Okhotsk Sea and Polar Oceans Research 8 (2024) 1-7

https://doi.org/10.57287/ospor.8.1

Article

Intra-seasonal and interannual variations in snowfall and rainfall during winter in Rikubetsu, inland Hokkaido, Japan

Naohiko HIRASAWA[1,2] and Hiroyuki KONISHI[3]

[1] *National Institute of Polar Research, Tachikawa, Tokyo, Japan*
[2] *Department of Polar Science, School of Multidisciplinary Sciences, SOKENDAI (The Graduate University for Advanced Studies), Tachikawa, Tokyo, Japan*
[3] *Division of Math, Sciences, and Information Technology in Education, Osaka Kyoiku University, Osaka, Japan*

(Received October 1, 2023; Revised manuscript accepted December 31, 2023)

Abstract

Global warming is likely to increase precipitation and the relative proportion of rainfall to precipitation. Since relatively few continuous and independent observations of snowfall and rainfall have been conducted worldwide, it is difficult to clarify the likelihood of future changes in the proportion of snow versus rainfall. Low-cost disdrometers, which have become more ubiquitous in recent years, can record snowfall and rainfall separately based on the characteristics of the precipitation particles. In this study, snowfall and rainfall amounts were investigated using disdrometer measurements for the winters from 2013 to 2023 in Rikubetsu (43.5°N, 143.8°E), Hokkaido, Japan. It represents the current status on snowfall in one of the southernmost regions of the Arctic. The results show that the total winter precipitation in each year ranged from 101.9 to 399.6 mm. Rainfall ranged from 5.9 to 80.2 mm, and therefore accounted for 17% of the total precipitation, 96% of which occurred in December and March. Rainfall accounted for 2% in January and February, and 27% in December and March, respectively. Large snowfall and rainfall events contributed significantly to total winter precipitation, and these events were associated with rising temperatures associated with synoptic-scale disturbances. Snowfall occurred when temperatures were below freezing after warming, and rainfall occurred when temperatures were above freezing. It is considered that future changes in temperatures during synoptic-scale disturbances will play a key role in the amount of rainfall in Rikubetsu as the climate changes.

Key words: snowfall, liquid precipitation, solid precipitation, climatological monitoring, disdrometer, Rikubetsu

1. Introduction

It has been hypothesized that global warming will promote an increase in water vapor, leading to an increase in precipitation. For example, in an analysis based on the Clausius-Clapeyron equation, Trenberth *et al.* (2003) proposed that the rate of increase in atmospheric water vapor capacity is approximately 7% K^{-1}, which implies that the overall rate of the increase in precipitation should follow the same trend (Clausius-Clapeyron scaling). This idea has subsequently been corroborated by several studies that were conducted primarily on rainfall (*e.g.*, Nayak and Takemi, 2020). Although the rate of the increase in snowfall remains an issue in the future, even in the Arctic region (north of 70°N) where snowfall is the main component of precipitation, precipitation has increased throughout the 20th century and is expected to increase at an escalating rate in the 21st century (*e.g.*, Vihma *et al.*, 2016).

Another concern related to the impact of global warming on precipitation is that it will reduce the frequency of snowfall, *i.e.*, the frequency of rainfall will increase. According to McCrystall *et al.* (2021), the fraction of snowfall in the Arctic decreased during the 20th century, and climate models (CMIP 5 and 6) predict that the relative contribution of snowfall to total precipitation will continue to decrease during the 21st century. The findings of their study showed that rainfall is expected to account for more than 50% of the total precipitation in autumn (September-November) by 2050. The timing of when rainfall is expected to exceed snowfall varies by season and region, but a common feature of current estimates is that there will be an increase in the proportion of future rainfall.

