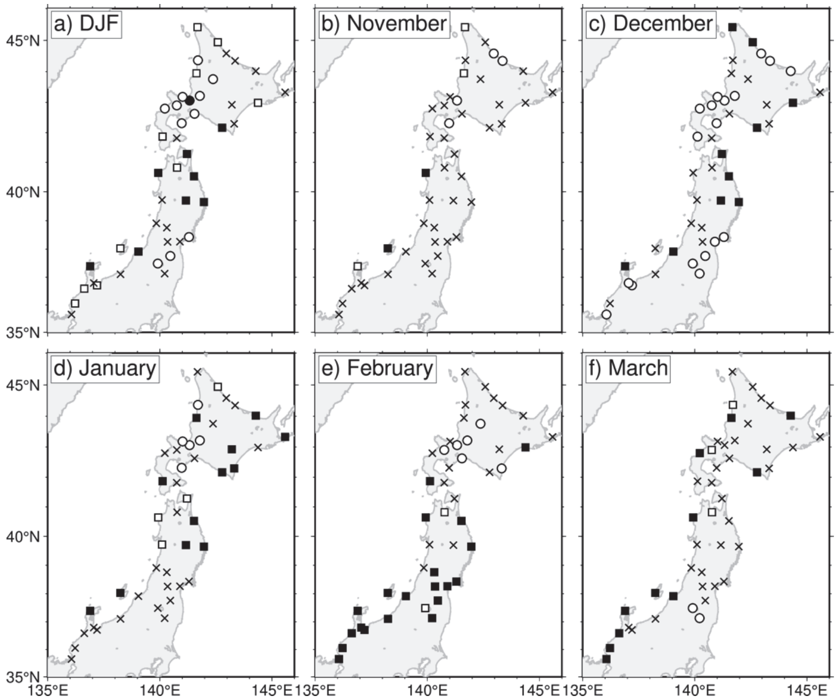

Fig. 3 Same as Fig. 2, but for the number of precipitation days

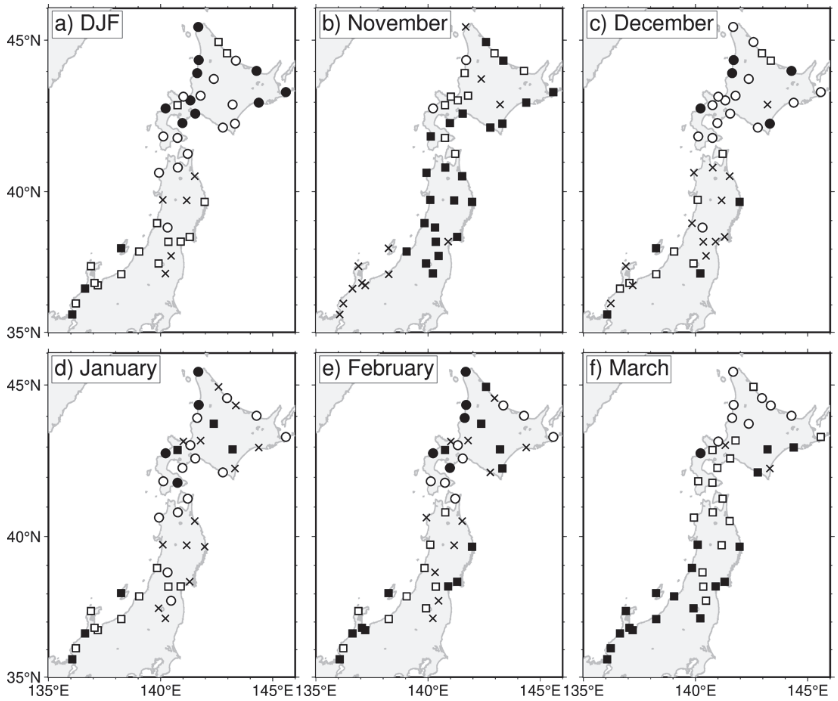

Fig. 4 Same as Fig. 2, but for the s/p ratio

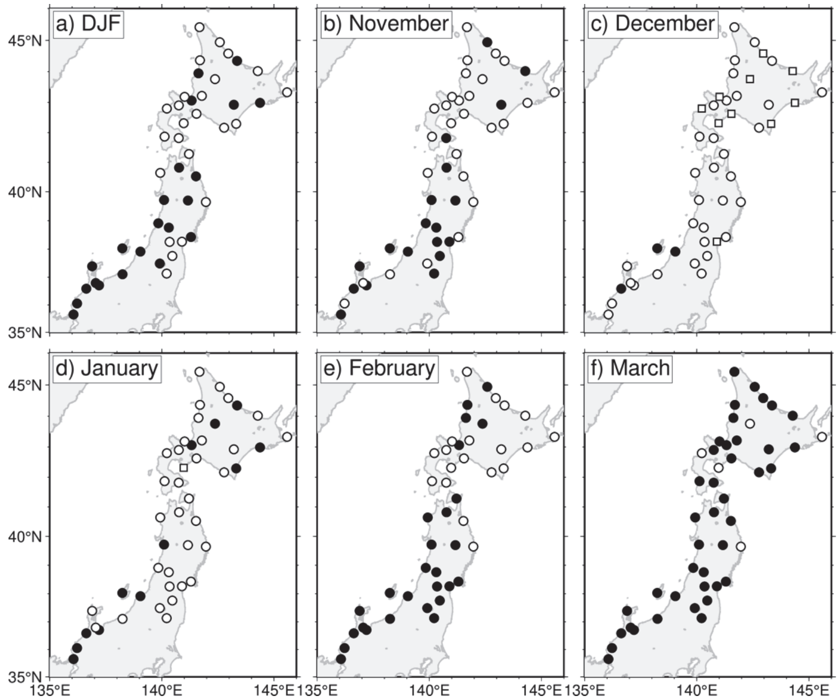

Fig. 5 Same as Fig. 2, but for the mean surface air temperature during precipitation days

the northern part of the district showed a statistically significant decreasing trend. The number of stations that showed a statistically significant trend for the number of precipitation days was less than those for the number of snow days in the Hokuriku district.

The characteristics of the long-term increasing and decreasing trends for the DJF s/p ratio differed among the three districts (Fig. 4a). Most stations in the Hokkaido district showed an increasing trend. Stations that indicated statistically significant increasing trends were located on the western and eastern coasts. For the Tohoku district, both increasing and decreasing trends appeared. The stations in the northern part of the district showed increasing trends, and the stations in the southern part showed decreasing trends. No station showed a statistically significant trend. All nine stations in the Hokuriku district showed a decreasing trend. Trends for three stations (Aikawa, Kanazawa, and Tsuruga) were statistically significant.

We analyzed the long-term trends of the mean surface air temperature during precipitation days to understand whether the long-term trends in the surface air temperature affected the long-term trends in the number of snow days (Fig. 5a). The mean surface air temperature during precipitation days in seasonal timescale had an increasing trend in all 46 stations. For the Hokkaido district, five stations had a statistically significant increasing trend. All nine stations in the Hokuriku district had a statistically significant increasing trend.

Intra-seasonal difference

To understand whether a particular timing contributed to the long-term changes for snowfall during winter, we investigated the long-term increasing and decreasing trends for the components analyzed in the previous subsection in monthly timescale from November to March.

Most of the stations showed a decreasing trend for the number of snow days for the months in which the snowfall amount was relatively small such as November and March (Figs. 2b, f). Statistically significant decreasing trends particularly appeared over the Hokkaido district in November and the Tohoku and Hokuriku districts in March. The spatial patterns for the increasing and decreasing trends over the Hokkaido district were similar to the DJF results in December, January, and February (Figs. 2c–e). For the Tohoku and Hokuriku districts, decreasing trends were dominant during winter. The number of stations that showed statistically significant decreasing trends increased in the latter winter season (Figs. 2e, f).