In Japan, there are few long-term data on snowfall rate as water equivalent, but analyses have been attempted using data from the Japan Meteorological Agency (JMA) and other sources. The JMA records total amount of rainfall and snowfall, and snow depth, with snow depth and depth of new snowfall mainly being used as surrogate data for snowfall (*e.g.*, Takahashi, 2021; Kawase *et al.*, 2023). Takahashi (2021) used data from weather stations throughout Japan to clarify in detail the trend in the change of snowfall from 1961 to 2012. Most of the weather stations in Honshu, Shikoku, and Kyushu have recorded a decreasing trend in snowfall, while in Hokkaido, some stations show an increasing trend and others show a decreasing trend. Kawase *et al.* (2023) investigated historical snowfall changes in Japan from 1959 to 2020 with a dynamical downscaling analysis forced by the Japanese 55-year Reanalysis data (JRA-55). The trends observed in the maximum snow depth and the maximum snowfall (increment in daily snow depth) in Hokkaido were generally insignificant, which differed slightly from the results reported by Takahashi (2021). The reason for the disparity between the findings of the studies could be attributed to differences between modeled values and observations. Kawase *et al.* (2021) used a climate model to calculate changes in snowfall in Japan due to global warming (RCP 8.5 and 2.6). In both cases, the change in precipitation is not pronounced in Hokkaido, but shows a trend from snowfall to rainfall before December and after February.

As global warming progresses, an increase in precipitation and the relative proportion of rainfall is expected to increase in Hokkaido and other snowfall regions. These changes will affect people's way of life in the future and are also important as one of the indicators of the state of the global climate. However, historically, few independent rainfall and snowfall observations have been conducted, and we do not have accurate and sufficient information about rainfall and snowfall events.

Disdrometers measure the size and fall velocity of precipitation particles, and based on the characteristics of these two parameters, rainfall and snowfall can be separated and their respective amounts can be estimated. Recent technological innovations have led to the commercial availability of low-cost disdrometers, and observations using these instruments are increasing worldwide. Based on these observations, it is meaningful to obtain information on rainfall and snowfall separately in snowfall areas in order to evaluate the potential for changes in the characteristics of these events in future.

In this study, we investigated the intra-seasonal and inter-annual variations in snowfall and rainfall amounts in Rikubetsu, Hokkaido, Japan, using a disdrometer. The observations were conducted from the winter of 2013 (December 2012 to March 2013) to 2023. Section 2 presents the observation site and the details of the measurements in Rikubetsu, Section 3 examines intra-seasonal and inter-annual variations in data, Section 4 presents case analyses, and Section 5 provides a summary of our findings.

2. Observation site and measurements

We have been conducting snowfall and meteorological measurements at an observation site in Rikubetsu (43.5°N, 143.8°E, 217 m above sea level) since 2012 (Figs. 1a and c). Rikubetsu is located on the eastern side of the central mountain range (white broken line in Fig. 1a) in Hokkaido. The mountains separate the site from the Sea of Japan side of the island, which typically experiences heavy snowfall during the Asian winter monsoon. During the heavy snowfall on the Sea of Japan side of Hokkaido, most of the areas on the Pacific Ocean side, including Rikubetsu, generally experience clear skies. Snowfalls in Rikubetsu are mainly attributed to frontal activity associated with synoptic-scale disturbances passing through the region (*e.g.*, Kawase *et al.*, 2023). Rikubetsu is a slightly elevated area that extends from Kitami city in the north to Obihiro city in the south and is one of the coldest areas in Japan (Sorai *et al.*, 2016), with daily winter minimum air temperatures often reaching approximately -30°C. This cold region is valuable as a test site for Arctic and Antarctic snowfall observations. Therefore, we have continued snowfall observations in Rikubetsu since 2012.

The observations were part of the WMO-directed Solid Precipitation Inter-Comparison Experiment (SPICE) that ran from 2013 to 2015 (Nitu *et al.*, 2018). The main objectives of SPICE were to understand the accuracy of the snowfall rate and snow depth observations being conducted in each country, to propose correction methods, and to learn about the performance of new instruments. The data used in this study were collected using a disdrometer named Laser Precipitation Monitor (LPM) manufactured by Theis, Germany (Fig. 1b). The LPM data were analyzed for the SPICE project (Hirasawa *et al.*, 2018) and also used to analyze diurnal variations in precipitation by Hirasawa and Konishi (2023). Over the two-year SPICE period, the observed values of this LPM were slightly overestimated as ratios of 1.1 and 1.2 to the SPICE reference data (DFIR: Double Fence Intercomparison Reference).

The LPM was placed in the center of a wooden double fence for wind protection (Fig. 1c). The double fence was constructed according to the standard specifications for measuring inter-comparison data in SPICE. This placement of the LPM was employed to increase the accuracy of precipitation measurements by suppressing the contributions of blowing snow due to strong winds during synoptic-scale disturbances. The LPM measures the size and fall velocity of precipitation particles, and based on correlations of their distribution, discriminates between rainfall (liquid precipitation) and snowfall (solid precipitation) (Gunn and Kinze, 1949), and then determines the relative amounts of each. Gunn and Kinze (1949) is an older results, however, it is still one of the most reliable empirical formulas today. In addition, the algorithm discriminates precipitation as snowfall when the ambient temperature is below -4°C and rainfall when the temperature is above 9°C. Since drizzle consisting of supercooled water droplets can cause rain even below freezing, we also believe it is possible to place the snowfall decision at -4°C. The accuracy of the rain/snow discrimination algorithm was recently verified by Pickering *et al.* (2019).

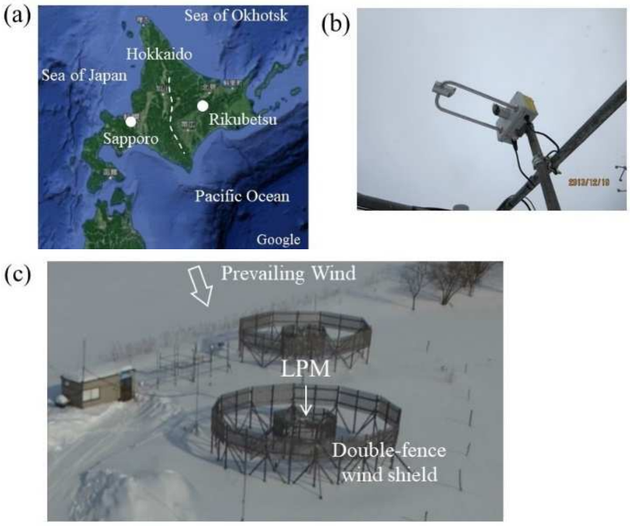

Fig. 1 (a) Map of Hokkaido showing the location of Rikubetsu and the topography of the region. The white dashed line indicates the mountain range that divides the island into the Sea of Japan side and the Pacific Ocean side. (b) Disdrometer, LPM. (c) Landscape surrounding observation site.

Solid and liquid precipitation can occur simultaneously or separately within the same precipitation events. In this study, such measurements will be referred to as snowfall and rainfall, respectively. In the figures, however, the terms "solid" and "liquid" are used.

An automatic observation system operated by JMA is located approximately 2 km away from our observation site, where temperature, humidity, wind direction and speed, precipitation amount (total of rainfall and snowfall), and snow depth are measured. This study refers to these data.

In this study, winter was defined as the period extending from December 1 to March 31. Observations spanned the period from the 2013 winter season beginning in 2012 until the 2023 winter beginning in 2022. However, data for the 2022 winter season were excluded from the analysis due to a malfunction of the equipment. Hourly and daily data were used for the analyses in this study. For the ten winters included in the analysis, periods during which no data were obtained for more than 12 hours occurred from 9:00 on December 5 to 14:00 on December 21 for the 2013 winter season and from 0:00 on February 14 to 8:00 on February 18 for the 2021 winter season. Times are in Japan Standard Time (JST).

3. Amount of snowfall and rainfall in each winter

3.1 Inter-annual variation over the entire winter season

Figure 2a shows a time series of cumulative precipitation for the winter season from 2013 to 2023. The highest precipitation recorded was 399.6 mm in the 2015 winter and the lowest was 101.9 mm in the 2021 winter. Although the JMA data underestimated the LPM measurements, the two datasets were generally consistent with respect to their inter-annual variability. Average precipitation was 204.7 mm as recorded by the LPM and 134.9 mm by the JMA, respectively, giving a ratio of 65.9%. Hirasawa et al. (2018) showed that the underestimation of the JMA instrument is due to reduced capture of precipitation particles by wind and further evaporation.

Snowfall (solid precipitation) was greater than rainfall (liquid precipitation) throughout the winter in all years. The mean value obtained for snowfall was 168.9 mm, with a maximum of 355.5 mm in the 2015 winter and a minimum of 90.5 mm in the 2021 winter. The mean value obtained for rainfall was 35.7 mm, with a maximum of 80.2 mm in the 2018 winter and a minimum of 5.9 mm in the 2017 winter. The relative proportion of rainfall (Fig. 2b) varied from 4.1% in the 2017 winter to 36.4% in the 2018 winter, and the mean was 17.0%.