The signals for the number of precipitation days were weak in November and March in the three districts (Figs. 3b, f). In March, stations in the Hokuriku district showed decreasing trends. In January, there was an east-west contrast for the increasing and decreasing trends over the Hokkaido district (Fig. 3d). For the Tohoku district, there was a north-south contrast for the increasing and decreasing trends in December (Fig. 3c). In February, the decreasing trends in the Hokuriku districts were apparent (Fig. 3e).

The long-term trends of the s/p ratio in the Hokkaido district had an intra-seasonal variability. In November, most stations showed a decreasing trend over the district. Stations in the Pacific Ocean and Sea of Okhotsk sides showed statistically significant decreasing trends (Fig. 4b). In December, many stations showed an increasing trend (Fig. 4c). Some stations showed statistically significant increasing trends in the Sea of Japan side from December to March. The intra-seasonal characteristics for the s/p ratio for the Tohoku and Hokuriku districts were similar to those for the number of snow days. The statistically significant trend appeared particularly in the beginning and end of the winter (Figs. 4b, f).

The mean surface air temperature during precipitation days had an increasing trend in most stations of the three districts. Increasing trends were dominant for stations in the Hokkaido district except for December (Fig. 5c). The statistically significant increasing trend particularly appeared in March (Fig. 5f). For the Tohoku and Hokuriku districts, the statistically significant increasing trend particularly appeared in November, February, and March (Figs. 5b, e, f).

4. Summary and Discussion

This paper investigated the long-term changes in snowfall for the Hokkaido, Tohoku, and Hokuriku districts over northern Japan by analyzing observational data from 46 meteorological stations from 1962 to 2020 winter. The results in seasonal timescale showed different trends between Hokkaido and the other two districts. Increasing trends were dominant for the Hokkaido district, particularly over the Sea of Japan side. The number of precipitation days and the s/p ratio also showed increasing trends in this area. For the Tohoku and Hokuriku districts, most stations showed a decreasing trend for the number of snow days. The increasing and decreasing contrast for Hokkaido and the other two districts were consistent with Takahashi (2021) who analyzed the long-term trends in DJF accumulated snowfall. In monthly timescales, few stations showed a statistically significant decreasing trend during the middle of winter (December–February). On the other hand, many stations showed a statistically significant decreasing trend around the beginning and end of winter. The results for the number of precipitation days were similar to the results for the number of snow days. In most stations, the mean surface air temperature during precipitation days had an increasing trend.

The results of the Mann–Kendall tests indicate that the warming trend contributed to the long-term changes in the stations that showed a decreasing trend for the snow days. Because the temperature is relatively high around the beginning and end of winter, we consider that these months tend to have a decreasing trend for the number of snow days due to the warming trend, which changed the precipitation from snowfall to rainfall. Moreover, it is considered that the warming trend of the mean surface air temperature during precipitation days contributed to the latitudinal contrast of the increasing and decreasing trends of the number of snow days over Northern Japan. The climatological mean surface air temperature during precipitation days during DJF for the Hokkaido, Hokuriku, and Touhoku districts are -2.8 ℃, 1.14 ℃, and 4.22 ℃, respectively. Because the climatological mean surface air temperature during precipitation days is relatively high in the Hokuriku and Tohoku districts compared to the Hokkaido district, the chance of snowfall relatively decreases in the Tohoku and Hokuriku districts.

It is considered that the winter monsoon flow and the Sea of Japan contributed to regional characteristics in the Hokkaido district. The Sea of Japan side directly receives the north-westerly wind from the continent and moisture from the Sea of Japan side. Thus, long-term changes in the winter monsoon flow and the SST of the Sea of Japan may have influenced the climate of the Sea of Japan side of the Hokkaido district. However, the Sea of Japan side of the Tohoku and Hokuriku districts showed decreasing trends for the number of snow days. The decreasing trends of the number of precipitation days and the s/p ratio indicate that the frequency of precipitation and its percentage for snowfall are both decreasing. Using the number of snow days as an index enabled us to understand the long-term changes in the frequency of a certain amount of snowfall. For further understanding, analyzing the amount of snowfall and depth of snow is useful, but comparing the snowfall data before and after 2005 remains an issue.

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