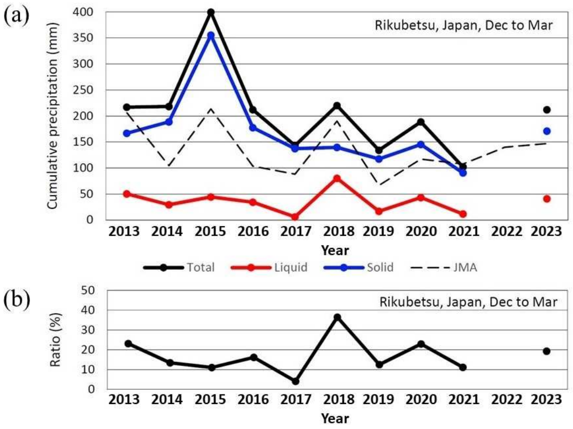

Fig. 2 (a) Time series of cumulative precipitation for the winter season from 2013 to 2023. The black, red, blue, and black dashed lines indicate total precipitation, liquid precipitation, and solid precipitation measured by the LPM, and total precipitation by the JMA, respectively. (b) Time series of liquid precipitation as a percentage of total precipitation.

3.2 Intra-seasonal variation

Figure 3 shows time series of daily precipitation, with all years overlaid. Snowfall was more frequent than rainfall, often with smaller daily precipitation amounts, and was generally distributed evenly from December to March. Rain rarely fell in January and February during the observation period. This is characteristic of the climate in Rikubetsu, which is one of the coldest regions in Japan.

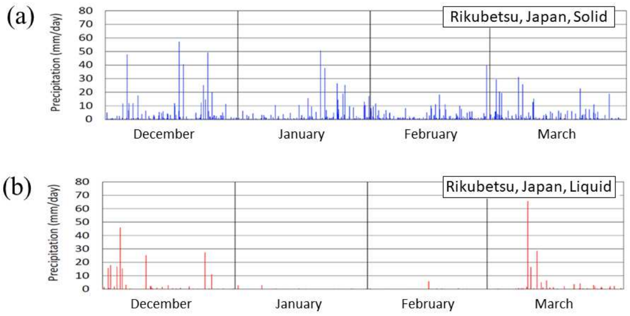

Fig. 3 Time series of daily precipitation overlaid for all years for (a) solid precipitation and (b) liquid precipitation.

Figures 4 and 5 show time series of cumulative precipitation amounts in December and March, and January and February from the 2013 winter to the 2023 winter. The cumulative rainfall in December and March in each year (red line in Fig. 4a) was almost the same as that of all years, while the cumulative total precipitation for the two months (black line in Fig. 4a) was less than that in all years. Thus, the relative proportion of rainfall during this period was greater than that of all years (Fig. 4b). The mean value was 26.6%, with a maximum of 48.4% in the 2018 winter and a minimum of 5.8% in the 2017 winter.

On the other hand, cumulative rainfall in January and February (red line in Fig. 5a) was very low compared to that in December and March, with a mean value of 1.6 mm, a minimum of 0.0 mm in the 2013 winter, and a maximum of 6.2 mm in the 2016 winter. The relative proportion of rainfall was also very low compared to December and March, with a mean value of 1.6%, a minimum of 0.0% the 2013 winter, and a maximum of 5.1% in the 2020 winter.

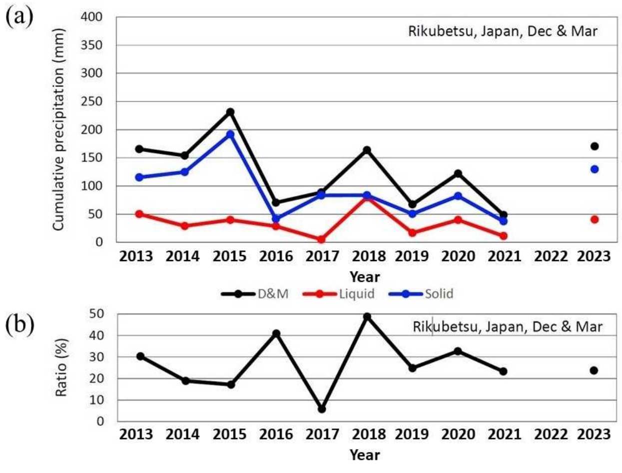

Fig. 4 Same as Fig. 2, but for December and March.

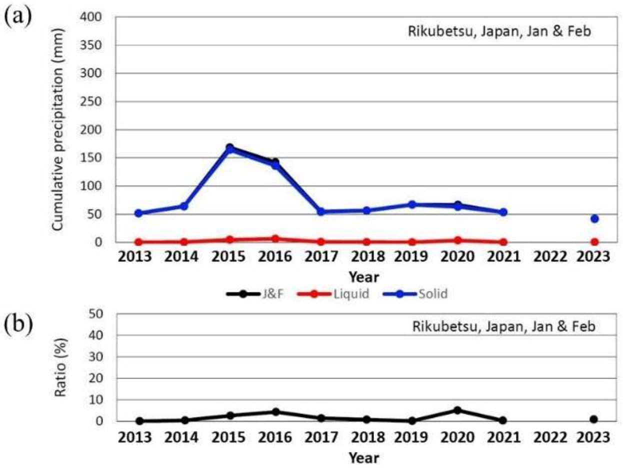

Fig. 5 Same as Fig. 2, but for January and February.

These findings indicate that in the current climate, almost all of the winter rainfall in Rikubetsu occurs in December and March, and that rainfall during those months accounts for 95.6% of the total winter rainfall.

Years with high snowfall and years with high rainfall were different, with each contributing to the variation in winter precipitation. For example, during the 2015 winter, multiple relatively large snowfall events that occurred from December to February (Fig. 6a) increased precipitation throughout the winter (Fig. 5a) and contributed to the annual maximum observed in this study (Fig. 2a). The 2016 winter had a notable snowfall event in January (Fig. 6b), which was the second highest precipitation event in January and February (Fig. 5a) observed over the analysis period, but no other notable precipitation events were observed. In the 2018 winter, a rainfall event measuring 65.6 mm was observed on March 9 (Fig. 6d). This event elevated the overall winter rainfall to the highest level within the analysis period (Fig. 5a), but snowfall was negligible. However, during the winter months, one, or possibly a few, relatively significant precipitation events, whether annual snowfall or annual rainfall, considerably influenced the overall amount of precipitation.

In the 2017 winter (Fig.6c), there were no significant rainfall events in December and March. The 2017 winter season had a significantly lower percentage of rainfall. This could be partially attributed to lower temperatures in December (-8.4°C compared to the 10-year average of -7.5°C) and March (-2.5°C, -1.6°C). The small precipitation amounts for individual precipitation events may reflect the low activity of the synoptic-scale disturbances, which are accompanied by warm air advection, and therefore less rainfall. Such inter-annual variability occurs in association with hemispheric-scale atmospheric circulation. Further investigation of this is a future work.

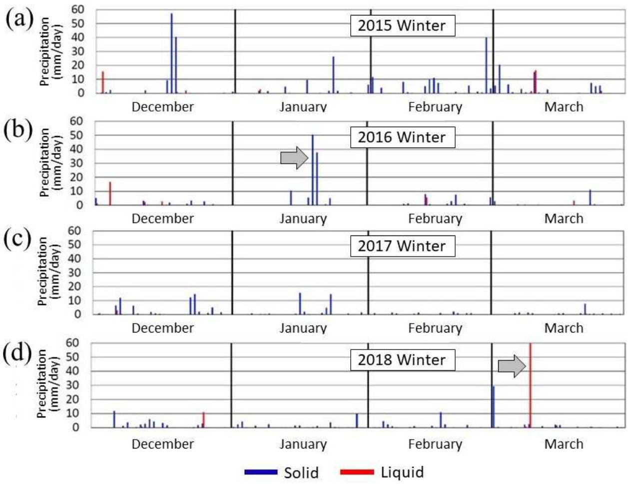

Fig. 6 Time series of daily rainfall and snowfall for selected years. Blue bars indicate daily snowfall and red bars indicate daily rainfall. (a) The 2015 winter, (b) the 2016 winter, and (c) the 2017–18 winter. Horizontal arrows in (b) and (c) indicate significant precipitation events, which are discussed in detail in Section 4.

4. Case studies

Here, we examine the surface meteorological and synoptic-scale atmospheric fields for significant snowfall and rainfall events on January 19–20, 2016 (Fig. 6b) and March 9, 2018 (Fig. 6c), respectively.

Figure 7 shows the surface weather maps for both cases. In each case, a synoptic-scale disturbance passed close to Hokkaido and caused precipitation.

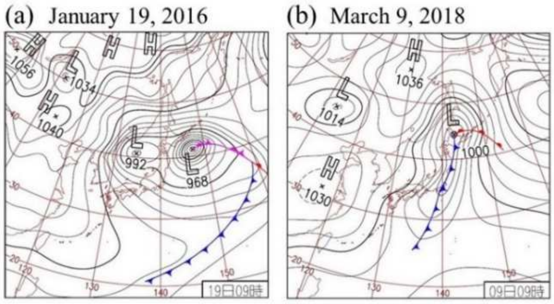

Fig. 7 Surface weather map, derived from the JMA, for (a) a snowfall event on January 19, 2016 and (b) a rainfall event on March 9, 2018.

Figures 8 and 9 show time series of precipitation and surface meteorological parameters. On January 19–20 and March 9, when precipitation occurred (Figs. 8a and 9a), the diurnal variation in temperature was moderated and temperatures remained relatively high (red lines in Figs. 8b and 9b). These conditions were likely attributed to warm air advection associated with the disturbances and the suppression of radiative cooling due to cloudy skies. Temperatures were the main factor separating the snowfall observed on January 19–20 from the rainfall observed on March 9. In the former case, temperatures were relatively high, but still below the freezing point, while in the latter case, they were above the freezing point. Closer examination of the precipitation observed on March 9 reveals that snowfall was initially observed, and the temperature at that time was below the freezing point. The LPM data appear to have distinguished between the snowfall and rainfall with considerable accuracy based on the characteristics of the measured precipitation particles.

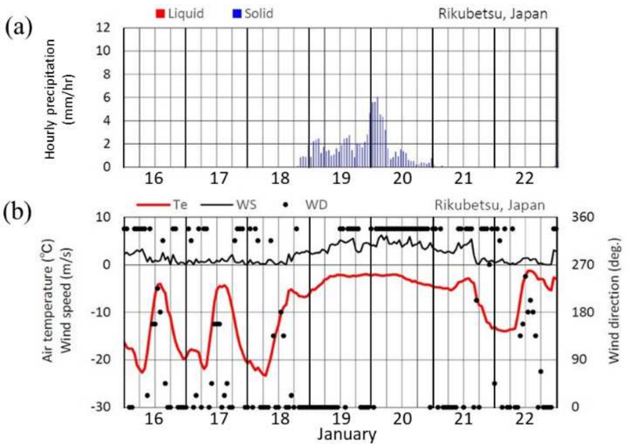

Fig. 8 Time series of (a) hourly rainfall (red bars) and snowfall (blue bars), and (b) surface air temperature (red line, °C), wind speed (black line, m/s), and wind direction (black circles, deg.) are shown for the period January 16 to 22, 2016.

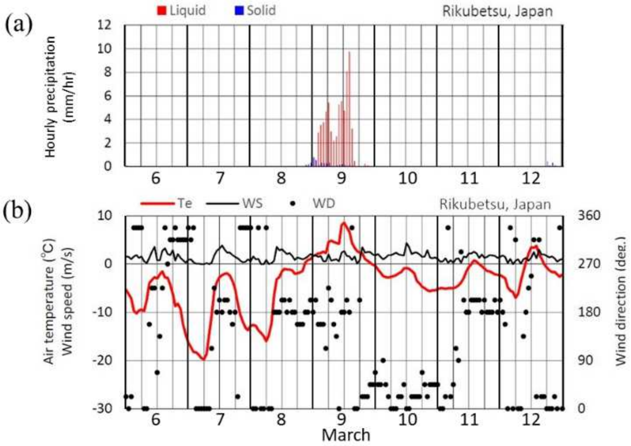

Fig. 9 Same as Fig. 8, but for March 6 to 12, 2018.

Finally, we examined the causes of this temperature difference, which is an important factor in distinguishing between the snowfall and rainfall. First, it is considered that temperature differences associated with seasonal progression (*i.e.*, intra-seasonal variation) would be involved. Focusing on the diurnal variation in temperature before each precipitation event, the minimum and maximum temperatures were below -

20°C and below -5°C before the snowfall event, but above -20°C and above -5°C before the rainfall event, respectively. The average daily temperature was -14.0°C on January 17 and -10.6°C on March 7, a difference of 3.4°C. Temperatures during the snowfall event were above -3.4°C from 6:00 JST on March 19 to 15:00 JST on March 20, and remained above -2.5°C for a relatively long time during that period. If the same phenomenon had occurred during a period of higher ambient temperatures, then it is considered likely that rainfall would have occurred.

In addition, the location of the synoptic-scale disturbance is also considered to be important. In the case of snowfall, the main disturbance passed over the Pacific Ocean to the east of Hokkaido, and in the case of rainfall, it passed over Hokkaido and was closer to Rikubetsu. The rainfall occurred when southerly winds blew, presumably during the passage of a cold front associated with the disturbance. In other words, rainfall occurred during pronounced warm air advection on a synoptic-scale, even though the associated wind speeds were not remarkably high. In contrast, in the case of the snowfall, northerly winds continued to blow throughout the event. Since Rikubetsu was to the north of the disturbance, it was not strongly affected by the warm air advection conditions.

5. Conclusion

This study investigated intra-seasonal and inter-annual variations in snowfall and rainfall amounts in Rikubetsu using disdrometer (LPM) data that were collected over the winters of 2013 (December 2012 to March 2013) to 2023. The LPM distinguishes between rainfall and snowfall amounts based on the characteristics of precipitation particles. The results show that the total winter precipitation for each year ranged from 101.9 to 399.6 mm. Rainfall ranged from 5.9 to 80.2 mm, accounting for 17.0% of the total precipitation, 95.6% of which occurred in December and March. Identifying the causes of inter-annual variation is a future challenge.

The time series findings of daily precipitation indicate that significant snowfall and rainfall events contributed significantly to total winter precipitation. Cases of a significant snowfall event on January 19–20, 2016 and a rainfall event on March 9, 2018 were examined in detail. The events occurred in rising temperatures associated with synoptic-scale disturbances. Snowfall occurred when temperatures were below freezing after warming, and rainfall occurred when temperatures were above freezing.

Temperatures during synoptic-scale disturbances are central to discriminating between snowfall and rainfall events. The conditions that determine whether temperatures will exceed the freezing point include the temperature distribution on a synoptic-scale; the horizontal scale of the disturbance, which affects air temperatures associated with advection; and the location and route of passage of the disturbance.

Although determining whether the location of disturbances that pass over Hokkaido will change with seasonal progression, and whether the location and passage of disturbances will be affected by global warming, lie beyond the scope of this study, these questions are relevant to whether precipitation in Rikubetsu will be dominated by snowfall or rainfall in the future. These studies are the subject of future work.

Japan has snowfall only in winter, and in terms of areas with snowfall, it is located at the southernmost tip of the Arctic snowfall region. It is possible that Japan may be removed from the Arctic snowfall region as a result of global warming. Rikubetsu is the coldest region in Japan, so it may be the last remaining snowfall area in Japan. This study summarized the current status on snowfall in such a region.

Acknowledgements

The observation was conducted as part of a scientific project of National Institute of Polar Research (NIPR) through Project Research No. KP-302. This study was supported by JAXA's (The Japan Aerospace Exploration Agency) EORA3 (The 3rd Research Announcement on the Earth Observations) program.

References

Gunn, R. and G. D. Kinzer (1949): The terminal velocity of fall for water droplets in stagnant air. *J. Atmos. Sci.*, **6(4)**, 243–248. https://doi.org/10.1175/1520-0469(1949)006<0243:TTVOFF>2.0.CO;2.

Hirasawa, N. and H. Konishi (2023): Diurnal variation in precipitation and cloud formation during winter in Rikubetsu, inland Hokkaido, northern Japan. *Okhotsk Sea and Polar Oceans Research*, **7**, 30-35. doi.org/10.57287/ospor.7.30

Hirasawa, N., H. Konishi, K. Nishimura, C. Genthon and project group of Japan Meteorological Agency (2018): SPICE site report: Rikubetsu, Japan. WMO Solid Precipitation Intercomparison Experiment (SPICE), *Instruments and Observing Methods*, **131**, Annex 8.3, December 2018.

Kawase, H., S. Fukui and 6 co-authors (2023): Historical regional climate changes in Japan in winter as assessed by a 5-km regional climate model with a land surface process. *Prog. Earth Planet. Sci.*, **10(1)**, 7. https://doi.org/10.1186/s40645-023-00536-4

Kawase, H., A. Murata and 7 co-authors (2021): Regional characteristics of future changes in snowfall in Japan under RCP2.6 and RCP8.5 scenarios. SOLA, 17, 1–7, doi:10.2151/sola.2021-001

McCrystall, M. R., J. Stroeve, M. Serreze, B. C. Forbes, and J. A. Screen (2021): New climate models reveal faster and larger increases in Arctic precipitation than previously projected. *Nat. Commun.*, **12(1)**, 6765. https://doi.org/10.1038/s41467-021-27031-y

Nayak, S., and T. Takemi (2020): Clausius-Clapeyron scaling of extremely heavy precipitations: Case studies of the July 2017 and July 2018 heavy rainfall events over Japan. *J. Meteor. Soc. Japan*, **98**, 1147–1162, doi:10.2151/jmsj.2020-058.

Nitu, R., and 42 co-authors (2018): WMO Solid Precipitation

Intercomparison Experiment (SPICE). *Instruments and Observing Methods*, **131**. https://library.wmo.int/opac/

Pickering, B. S., R. R. Neely III and D. Harrison (2019): The Disdrometer Verification Network (DiVeN): a UK network of laser precipitation instruments, *Atmos. Meas. Tech.*, **12**, 5845–5861, https://doi.org/10.5194/amt-12-5845-2019.

Sorai, T., H. Hamada, T. Kameda, and S. Takahashi (2016): Rikubetsu, the coldest town in Japan: according to the meteorological data by Japan Meteorological Agency from 2007 to 2016 in winter seasons. *Tenki*, **63**, 879-887. (in Japanese)

Takahashi, H. G. (2021): Long-term trends in snowfall characteristics and extremes in Japan from 1961 to 2012. *Int. J. Clim.*, **41(4)**, 2316–2329. https://doi.org/10.1002/joc.6960

Trenberth, K. E., A. Dai, R. M. Rasmussen, and D. B. Parsons, (2003): The Changing Character of Precipitation. *Bull. Amer. Meteor. Soc.,* **84(9)**, 1205–1218. https://doi.org/10.1175/BAMS-84-9-1205.

Vihma, T., J. Screen and 6 co-authors (2016): The atmospheric role in the Arctic water cycle: A review on processes, past and future changes, and their impacts. *J. Geophys. Res. Biogeosci.*, **121(3)**, 586–620. https://doi.org/10.1002/2015JG003132

Summary in Japanese

和文要約

北海道内陸部の陸別における冬季の降雪量と降雨量の季節内変動と年々変動

平沢尚彦[1,2], 小西啓之[3]

[1]国立極地研究所, [2]総合研究大学院大学, [3]大阪教育大学

地球温暖化によって降水量は増加し、降雨の比率が増加する可能性がある。これまで世界的にも降雪と降雨を分離した継続的観測はほとんど行われておらず、降雪と降雨の比率の今後の変化を示すことは難しい。最近世界中で利用され始めた低価格のディスドロメータは降水粒子の特性に基づいて降雪と降雨を別々に記録できる。本研究は、現在の気候に関する情報の一つとして、北海道陸別における2012-13年から2022-23年の冬期の降雪量と降雨量をディスドロメータの観測値を用いて調べた。それは北極降雪圏の最南端の一地域の現状を表す。その結果、各年の冬期の総降水量は101.9～399.6 mm、降雨量は5.9～80.2 mmで総降水量の17%を占め、そのうちの96%は12月と3月に発生していた。降雨の占める割合は、それぞれ、1月と2月に2%、12月と3月に27%であった。顕著な降雪と降雨は冬期の総降水量に大きく寄与したが、それらは総観規模擾乱に伴って昇温とともに発生した。昇温後の気温が氷点下の時に降雪、氷点を上回った時に降雨となっていた。今後の気候変化において、総観規模擾乱時の気温が陸別の降雨量の鍵を握っていると考えられる。

Correspondence to: N. Hirasawa, hira.n@nipr.ac.jp